Geospatial Analysis of Risk Components for Elevated Blood Lead Levels in Kansas: Geologic and Anthropogenic Factors

by

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Abstract

Children are the demographic most susceptible to and affected by lead poisoning. Lead contamination in soil has been recorded as being primarily from lead-based paint, historic leaded gasoline emissions, and from lead point-source emitters. The highest risk of elevated blood lead level (BLL) is correlated with living in an area dominated by pre-1950's housing. From 1976 to 1994, midst the phasing out and removal of lead from gasoline, the blood lead levels of children in the United States decreased from 16 µg/dL to 3.2 µg/dL. There is evidence showing the irreversible effects of intellectual impairment still occur at levels of BLL below 10 µg/dL. In Kansas, Barton and Ellis counties residential soils were sampled, and chemical composition was examined with a handheld XRF and an HR ICP-MS. Particle size and pH were recorded for all samples. The presence or lack of of lead sulfate and lead carbonate was identified using XRD. Chemical tests revealed elevated Zn and As with increasing Pb concentrations. There was weak evidence of lead sulfate in one of eight tested samples. Barton county has courser sediments and the top five highest Pb concentrations recorded in this study. There is a significant correlation with Pb concentrations and age of housing for houses built prior to1950. Pb Isotopic analysis on eight samples showed multi-source contamination in the soil. We believe the source of most of the lead is from ambient lead mixed with historic leaded gasoline deposits and possible output from factories/coal, along with leaded paint in older homes. Three of the eight samples had paint chips which tested positive for lead. Maps were created showing central Kansas having elevated blood lead levels in children and overlays were made illustrating oil well density in counties. Five variables were used to create a risk assessment map for Kansas: housing age, poverty levels, blood lead levels, number of oil wells, and population.

Table of Contents

List of Figures

List of Tables

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Chapter 1 - Introduction

1.1 Lead in the Environment: Geological and Anthropogenic

Heavy metal pollution in soil and water is a national and global problem with the potential to greatly impact human health. Lead (Pb) and its harmful effects have been examined and researched for centuries (Davies, 1988; Casas and Sordo, 2006; EPA, 2013). The use of Pb has been traced back to the Roman Empire and has historic uses in cosmetics, kitchen appliances and utensils, bullets, paints, infrastructure, and in gasoline as an antiknocking agent (Casas and Sordo, 2006).

In the natural environment, the earth's crust contains about 13-15 mg Pb/kg and is considered a trace element in soil (WHO, 1977; Davies 1988). A higher concentration is typical in lead ore deposits (WHO, 1977) and has a positive correlation with silica content (Davies, 1988). Igneous and metamorphic rocks tend to have 10-20 mg/kg lead concentrations (WHO, 1977; Davies, 1988). Sedimentary rocks, of which 80% are shales and mudstones, have an average lead content of 23 mg/kg (Davies, 1988). Phosphate rocks have been proven to be able to exceed 100 mg/kg Pb content (WHO, 1977). Pb may be released during weathering as an ion in solution and/or as a trace element through weathering processes (Davies, 1988).

While Pb is naturally occurring in the environment, the high concentrations that have the risk of negative health impacts found in soil (over 400 mg/kg), water (over 0.015 mg/kg), and atmosphere (over 0.05 mg/kg) are commonly attributed to anthropogenic sources (EPA, 2006). Patterson's (1991) experiments tested the tooth enamel, femur and ribs of pre-industrial humans who lived 700 years ago and showed that a mean burden of 40 μg Pb/70kg existed in them, whereas an American in the 1990s had 40 mg Pb/70kg. This Pb increase is a result of activities such as: mining, smelting, burning coal, oil, waste, historic use of leaded gasoline, lead-based paint, and disposal of lead products (EPA, 2006; Sergio, 2006; Dikilitas et al., 2016). Areas of extreme contamination that endanger human health may be turned into EPA superfund sites where federal resources are spent on remediation of the land. Living near Pb-related superfund sites may also increase Pb exposure (Stroh, 2009).

This paper focuses on lead in soil. Figure 1-1 demonstrates that the predominate pathway of exposure to lead is through outdoor soil/dust (EPA, 2006).

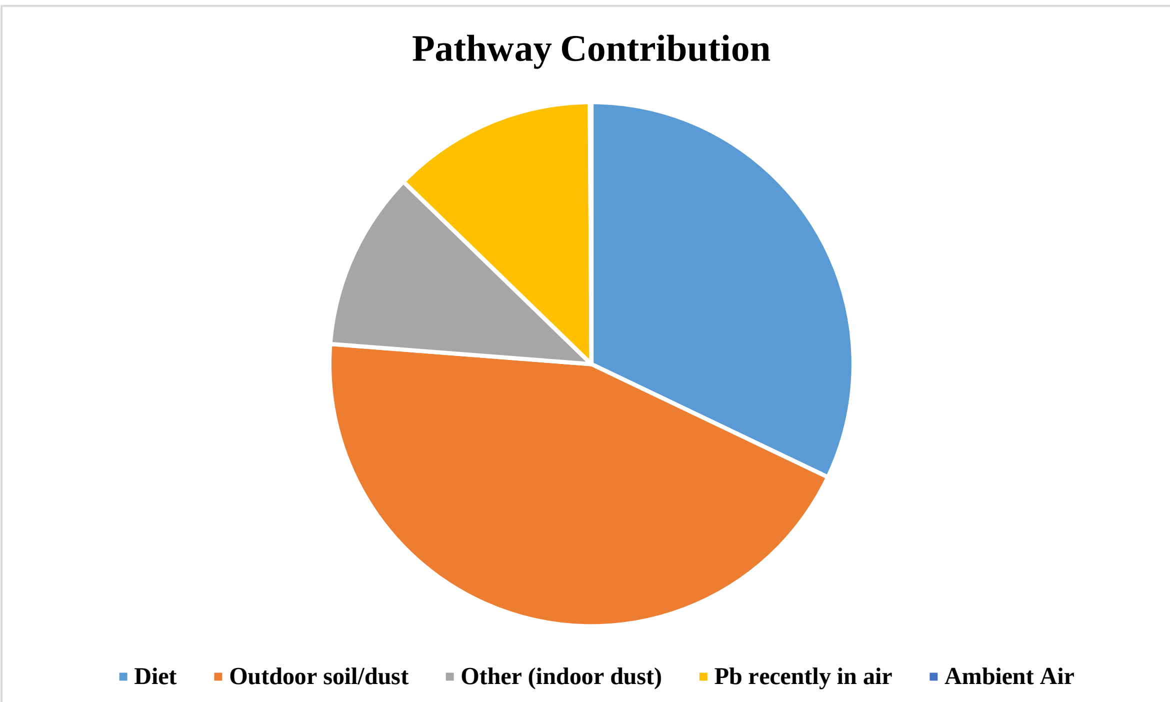


Figure 1-1: Various pathways to Pb exposure (ATSDR, 2007)

Normal soil ranges have been identified as averaging between 10-200 mg/kg (Davis, 1988). Soils represent a major sink for lead in the biosphere (Davies, 1988; Yang, 2014), and the higher than naturally expected concentrations of Pb found in soils (over 400 mg/kg) is usually attributed to anthropogenic sources (EPA, 2006). Humans are primarily exposed to lead through inhalation and ingestion (EPA, 2013; Henry, 2015). While there can be many other sources of lead, and research has been done in identifying sources through isotopic ratios in blood (Oulhote, 2011), there is still difficulty in doing a holistic assessment.

However, within soil, Burgoon et al. (1995) identify three primary sources of elevated lead in soil:

1) Lead-based paint
2) Leaded gasoline emissions
3) Lead point-source emitters (mines, smelters)

Clark et al.'s (2006) study of 103 gardens in Boston accredits the Pb concentration to be 40-80% from leaded paint and the rest from a historical buildup of leaded gasoline. Lead in soils tends to adsorb strongly onto soil sediments and remain in the upper layer of the soil profile (EPA, 2013). For this reason, historic use of lead in gasoline, house paint, and pesticides are important, as overtime they have been shown to increase in soil Pb levels (EPA, 2013).

The more complicated contamination origins to identify in children tend to be from sources introduced by parents through work. Khan (2011) discussed a "take-home" exposure of Pb occurring from workers at oil field sites. A threading compound called pipe dope may contain large amounts of lead and be brought into contact with children through worker's clothing, hands or vehicles. The CDC identifies other jobs and industries of risk with Pb exposure including: battery manufacturers, lead miners/refiners/smelters, coal burning facilities, manufacturers of bullets/ceramics/electrical components, recyclers of metal/electronics/batteries, rubber product manufacturers, solid waste incinerator operators, and steel welders (EPA, 2006). These exposures tend to be more direct and are identified as take-home exposures where spikes in children's blood lead levels cannot be explained through contaminated air, soil, or water and the parents are workers in at-risk fields. While the take-home sources will be estimated in the risk assessment portion of this study, specific data have not been gathered on take-home sources.

1.2 Leaded Paint

Walvraven (2015) identified the most common forms of Pb in paint:

- Red lead: Pb_3O_4
- White lead: $2PbCO_3*Pb(OH)_2$
- Pb sulfate: PbO_2*PbSO_4
- Pb chromate: $PbCrO_4$

Lead released from paint can occur at any time from the moment it is placed on the structure to its removal (Barnes and Davis, 1996). Hunt (2016) analyzed samples of leaded paint for their relative bioavailability (RBA). Bioavailable lead means the lead which can be absorbed by an organism and it is often less than total lead (Hettiarachchi and Pierzynskib, 2004). Hunt (2016) found that the RBA of leaded paint decreases in soil and is usually lowest when structurally bound within apatite. Phosphate is a known remediation tool for lowering the bioavailability of lead; it assists in stabilizing lead into a mineral (e.g. pyromorphite, $Pb_5(PO_4)_4Cl$) less soluble in the lower pH ranges found in human stomachs (Mielke et al., 2007).

Carbonate (e.g. cerussite) and sulfate (e.g. anglesite) based leaded paint is also more bioavailable than paints with a phosphate mixture (Hunt, 2016). The highest percentage of RBA was found in a lead tetroxide mineral containing both Pb^{2+} and Pb^{4+}. Pb (IV) can be more toxic to humans, because it may be readily absorbed through skin (Casa and Sordo, 2006). Within soil, Pb commonly adsorbs to Fe and Mn (hydr)oxides and can be considered inert. However, lead oxides, sulfates, and carbonates are more soluble in acidic environments and may pose a greater toxicological risk when ingested (Triana and Laperche, 1999).

The highest risk of elevated blood lead level (BLL) is correlated with living in an area dominated by pre-1950’s housing (Mcclure et al., 2016). In the 1950s, paint industries began voluntarily reducing their lead content and by 1978 leaded paint was banned nationwide and a limit of 0.06% lead content was implemented. Homes with chipping, chalking, peeling, or damaged leaded paint can expose children to leaded dust or children may ingest these chippings (Hettiarachchi and Pierzynskib, 2004). Children with pica disorder are at a greater risk and it is estimated that 75% of infants and 15% of toddlers are affected by pica (Boris, 2000).

1.3 Smelting/Mining Processes

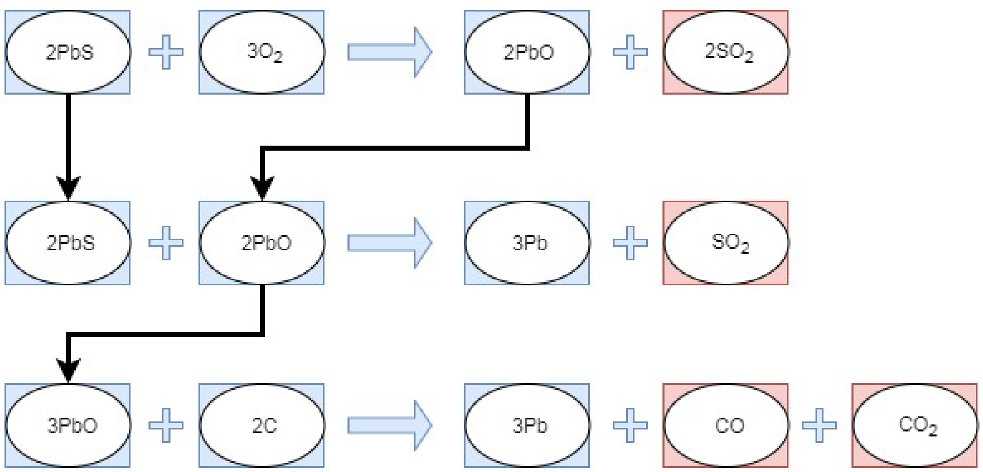


Figure 1-2: Basic chemical process of smelting galena (PbS).

The smelting process of lead impacts the environment through the volatiles released and the sludge left behind. Figure 1-2 shows the basic chemical formula for the smelting process (Casas and Sordo, 2006). It starts with part of the mineral galena (PbS) being oxidized and then the PbO is reacted with the unoxidized galena. Lastly, the lead oxide is reduced with carbon. Living near smelting or mining sites has been determined to pose a threat to human health even years after facilities have been shut down (Stroh et al., 2009; Johnson et al., 2016). Research has shown that the zone of air pollution from a smelter site can extend 5 km and soil contamination can extend 10 km (Landrigan et al., 1975).

1.4: Organic Lead from Leaded Gasoline

Organic lead, usually found as tetraethyl lead, $Pb(C_2H_5)_4$, was used as an antiknocking agent in gasoline and 1,2-dibromoethane and 1,2-dichloroethane were used to maintain the engine's health until its official ban in 1996 (Casas and Sordo, 2006; ATSDR, 2007). Pb halides (e.g. PbClBr) are one of the resultant volatile releases from the car's engine and from oxidation, $PbSO_4$ is the form usually found in soils (Harrison et al., 1981). However, in diluted phosphate solutions Pb halides have been shown to convert to the less soluble and less bioavailable form of pyromorphites (Nriagu; 1974). Due to the historic accumulation of leaded gasoline, testing done near highways has demonstrated concentrations of Pb upwards 11,000 mg/kg (NRC, 1980).

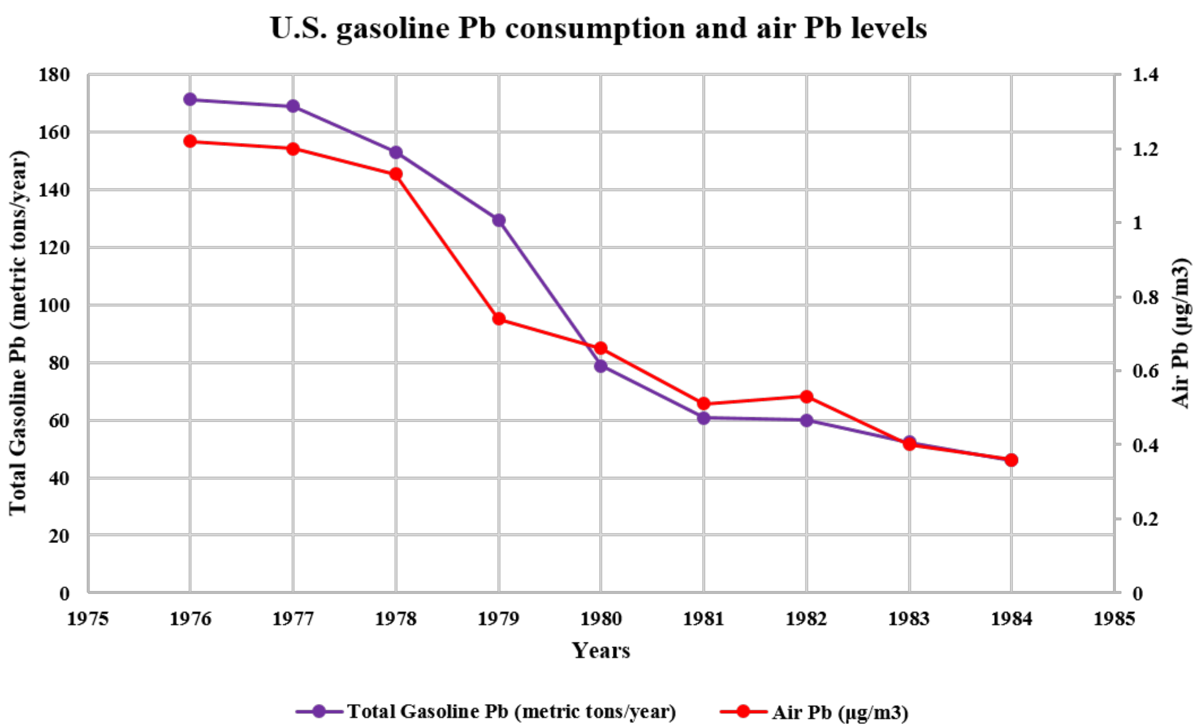


Figure 1-3: Correlation between leaded gasoline consumption and atmospheric Pb from 1974-1984.

Organic lead may be more toxic because the body absorbs it more readily (ATSDR, 2007). While no longer considered a pathway of importance, before the banning of leaded gasoline, organic lead was absorbed directly through the skin and metabolized in the liver (ATSDR, 2007).

Figure 1-3 illustrates the correlation between leaded gasoline consumption and air Pb levels from 1974 to 1984 (ATSDR, 2007). From 1976 to 1994, midst the phasing out and removal of lead from gasoline, the blood lead levels of children in the United States decreased from 16 µg/dL to 3.2 µg/dL (Gilbert and Weiss, 2006). National Health and Nutrition Examination Survey (NHANES) estimates an average of 1.1 µg/dL blood lead concentration in children for 2009-2010. However, while less of a concern, aviation gasoline remains the largest source of lead emissions in the air (Carr et. al, 2011). In 2005, half of the national inventory of Pb emissions to air were due to leaded aviation gasoline (U.S. EPA, 2009). In aviation gasoline, 100 octane low lead is the most common and contains 2.12g of Pb per gallon (ASTM, 2005). Proximity to airports can also be considered another risk of exposure.

1.5 Pb Isotopes

While Pb isotopes are commonly described as fingerprints to trace Pb contamination, there still exists a gap in interpreting Pb-isotope ratios retrieved from local-scale fieldwork and, therefore, attributing sources of anthropogenic origin (Reimann et al., 2012). Natural background Pb-isotope ratios in soil is spatially variable and poorly documented (Reimann et al., 2012). However, the database of Pb isotopic ranges is improving with the increasing use of Pb isotopes to assess sources of Pb in the environment (Fillion et al., 2014). There are four naturally occurring isotopes of lead, three of which are radiogenic: ^{208}Pb, ^{206}Pb, ^{207}Pb; , ^{204}Pb is stable .

Activities such as ore mining and smelting, and coal and petroleum combustion can be recognized in the environment because their Pb isotope compositions tend to be distinct from other geologic materials (Lise et al., 2015).

Table 1-1 illustrates various common sources of lead and their associated $^{206}Pb/^{207}Pb$ ratios in soil as found in the literature. This ratio is relatively simple to measure via ICP-MS analysis and is chosen as the conventional method for which to unravel anthropogenic sources. The radioactive decay of ^{238}U ultimately leads to the production of radiogenic daughter ^{206}Pb, U^{235} ultimately produces radiogenic daughter ^{207}Pb, and ^{232}Th leads to the production of radiogenic daughter ^{208}Pb.

Lead, in the form of ethyl lead, was a common additive to gasoline (used as an anti-knock agent) until about 1980. This lead from gasoline emissions had a wide range in $^{206}Pb/^{207}Pb$ isotope ratios (Table 1-1), from the low ratios of Idaho ores (1.04) to the high ratios of Mississippi Valley ores (1.45) for the higher ranges (Table 1-1). A transition of Western USA lead to Mississippi Valley lead in the manufacturing of ethyl lead occurred progressively from the late 1960s to the early 1980s (Hurst et al. 1996). Once the phase-out of leaded gasoline occurred, most atmospheric emissions of lead were not related to gas emissions and the $^{206}Pb/^{207}Pb$ dropped to 1.16 by the 1990s (Bollhöfer and Rosman, 2001).

Pb-isotope signatures have been shown to change through the influence of multisource contamination, including the overwhelming effect during the 50s, 60s, and 70s of atmospheric gasoline emissions (Reimann et al., 2011; Erel et al., 1994). Because of the waxing and waning of various sources of anthropogenic lead emitted into the environment through time, specific locations have differing $^{206}Pb/^{207}Pb$ ratios (Marcantonio et al., 2001). For this reason, while testing isotopes of soil, it is important to compare it with hypothesized sources.

Table 1-1: Lead Sources (USA) and isotope ranges in literature.

Source	$^{206}Pb/^{207}Pb$ Values	Literature Source
Common Pb deposits	0.98-1.42	Sangster et al., 2000
Bedrock	1.09-2.64	Reimann et al., 2011
Background	1.1901-1.1919	Hurst et al., 1996
Soil	1.19-1.32	Reimann et al., 2008
Coal	1.126-1.252	Chow and Early, 1972
Gasoline (Mississippi Valley-Pb) Gasoline (Other)	1.3-1.45 1.040-1.390	Reimann et al., 2011 Sturges and Barrie, 1987
Mining (Tri-State Mining District)	1.210-1.360	Rabinowitz. 2005

1.6 Children's Blood Lead Levels

Children are the demographic most susceptible to and affected by lead poisoning (Flora et al., 2012; Mcclure et al. 2016). Pb exposure can occur as early as in the womb through transplacental transfer, which may be related to the concentration of Pb within the maternal skeleton (EPA, 2013). This can result in premature births or lower birth weights (EPA, 2006). During pregnancy, maternal BLL can increase as the body mobilizes lead stores (EPA, 2013) and a newborn's BLL is commonly similar to its mother's (Abadin et al., 1997). Postnatal and beyond, the most common methods of ingestion of Pb are through soil and lead paint due to the hand-to-mouth behavior of children (Malcoe et al., 2002). Galke (2001) estimates that the Pb exposure of the average two-year-old in America originates 44% from dust, 40% from food, 14.6% from water, and 1% from inhalation (Elias, 1985). Since dust levels can be influenced by soil Pb levels, soil testing is an integral part of monitoring Pb exposure (Lanphear et al., 1997; Clark et al., 2004). Some Pb-related cognitive effects may be irreversible (EPA, 2013).

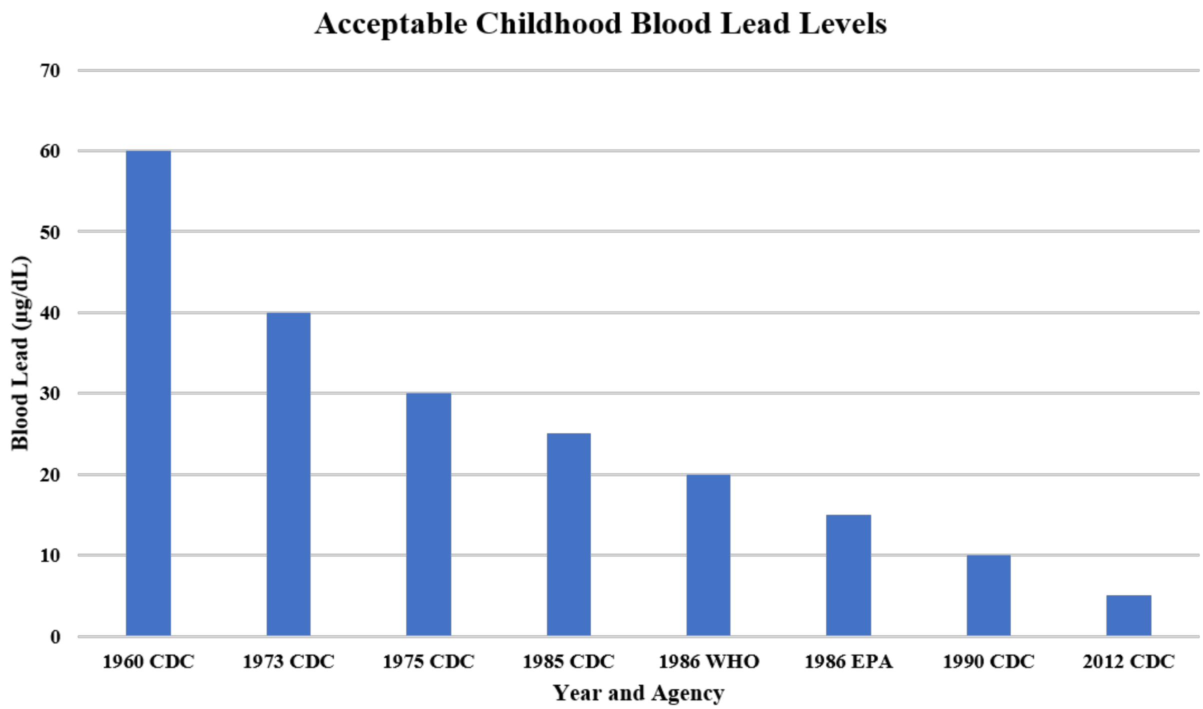


Figure 1-4: Acceptable Childhood Blood Lead Levels 1960-present (EPA, 2013)

While 85-95% of lead is stored in the cortical bones of adults, only 70% is stored in that of children with a greater percentage retained in their soft tissue (blood, liver, lungs, spleen, kidneys, and bone marrow) (Flora, 2012). The current median BLL in America is 1.1 µg/dL based on the 2009-2010 National Health and Nutrition Examination Survey (NHANES) (CDC, 2012). CDC's Advisory Committee on Childhood Lead Poisoning Prevention claims that there is no safe level has been identified. However, in 2012, BLL reference threshold adopted by the CDC was lowered to 5.0 µg/dL from 10.0 µg/dL. This new level was calculated from the 97.5th percentile of the NHANES-generated BLL distribution in children. The CDC (2012) estimates there are approximately 450,000 U.S. children with levels above this threshold. Figure 1-4 illustrates the change in acceptable BLL through the years by different government agencies. Since 1960, when the CDC first came out with acceptable blood lead levels in children, the threshold has steadily been decreasing from 60 µg/dL as more research and evidence is gathered to demonstrate the harmful consequences of blood lead levels. Changes adopted in the 1970s, specifically the removal of lead in gasoline caused a significant decrease in blood lead levels

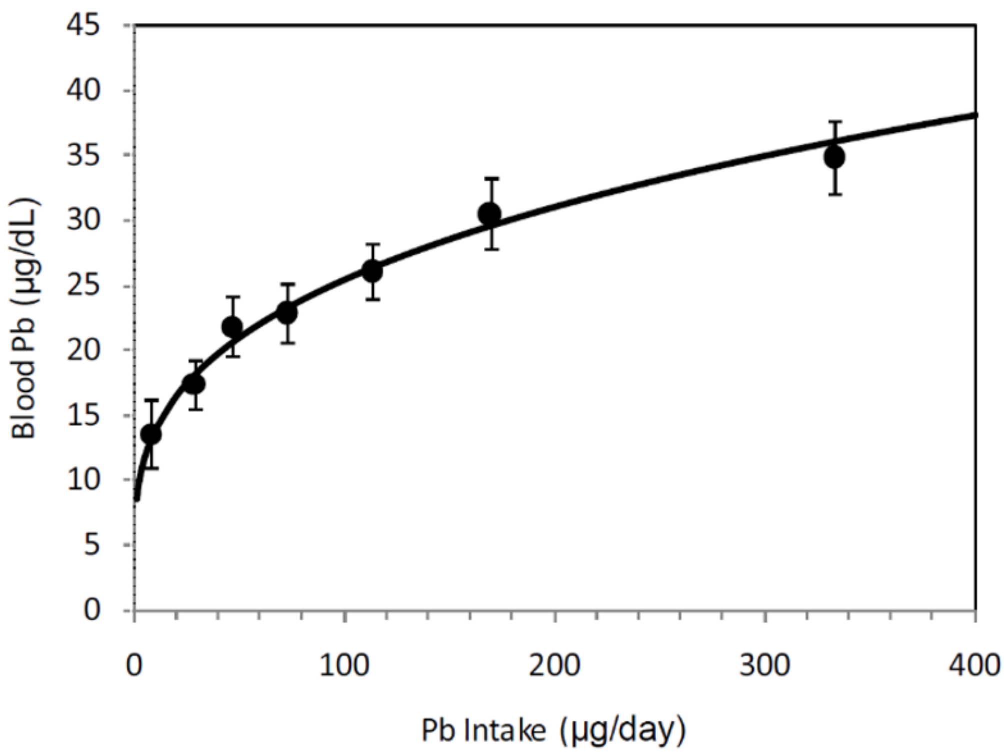


Figure 1-5: BLL and Pb intake (Sherlock and Quinn, 1986; ATSDR, 2007)
(Banner and Kahn, 2014).

Examining Figure 1-5, created by ATSDR (2007) with data adapted by Sherlock and Quinn (1986), illustrates the correlation between blood lead levels and Pb intake. The fact that Pb intake approaching 0 is correlated with blood Pb levels above 5 µg/dL demonstrates the ambiguity of sources within the environment. With lead, it is difficult to determine the lowest acceptable dosage due, in part, to the multiple sources and pathways, and the permanent effects on mental health seen at very low persistent exposure.

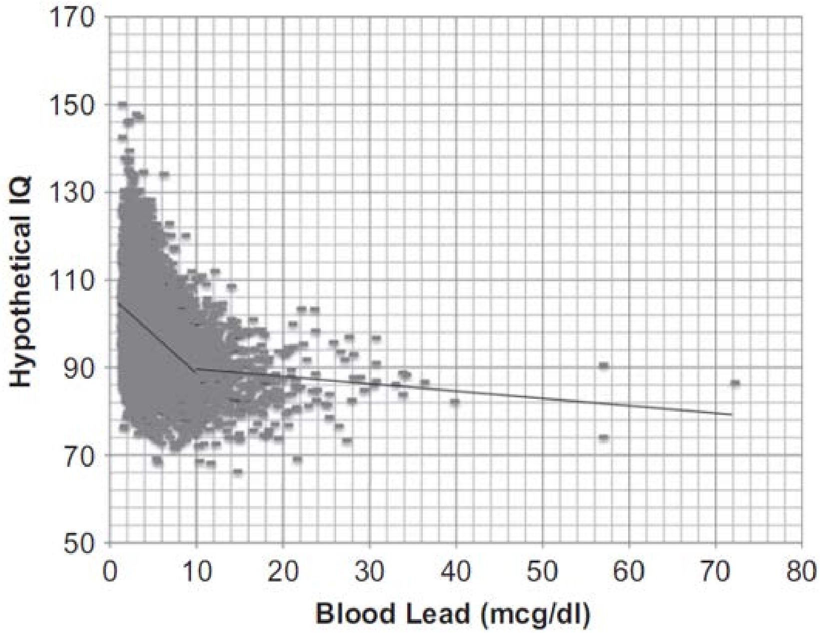


Figure 1-6: Hypothetical IQ vs. BLL (Banner and Khan, 2014; NHANES III)

A reference dose has not been established by the EPA, because health effects may be caused with BBL at incredibly low levels (IRIS, 2004). Since the CDC also declared that there may not be a threshold below which lead exposure may be acceptable, Rabito et al. (2014) tested a cohort of pregnant women with average blood lead levels under 1 µg/dL. Their results demonstrated a significant rise in material BLL from the second trimester to delivery. They found BLL below the 5 µg/dL threshold in pregnant women behaved similar to BLL at clinically significant levels. The lead in the mother was able to be mobilized and transferred to the fetus/infant which could result in damaging effects to the baby.

Gilbert and Weiss (2006) estimate that 2 µg/dL would be the lowest acceptable blood lead level where there would be no observable adverse effects for most of the population. Banner and Kahn (2014) point out how recent studies into IQ and blood lead levels illustrate that studies done at progressively lower mean blood lead levels demonstrate how the apparent slope of association increases. The current debate on acceptable blood lead levels of children is due to the evidence showing the effects of intellectual impairment occuring at levels of BLL below 10 μg/dL (Gilbert and Weiss, 2006; Lanphear et al., 2005; Canfield et al., 2003; Schwartz, 1994). Figure 1-6 by Banner and Kahn (2014) illustrate a plot of randomly generated values of IQ from the NHANES III data and blood lead levels with two simple regression lines for above and below 10 μg/dL. We can see that the slope of the IQ simple regression line is steeper for Pb levels less than 10 μg/dL relative to that for Pb levels greater than 10 μg/dL the.

Gilbert and Weiss (2006) estimate that 2 μg/dL would be the preferred BLL, because it provides a tangible goal that can be attained; a goal of 0 would likely be impossible. The lowest no observed adverse effect level (NOAEL) according to the Scientific Committee on Health and Environmental Risks (SCHER) without a drop in IQ is 5 μg/dL.

Surkan et al. (2007) did various intelligence-based tests on 534 children age 6-10 and compared them with their levels of blood lead, focusing on correlations under 6 μg/dL. The WISC[1] IQ test, WIAT[2] Math and WIAT Reading scores appear to be influenced by blood lead levels. There is an overall trend of decrease in IQ and scores as blood lead levels increase as evident by the data collected. However, the variations at 1-4 μg/dL may be indicative of normal variations within the population studied. At 5 μg/dL, there is a significant drop in IQ and scores, the largest one is from 99.57 to 84.89 in mathematics. For IQ the drop between 4 μg/dL to 5 μg/dL is 99.71, close to the mean of 100, to 91.40, over an 8-point IQ drop.

[1] Wechsler Intelligence Scale IQ Test

[2] Wechsler Individual Achievement Test

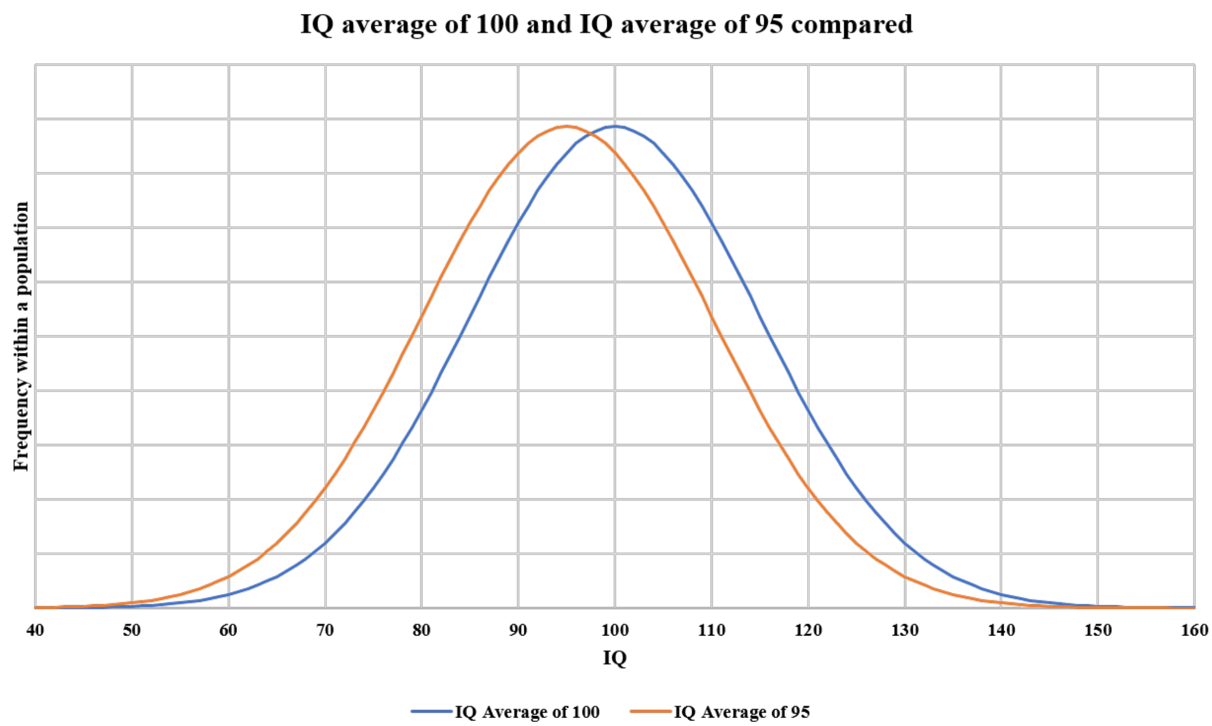


Figure 1-7: IQ bell curve analysis with a median IQ of 100 and 95 (Weiss, 1999)

Figure 1-7 was created using an IQ distribution curve with a standard deviation of 15 and belief that 100 would be the mean. Calculations were made using the NORM.DIST function in Excel, with IQ score, average (100 or 95), standard deviation of 15, and FALSE cumulative. Weiss (1999) estimated that within the bell curve about 6 million people fell under the category of mentally retarded by possessing an IQ of 70. If there were a worldwide decrease of the average IQ shifting 5 points, the rankings of those considered mentally retarded would increase to 9.4 million. These graphs show that there would be a large shift if the average IQ were to shift 5 points. Surkan et al. (2007) demonstrated an 8-point IQ drop on average with BLL of 5 µg/dL. These papers illustrate the ongoing conversation of decreasing the 5 µg/dL threshold by the CDC further.

IQ points have also been tied to monetary gains. Based on a cohort of 5-year olds, and assuming a loss of 0.25 IQ points per 1 µg/dL of blood lead, Landrigan et al. (2002) estimated the financial loss to be $43.4 billion in lifetime earnings from those affected. In 1990 the EPA estimated the Clean Air Act helped save money from a drop of IQ due to the banning of leaded gasoline. They calculated that $3,000 was lost per IQ point loss per person in economic value. This $3,000 in 1990 is equal to $5,591.50 in today's money based on the (CPI in 2017)/(CPI in 1990) * 1990 USD value. An IQ of less than 70 was estimated to be a loss of $42,000 per person ($78,280.99 in today's money). Educational, societal, and economical factors all relate to the historic and continual lowering of acceptable BLLs.

1.7 Toxicological Risk Assessment Overview

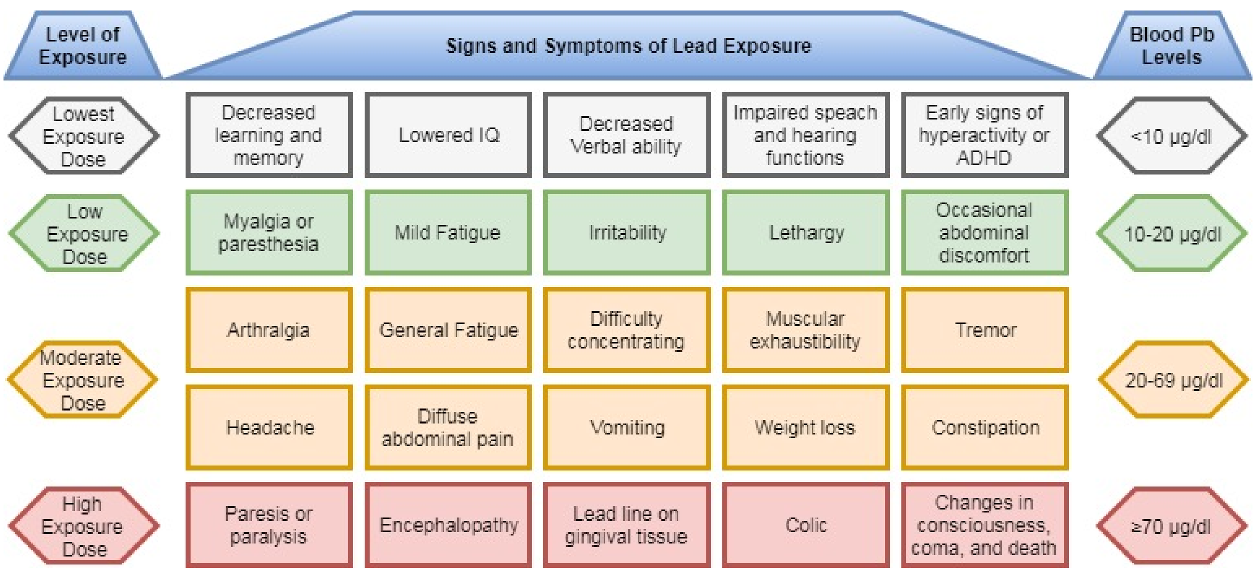


Figure 1-8: Signs and symptoms of lead exposure and levels of Pb in the blood

There are many papers published and statements from government agencies which claim that there may not be an acceptable threshold of blood lead levels (ATSDR, 2007; Rogan and Ware, 2003;). Figure 1-8, created using draw.io with ATSDR's WB 1105 course Manuel listing signs and symptoms and NHANES III levels, demonstrate the signs and symptoms of lead exposure at varying dose ranges. In rats the Lethal Dose at 50% of the population (LD50) was found to be 70mg/kg bodyweight (Rautiu et al., 2001). In a human diet it is estimated that a lethal dose would need to be approximately 10g per day in approximately 96 hours (Rautiu et al., 2001).

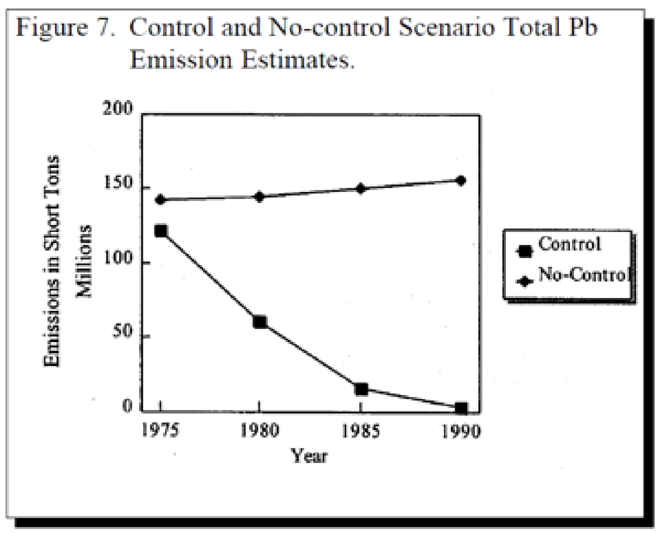


Figure 1-9: The emission of Pb with and without the EPA's Clean Air Act by the EPA's Retrospective study.

Historically, leaded gasoline accounted for the greatest risk of elevated BLL. Figure 1-9, taken from the EPA's Retrospective study from 1970-1990, illustrates two scenarios – with and without the Clean Air Act. As mentioned previously, Pb emissions from gasoline were output as organic lead, which is more readily absorbed by the human body and therefore more dangerous than inorganic lead. However, with the banning of leaded gasoline emissions, the focus has turned to lead from other sources such as leaded paint, lead in infrastructure, lead in water, lead contamination through mining/smelting, and other commercial processes. Much of this lead pollution ends up in the environment, especially in soil. Figure 1-10 was created with Mielke et al. (2007) data set of measuring 5,467 soil samples and 55,551 blood lead measurements in children in the metropolitan area of New Orleans. The correlation between soil Pb and BBL is striking. Even with 0 lead recorded in the soil, the BLL is still measured as 2.038 µg/dL indicating contribution from other sources.

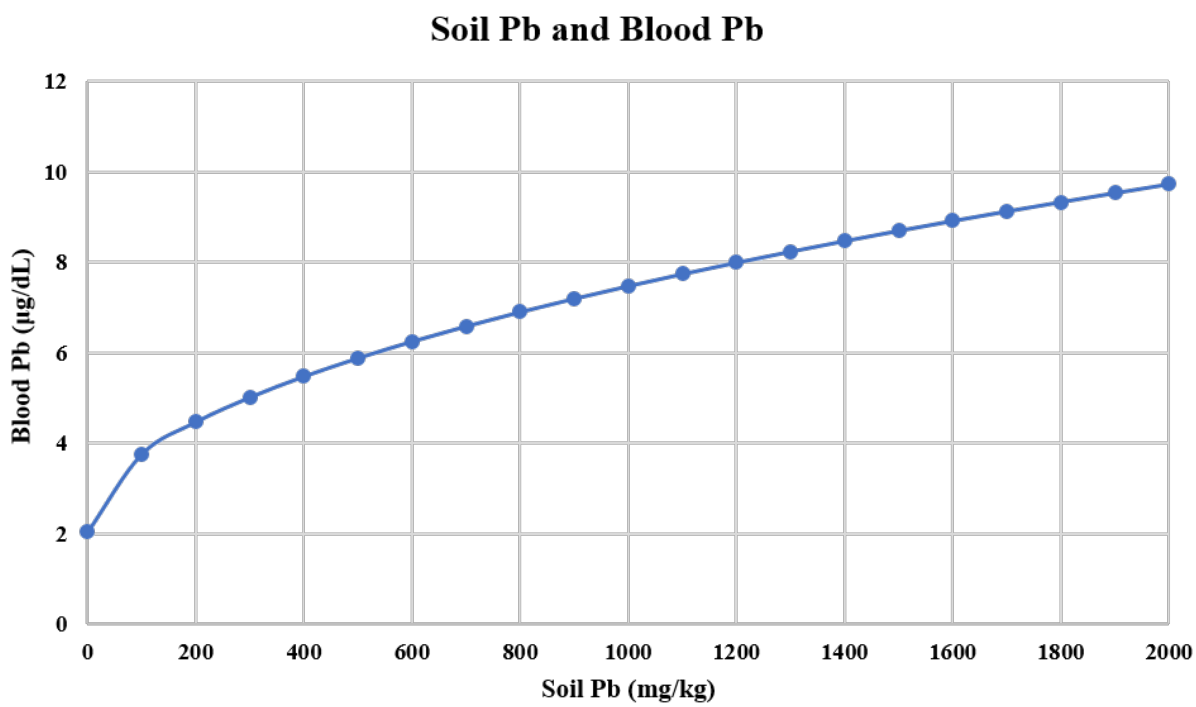


Figure 1-10: Correlation between soil lead and blood lead levels (Mielke et al., 2007)

Take home contamination from adults working in high risk fields is another factor to consider. Factory emissions, not all captured by the Toxic Release Index (TRI), is another concern. An example is from a battery factory, Exide, in Saline County, Kansas, which was found to be emitting lead and impacting local children's BLL (Thompson, 2016). The battery factory was releasing 1.45 tons of contaminants into the air in 2011; after renovations in filtration

0.35 tons was recorded in 2015. Take-home contamination contribute to exposure but is rarely addressed in risk assessments.

Chapter 2 - Background

2.1 Pb in Kansas Soils

Kansas, with its 105 counties, has many different sources of lead. In southeast Kansas, high levels of lead originate from the historic Tri-State Mining district. The eastern counties are also home to several Superfund sites, which are sites identified by the EPA as being contaminated by hazardous waste and pose risk to human health and/or the environment. In Kansas, some lead contaminated superfund sites exist such as Chemical Commodities, Inc. in Johnson County and Former United Zinc & Associated Smelters in Allen County. Western Kansas, while less developed and less populated, tends to have older homes with higher risk of leaded paint exposure. Bituminous coal deposits are found in eastern Kansas; Pottawatomie, Linn, and Douglas county have working coal-fired power plants. Central Kansas and parts of eastern Kansas have the most active oil producing counties in the state.

The importance of the Tri-State mining district, which encompasses northeastern Oklahoma, southeastern Kansas and the southwestern part of Missouri, cannot be ignored due to their historic release of toxins from smelting and mining activities (Johnson et al., 2016; Junge and Bean, 2006). In Kansas, two Pb-related superfund sites exist: one in Cherokee County due to historic mining operations (listed: 09/08/1983) and one in Sedgwick County due to sludge contamination (listed: 09/08/1983). A study of Cherokee County found that lead, zinc, and cadmium contamination was confined to the upper 2 feet of the soil profile, with most in the upper 6 inches (USGS, 2013). The mining and smelting pollution that has occurred in these areas was influenced by the geology of the region and the economic value of the ores.

In 1945, the Tri-State district was responsible for 3,334,057 tons of lead production which, coupled together with the zinc production, was valued at over a billion dollars (Martin, 1946). Hagni and Grawe (1964) considered the ore deposits in the Tri-State to be outstanding due to their lack of association with igneous rocks, areal extent, and shallow occurrence in the crust. All mined ore deposits are less than 475 feet from the surface, making them easy to retrieve (Hagni and Grawe, 1964).

Kansas also has a history with oil and drilling. The first oil well in Kansas, which was the second in America, was drilled in 1860 in Paola city in Miami County. Data from 2018 show that 470,045 wells on record have been drilled since then. In 1873, with gas discovered near Iola county, large industrial complexes of various foundries, plants and smelters were developed in southeastern Kansas all due to the cheap wells (Merriam, 2011). By 1982, drilling depth increased and exploration moved west towards the Cherokee Basin and then to the Nemaha Anticline (Merriam, 2011). In 1916, Kansas was the top state in the union for oil production. Oil was discovered in Ellis on Phillips Ranch in 1936, which helped the local economy after the Great Depression (KSHS, 2018). By 2011, Kansas fell to tenth in national oil production and has been declining since then. According to Kansas Geological Survey, many of the oil wells in Kansas are strippers (wells nearing the end of their economically useful life); however, they still produced about 26,987,203 bbls in 2017, down from a high of 49,504,847 in 2014.

With the assistance of ATSDR's region 7 regional director, Dr. Spencer Williams, two counties of interest were selected for this study: Barton and Ellis counties. Both are located in central Kansas, far removed from most smelting and mining sites, but are active oil producers. The counties selected for fieldwork are located within the Central Kansas Uplift.

2.2 Socioeconomics in Ellis County

According to the population 2010 census, Ellis county has a population of 28,452 with the city of Hays having 20,510 people. Hays contains 74.5% of the homes within Ellis county, 69.7% of which were built before 1978. In Hays the top employers are Hay's Medical Center (1235), Fort Hays State University (1000), USD 489 school district (775), and local government (427). Figure 14, created from data provided by the Ellis County Coalition for Economic Development (ECCED, 2018), highlights the jobs in Ellis County from major employers. Highlighted in yellow is an example of oilfield supply manufacturer and sealed lead battery manufacturer. The oilfields are primarily located in the north part of the county and east of Hays. The lead battery manufacturer is found approximately 4 miles north west of Hays.

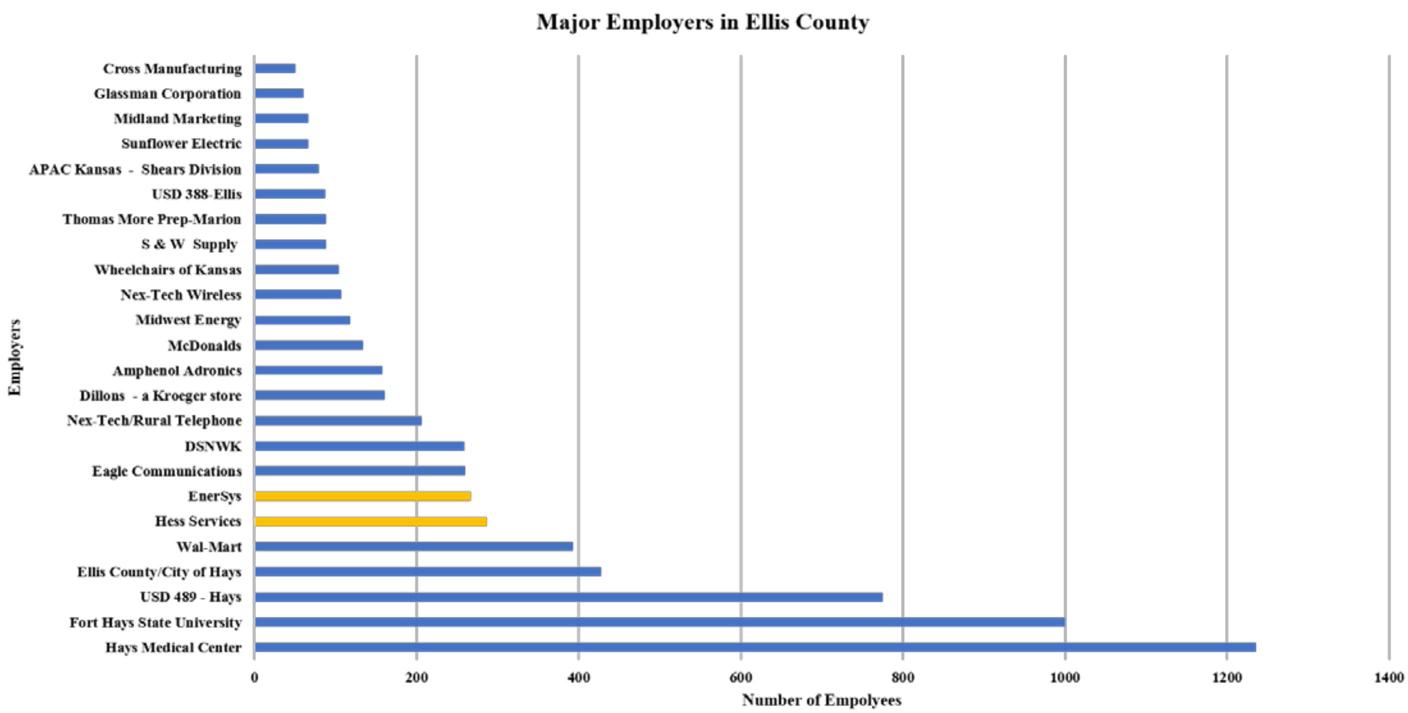


Figure 2-1: Major employers in Ellis County: Ellis County Coalition for Economic Development (haysamerica.net)

According to the United States Census Bureau (2016), 90.1% of the population is white, 1.1% black, 0.4% American Indian or Alaskan Indian, 1.7% Asian, 0.1% Native Hawaiian, 5.6%

Hispanic or Latino, and 1.5% mixed. Of the population over the age of 25 years old (2012-2016), 93.3% have graduated high school or are pursuing higher education, with 34.1% having a bachelor's degree or higher. 7.4% of the population under the age of 65 years old lives with a disability (2012-2016. The median household income in 2012-2016 in 2016 dollars was $50,140 with 12.4% of the population in poverty.

2.3 Socioeconomics in Barton County

According to the population 2010 census, Barton county has a population of 26,775 with the city of Great Bend having 15,349 people. Great Bend contains 65% of the homes within Barton county, 87.1% of which were built before 1978. In Great Bend, the largest city in Barton County, some of the top employers are in education (600+ in USD 428, and 500+ in Barton Community College), utility (500+), retail discount (300-500), medical services at the regional hospital (300-500), pension (250+), wire manufacturing (250+), manufacturing (150-225), agriculture/livestock (150-225), and asphalt road construction (150-225). Barton has a greater focus on agriculture than Ellis county, with 694 farms located in 566,088 acres with $278.96 million in crop and livestock sales in 2012 according to the USDA 2012 Census of Agriculture. The employment in the oil and gas fields is lower in comparison to Ellis county, with only an estimated 50-100 people employed in oilfield service at two different companies.

According to the United States Census Bureau (2016), 81.6% of the population is white, 1.9% black, 0.9% American Indian or Alaska Native, 0.3% Asian, 0.1% Native Hawaiian, 14.7% is Hispanic or Latino, and 1.8% are mixed. Of the population over the age of 25 years old (2012-2016), 86.8%have graduated high school or are pursuing higher education with 16.7% having a bachelor's degree or higher. The proportion of the population living with disability under the age of 65 years old (2012-2016) is 8.7%. The median household income in 2012-2016 in 2016 dollars was $44,449, with 13.9% of the population in poverty.

Great Bend is also home of the Plating, Inc. Superfund Site, which was a former chromium and zinc plating facility.[3] During the coating process metal plating and polishing can emit cadmium, chromium, lead, manganese and nickel (DTSC, 2011). It was found culpable of improper operations and waste management between 1968-1989. The company contaminated groundwater, soil, and buildings with chromium. Cleanup is currently ongoing.

[3] https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0705326

Chapter 3 - Methods and Materials

3.1 Sample Collection and Processing

The samples for Ellis County and Barton County were collected over 10 days, during the weekends from May-July 2017. Weekends were chosen due to the likelihood of people being home. One day involved distributing flyers (Figure 3-1), to mailboxes and speaking with people directly about the research.

Figure 3-1: Flyers handed out to inform residents of the research

The following weekend I knocked on people's doors, explained my research, and requested samples of soil, paint testing of the façade of the house, and installation of Victor Roach/Insect Pheromone Traps M327 to catch cockroaches. The roach traps were later removed from the research due to insufficient laboratory resources, scheduling conflicts and time constraints. Some residents were welcoming, many hesitant to associate their addresses with this research, and some refused to sign off on paperwork. For this reason, nowhere in this paper do the raw data of the residential addresses appear. This information may be obtained through a written request to Professor Saugata Datta of Kansas State University. Some factors precluding perfect grid-like sampling include: refusal to allow permission due to disinterest or distrust, not home, vacant lots, and language barriers.

Homes which did allow sampling also dictated where sampling was preferred so not all parts of a home could be sampled. A single GPS point was taken using a Garmin etrex 10. Houses were allocated into the following sample types: backyard, front yard close to house, front yard close to road, garden, drip zone, and side yard. Each type, if sampled, was sampled in the four corners and center at a depth of 6 inches, unless otherwise marked. A depth of 6 inches was chosen, as this adheres to EPA's SoilShop lead testing recommendations. The measurement of each hole was taken with a ruler. The samples were mixed in a pre-cleaned bucket for one minute and placed into 4x6 in polyethylene zip bags for storage. Paint chips were collected, if available, near the drip zone areas of the house. Some owners allowed the paint to be tested with 3M LeadCheck Instant Lead Test Swab kits. Some sample locations were spatially clustered, this was partially due to neighbors being out for yard sales or children playing outside and an interest led to multiple people allowing sampling of their property. Freely provided information was recorded: whether children were present, visible toys, style of the house, and relevant information residents said (such as remodeling or repainting plans).

To avoid cross contamination per area, four different buckets and six different gardening tools were used. Each was cleaned with alconox, rinsed with distilled water (DIW) twice, and dried with paper towels between each sample. Storage containers were used to properly dispose of the liquid on return to the laboratory – nothing was dumped on the streets.

In total, 40 homes were visited with 86 samples collected. In transit, samples were stored in a cooler, and in the laboratory, they were stored at approximately 5°C until they were air dried. Thirty to forty grams of each sample were placed in plastic 46mm base diameter weighing boats on paper plates and loosely covered with another plate to air dry for about a week. After air drying, a wooden roller was used to disaggregate the clumps of soil and tweezers were used to remove any visible organics such as twigs or grass. The disaggregated sediment was sifted with a brass, U.S. Standard Size No. 10 sieve to remove particles > 2mm. The <2mm fraction was used for most analysis. The same procedure was followed for total organic carbon and XRD preparation. The eight samples chosen for isotope analysis were dried for four days in the oven at 50°C.

3.2 Soil pH, Alkalinity, and Total Organic Carbon

All samples had their pH tested with a handheld pH probe. Samples were prepared with a 1:2 mix of dry soil to deionized water and mechanically shaken with a MaxQ™ 2508 Dual Action Orbital Reciprocating Shaker for 4 hours.

Total alkalinity was tested for the eight specified samples using the Total Alkalinity Titret® Kit. The samples were prepared with 1:5 dry soil to water, mechanically shaken for 12 hours and left to rest for 24 hours. 20mL of water was used from the samples. A-98000 Activator Solution was added, stirred until green, then tested with the Titrettor until the solution inside went from clear to pink to green. Alkalinity is expressed in mg/L calcium carbonate ($CaCO_3$).

Approximately 5 grams of the eight selected samples were dried and grounded with an agate pestle and mortar and submitted to the Soil Testing Lab at Kansas State University. The eight samples were tested for Total Organic Carbon by using the Walkley-Black procedure by digesting 1 g of prepared soil with sulfuric acid and dichromate with a direct colorimetric measurement of the reduced $Cr_2O_7^{2-}$ ion (Brown, 1998).

3.3 Particle Size Analysis of Soil Samples

Particle size analysis (PSA) was done on a Malvern Mastersizer 3000 laser diffraction particle size analyzer with a Hydro EV wet dispersion accessory in the Geography Department of Kansas State University. The preparation began with 0.5g of air dried sample placed in a 50 mL centrifuge tube where 1mL 30% hydrogen peroxide and 5mL of DIW were added to the tube. The samples were left to react until rapid effervescing stopped which usually took approximately 5 minutes. Once the reaction stopped, the tubes were filled with deionized water to a volume of 30mL. The tubes were then placed in an 80°C water bath until all bubbling ceased. This took approximately 12-15 hours, depending on the sample batch. Samples were removed and cooled to room temperature before being washed with deionized water and centrifuged at 6000 rpm for 2 minutes. The supernatant liquid was carefully poured off to avoid disturbing the solid particles at the bottom of the centrifuge tube. This process was repeated three times. Deionized water was then added to the tubes to return the total volume to 30 mL. The PSA was conducted with the propeller on the wet dispersion accessory set at 1500rpm. After the tube was agitated for 15 seconds a pipette was used to extract a 1-2mL representative sample which was then analyzed by the Malvern Masterszier 3000. Particle size data are originally reported as “% by volume” by the Mastersizer software and then converted to “% finer than” for the final reported values.

3.4 X-Ray Fluorescence Analysis of Soil Samples

X-Ray Fluorescence (XRF) analysis allows us to retrieve elemental concentration data reported in weight percent. Since moisture content and aggregates alter the soil matrix for which the XRF is calibrated, the samples must be dried and homogenized (Kodom et al., 2012, EPA, 1998). After samples were air dried for 7 days, ~4g was grounded down to a fine powder and placed in a small plastic Chemex® XRF sample cup with one end covered by a 4μm thick Prolene® film. To avoid cross-contamination, each sample was carefully identified with a specific I.D. code and kept separate from other samples at all stages of sample preparation and analysis, beginning with field collection and including, air drying, pulverization, and loading into the sealed XRF sample cups.

Two XRF machines were used, the Bruker Tracer III Handheld X-Ray Fluorescence and the Niton XL3t Handheld X-ray Fluorescence Analyzer. The Niton XRF, from the agronomy department, was calibrated specifically for lead and used to determine lead mg/kg. The NIST 2711A and RCRA 180-436 standards were used with those runs. In the interest of time using a borrowed machine, these samples were run three times each.

The Bruker Tracer III Handheld XRF was used to determine the bulk elemental composition. The Bruker mudrock calibration was used with the Woodford RTC-WS-220 standard and the NIST 2711A standard. Each sample was analyzed for trace elements (Co, Ni, Cu, Zn, Ga, As, Rb, Sr, Y, Zr, Nb, Mo, Ba, Pb, Th and U), with a yellow filter (12 mil Al + 1 mil Ti) at 40kV and 12.4 μA for 120 seconds. Majors elements (Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn and Fe) were analyzed with no filter at 15kV and 25 μA for 180 seconds with a vacuum pump. Each sample was analyzed six times at different spots by rotating and moving the sample with the results being the average.

3.5 Bulk Digestion and HR ICP – MS, and Isotope Analysis of Eight Soil Samples

Of the 86 samples, further analysis was performed on eight samples (Table 3-1). These eight samples were chosen randomly from samples in four groups defined on the basis of Pb concentration: >1,000mg/kg, >300 mg/kg, >100 mg/kg, <100mg/kg. Five of these samples originated in Barton county and three in Ellis county. These samples were prepared in the Geology Department of Kansas State University but digested and analyzed at Texas A&M University.

Table 3-1: Information on the eight samples chosen for further analysis.

Sample I.D.	**Sample County**	**Pb (mg/kg)**	**Pb Error (mg/kg) - 2σ**	**Sample Location**
GB-2D	Barton	2046	51	Drip Zone
GB-4B	Barton	3909	74	Drip Zone (top)
GB-3B	Barton	339	21	Near Washing Machine, backyard
H-16A	Ellis	322	19	Front Yard
H-14C	Ellis	133	13	Front Yard
GB-8A	Barton	114	12	Front Yard (Close to house)
H-13A	Ellis	97	11	Drip Zone (top)
GB-6A	Barton	91	11	Front Yard

In the Texas A&M laboratory, ~ 0.05g of dried homogenized sample was placed into a beaker where 1ml of peroxide was added at room temperature. After the contents of the beaker stopped effervescing, the beaker was placed on a hot plate set at 190°C. Then the beaker was cooled and 1 ml of perchloric acid was added. The temperature was reduced to avoid fast reaction and spilling. In approximately half an hour the effervescing stopped and 1 ml of HNO_3 was added and the temperature was raised back to 190°C. After dense white fumes appear, the beaker was capped and left to reflux for about 40 minutes. Then the caps were removed and 2ml of hydrofluoric acid was added until white fumes appeared, and the beaker was covered again. The last step was repeated until the solution remained clear; in total 6 ml of HF was added to all samples. After the solution cleared, the beakers were left uncovered until most of the liquid evaporated at 190°C. Once a thick residue remained, 1 ml of nitric acid was added, and the solution was transferred to a 50 ml centrifuge tube. Milli-Q water was used to rinse the beaker of all residue into the centrifuge tub and extra milli-q water was added until the solution reached 50 ml. The samples were diluted further until a 25000 dilution was reached. Samples were fully digested and partially digested; the partially digested samples did not have HF or perchloric acid added. All samples were then analyzed with an Inductively Coupled Plasma-Optical Emission Spectrometer. The raw data from the mass spectrometer is in counts per second and the mass spectrometer software gives the concentration if a series of known external standards are used. Five different standards were used during the procedure to get a linear regression line which gave the concentration for the field samples. Isotopes were measured through the raw data taking into account the abundance and interferences.

3.6 X-Ray Powder Diffraction Analysis of Eight Samples

The eight samples previously discussed were chosen for X-Ray Diffraction (XRD) analysis. These samples were analyzed with a PANalytical Empyrean X-Ray Diffractometer, using a PIXcel 3D scanning line detector. Approximately 3-4g of the <3mm fraction of the air dried, sieved sediment was ground to a fine powder (~50μm) with an agate mortar and pestle. The mortar and pestle were cleaned between uses with a double rinse of DIW followed by alcohol and a wiped down with Kimwipes. The sediment was then frontloaded and packed firmly into a 27mm sample holder mounted into a spinning sample stage and rotated at 4rpm. Peak data for each sample were analyzed using Highscore Plus® software. The purpose of this analysis was to identify whether the lead present was complexed with carbonate (cerussite) or sulfate (anglesite). According to Lindsay's (1979) analysis of lead solubility, $PbSO_4$ (anglesite) is the most stable below pH 6 and $PbCO_3$ (cerussite) is the most stable at higher pH values. For lead carbonate, Keisch (1971) paint analysis XRD set up was used and for lead sulfate Sajadi (2011) was used. X-rays were generated with a Cu tube and Ni-filter at a setting of 45kV, 40mA, through a rage of 2.5° to 70° (2θ).

3.7 Geospatial and Statistical Analysis

Data gathered for large scale analysis were procured through various sources. The addresses of all residential houses in Kansas and their housing age was collected by calling each county's Register of Deeds office, Housing Authority, Housing Department, Property Tax Department, or the Assessor's office. Most data were provided in tab-delimited files, Jackson County provided an SQL file from which necessary data were extracted. Some counties charged for their services whereas others waived fees. Most fees ranged from $20-$75. All counties required a "Request Pursuant To Kansas Open Records Act" form. These data may be requested from the Kansas State University Geology Department but will not be made public in this thesis.

```
>>> import httplib
import urllib
import csv
import json
with open('E:\Thesis Pieces\Mapu\Excel\EllisF.csv', 'r') as csvinput:
    with open ('E:\Thesis Pieces\Mapu\Excel\EllisLL.csv', 'w') as csvoutput:
        writer = csv.writer(csvoutput)
        for row in csv.reader(csvinput, delimiter=' '):
            if row[0] == "Address":
                writer.writerow(row+["Latitude", "Longitude"])
            else:
                addr = row[0]
                encoded_addr = urllib.quote(addr)
                conn = httplib.HTTPSConnection("maps.googleapis.com")
                conn.request("GET", "/maps/api/geocode/json?address=" + encoded_addr)
                response = conn.getresponse()
                response_body = response.read()
                geodata = json.loads(response_body) # string of characters to a hash (dictionary)
                if response.status== 200 and geodata["status"] != "ZERO_RESULTS":
                    lat = geodata["results"][0]["geometry"]["location"]["lat"]
                    lng = geodata["results"][0]["geometry"]["location"]["lng"]
                    writer.writerow(row+[lat,lng])
                else:
                    writer.writerow(row + ["N/A", "N/A"])
```

Figure 3-2: Python code written to retrieve latitude and longitude values

The latitude and longitude values were retrieved by the python code created specifically for these files (Figure 3-2). Specific point values were used to map the data for Ellis and Barton Counties.

Many of the government websites have undergone changes in the last year due to changes in political agenda. While the Toxic Release Inventory (TRI) has changed formatting, it still feeds into the National Air Toxics Assessment (NATA), however, due to time constraints this data was not mapped but it is available for download on the epa.gov website. Census data about population, ethnicity, local economies, healthcare, and socioeconomics were gathered from census.gov/data.

Blood lead level data and surveillance data were provided by Kansas Department of Health at the county level. A BEPHI RD-1 Data Request Application Rev. 5/2014 was filled out with specific instructions on how the data would be used. These data will not be provided in the appendix to uphold privacy agreements. All data used for analysis in this thesis will be displayed as percentages. The data may be gained by interested parties by going through KDHE's application process.

Numerical oil field data are available from the Kansas Geological Survey at kgs.ku.edu. The point data of each drilling well location was retrieved from Drilledge.com which supplies information on wells, leases, permits, operator details, production data, and well logs. Conmanche County has no oil data. In total, 470,045 total data points were recorded in Kansas.

Well types were allocated as:

- CBM (Coalbed methane wells)
- D&A (Dry and abandoned)
- EOR (Enhanced oil recovery)
- GAS (gas well)

- INJ (injection well)
- Intent (intent to create a well)
- LOC (location, status unknown; or location never drilled)
- O&G (Oil and gas)
- OIL (oil well)
- Plugged and Abandoned
- SWD (Saltwater disposal)

Certain points were disqualified from consideration for either being “Blank” or a subsect of “Other” status. The following categories were available under well types:

- Active Injection (2)
- Approved for plugging – CP – 1 (2,230)
- Approved intent to drill (38,436)
- Authorized Inj Well Split From (165)
    - All are EOR
- Authorized Injection Well (16,027)
- Cancelled API Number (1905)
- Converted to EOR Well (8,260)
- Converted to Producing Well (1,473)
- Converted to SWD Well (3,378)
- Development (23)
- Expired Intent to Drill (C-1) (17,620)
- Expired Plugging Application (5)
- Inactive Well (14,837)

- Injection Authorization Terminated (1,714)
- Injection Well Split to another (550)
- KCC Fee Fund Plugging (10,596)
- On List (5,401)
    - Under KCC review
- Pending Injection Application (4)
- Permitted Well (2)
- Plugged and Abandoned (217,608)
- Producing (83,427)
- Recompleted (11,742)
- Re-Plugged (non Fee-fund) (52)
- Special (3)
- Spudded (6,583)
- Temporarily Abandoned (1)
- UIC Application Denied (21)
- UIC Application Dismissed (242)
- UIC Application Withdrawn (243)
- Unknown (58)
- Unplugged Former Injection Well (494)
- Well Drilled (5,546)
- Wildcat (3)
    - Exploration oil wells drilled in areas not known to be oil fields
- Blank (21,407)

From the complete list the following were combined and used in mapping and geospatial analysis:

- **Inactive** (245,321)
    - Approved for plugging – CP – 1 (2,229)
    - Inactive Well (14,836)
    - KCC Fee Fund Plugging (10,596)
    - Plugged and Abandoned (217,608)
    - Re-Plugged (non Fee-fund) (52)
- **Active** (93,158)
    - Converted to Producing Well (1,472)
    - Converted to EOR (8,259)
    - Producing (83,427)
- **Spudding** (6,582)
    - Spudded (6,582)
- **Possible Future Drilling** (43,837)
    - Approved intent to drill (38,436)
    - On List (5, 401)
- **Injection wells** (15,428)
    - Authorized Injection Well (15,426)
    - Active Injection (2)
- **Other Well types** (15,119)
    - Converted to SWD Well (3,377)

- Recompleted (11,742)

Points were eliminated which would not become wells, were not classified as petroleum related wells, were blank, and those without enough information. In total, 419,445 points were considered out of 470,045. The master list used by KGS has a total count of 430,989 wells out of 481,309 points as of 2017. KGS tally a total of 69,023 producing oil wells and 24,294 gas wells in Kansas while the master list I used in this thesis has 61,072 producing oil wells and 15,208 gas wells. Variability may be accounted through the different categorical descriptions.

Hotspot maps were created in ArcGIS's ArcMaps with point density function with an output cell of the default 0.1600008004 and a radius of 1 map unit in a circle. Housing age maps were generated using spreadsheet data of each county and the points data were used only for Ellis and Barton county analysis. All county level data were entered in a cb_2015_us_county_500k shapefile from the United State Census bureau shapefile database. Oil data points and residential housing points distance from oil points and residential homes was

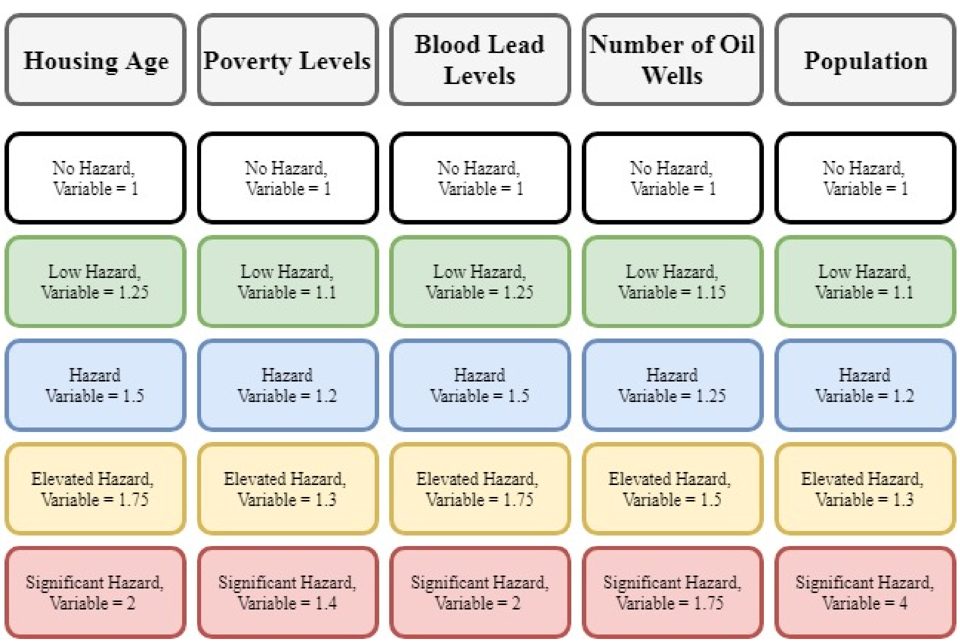


Figure 3-3: Variables used in creating a risk assessment map

estimated with the Generate Near Table which calculates distances between features in one or more feature class or layer.

The risk assessment map was created with variable values described in Section 4.6 (see below). The main variables examined for each county are: Housing Age, Poverty Levels, Blood Lead Levels, Oil Well Numbers and Population. The variables were subdivided into five levels ranking from low hazard to high hazard; incremental increases in values were given based on correlation coefficients and literary review of importance (Figure 3-3). For example, housing age has the highest risk for children and therefore had a large variable increase between the levels (1, 1.25, 1.5, 1.75, 2) from low to high percentage of houses built pre-1978. Population was included as research has shown that non-mining cities are affected by city size and the urban location as well as the age of surrounding housing (Wixson and Davies, 1993). Children in poverty tend to have poor nutrition (Miller and Korenman, 1994). The nutrition of the child impacts bioavailability and poverty in this risk assessment takes the place of measured nutrition. Children living in counties with elevated BLL may be at greater risk of exposure. Take home exposure from oil field workers or the travel of heavy metals in the installation of oil rigs may increase the risk of exposure (Khan, 2011).

All low/no hazard values were placed at 1, which means a multiplication of that variable would not change the risk. Increased ranking levels increased the risk of the county. Each county has varying levels of hazard for each variable and the multiplication across these five variables yields a risk assessment map created in Section 4.9.

Chapter 4 - Results

4.1 Field Observations

Most people who participated in the research study were families, identified as having children present during sampling or toys visible on the property (Figure 4-1). Many single adults who assisted appeared to be attending college or recently graduated. Multiple adults were identified as retired couples or adult roommates living together. If an elderly couple lived together and had no evidence of children and/or confirmed that children do not visit, they were categorized as "multiple adults".

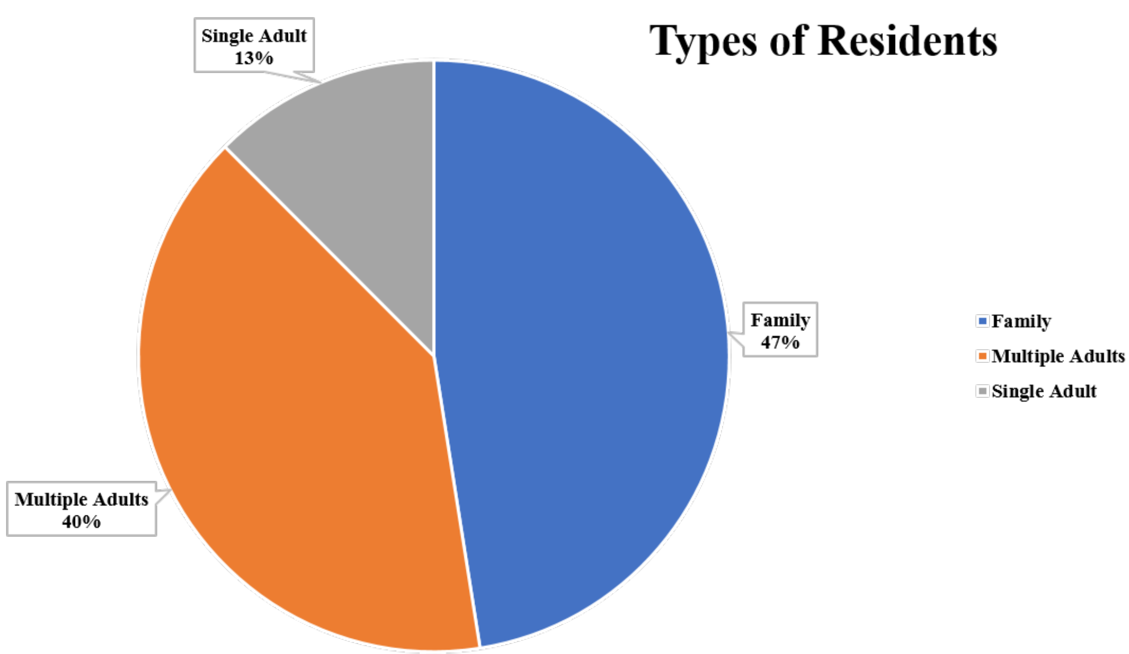


Figure 4-1: Types of residents who allowed sampling on their property

Appendix A contains the list of age of housing per county. The average build year of the homes sampled was 1940. Some risk bias exists due to the possibility of houses being old but being made of brick and therefore not having leaded paint. Houses that have been remodeled or demolished and rebuilt did not have their build year updated.

Approximately 21% of the samples were gathered at drip zones, 5% of samples were from gardens in private use, the rest were taken from front yards, side yards, and backyards. Great Bend city has front yards which are divided by a sidewalk (Figure 4-2) and therefore some front yards were subdivided to “close to the road” or “far from the road”. There was no noticeable difference between the lead close to the house or far from the house on the XRF.

Figure 4-2: Shahid Akhter assisting in soil collecting from a residential home in Great Bend

4.2 pH, Alkalinity, Total Organic Carbon, and Total Nitrogen

The average pH in the Great Bend samples is 7.43 ± 0.28 (1σ, n = 45). The soil samples in Hays are more basic, i.e. pH of 7.70 ± 0.32 (1σ, n = 41). While both soils are slightly alkaline they are within average ranges of expected soil pH (4-10). There is no visible relation between pH and Pb concentrations in the fieldwork samples (Figure 4-3).

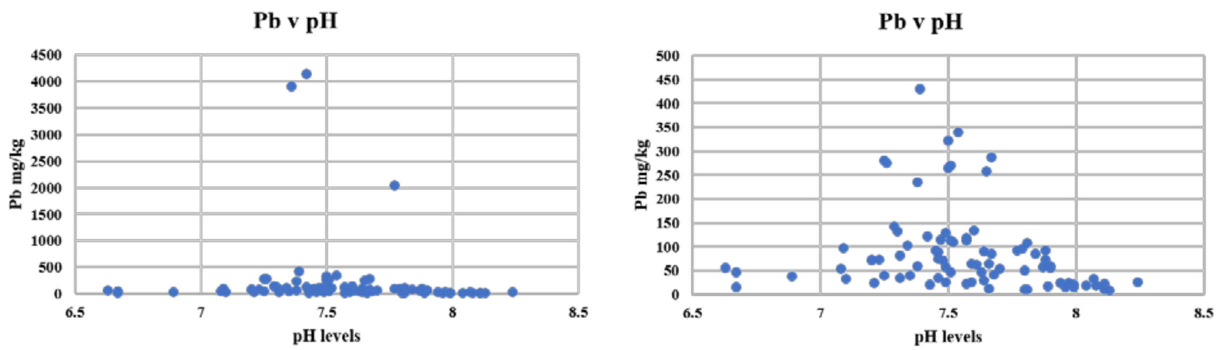


Figure 4-3: Pb concentrations vs pH graphs. The graph on the right eliminates the top 3 Pb readings.

The eight selected samples were also tested for total organic carbon, total nitrogen, and alkalinity shown in Table 4-1, which also includes their specific pH values. Alkalinity is expressed in mg/L calcium carbonate ($CaCO_3$).

Table 4-1: pH, alkalinity, total organic carbon, and total nitrogen for eight specific samples.

	Pb mg/kg (XRF)	pH	Alkalinity in mg/l	Total Organic Carbon (%)	Total Nitrogen (%)
GB-2D	2046.3	7.8	150	3.3	0.3
GB-3B	339.5	7.5	225	4.8	0.2
GB-4B	3909.7	7.4	200	6.3	0.5
GB-6A	91.9	7.5	210	3.1	0.3

GB-8	114.6	7.5	275	3.0	0.3
H-13A	97.6	7.6	275	3.3	0.3
H-14C	133.4	7.6	300	2.2	0.3
H-16A	322.3	7.5	250	4.6	0.4

4.3 Results from Particle Size Analysis on Soil Samples

PSA was conducted on all samples. Comparing samples from Hays with those from Great Bend, we can see that the samples collected from Great Bend tend to have courser sediments (Figure 4-4). Great Bend samples also have the top five highest Pb concentrations recorded.

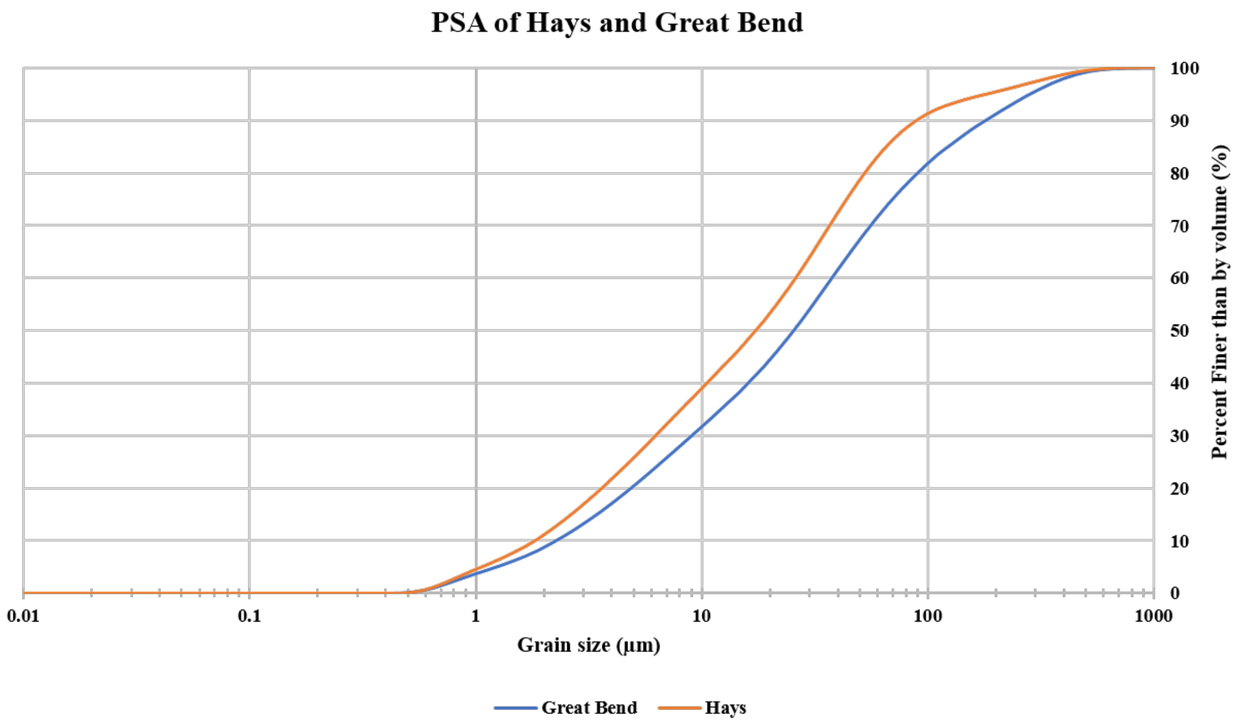


Figure 4-4: Cumulative particle grain size of Hays and Great Bend

When comparing the 20 samples with the highest Pb concentrations with the samples with the lowest Pb concentrations, we see that the higher Pb levels correlate with coarser soils (Figure 4-5). However, Figures 4-6 and 4-7 show that there are no obvious trends in Pb concentration with percentages of silt, sand, and clay. The y axis goes from lowest to highest Pb concentration and the silt, sand, and clay percentages do not change significantly with rising Pb concentrations. Research has shown that particle size influences Pb absorption (Wuana and Okieimen, 2011). Pb tends to be enriched in clay-sized fraction (Wuana and Okieimen, 2011; Lu et al., 2003). Therefore, most of the Pb in samples with elevated Pb, such as H-16A and GB-2E, would probably occur in the clay fraction. We expect any Pb in the sand fraction to be desorbed Pb (Margrisso et al., 2009).

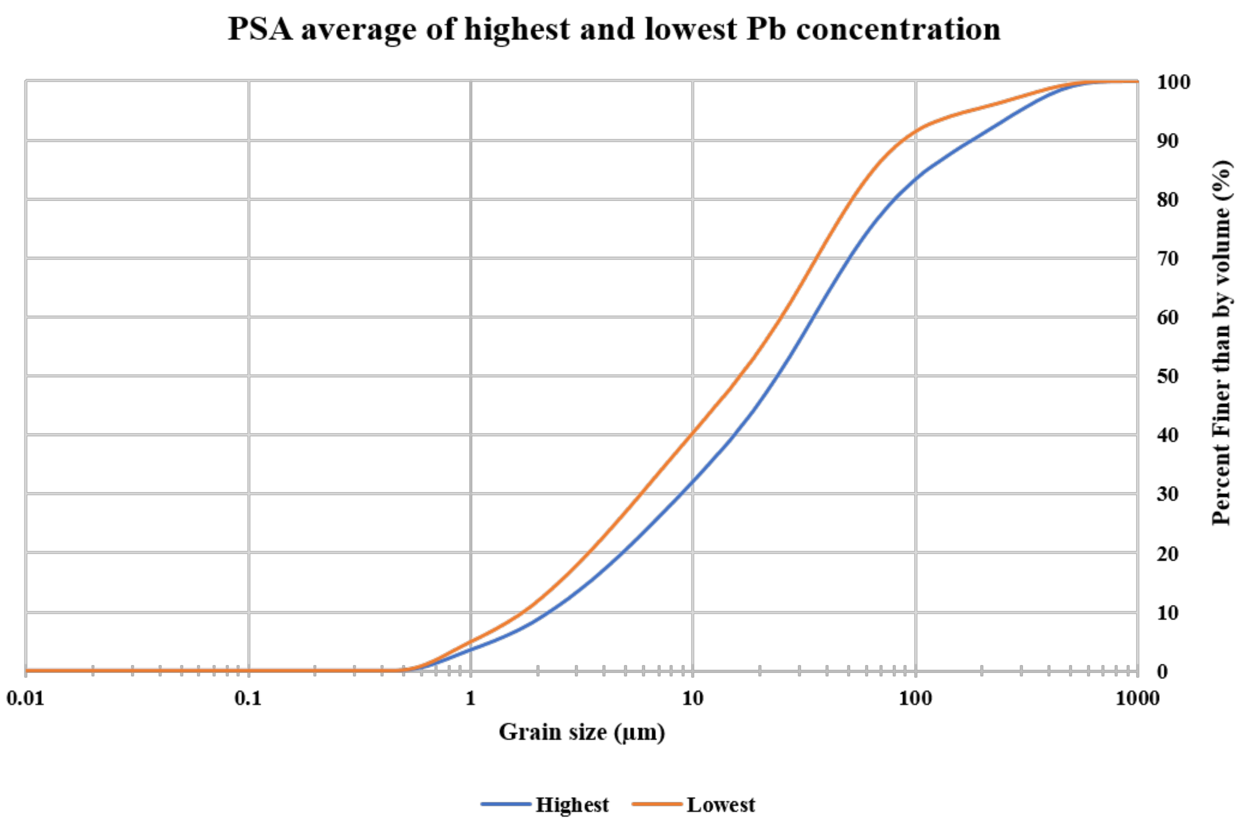


Figure 4-5: Particle size of the highest 20 and lowest 20 Pb concentrations

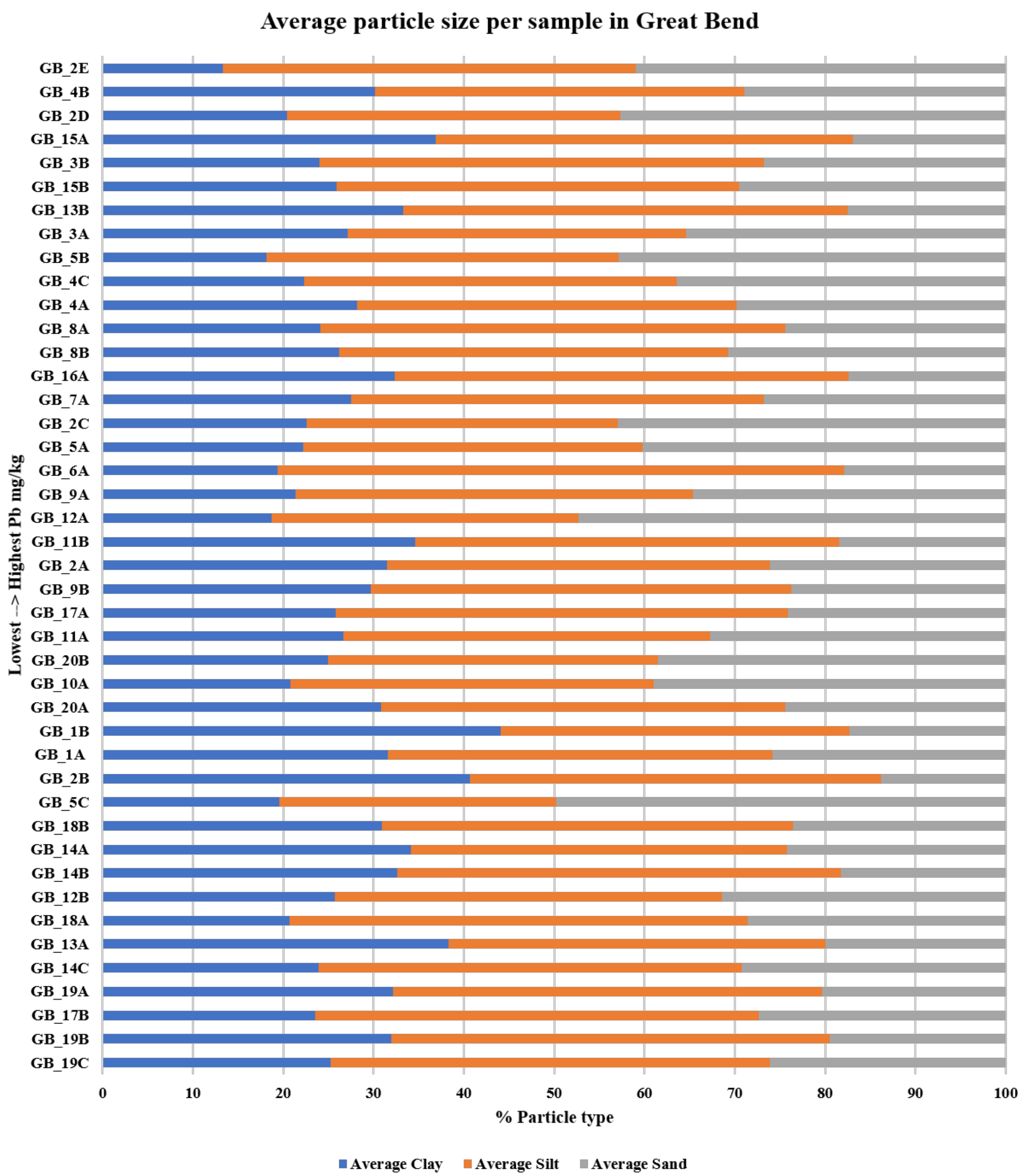


Figure 4-6: PSA in Great Bend; samples organized by Pb concentration with highest concentration samples at the top and lowest concentration samples at the bottom

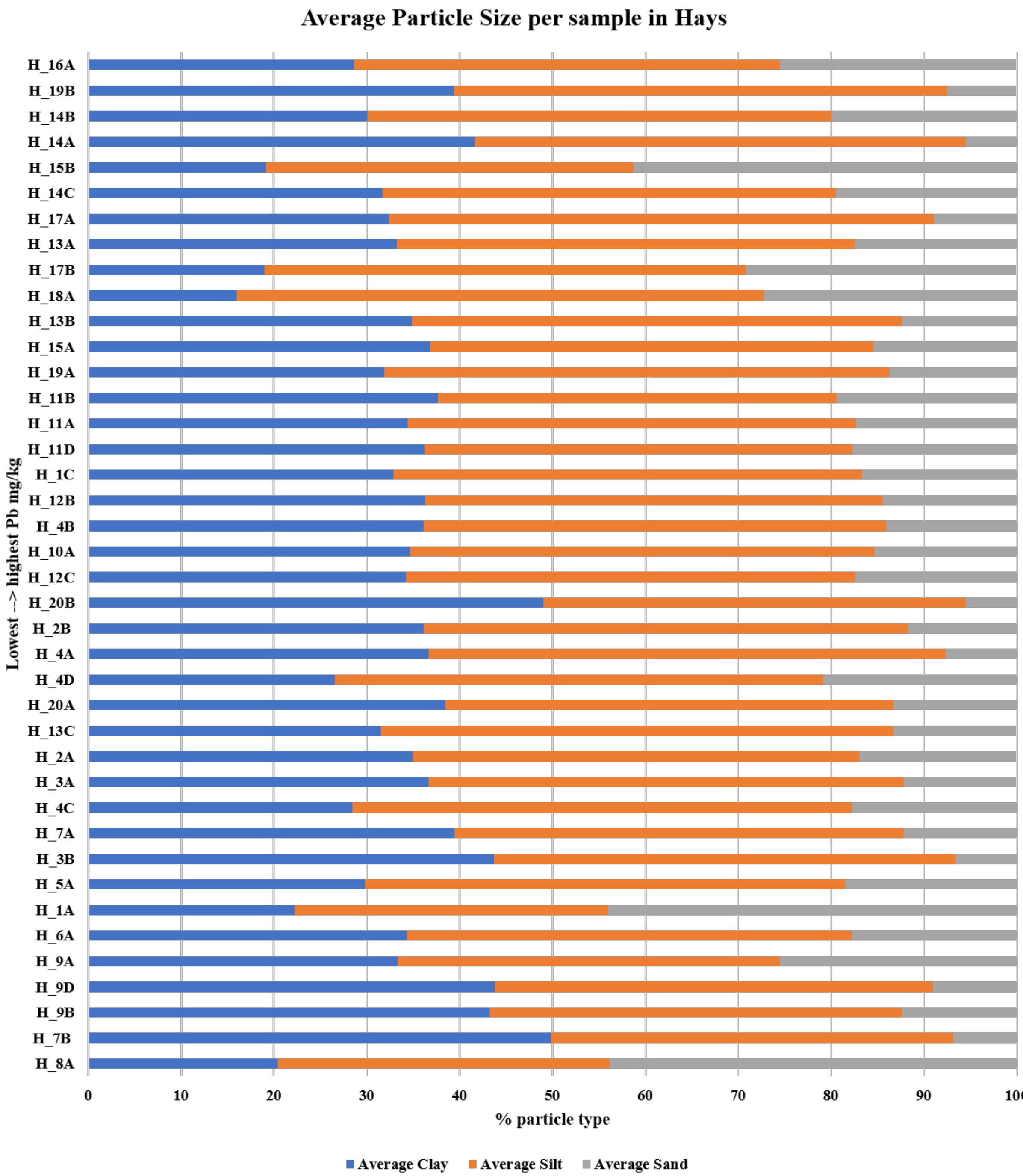


Figure 4-7: PSA in Hays; samples organized by Pb concentration with highest concentration samples at the top and lowest concentration samples at the bottom

4.4 Results from X-Ray Fluorescence on Soil Samples

Handheld XRF analysis performed on the 86 samples is provided in Appendix D. Figure 4-8 maps the maximum Pb mg/kg levels observed at one of each of the 40 sites. Sample points were enlarged to protect private identities. As evident by the map, historically the towns began centrally in a downtown district where the oldest homes are currently found, radiating outward where newer and newer homes were built. Socioeconomically disadvantaged populations tended to be located in the older areas (Hood, 2005; Pendall et al., 2014).

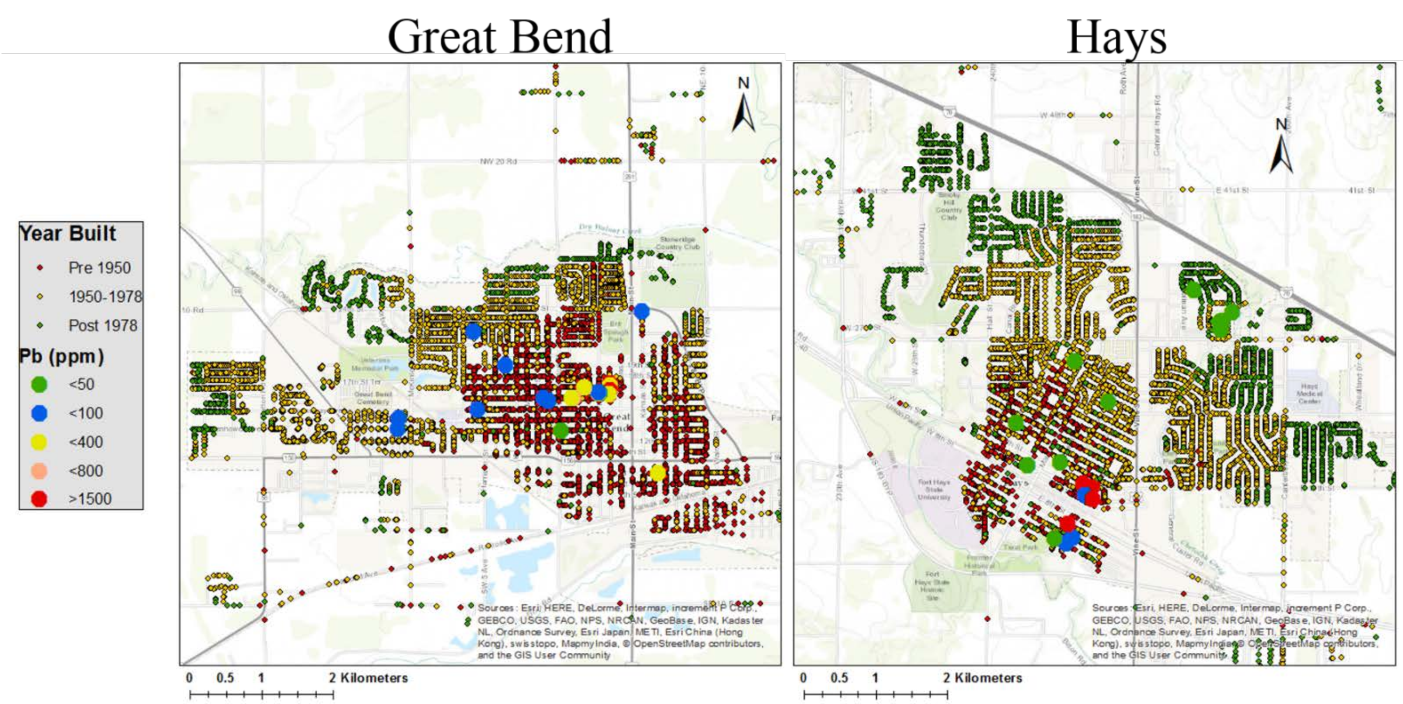


Figure 4-8: Maps of Great Bend and Hays city with residential housing age units and Pb concentration points plotted together

Figure 4-9 shows a box plot of the correlative relationship between the fieldwork samples and the housing age of the sites. The y-axis is broken to accommodate the two samples with significantly higher Pb contents. The data show a clear correlation between the age of housing and soil Pb levels, with newer homes being associated with the lowest Pb concentrations in soil.

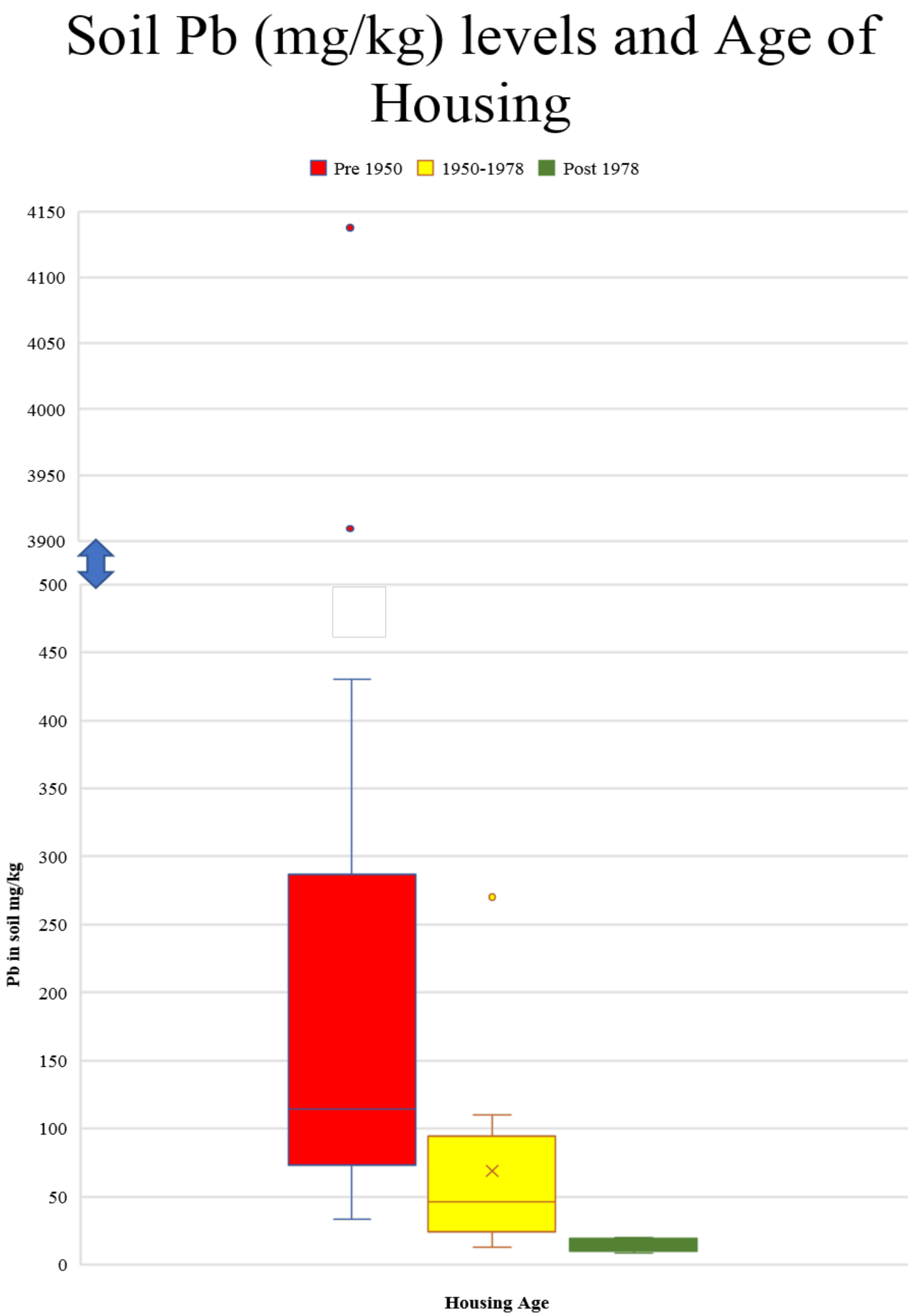


Figure 4-9: XRF Pb values compared with housing age ranges

Variations in Pb concentrations exist, depending on where samples were taken (Figure 4-10). Both the highest and lowest Pb samples were predominantly taken from the front yard, as it was the location most commonly allowed by property owners for sampling. 54% of residents allowed sampling in the front yard, 14% in the backyard, 5% in the side yard, 6% in the garden,

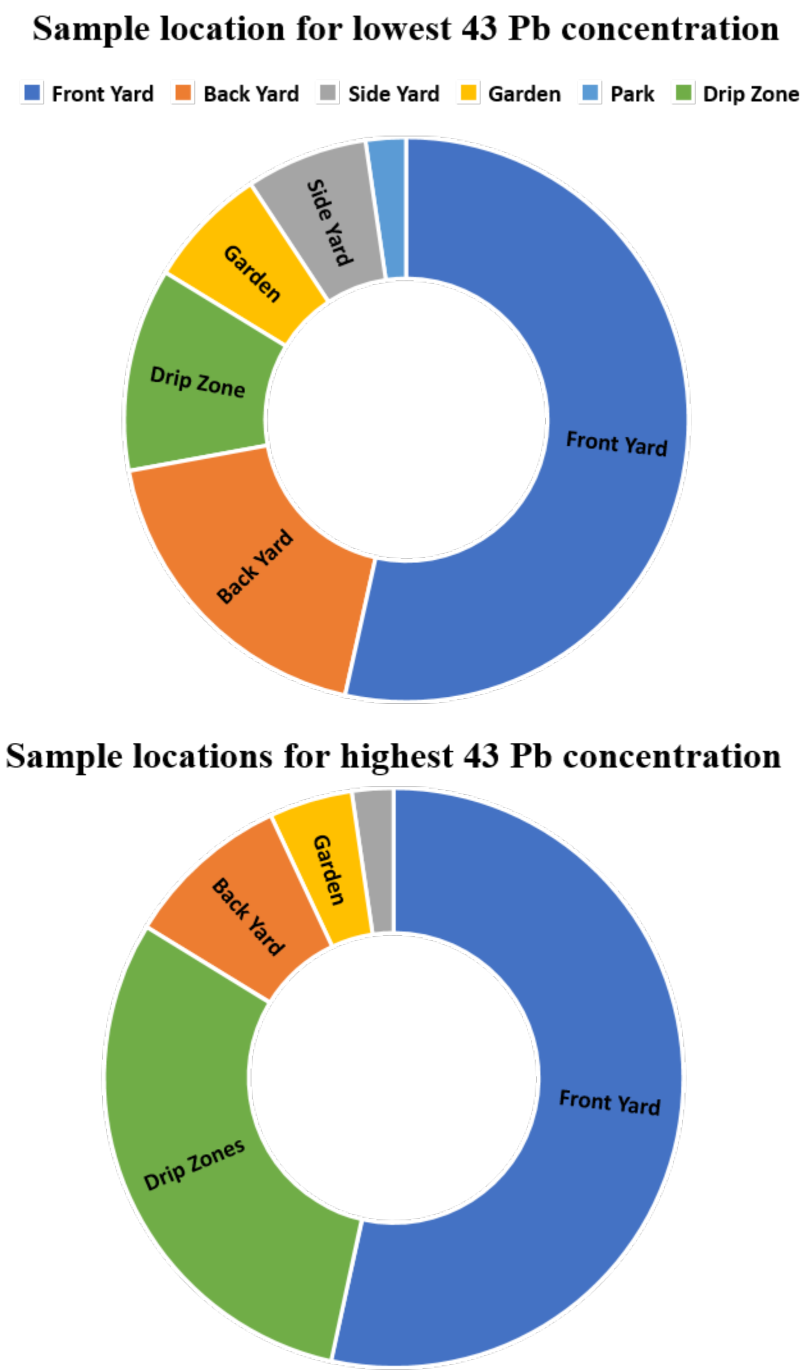


Figure 4-10: Sample locations for the highest and lowest Pb concentrations

21% in the drip zone and 1% of samples were collected from a public park. The location with the next highest Pb concentration came from drip zones at 30.2% of sampling sites with elevated lead. Overall, 66% of the drip zones sampled had Pb above 100 mg/kg compared with 15% of Front yards.

A common lead phosphate mineral, favored in lower pH soils, is pyromorphite. Presence of this mineral leads to low solubility of lead. Ground agricultural limestone and phosphate fertilizer can help to rehabilitate some lead contaminated soils. Figure 4-11 shows the results of phosphorous and lead concentrations.

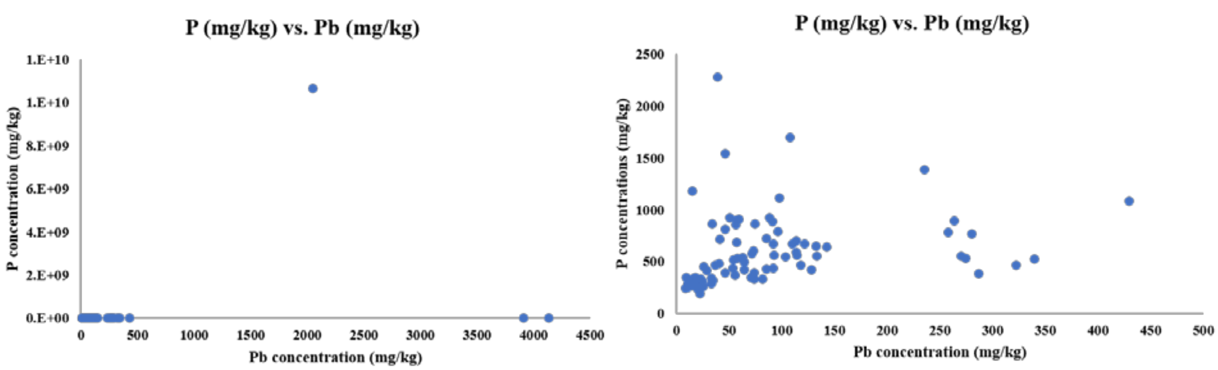


Figure 4-11: Phosphorous vs lead concentrations (mg/kg). Graph on the right eliminates the top 3 Pb concentrations.

Previous research suggests that the concentrations of elements such as Zn have a strong correlation with Pb (0.64) and As, Ga, and Cd have a good correlation (>0.4) with Pb concentrations in soils (Salminen et al., 2005). Figure 4-12 demonstrates the lead correlating with zinc with 0.47 R^2 value.

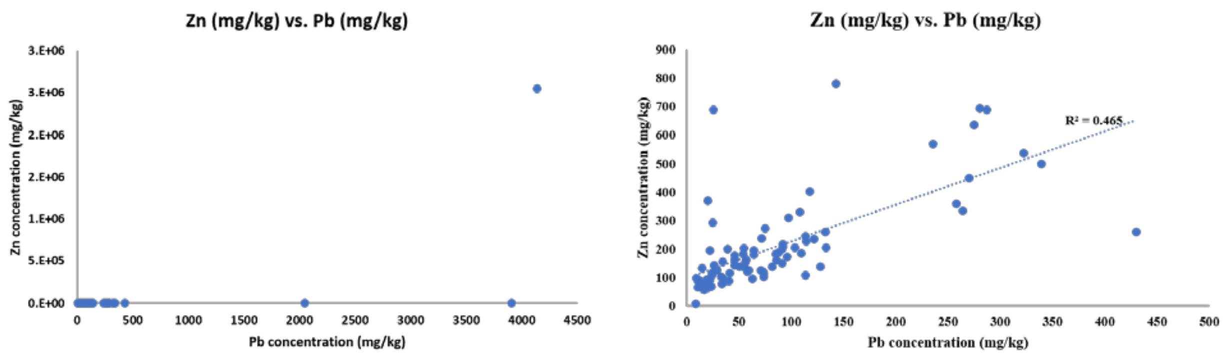


Figure 4-12: Zinc vs. lead concentrations (mg/kg). Graph on the right eliminates the highest three lead values.

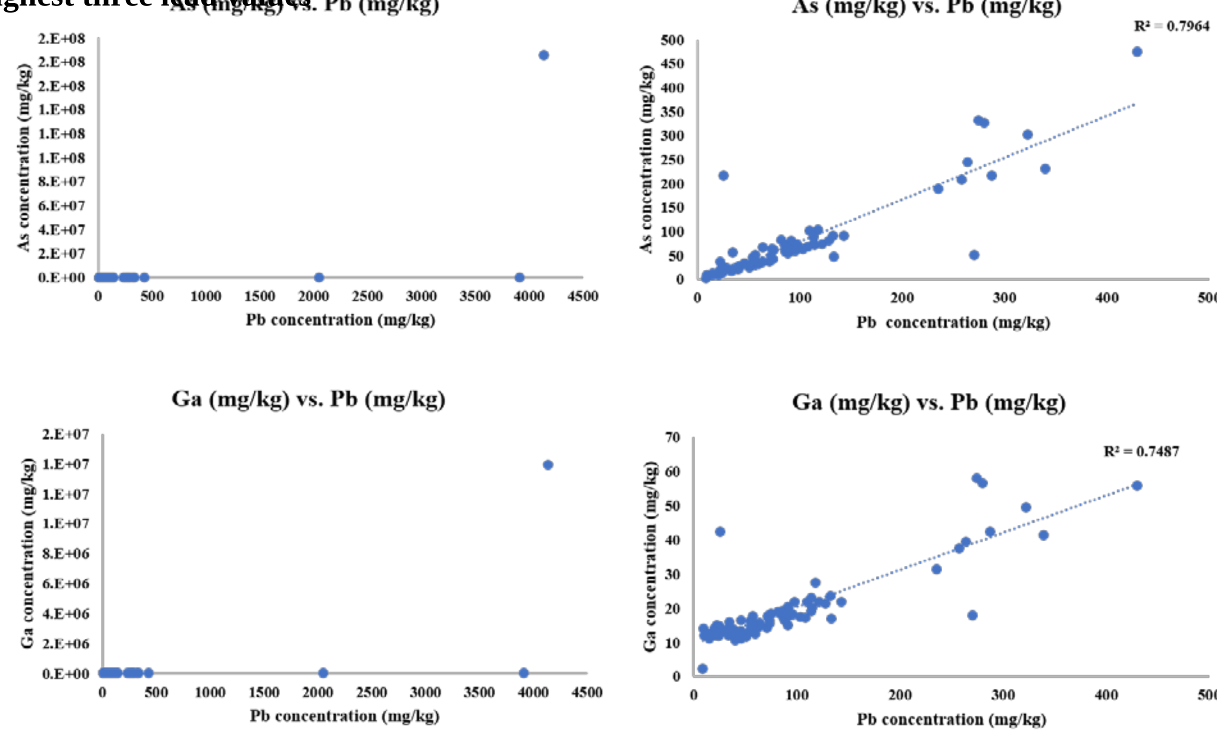


Figure 4-13: Ga and As concentrations compared with Pb (mg/kg). Graphs on the right eliminate the highest three lead values.

Figure 4-13 shows a trend of increasing arsenic (0.8 R^2 value) and gallium (0.7 R^2 value) with increasing lead. The graphs on the right zoom into the trend at the lower levels, excluding the points at the top 3 Pb concentrations. Gallium is known to be high in substrate rich in feldspar and phyllosilicate minerals such as mica and clays (Salminen et al., 2005). Fe concentrations averaged 20,617 ± 3003 mg/kg (1σ, n = 86) with no significant correlation with Pb. Cd was not tested under the HH-XRF spectrum.

Since two XRF machines were used, a comparison was made between the two Pb values (Table 4-2). Analysis of NIST 2711A on the Bruker Tracer III yielded 2,859 ± 309 mg/kg (n= number of analyses; state whether 1 or 2 sigma); the same standard analysed on the Niton yielded 1277 ± 57 mg/kg. The NIST certificate value for NIST 2711A is 1100-1400mg/kg of Pb. The lower the Pb concentrations the greater the Bruker accuracy; however, for most results the Bruker underestimated lead levels except in the lowest and highest concentrations, where overestimation occurred. The Niton HH-XRF tended to yield higher values for Pb concentration for all but six of 86 samples (Table 4-2).

Table 4-2: Difference between Pb concentration readings on the Niton and Bruker HH-XRF machines

Sample #	**Pb Niton**	**Pb Bruker**	**Difference %**
2E	4138	239279800	-5782995%
4B	3910	13727	-251%
2D	2046	4283	-109%
15A	430	214	50%
3B	340	56	83%
H-16A	322	135	58%
H-19B	287	90	69%
H-14B	280	202	28%
H-14A	275	185	33%
H-15B	270	20	93%
15B	264	60	77%
13B	258	48	81%
3A	235	18	92%
5B	143	14	90%

Sample #	**Pb Niton**	**Pb Bruker**	**Difference %**
1B	63	19	70%
1A	60	18	70%
2B	58	19	67%
H-11B	57	18	69%
5C	57	19	67%
H-11A	56	18	68%
18B	56	20	64%
14A	54	20	63%
14B	54	19	65%
H-11D	51	17	66%
12B	46	18	60%
18A	46	18	61%
H-1C	46	20	57%
13A	41	18	57%

H-14C	133	19	86%	14C	40	16	61%
4C	133	14	89%	H-12A	39	17	57%
16B	128	13	90%	19A	37	17	55%
4A	122	15	88%	17B	34	22	35%
H-17A	118	6	95%	H-12B	34	17	51%
8A	115	16	86%	19B	33	15	54%
8B	114	11	90%	H-4B	33	16	52%
16A	114	17	85%	H-10	29	17	41%
7A	110	14	87%	H-12C	26	17	35%
2C	108	19	82%	H-20B	26	90	-253%
5A	103	18	83%	H-2B	25	15	40%
H-13A	98	17	83%	H-4A	24	15	38%
H-17B	96	18	81%	H-4D	24	15	39%
H-18	92	19	80%	19C	23	15	34%
6A	92	19	79%	H-20A	22	19	14%
9A	92	16	83%	H-13C	22	16	27%
12A	91	21	77%	H-2A	20	12	39%
11B	88	18	79%	H-3A	20	14	32%
2A	86	19	77%	H-4C	20	14	30%
9B	85	19	78%	H-7A	18	14	24%
17A	82	20	75%	H-3B	16	13	20%
11A	75	20	73%	H-5A	15	13	16%
20B	74	19	74%	H-1A	15	13	9%
20C	73	20	73%	H-6A	15	13	13%
10A	73	16	78%	H-9A	13	12	3%
H-13B	72	20	72%	H-9D	11	13	-20%
20A	71	19	73%	H-9B	11	13	-21%
H-15A	64	18	72%	H-7B	9	14	-45%
H-19A	64	19	70%	H-8A	9	6	29%

4.5 Results of Bulk Digestion, HR ICP-MS Analysis

Accuracy of the lead concentrations determined using the Niton HHXRF was tested by comparing the results with concentrations determined by HR ICP-MS (Table 4-3). GB – 4B's actual value was about 2.3 times higher on the HR ICP-MS and GB-8A's was 2.3 times lower on the HR ICP-MS. On the ICP the NIST 2711A standard averaged 1183.28mg/kg of Pb with a standard deviation (1σ) of 25.182, within the certificate reference values of 1100-1400mg/kg.

Table 4-3: Pb concentrations from the Nitron HHXRF and HR ICP-MS.

Sample ID	Sample Location	Test on paint outside the house	Year House Built	Remodel Year	County	Pb – HHXRF (mg/kg)	Pb- ICP (mg/kg)
GB -2d	Drip Zone	Positive	1920		Barton	2046	1052
GB -4b	Drip Zone	Positive	1920	1996	Barton	3910	8982
GB -3b	Near washing machine	N/A	1920		Barton	340	385
H-16a	Front Yard	Negative	1918		Ellis	322	415
H-14c	Front Yard	Positive	1945		Ellis	133	64
GB -8a	Front Yard	Positive in the cracks	1920	2001	Barton	115	50
H-13a	Drip Zone	Negative	1950		Ellis	98	102
GB -6a	Front Yard	Negative	1920	1994	Barton	92	90

HR ICP-MS tests were done on other elements that commonly interact with lead (Table 4-4). Figure 4-14 shows the best example of positive correlation between lead concentration and another element, zinc.

Table 4-4: HR ICP-MS results on the eight selected samples and specified chemicals.

Sample	Pb (mg/kg)	Ba (mg/kg)	Fe (mg/kg)	P (mg/kg)	Mn (mg/kg)	Si (mg/kg)	Na (mg/kg)	Zn (mg/kg)	Ca (mg/kg)	As (mg/kg)
GB-2D	1052.0	7358.7	15953.9	313.6	180.1	2523.0	5587.0	468.3	5141.2	4.3
GB-3B	384.6	10396.4	49787.9	1016.6	651.8	2372.0	12407.3	225.3	44186.1	19.9
GB-4B	8981.8	12178.3	25188.1	1180.6	249.7	549.8	10544.9	1227.3	19951.8	5.5
GB-6A	90.3	9167.8	32347.6	1158.4	301.1	1476.7	18065.4	77.1	15435.2	4.0
GB-8A	49.9	7677.5	29583.4	881.7	279.6	3398.9	16345.6	78.2	13688.4	5.4
H13-A	101.6	7400.8	33634.6	1765.9	372.7	452.0	20481.1	142.8	16788.4	6.1
H14-C	64.2	7655.3	38579.3	1488.5	405.9	1398.9	12177.6	76.4	16274.4	6.0
H-16A	414.8	7204.2	32742.2	1005.9	342.8	55.2	10610.3	356.0	15496.0	5.8

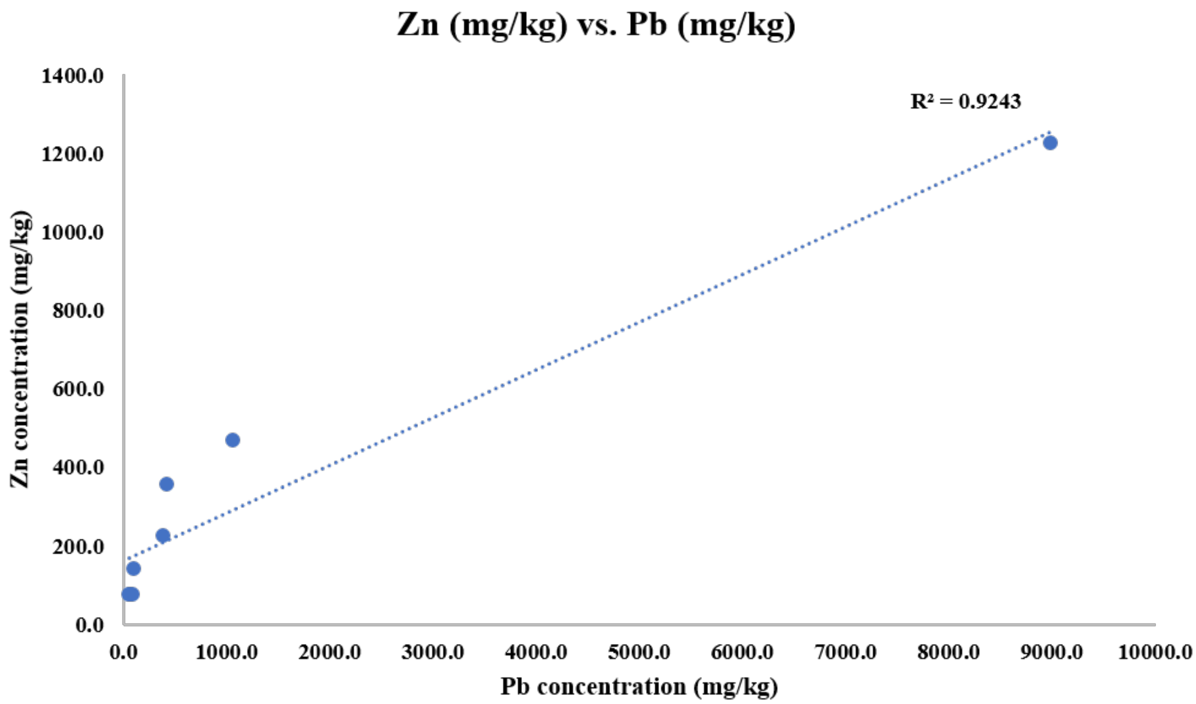


Figure 4-14: Total Soil Zn vs Pb graph (HR ICP-MS)

4.6 Pb Isotope Results of Eight Samples

The isotopic ratios measured from the eight samples reflect a combination of multi-source lead. Table 4-5 outlines the isotopic results of the ratio $^{206}Pb/^{207}Pb$ and the HR ICP-MS concentrations which were plotted in Figure 4-15 (1σ, n=8). The red and black dots represent two separate digestions of the soil samples. The analysis indicated with the red dots are the full digestions and the black dots represent partial digestions that were run multiple times to check reproducibility with the same sample and the reproducibility with the ICP-MS. There is disagreement in the partial digestion between two samples, GB-6A and H-16A. We attribute that to sample heterogeneity where there were multiple sources of Pb in the sample.

Table 4-5: HR ICP-MS and Isotope ratio results in mg/kg.

	Pb concentration (mg/Kg)	$^{206}Pb/^{207}Pb$
GB-2D	1052.0	1.19
GB-3B	384.6	1.70
GB-4B	8981.8	1.16
GB-6A	90.3	1.14
GB-8	49.9	1.27
H-13A	101.6	1.15
H-14C	67.8	1.14
H-16A	414.8	1.17

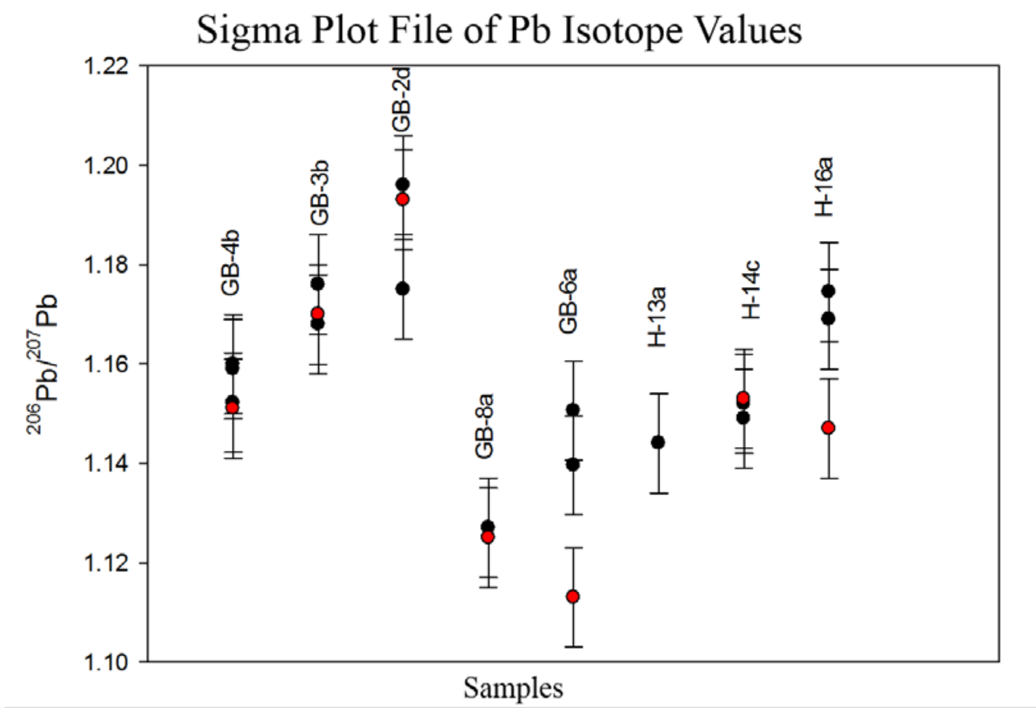


Figure 4-15: Sigma Plot of Pb isotope values for the eight soil samples with 1σ error bars. Red dots indicate complex dissolutions; black dots indicate partial digestions

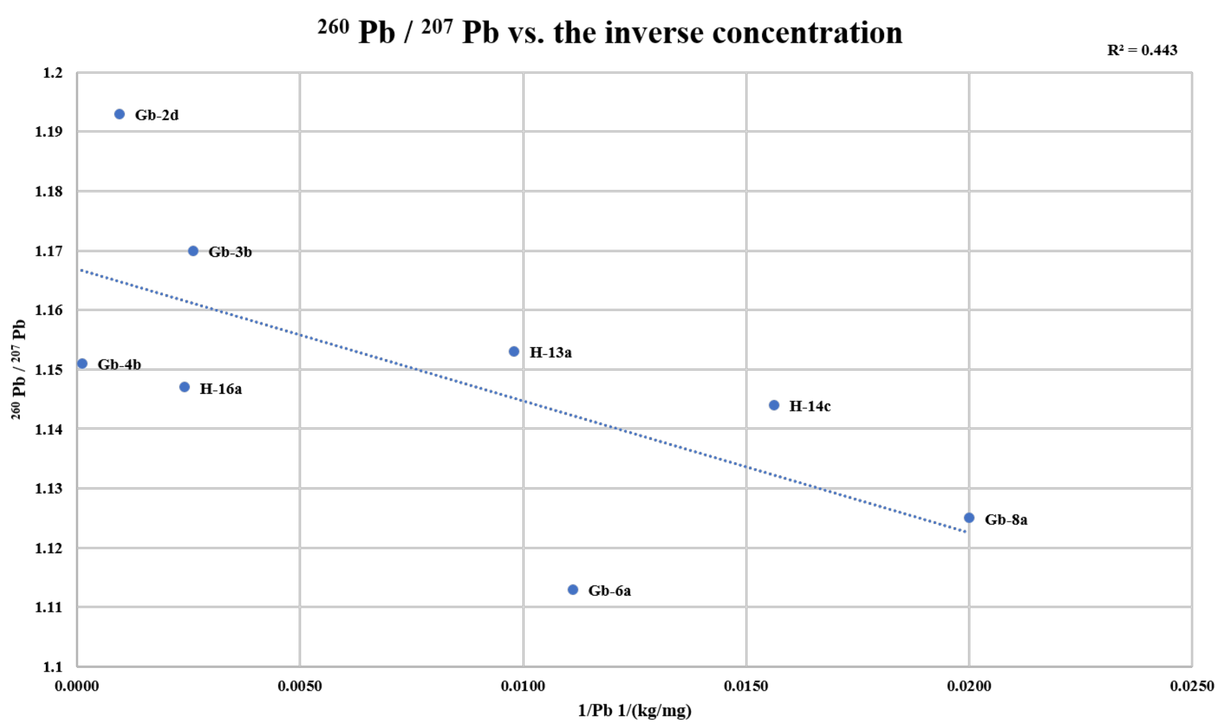


Figure 4-16: 206Pb/207Pb ratio vs the 1/Pb concentration for eight soil samples

Figure 4-16 illustrates $^{206}Pb/^{207}Pb$ ratios vs the inverse of Pb concentration and shows a negative trend (slope = -2.5) for the eight samples analyzed. These samples were plotted using the results of the full digestion. The lower right samples have a low isotopic composition and a low concentration of lead; the upper left samples have a high isotopic composition and a high concentration of lead. We believe there are more than two sources of lead within most of the samples. Samples GB-2D, GB-4B, and H-14C tested positive for lead in the outside housing paint using the 3M LeadCheck Instant Lead Test Swab kit. GB-8A tested positive in the cracks of the paint with the third or fourth layer of paint having detectable lead concentrations.

4.7 X-Ray Powder Diffraction Results

XRD analysis was performed on the eight specific samples listed. All X-ray spectra are provided in Appendix F. The XRD was used for mineralogical analysis to identify the presence of cerussite ($PbCO_3$, lead carbonate) and/or anglesite ($PbSO_4$, lead sulfate). A visible inspection during the sieving and grinding process showed that most soils contained quartz, feldspars, and muscovite. None of the samples contained any visible peaks associated with lead carbonates. There were better associations with lead sulfate, especially in H-13A (Figure 4-16). H-14C and GB-6A showed evidence of lead sulfate; however, the expected peaks did not match most measured peaks. In Figure 4-16, there is uncertainty on whether lead sulfate is visible since it is an amorphous mineral and it usually will not show up in the XRD peaks. The peaks in the 27 2θ range may be quartz (quartz peak = 26.6, 2θ).

The other samples did not contain enough matches. Figure 4-17 shows the top 5 peaks estimated by the program of matching in percentages, however, there doesn't appear to be a strong match with almost any of the peaks. Some of them may be background noise. The XRD tests did not provide conclusive evidence of lead sulfate /carbonate mineralogy in the soil.

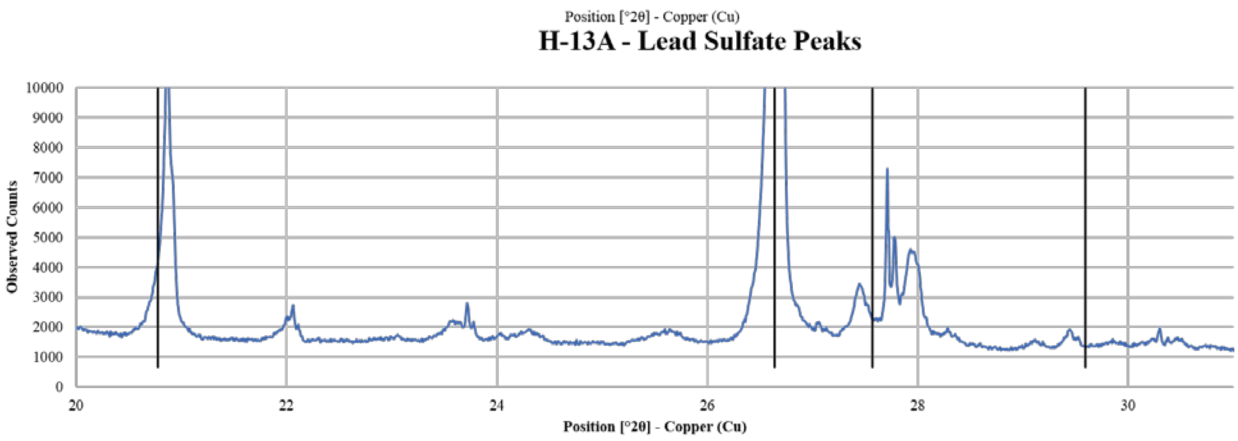


Figure 4-17: XRD results of lead sulfate peaks for sample H-13A

4.8 Geostatistical and Spatial Analysis: Kansas

Table 4-6 illustrates the variable statistics for all of Kansas used for geospatial analysis in Section 4.10 below. These variables were examined with correlative statistics in Table 4.7 and then assigned numerical values for a variable map in Table 4.8.

Table 4-6: Variables analyzed in risk assessment for Kansas counties. Housing age data are from 2017, poverty levels since 2013, blood lead levels since 2013, number of active wells since 2017, and population since 2010 census data.

	Housing Age (% built pre 1978)	Poverty Levels (%)	Blood Lead Levels (% tested above 5µg/dL)	Oil (number of active oil wells, KGS)	Population (2010 census data)
Mean	78.8	18.7	1.8	494.3	25,607.9

Minimum	42.4	7	0	0	1534
Maximum	92.3	38.3	11.9	3406	452,869
Mode	77.1	22.7	0	0	N/A
Median	82.8	18.2	0.2	177	7673
Standard Deviation (1σ)	11.7	5.1	2.8	676.3	65361.8
Variance	136	26	8	457318	4*E9

While the average population in Kansas counties is about 25,607if large cities are excluded, the average population of most counties is about 7,500. The county with the youngest housing stock has 42% of houses older than 1978, whereas the county with the oldest house stock has over 92% of houses older than 1978. In Table 4-7, the highest correlation between these parameters is seen between housing age and population, with a correlation coefficient of -0.45. This is consistent with an interpretation in which demand for new construction increases as more people move into an area, thereby lowering the average age of housing in the county.

Table 4-7 show a weak positive correlation between housing age and poverty across all years for which data are available. There is also a weak positive correlation between the number of oil wells in a county and BLL in children in 2010. The correlative values between number of oil wells per county and BLL following 2010 go up and down, which may be attributed in part to uncertainty in surveillance testing. For example, in 2010, Philips county has 0% of children recorded with elevated BLL, then 11.54% in 2011, and back to 0% in 2012 and 2013. In 2011, the most children had their blood tested for lead with 2013 having the least tested in Kansas.

Figure 4-18 illustrates the weak positive correlation between the number of oil wells in a county and BLL in 2010.

Table 4-7: Correlation values for various variables.

Variables	**Correlation 2010**	**Correlation 2011**	**Correlation 2012**	**Correlation 2013**	**Average**
BLL & Poverty	0.14	0.03	0.18	0.18	0.11
BLL & Housing Age (2017)	0.08	0.04	0.01	0.06	0.07
BLL & Oil	0.35	0.20	0.29	0.26	0.29
Poverty & Housing Age	0.32	0.23	0.18	0.23	0.24
Poverty & Oil	0.12	0.14	0.20	0.18	0.16
Surveillance & Oil	0.04	0.05	0.04	0.17	0.08
Housing Age & Population	X	X	X	X	-0.46

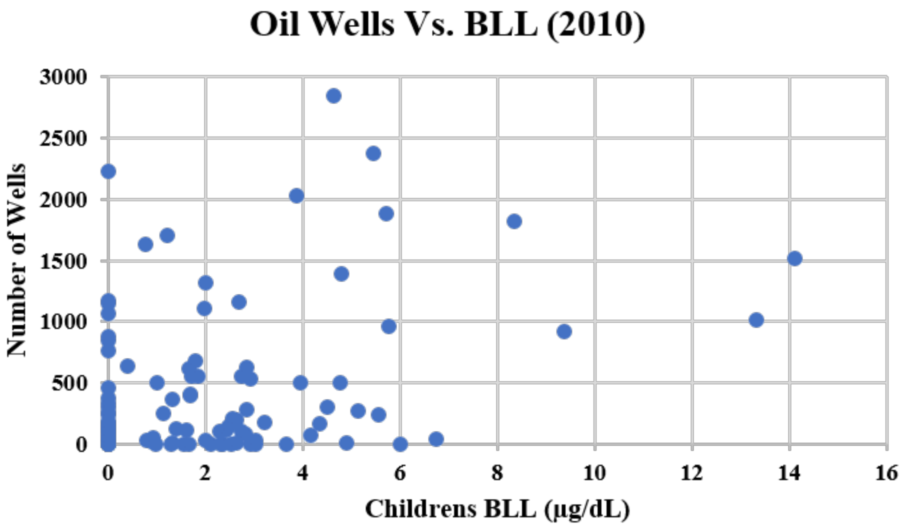


Figure 4-18: Number of oil wells vs. BLL in 2010 for all counties in Kansas

Using the variables described earlier (Section 1.7, 3.7) a risk assessment map was created. Each variable was designated a value at five incremental points. Since the literature indicates that housing age has the highest risk for children it was assigned higher incremental values in Table 4-8 (Hunt, 2016; Mcclure et al., 2016; EPA, 2013; Burgoon et al., 1995). Both housing age and BLL increased by increments of 0.25. BLL is its own variable due to the possibility of inadequate surveillance with increments of 0.25. Table 4-8 illustrates the variables used to create the map in Section 4.10 below. Population and poverty levels increase by a factor of 0.1 for each section since neither has been shown to strongly affect children's blood lead levels. The values in Table 4-7 will be multiplied across each county line to produce a variable risk assessment map. The ranking level of 1 across all variables within a county equates to a risk of 1, which would mean no risk. Increasing ranking levels, means increasing risk.

Table 4-8: Five levels of risk with their assigned variable numbers for specified ranges

Ranking levels	**Percent of Houses Built Pre-1978 (stagnant values)**	**Percent Population living in Poverty**	**Percent of Children with Elevated BLL**	**Number of Oil Wells**	**Population (stagnant values)**
1	<50% *No Hazard* Value = 1	<4.99% *No Hazard* Value = 1	0% *No Hazard* Value = 1	0-10 *No Hazard* Value = 1	>5,000 *No Hazard* Value = 1
2	51%-60% *Low Hazard* Value = 1.25	5%-9.9% *Low Hazard* Value = 1.1	1-3.9% *Low Hazard* Value = 1.25	1-250 *Low Hazard* Value = 1.15	5,001-10,000 *Low Hazard* Value = 1.1
3	61%-70% *Hazard* Value = 1.5	10%-20.9% *Hazard* Value = 1.2	4-6.9% *Hazard* Value = 1.5	251-999 *Hazard* Value = 1.25	10,001-40,000 *Hazard* Value = 1.2
4	71%-80% *Elevated Hazard* Value = 1.75	21%-30.9% *Elevated Hazard* Value = 1.3	7 -9.9% *Elevated Hazard* Value = 1.75	1,000-1,999 *Elevated Hazard* Value = 1.5	40,001-90,000 *Elevated Hazard* Value = 1.3
5	>80% *Significant Hazard* Value = 2	>30% *Significant Hazard* Value = 1.4	>10% *Significant Hazard* Value = 2	>2,000 *Significant Hazard* Value = 1.75	>91,000 *Significant Hazard* Value = 1.4

4.9 Geostatistical and Spatial Analysis: Barton and Ellis County

Out of the 470,045 available oil well points, 58,259 (12%) points were not used to due containing blanks or other incomplete status delineations as described in section 3.7. Figure 4-19 shows the well types predominantly found in Kansas.[4]

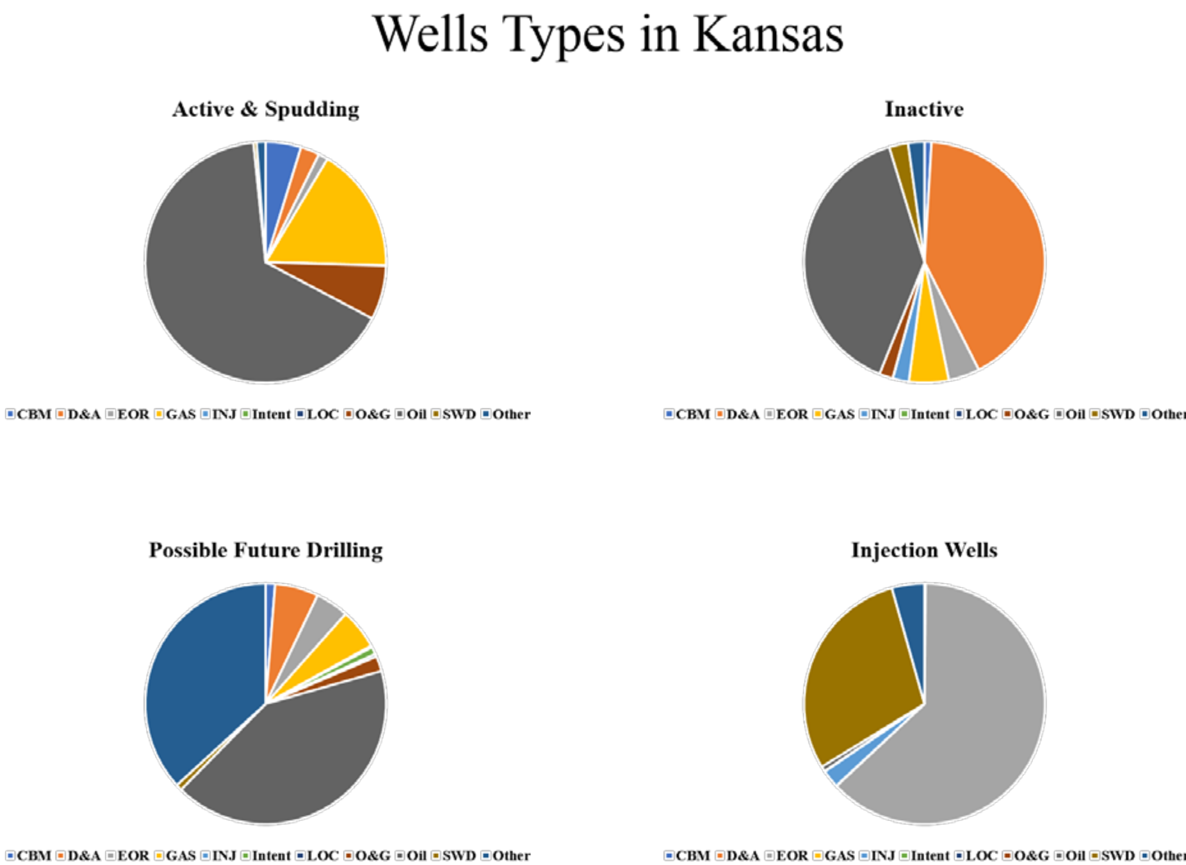


Figure 4-19: Well types in Kansas

[4] CBM = Coalbed methane wells, D&A = Dry and Abandoned, EOR = Enhanced Oil Recovery, INJ = Injection well, Intent = Intent to create a well, LOC = Location status unknown, O&G = Oil and Gas, SWD = Saltwater disposal, Other = Mixture of categories

About 7% of the active wells are spudding wells; 11% are being introduced as possible future drilling sites. However, about 60% of the well point data are from inactive wells. Most of the active wells are oil specific wells; however, as seen in Figure 4-20, oil wells are one of the most common ones to be plugged. The dry and abandoned wells are still classified into well types of active, and active and spudding due to not being plugged. Thirty-four percent of dry and abandoned wells remain classified as spudding wells, because they have not been plugged and closed.

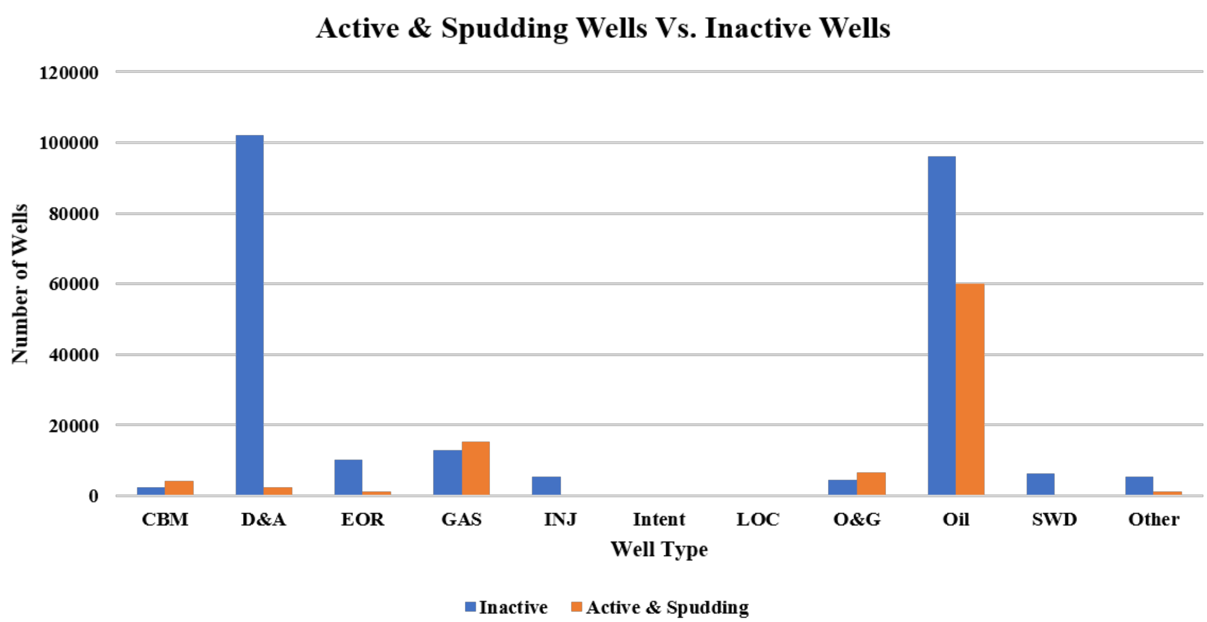


Figure 4-20: Number of active wells vs. inactive wells in Kansas

Within Ellis county, 18% of the active wells are spudding. Future drilling is predominantly in oil and Dry and Abandoned (D&A) with a few applications for saltwater disposal (SWD) wells. There are also no injection wells in Ellis county. When comparing the Barton County oil production graph (Figure 4-22) with Ellis County (Figure 4-21), the latter produces significantly more oil.

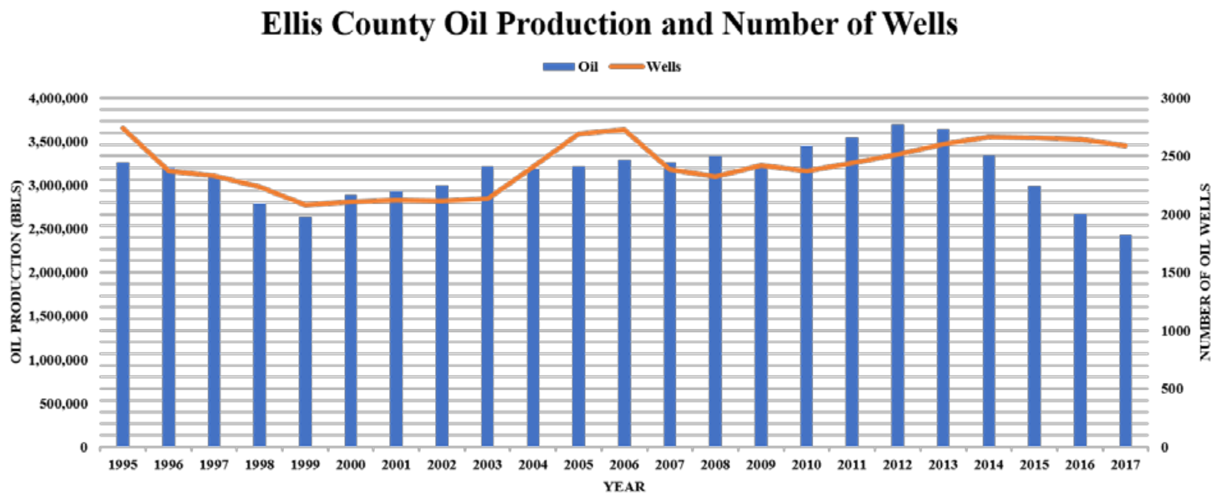


Figure 4-21: Oil production and number of oil wells in Ellis county from 1995-2017

Within Barton county, most wells are oil wells with 32% of the spudding wells labeled dry or abandoned. There have been no injection wells recorded in Barton county. Most inactive wells are dry and abandoned with 53% of inactive wells being oil wells. Possible future drilling in Barton has applications for areas with active oil wells and Dry and Abandoned (D&A) wells for re-drilling. Oil production appears to have a greater decline in production over the past five

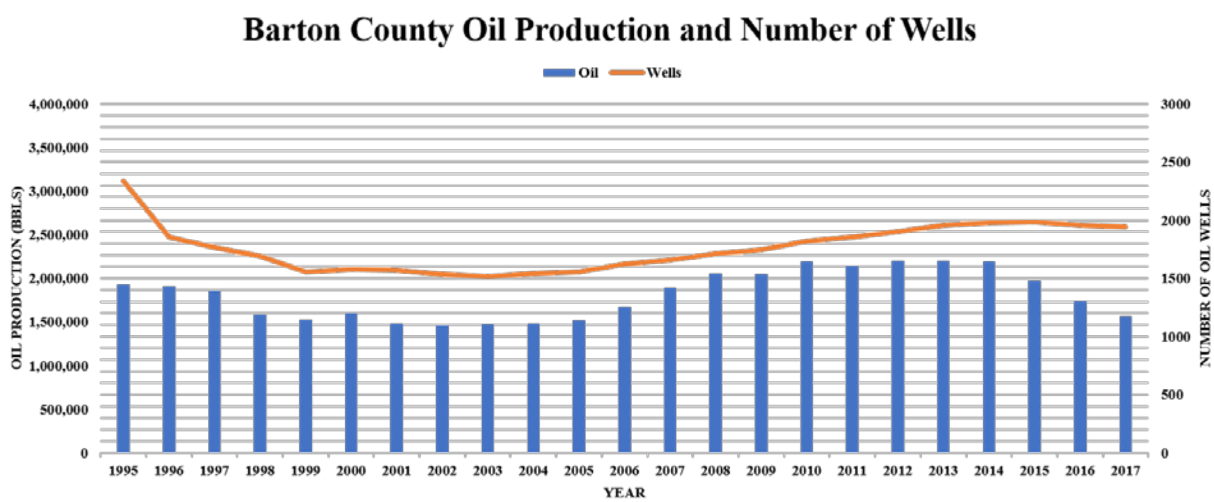


Figure 4-22: Oil Production and number of oil wells in Barton county from 1995-2017

years in both counties, consistent with the significant drop in the price of oil after 2013 (Baffes et al., 2015).

4.10 Geospatial Analysis

A geospatial analysis of the data is presented in Figures 4-23 through 4-30. Figure 4-23 shows small changes in areas where more than 10% of children tested with elevated BLL (>5µg/dl). Areas in central Kansas appear to have an increase in children who tested with elevated BLL from 2010 to 2013. Surveillance throughout the years has a decreasing trend from 2010 to 2013 with 28,088, 30,709, 28,088, 25,968 children tested (Appendix G).

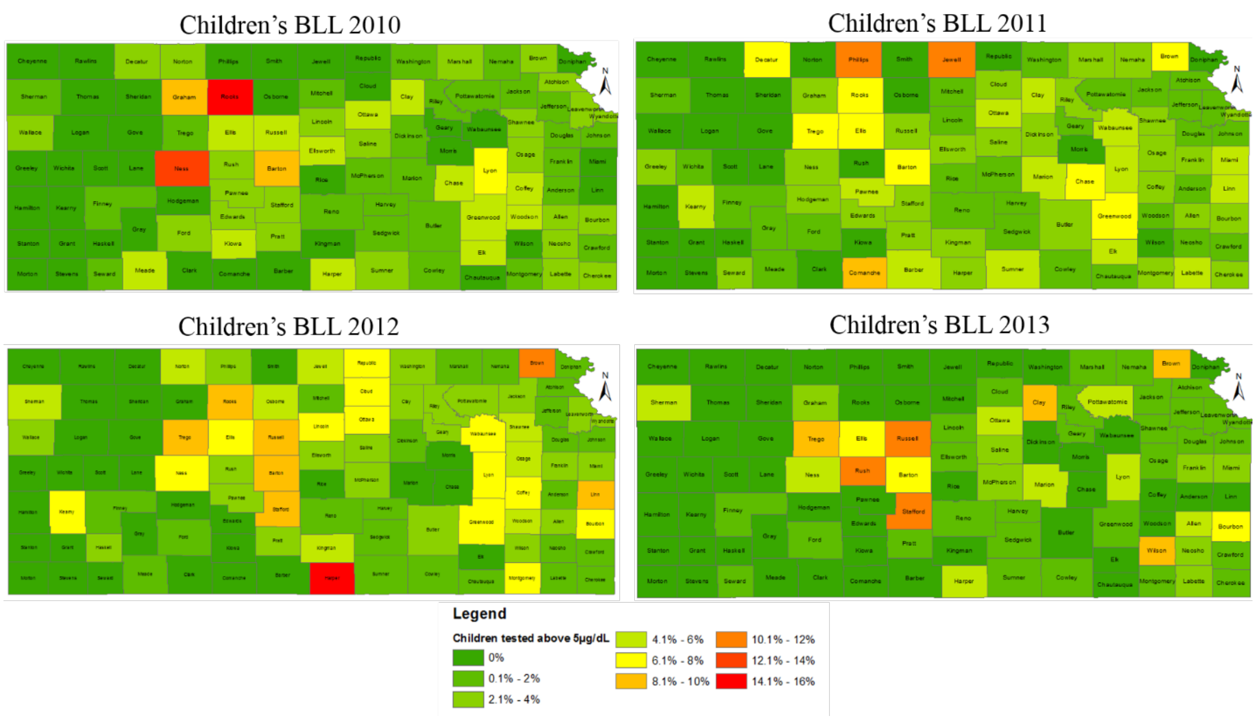


Figure 4-23: Children's BLL 2010-2013

A density map was generated of active wells (93,158) to examine hot spot regions of oil production. Figure 4-24 shows areas of mass oil activity which is in central Kansas and in south eastern Kansas. Overlaying the density map with the latest available BLL map provides Figure 4-25.

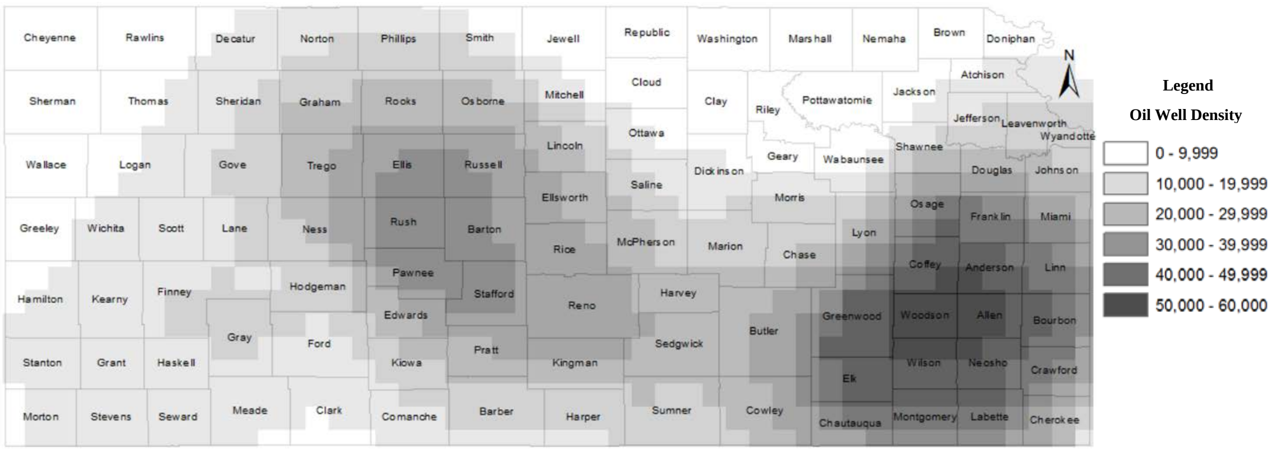


Figure 4-24: Density map of Kansas showing the hot spots of active wells (active and spudding)

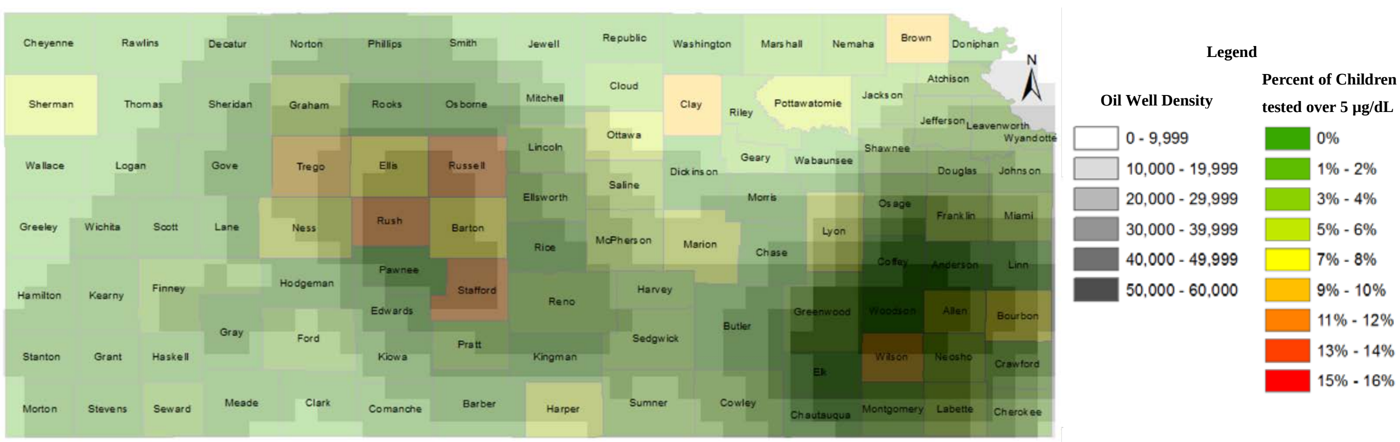


Figure 4-25: Kansas map combining BLL data from 2013 and active oil well data

A map of poverty levels as recorded in 2013 is shown in Figure 4-26, which shows that counties in south eastern Kansas have some of the highest levels of poverty in the state. Figure 4-27 shows that south eastern Kansas is where most of the future drilling applications have been placed for oil and gas wells.

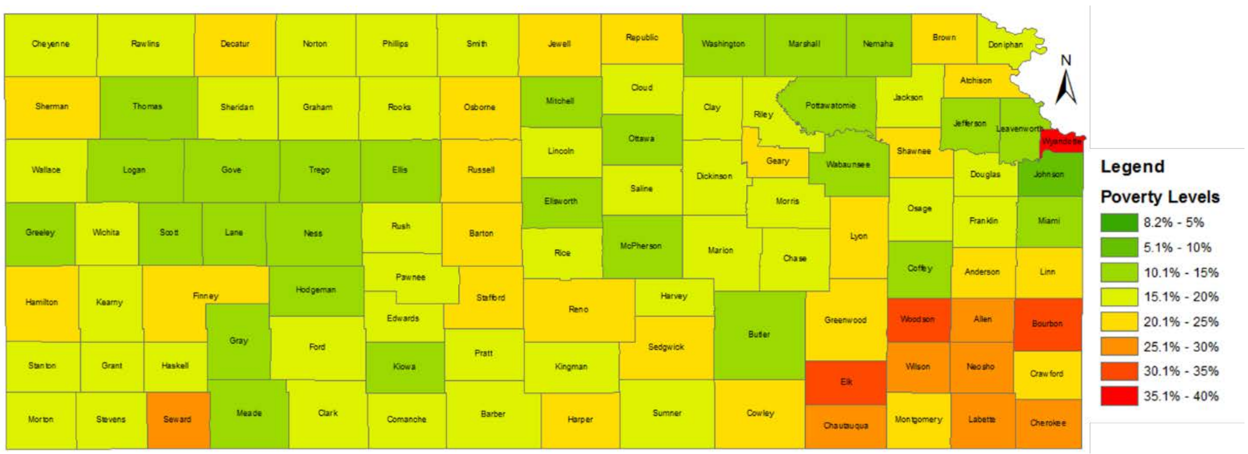


Figure 4-26: Kansas Map of poverty percentages in 2013

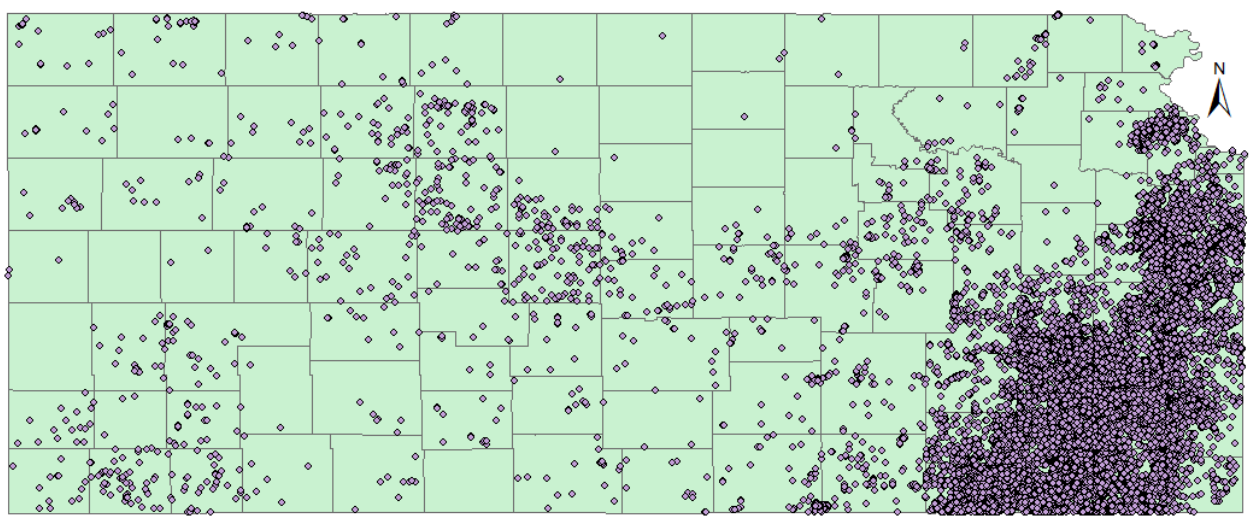


Figure 4-27: Map illustrating Possible Future Drilling (43,837 points)

According to the census data in 2010, eastern Kansas is significantly more populated than the rest of the state. Figure 4-28 overlays a population map with currently active and spudding wells. This shows some overlap between regions with higher populations (>10,000) and locations of oil wells.

Using the variables laid out in Section 4.7, Figure 4-29 was created. The range of values of risk are 2.25-8.58 with an average of 3.98 ± 1.31 (1σ, n = 105). The assigned variable values

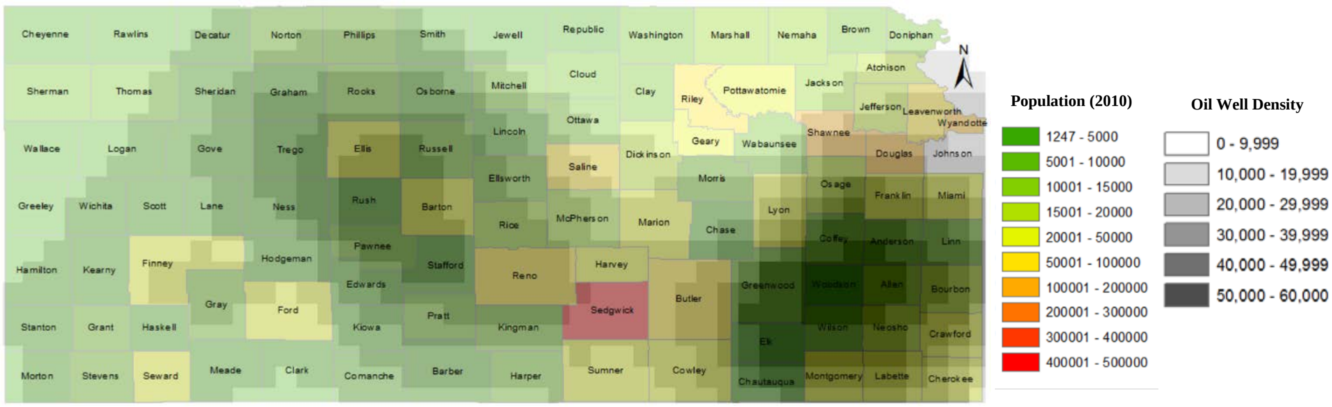


Figure 4-28: Population according to census 2010 data overlaid with active well density

(Table 4-7) were multiplied in each county and the highest areas of impact with houses built pre-1978, poverty levels, elevated BLL, high number of oil wells, and high populations are clustered in central Kansas and parts of south eastern Kansas.

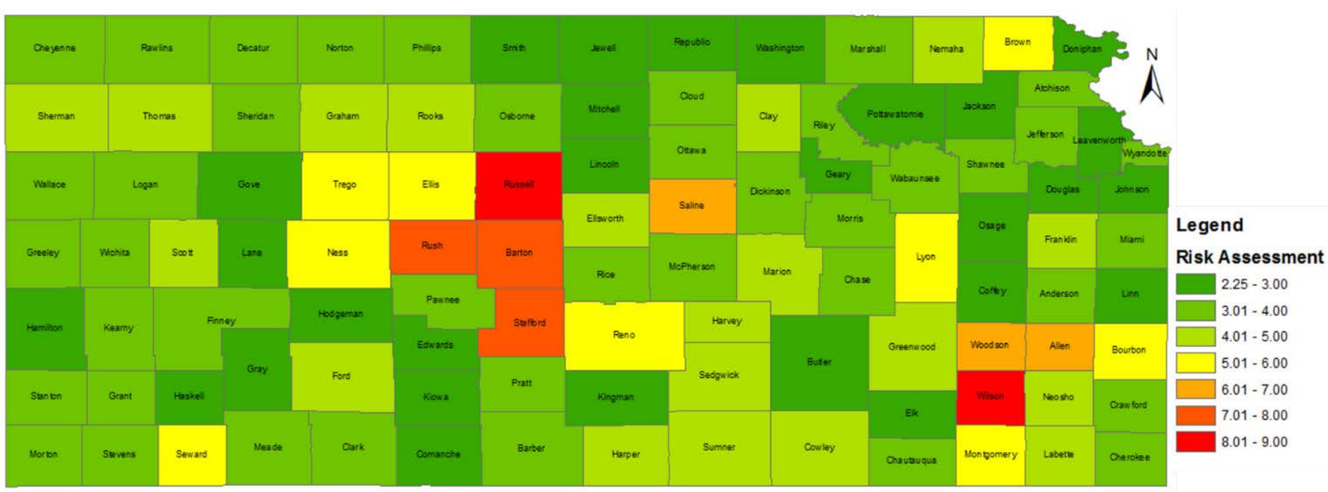


Figure 4-29: Risk assessment map created using variables laid out in 4.6 with methods described in 3.7

Looking specifically at Barton and Ellis counties (Figure 4-30), we can see that the these counties have similar number of oil wells, 3842 and 3380, respectively. However, Barton oil wells occur closer to residential areas. Cheyenne Bottoms Refuge, a wetland, is represented by the large empty space in the map of Barton County where there are no points plotted.

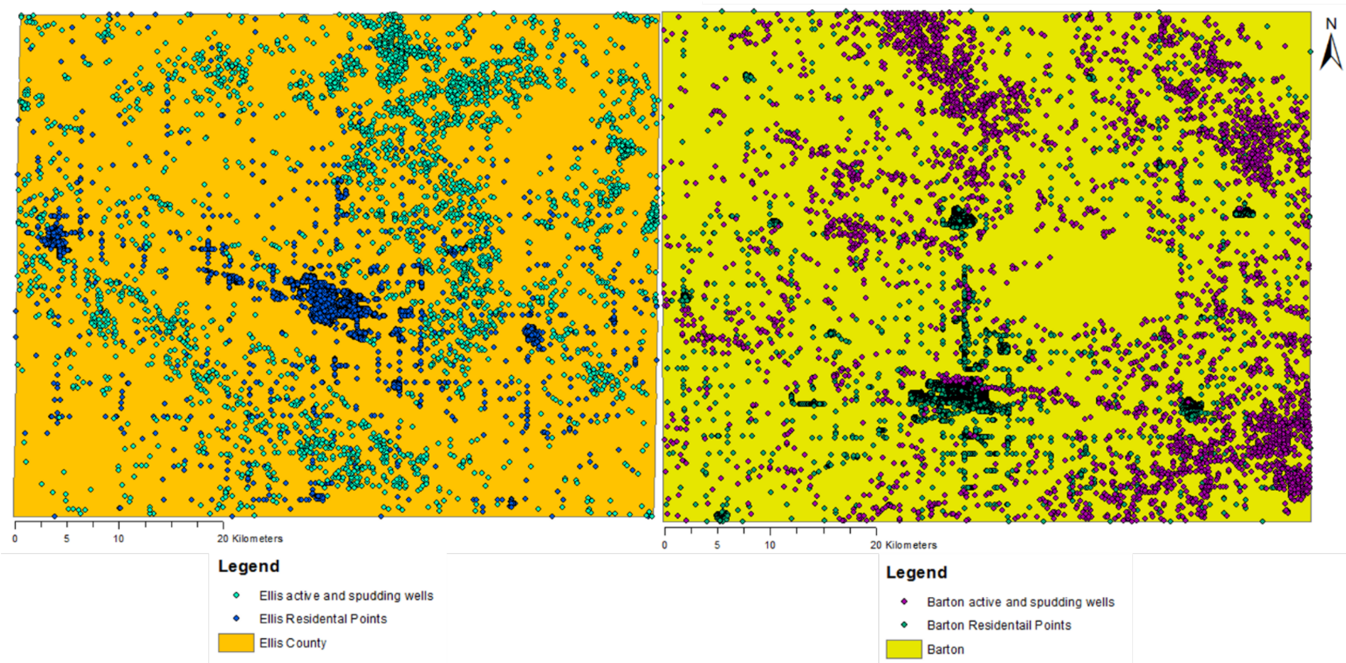


Figure 4-30: A map of Ellis and Barton county active well points and residential housing points

Using the Near Table Analysis function within ArcGIS (described in Section 3.7), the average distance the average distance between residential dwellings and wells in Barton county was determined to be 807m, with a collective range of 3.98-5215.6m and a median of 722.94m (Figure 4-30). Ellis county exhibited an average of 1,209.5 m between residential dwellings and wells, with a range of 55.1 meters to 4,197.59m and a median of 922.42m.

Chapter 5 - Discussion

5.1: Soil Properties

While no relationship was seen between particle size and Pb concentration in the studied samples, previous studies suggest that Pb will be enriched in the clay-sized fraction (Yao et al., 2015; Duggan and Inskip, 1985). Hays soils contain more clay and silt than those from Great Bend (71.3% vs. 82.71%), potentially retaining more lead within the clay fraction. The lead may also be more bioavailable, as both smaller particle size and greater Pb concentrations in smaller particles increase bioavailability, however it would be primarily dependent on the speciation of the lead (Chaney et al., 1989). Magrisso et al. (2009) studied the bioavailability of Pb in the larger particle size fractions. They found that 55% of the desorbed Pb in the larger particle size fraction, specifically soils rich in quartz which have the lowest affinity for Pb, may be bioavailable. Speciation of lead impacts the bioavailability of it, regardless of which size fraction the lead is found in (Chaney et al., 1989). The Pb in the sampled Great Bend soils may be less bioavailable when ingested by humans than the soils in Hays, however, without knowing the speciation of the lead in these size fractions we cannot say for certain. As Figure 5-1 illustrates the mineral form, particle size, and encapsulation of the lead all impact the bioavailability. Without knowing the mineral form, we cannot draw conclusions about the bioavailability of our samples.

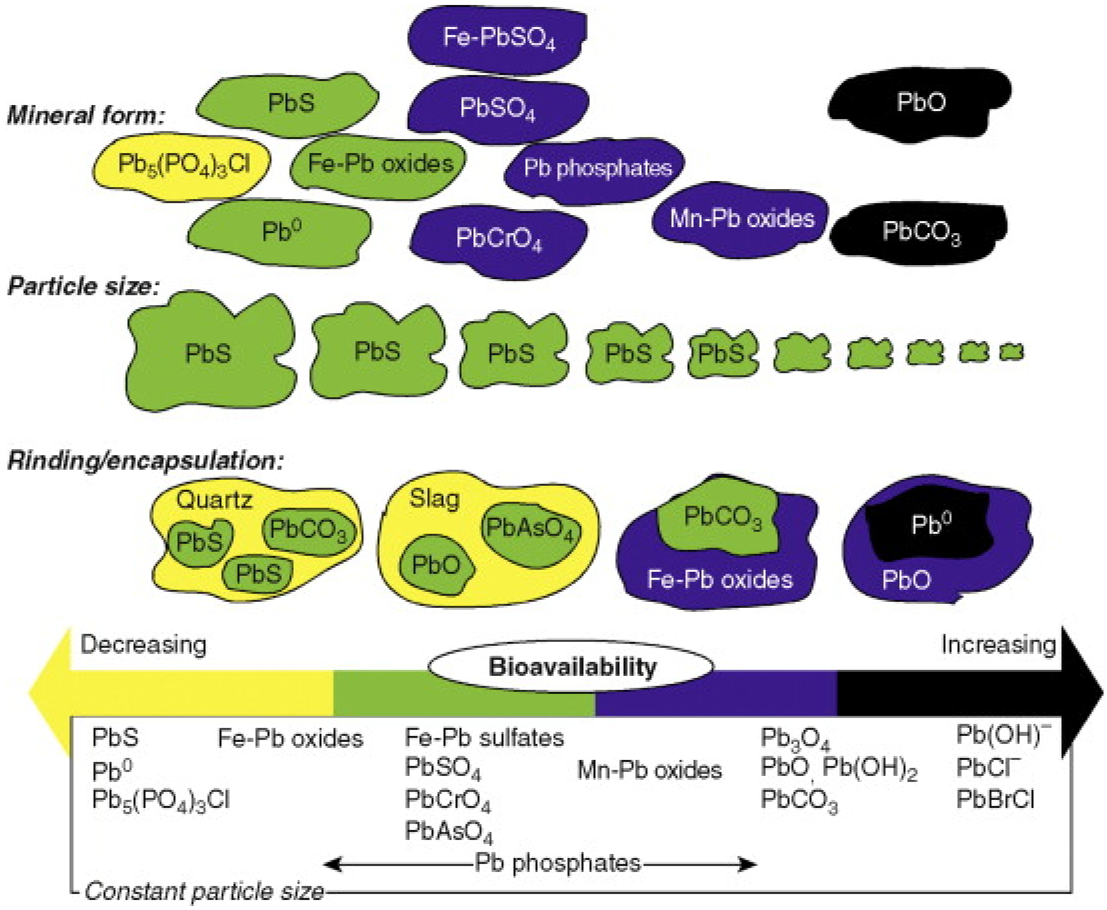


Figure 5-1: Diagram illustrating the increase in bioavailability from species of lead and particle size (Lanzirotti et. al, 2010)

While pH did not seem to influence the soil Pb levels observed in this study, pH is known to influence the types of Pb-bearing minerals available (Hettiarachchi and Pierzynskib, 2004; Lindsay, 1979; Nriagu, 1974). Solutions at the pH of human intestines (6-7.4) has been shown to allow soil components to adsorb Pb and reduce Pb adsorption in the body (Chaney et al., 1989). At low soil pH levels (<6), Pb tends to be more soluble and therefore more bioavailable. At near neutral and higher pH (>6.5), the solubility of Pb in soil is significantly lower. The city of Hays (7.43 ± 0.28) and Great Bend (7.70 ± 0.32) both have slightly alkaline soils, with Hays being more basic on average, which will tend to reduce mobility of Pb relative to more acidic localities for native soil Pb bioavailability.

5.2 Soil Chemistry and Lead Isotope Systematics

Two different methods were used to determine elemental compositions of the soil collected, Niton and Bruker HHXRF and HR ICP-MS. The HR ICP-MS method gave results higher than both HH-XRF instruments. While the HR ICP-MS results are more accurate, both HH-XRF gave acceptable data quality to assess Pb risk. For example, samples tested below 400 mg/kg, EPA's threshold for children play areas, remained close or under this value on all methods. The HH-XRF appears to be an acceptable, and low-cost, way to determine Pb concentrations.

Nriagu (1974) demonstrated that many lead phosphates are important for controlling lead mobility in natural environments. Chloropyromorphite, $Pb_5(PO_4)_3Cl$, for example, is the most insoluble of lead phosphate minerals and has the capability of controlling lead solubility throughout the pH range of most soils (Lindsay, 1979). Phosphorous concentrations varied greatly in soils analyzed by HHXRF and HR ICP-MS (Figure 4-10), and this variability maybe attributable to whether fertilizer was used in residential gardens and yards (Nziguheba and Smolders, 2008). Higher P is expected in areas maintained with fertilizer, and Pb in soils with elevated P have probably complexed with it (Hettiarachchi et al., 2004; Niriagu, 1974). If so, the Pb in these soils may be less bioavailable. However, this study did not constrain fertilizer use at the study sites, so detailed analysis of fertilizer type, quantity, application history, etc., would be needed to confirm whether the variations in P concentration observed are related to application of fertilizer.

Calcium phosphates and fiber have been shown to decrease the absorption of lead within the human body (Blake and Mann, 1983). A combination of calcium and phosphorous has a greater ability to inhibit lead absorption than calcium alone (Blake and Mann, 1983). Ingested Pb has been shown to replace calcium in bones and disrupts Ca^{2+} metabolism; it also substitutes for calcium in Ca^{2+}/Na^{2+} adenosine triphosphate (ATP) pump and blocks Ca^{2+} uptake into mitochondria and endoplasmic reticulum (Casas and Sordo, 2006). Lead's ability to pass through the blood-brain barrier is primarily due to its ability to substitute for calcium ions (Casas and Sordo, 2006). However, the HHXRF and HR ICP-MS results show no correlation between lead and calcium concentrations (Appendix E). We believe the bioavailability and absorption of Pb in the soils sampled through human ingestion would largely depend on the nutritional health of the child and the speciation of the available lead.

As well as complexing with phosphates, Pb may also adsorbs onto Fe and Mn (hydr)oxides, and in this form it can be considered inert (O'reilly and Hochella; 2003). While no correlations were observed between Fe or Mn and Pb concentrations in the studied samples (Appendix E), based on previous studies it can be assumed that Pb in the Barton and Ellis soils have adsorbed onto available Fe and Mn oxyhydroxides in the soil, helping to reduce their mobility and reduce risk.

Other forms of lead, such as lead oxides, sulfates, and carbonates, are more soluble in acidic environments and may pose a greater toxicological risk when ingested (Triana and Laperche, 1999). Results from the XRD analysis (Appendix F) are ambiguous as to the presence of lead sulfate, but no lead carbonates were found. As lead carbonates and sulfates tend to be amorphous minerals, they cannot be readily detected by XRD. Lead carbonate is expected to be present in the Barton and Ellis, as it is more stable at higher pH. A more comprehensive analysis of the sample set is required to establish the nature of the Pb-bearing phase(s).

Within cities and urban areas, elevated Pb concentrations have been seen in association with other heavy metal substances, such as zinc. Ingestion of soils with elevated Pb and Zn concentrations by children with iron and calcium deficiencies increase lead bioavailability (Mielke & Heneghan, 1991). Figure 4-12 shows the positive correlation between Zn and Pb concentrations measured with HR ICP-MS. Figure 4-11 shows the P v Pb relationship for all 86 samples measured by HHXRF. We did not see any correlation with rising Pb concentrations and P concentrations. Zinc is usually present in soil due to atmospheric deposition (Shen et al., 2016), but within Great Bend, there is a zinc and chromium superfund site that may represent a more local source for historic deposition of zinc. Another heavy metal at risk to human health, As, shows a positive correlation with Pb concentration in the area (Figure 4-13). The higher concentrations of zinc may be due to historic use of fertilizers that contain elevated trace metal concentrations (Chen et al., 2008). The elevated arsenic may be attributed to arsenic bearing pesticides (Matera et al., 2003).

Figure 4-8, the map overlaying Pb concentration data with age of housing stock, shows the potential for increased risk from soil with elevated Pb when living in homes built prior to 1950. The primary source of lead in soil adjacent to such homes is likely to be from leaded paint, although this study does not confirm or refute that assumption. There was no statistical difference in the lead concentrations observed when sampled close to homes versus close to roads. The highest levels of lead came from the front yard and drip zones, especially areas where paint chips were visible. This may indicate that the major source of the elevated lead (400+ mg/kg) may be from paint chips found predominately at drop zones with additional lead from sources such as historic leaded gasoline, factory emissions, fertilizers with trace metals, or aviation related releases.

Sample GB-4B, from Great Bend, with a Pb concentration of 8,981 mg/kg (measured by HR ICP-MS), also has the highest total organic carbon at 6.25% and total nitrogen of 0.48%. For the eight tested samples the range of total organic carbon was 2.20-6.25%. As the samples were taken 6 inches from the surface, where there tends to be most of the organic matter, these ranges are expected with 1-6% being the average range. Soil organic matter helps to decrease bioavailability (Sauvé et al., 1998). Most of the 86 samples contained organic matter, as noted during field work sampling and seen in PSA digestion. A better understanding the impacts on Pb mobility from TOC and TN for the studied areas will require more detailed information on the history and use of the soils, which is beyond the scope of this study.

Isotopic signatures of potential local sources, (e.g. factories, leaded gasoline, leaded paint, or oil rigs), were not determined as part of this study, so we have used more generalized reference values (Table 1.1) to guide our interpretation of the isotopic results. Examining Figure 5-2, shows the lower right is a cluster of lead values with a low isotopic ratio. Possible sources with similar lead isotope ratios include historic leaded gasoline emissions when Idaho lead ore was in use as an additive in gasoline and local bedrock. At higher isotopic ratios and elevated Pb concentrations, the anthropogenic sources may derive from Mississippi-Valley-ore-generated gasoline emissions combined with other anthropogenic sources such as coal combustion emissions. Coal emissions have a Pb^{206}/Pb^{207} ratio of 1.126-1.252 range which all our samples fall between. None of the lead within our samples were probably sourced from the Tri-State Mining District as the ratio range is too high 1.210-1.360.

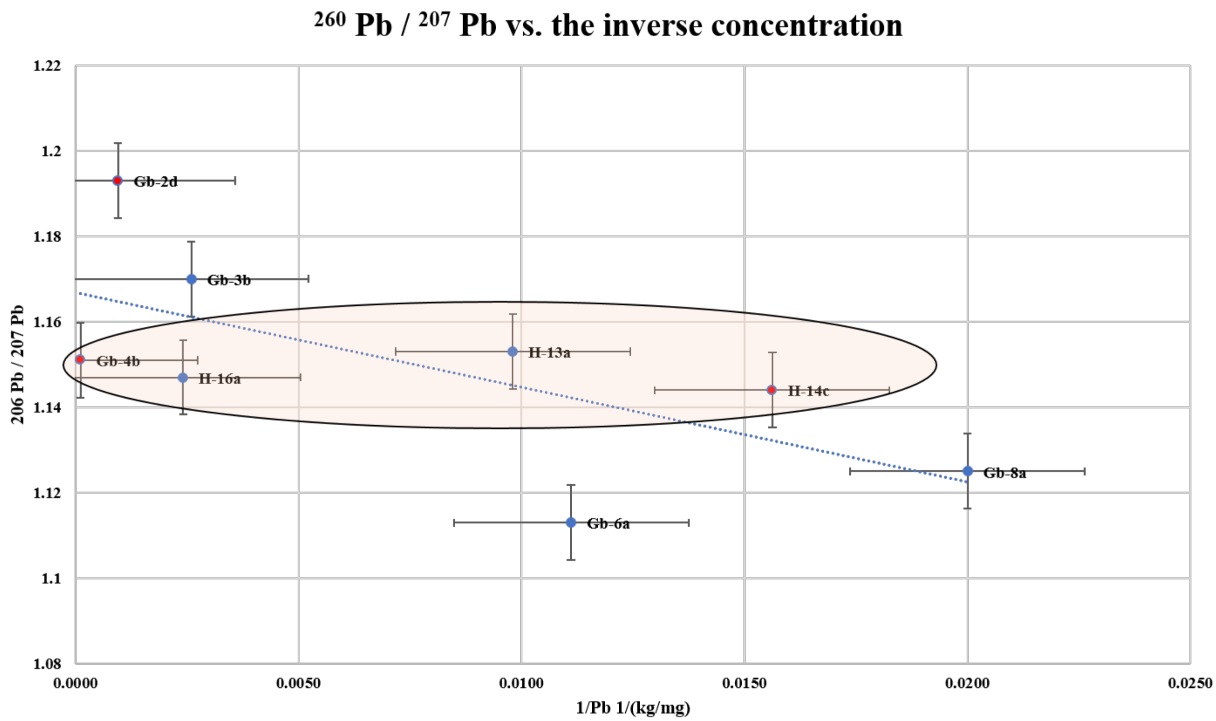


Figure 5-2: 206Pb/207Pb vs 1/Pb with a possible commonly shared source highlighted. The red dots are samples that tested positive for lead in the top layer of paint.

Samples Gb 4-B, H-16A, H-13A, and H-14C have similar isotopic compositions though they have a wide range of Pb concentrations. This suggests that Hays may have a similar source or sources at all the samples measured. Samples at Great Bend range widely in isotopic composition, suggesting a wider range of contributing sources or different sources.

The red dots in Figure 5-2 are for samples that tested positive for lead in the top layer of the house paint. The house in GB-4B was built in 1920 and remodeled in 1996. It is possible that during the remodeling, if the outside paint were sanded down, Pb dust fell into and was preserved in the soil, creating an elevated Pb concentration (8982 mg/kg on the HR ICP-MS). The isotopic composition of leaded paint at the residential homes cannot be determined without testing the paint chips. Sample GB-3B was taken from an oil field worker's home near the outdoor washing machine where he washed his work clothes and hung them up to dry. GB-3B's isotopic signature could include "take-home" Pb from the oil field.

The soil samples that were taken near homes that tested positive for elevated lead in paint chips were built during two different periods, GB-2D and GB-4B in 1920, and H-14C built in 1945. H-14C has a similar isotopic composition as GB-4B but a lower concentration. If these lead isotope ratios are due to the presence of leaded paint in the soils, one explanation for the variation is that the same ore lead was used in the paint, but Pb concentration was lower in the paint used at H-14C, because lead in paint was being phased out. Regardless, the wide range of isotopic compositions observed for the Great Bend samples implies that, even if leaded paint is contributing to the Pb inventory in the soil, it is either isotopically heterogeneous, or is not the main (or only) source of Pb in the soil.

Although our data do not resolve the question of Pb sources in Barton and Ellis soils, they do highlight the potential for such data to be able to achieve this end. In order to fully deconvolve the various sources of lead in this study, future work needs to include the isotopic analysis of 1) paint chips, 2) local factory emissions, 3) soil from nearby oil rigs 4) aviation gasoline if the airport if geospatially relevant. Also, ambient atmospheric emissions in central Kansas need to be estimated by going to an undisturbed lake and a sediment core to measure the lead isotope compositions.

Without gathering Pb isotopic data from the former zinc and chromium plating facility, we cannot determine whether it is a source of elevated lead in Great Bend. Samples from the local lead battery manufacturer in Hays would have to be sampled as well. Soil near aviation sites, such as the Hays Regional Airport in Ellis County and the Ellinwood Municipal Airport in

Barton County would need sampling as well. With better constraints on potential end members, it may be possible to constrain the Pb sources in these soils.

5.3 Geospatial & Statistical Analysis

A principal aim of this study is to identify sources of lead that may contribute to risk of elevated BLL in children. One way to assess the impact of housing age and number of oil wells would be to examine specific data on each child reported with elevated BLL and record the age of the house and surrounding number of oil wells a set distance away. However, this would involve the cooperation of multiple agencies and an institutional review board (IRB). The conclusions and correlations drawn in this thesis are limited by the data provided and publicly available. An issue with relying on correlative data is the lag that may occur between one event and impacting a child's blood lead level. However, the variables chosen (e.g. poverty levels, housing age, BLL, number of oil wells, and population) may provide a picture of the possible influences on children's blood lead levels in various counties in Kansas.

Unfortunately, systematic monitoring has decreased from 2010 to 2013, due to lack of funding. Federal funding for programs that screened children, removed lead hazards from homes, and increased public awareness was cut in 2012 from the CDC and other government agencies. In 2014, some programs were refunded, but Kansas did not apply for available aid. Kansas Healthy Homes and Lead Hazard Prevention Program (HHLHPP), funded by the EPA and HUD, is the only government aid given to residents by the Kansas Department of Health and Environment. HHLHPP primarily deals with education, surveillance, and monitoring according to their website. According to Reuters Investigates, Kansas, along with Utah and Alaska, claim to not follow a federal requirement to test Medicaid children (Schneyer & Pell, 2016). Children in poverty who are exposed to lead may not be included in a monitoring scheme and, therefore, the BLL values per county may be and underestimate.

Approximately 11% of the oil well points are applications for new drilling sites, 7% of the active wells in Kansas are spudding wells, And 60% are inactive wells. While oil production appears to be on the decline in Barton and Ellis county, this may be due to the significant drop in the price of oil after 2013 (Baffes et al., 2015). Both counties have economic ties to oilfields and a lead battery manufacturer is found approximately 4 miles northwest of the city of Hays. Lead exposure from factories, mines, and superfund sites could not be unambiguously identified, based on the results of this study. Future work will be required to assess their respective contributions to the Pb budget in the region.

Figures 4-23, 4-25, 4-29 highlight the existence of zones with elevated BLL in children in central Kansas and parts of south eastern Kansas. Since most of central Kansas is far removed from historic mining, the major cause(s) of elevated BLL is uncertain. Barton and Ellis county sit on the central Kansas uplift and have significant oil production. In 2015, according to KGS, Ellis was the number one producer of oil with 2,643,010 bbl, followed by Haskell at 2,453,479 bbl, and Barton at 1,699,851 bbl. Haskell sits in the Anadarko basin and has 447 oil wells, whereas Ellis has 2,516 and Barton has 1,900. The data suggest that along with average age of housing, there is a geospatial correlation between the number of active oil wells and blood lead levels in children (Figure 4-24).

Given that the BLL levels in the most affected areas exceed 5 μg/dL values, some children in central Kansas may be suffering from irreversible loss in IQ. Studies suggest that this may affect their ability to pursue higher education and may also lead to monetary losses over their lifetime (Landrigan et al., 2002).

The ArcGIS near table analysis showed that Barton county residents, on average, live closer to oil wells than Ellis county residents, and children in Barton County have higher average BLL than those in Ellis. However, the latter may also be explained by age of housing: Ellis County has 69.7% of homes built before 1978 and Barton has 87.1% built before 1978. Ellis county employs more people in the oilfield industry and has a sealed lead battery manufacturer. There are multiple variables associated with elevated BLL and the results of this study do not allow us to distinguish their relative contributions.

In Kansas, most future drilling applications have been placed for areas in the Cherokee Basin where there are contaminated sites related to the historic tri-state mining. The instillation process of oil rigs including the use of pipe dope as a threading compound. Pipe dope contains significant amounts of lead and there may be a possibility of increased risk of take home lead exposure from oil workers as occurred in Oklahoma (Khan, 2011).

5.4 Risk Assessment: Kansas Counties

Concentration of lead in soil, the particle size, chemical species, and nutritional factors of humans affect the risk from soil lead (Mielke and Heneghan, 1991). Fieldwork was designed to examine the lead concentration, PSA, and other elements found within the soil. Nutritional factors of humans are not in the scope of this project; however, poverty negatively impacts children's nutritional status (Miller & Korenman, 1994). The variable of poverty increases the risk of poor nutrition and thereby with exposure to lead may increase adsorption of lead into the body. The population variable is used to indicate city size and the level of urbanity in the county as high traffic towns tend to have higher concentrations of lead (Wixson & Davies, 1993).

While not considered in the overall risk assessment map, superfund sites and certain factories could also impact exposure. This may be a fruitful avenue to pursue in any continuation of this project. Currently available data suggest that central Kansas may have a continued risk of elevated blood lead levels in children. The monitoring in the at-risk areas in central Kansas are varied in terms of the proportion of children tested: Russel (17.0%), Rush (24.6%), Stafford (12.2%), Barton (13.3%), and Saline (10.4%). Saline, while not recorded on the risk assessment map, had childhood BLL effects through Exide's air pollution in 2011 (Thompson, 2016). These counties may be used to do further field work to examine soils and identify other sources of lead exposure.

The highest possible value in the risk assessment map could be 13.72 (2*1.4*2*1.75*1.4) with 1 being the lowest (1*1*1*1*1). The variables that hold the highest values in each rank are BLL and housing age, followed by oil, and then poverty levels and population. These values were deliberately chosen on the basis of literature and hazard assumptions (Hunt, 2016; Mcclure et al., 2016; EPA, 2013; Khan, 2011; Burgoon et al., 1995; Wixson and Davies, 1993). Housing age is important for the probability of leaded paint, which is a known risk to children. Population was included as research has shown that non-mining cities are affected by city size and the urban location as well as the age of surrounding housing (Wixson and Davies, 1993). Children in poverty tend to have poor nutrition (Miller & Korenman, 1994). The nutrition of the child impacts bioavailability and poverty in this risk assessment takes the place of measured nutrition. Children living in counties where there is a record of elevated BLL may be at risk due to decreased monitoring. Take home exposure from oil field workers or the travel of heavy metals in the installation of oil rigs may increase the risk of exposure (Khan, 2011). There are other factors not considered such as factories, mining/smelting sites, airports, superfund sites, and year schools/daycares were built.

The risk assessment map, created by multiplying variable values, identifies Wilson (8.19), Stafford (7.8), Rush (7.8), Barton (7.56), Saline (6.65), Woodson (6.13), and Allen (6.06) as counties where more research may be beneficial, as the variables considered point to high risk in these areas. Haskell (risk assessment of 3), the number 2 producer of oil in 2015 in Kansas, is not deemed to be at elevated risk due to its variable values in population, age of housing, BLL, poverty and number of oil wells. Wilson, the most at risk according to the risk assessment map, had over 10,000 oil wells recorded in 2013 with a population of 8,723 in 2010 and almost 9% of the children having elevated BLL in 2013. In 2013, poverty in the county was determined to be at about 28% of the population. A more in-depth profile of Wilson county may reveal other factors influencing the elevated blood lead levels.

Chapter 6 - Conclusions

Fieldwork was conducted in the cities of Great Bend (Barton County) and Hays (Ellis County) by sampling residential soil in various parts of the property. Our data suggest that soils from near homes built prior to 1950 have a higher probability of containing greater quantities of lead than houses built after 1978, when leaded paint was banned (Figure 4-9). Soils from drip zones tend to have higher lead concentrations than other parts of the property, as it is the closest to the exterior of the house where dislodged paint chips may fall and become incorporated.

Elevated soil Pb levels were also seen concurrently with higher Zn and As concentrations. Elevated Zn and As concentrations may have a compounding negative impact on human health. The source of these elements was not determined, but we hypothesize they may originate from either fertilizer/pesticide application or outputs from a factory known to emit lead contaminates into the environment. Phosphorous concentrations varied widely, probably due to anthropogenic disturbances by residents through soil fertilization or remediation efforts. Some remediation efforts, such as phosphate fertilizer, importing soil, or soil abatement can affect the Pb concentrations and bioavailability in the soil (Ibrikci et al., 2005). Elevated phosphate may decrease bioavailability of lead through complexation (Niriagu, 1974; Hettiarachchi et al., 2004). Fe concentrations averaged 20,617 ± 3003 mg/kg (1σ, $n = 86$) with no significant correlation with Pb. Absorption of Pb by Fe and Mn oxyhydroxides, but XRF and HR ICP-MS showed no evidence of positive correlation in their concentrations.

The alkaline soil suggests that lead absorption into the blood stream may be less than in more acid soils, if ingested by children. XRD results showed that, regardless of the pH, some lead sulfate minerals may have been present in at least one of the soil samples; however, the tendency for these minerals to be amorphous makes their identification difficult and easily masked by other minerals, such as quartz and feldspar.

The high organic content of the soil, as seen from the time of effervescence for PSA tests and TOC values, is most likely due to the shallow sampling procedure. Some of the organics from site GB-3B are believed to come from oil, as the sample was taken from near an outdoor washing machine that was used by an oil field worker. The threading compound used in oil rig construction may result in lead contamination through take-home sources. Proposed sites for new oil wells in Kansas are centered in the southeastern area (Figure 4-27). Installation processes may create a risk for elevated BLL in the upcoming years.

To conclusively prove environmental sources of elevated Pb in Kansas, isotopic tests need to be done on the possible end member materials. The eight samples analyzed showed that there are probably multiple sources contributing to the lead in the soils. Samples with low $^{206}Pb/^{207}Pb$ (1.11 – 1.15) and low Pb concentrations may reflect local bedrock lead combined with historic leaded gasoline emissions when Idaho ore was in use. Samples with higher $^{206}Pb/^{207}Pb$ (1.15 – 1.20) are consistent with transition to Mississippi Valley ore (if combined with a lower Pb concentration in the petroleum) and / or additional Pb sources such as leaded paint, coal combustion, and other anthropogenic emissions. Important sources to consider for future evaluation are the zinc and chromium plating facility in Barton County and the leaded battery manufacturer in Ellis County. Isotopic tests need to be run on paint chips to confirm a contribution to the soil, and the risk of oil wells need to be confirmed by tests in children's BLL or sampling near oil rigs. Local bedrock contributions to the lead budget need to be determined as well as potential aerosol contributions.

BLL monitoring has decreased over the past three years, making it harder to identify potential sources and risks when too few children are being tested. The maps presented in Section 4.10, suggest the number of oil wells in central Kansas may be a factor contributing to elevated BLL in children in some areas. However, the variables chosen for the risk assessment map (Figure x or table) had low correlative values with BLL, most likely due to the multiple factors influencing BLL and their varying proportion from one locality to the next. The variables in the risk assessment map include: BLL, housing age, number of oil wells, poverty percentage, and population. Water, toys, and dust were not examined as other pathways of exposure. Variables were designated values at 5 levels and multiplied to create a risk assessment map which showed Wilson (8.19), Stafford (7.8), Rush (7.8), and Barton (7.56) as areas at risk, based on 2013 data. Further research into these counties is recommended using more recent data or conducting fieldwork.

The variables in this study give only a single value per county in Kansas. Future studies may build better risk assessment maps working with geocoded point data within cities and towns; however, an Institutional Review Board and involvement of various federal agencies would be required. Expanding isotope tests on BLL samples should include multiple environmental samples (tap water, dust, paint, soil, and any local potential anthropogenic source) in order to better constrain the compositions of potential end members, similar to the work of Fillion et al. (2014).

Chapter 7 - References

Abadin, H. G., Hibbs, B. F., & Pohl, H. R. (1997). Breast-feeding exposure of infants to cadmium, lead, and mercury: A public health viewpoint. Toxicology and industrial health, 13(4), 495-517.

ATSDR (Agency for Toxic Substances and Disease Registry). (2007) Toxicological profile for lead. Atlanta, GA.

Baffes, J., Kose, M. A., Ohnsorge, F., & Stocker, M. (2015). The great plunge in oil prices: causes, consequences, and policy responses. Development Economics World Bank Group. Retrieved from https://www.worldbank.org/content/dam/Worldbank/Research/PRN01_Mar2015_Oil_Prices.pdf.

Bacon, J. R. (2002). Isotopic characterisation of lead deposited 1989-2001 at two upland Scottish locations. Journal of Environmental Monitoring, 4(2), 291-299. doi:10.1039/b109731h

Barnes, G. L., & Davis, A. P. (1996). Dissolution of lead paint in aqueous solutions. Journal of Environmental Engineering, 122(7), 663-666. doi:10.1061/(asce)0733-9372(1996)122:7(663)

Bellinger, D. C. (2006). Childhood lead poisoning: The torturous path from science to policy. Journal of Clinical Investigation, 116(4), 853-857. doi:10.1172/jci28232

Blake, K., Barbezat, G., & Mann, M. (1983). Effect of dietary constituents on the gastrointestinal absorption of 203Pb in man. Environmental Research, 30(1), 182-187. doi:10.1016/0013-9351(83)90178-0

Bollhöfer, A., & Rosman, K. (2000). Isotopic source signatures for atmospheric lead: The Southern Hemisphere. Geochimica Et Cosmochimica Acta, 64(19), 3251-3262. doi:10.1016/s0016-7037(00)00436-1

Boris, N. W., & Dalton, R. (2000). Pica. In R. E. Behrman, R. Kliegman, & H. B. Jenson (Eds.), Nelson textbook of pediatrics. Philadelphia: W.B. Saunders.

Brown, J. R. (1998). Recommended chemical soil test procedures for the North Central Region. Columbia, MO: Missouri Agricultural Experiment Station, University of Missouri--Columbia.

Burgoon, D. A., Brown, S. F., & Mention, R. G. (1995). Literature review of sources of elevated soil-lead concentrations. In S. D. Iske (Author) & M. E. Beard (Ed.), Lead in paint, soil, and dust: Health risks, exposure studies, control measures, measurement methods, and quality assurance. Philadelphia, PA, U.S.A.: ASTM.

CDC (Centers for Disease Control and Prevention). (2012) Low level lead exposure harms children: a renewed call for primary prevention. Washington, DC: U.S. Department of Health and Human Services. http://www.cdc.gov/nceh/lead/acclpp/final_document_030712.pdf

Canfield, R. L., Henderson, C. R., Cory-Slechta, D. A., Cox, C., Jusko, T. A., & Lanphear, B. P. (2003). Intellectual impairment in children with blood lead concentrations below 10 µg per deciliter. Obstetrical & Gynecological Survey, 58(9), 590-591. doi:10.1097/01.ogx.0000083449.93960.d0

Carr, E., Lee, M., Marin, K., Holder, C., Hoyer, M., Pedde, M., . . . Touma, J. (2011). Development and evaluation of an air quality modeling approach to assess near-field impacts of lead emissions from piston-engine aircraft operating on leaded aviation gasoline. Atmospheric Environment, 45(32), 5795-5804. doi:10.1016/j.atmosenv.2011.07.017

Casas, J., & Sordo, J. S. (2006). Lead: Chemistry, analytical aspects, environmental impact and health effects. Amsterdam: Elsevier.

Casteel, S. W., Weis, C. P., Henningsen, G. M., & Brattin, W. J. (2006). Estimation of relative bioavailability of lead in soil and soil-like materials using young swine. Environmental Health Perspectives, 114(8), 1162-1171. doi:10.1289/ehp.8852

Chaney, R. L., Mielke, H. W., & Sterrett, S. B. (1989). Speciation, mobility, and bioavailability of soil lead. Environ. Geochem. Health, 11, 105-129.

Chen, W., Krage, N., Wu, L., Pan, G., Khosrivafard, M., & Chang, A. C. (2008). Arsenic, cadmium, and lead in california cropland soils: Role of phosphate and micronutrient fertilizers. Journal of Environment Quality, 37(2), 689. doi:10.2134/jeq2007.0444

Chow, T. J., & Earl, J. L. (1972). Lead Isotopes in North American Coals. Science, 176(4034), 510-511. doi:10.1126/science.176.4034.510

Clark, S., Menrath, W., Chen, M., Succop, P., Bornschein, R., Galke, W., & Wilson, J. (2004). The influence of exterior dust and soil lead on interior dust lead levels in housing that had undergone lead-based paint hazard control. Journal of Occupational and Environmental Hygiene, 1(5), 273-282. doi:10.1080/15459620490439036

Datko-Williams, L., Wilkie, A., & Richmond-Bryant, J. (2014). Analysis of U.S. soil lead (Pb) studies from 1970 to 2012. Science of The Total Environment, 468-469, 854-863. doi:10.1016/j.scitotenv.2013.08.089

Davies, B. E. (1988). Lead in soils: It's sources and typical concentration. (B. G. Wixson, Ed.). In B. E. Davies (Ed.), Lead in soil: Issues and guidelines. Science Reviews.

Dikilitas, M., Karakas, S., & Ahmad, P. (2016). Effect of lead on plant and human dna damages and its impact on the environment. *Plant Metal Interaction*, 41-67.

DTSC (Department of Toxic Substance Control - State of California). (2011). Investigation and Remediation of Plating Facilities. Sacramento, California. https://clu-in.org/download/contaminantfocus/chromium/Chromium-Plating-2011.pdf

Duggan, M. J., & Inskip, M. J. (1985). Childhood exposure to lead in surface dust and soil: A community health problem. Public Health Reviews, 13, 1-54.

ECCED (Ellis County Coalition of Economic Development). (2018) Retrieved from http://www.haysamerica.net/

Elias, W. R. (1985). Lead exposures in the human environment. In K. R. Mahaffey (Ed.), Dietary and environmental lead: Human health effects. Amsterdam: Elsevier.

Erel, Y., Veron, A., & Halicz, L. (1997). Tracing the transport of anthropogenic lead in the atmosphere and in soils using isotopic ratios. Geochimica Et Cosmochimica Acta, 61(21), 4495-4505. doi:10.1016/s0016-7037(97)00353-0

Farmer, J. G., Eades, L. J., Mackenzie, A. B., Kirika, A., & Bailey-Watts, T. E. (1996). Stable Lead Isotope Record of Lead Pollution in Loch Lomond Sediments since 1630 A.D. Environmental Science & Technology, 30(10), 3080-3083. doi:10.1021/es960162o

Flora, G., Gupta, D., & Tiwari, A. (2012). Toxicity of lead: A review with recent updates. Interdisciplinary Toxicology, 5(2).

Galke, W., Clark, S., Wilson, J., Jacobs, D., Succop, P., Dixon, S., . . . Chen, M. (2001). Evaluation of the HUD lead hazard control grant program: early overall findings. Environmental Research, 86(2), 149-156.

Gilbert, S. G., & Weiss, B. (2006). A rationale for lowering the blood lead action level from 10 to 2 µg/dL. NeuroToxicology, 27(5), 693-701. doi:10.1016/j.neuro.2006.06.008

Hagni, R. D., & Grawe, O. R. (1964). Mineral paragenesis in the Tri-State District, Missouri, Kansas, Oklahoma. Economic Geology, 59(3), 449-457. doi:10.2113/gsecongeo.59.3.449

Hansmann, W., & Köppel, V. (2000). Lead-isotopes as tracers of pollutants in soils. Chemical Geology, 171(1-2), 123-144. doi:10.1016/s0009-2541(00)00230-8

Harrison, R. M., Laxen, D. P., & J, W. S. (1981). Chemical associations of lead, cadmium, copper, and zinc in streets dusts and roadside soils. Environ. Sci. Technol, 15, 1378-1383.

Henry, H., Naujokas, M. F., Attanayake, C., Basta, N. T., Cheng, Z., Hettiarachchi, G. M., . . . Scheckel, K. G. (2015). Bioavailability-based in situ remediation to meet future lead (pb) standards in urban soils and gardens. Environmental Science & Technology Environ. Sci. Technol., 49(15), 8948-8958. doi:10.1021/acs.est.5b01693

Hettiarachchi, G. M., & Pierzynski, G. M. (2004). Soil lead bioavailability and in situ remediation of lead-contaminated soils. ChemInform, 35(27). doi:10.1002/chin.200427277

Hood, E. (2005). Dwelling disparities: How poor housing leads to poor health. environmental health perspectives, 113(5). doi:10.1289/ehp.113-a310

Hunt, A. (2016). Relative bioaccessibility of Pb-based paint in soil. Environ Geochem Health Environmental Geochemistry and Health, 38(4), 1037-1050. doi:10.1007/s10653-015-9789-6

Hurst, R. W., Davis, T. E., & Chinn, B. D. (1996). Peer Reviewed: The Lead Fingerprints of Gasoline Contamination. Environmental Science & Technology, 30(7). doi:10.1021/es962319i

Ibrikci, H., Ryan, J., Ulger, A. C., Buyuk, G., Cakir, B., Korkmaz, K., . . . Konuskan, O. (2005). Maintenance of Phosphorus Fertilizer and Residual Phosphorus Effect on Corn Production. Nutrient Cycling in Agroecosystems, 72(3), 279-286. doi:10.1007/s10705-005-3367-8

Johnson, A. W., Gutiérrez, M., Gouzie, D., & Mcaliley, L. R. (2016). State of remediation and metal toxicity in the tri-state mining district, usa. Chemosphere, 144, 1132-1141. doi:10.1016/j.chemosphere.2015.09.080

Junge, A., & Bean, R. (2006). A short history of the zinc smelting industry in Kansas. Topeka, Kan.: Kansas Department of Health and Environment.

KSHS (Kansas Historical Society). (2018) Retrieved from https://www.kshs.org/

KGS (Kansas Geological Survey). (2018) Retrieved from http://www.kgs.ku.edu/PRS/petroDB.html

Keisch, B. (1971). X-Ray diffraction and the composition of lead white. Studies in the History of Art, 4, 121-133. Retrieved March 04, 2018, from http://www.jstor.org/stable/10.2307/42617728?refreqid=search-gateway:670196e682d858c4228a36f9fec01024

Kodom, K., Preko, K., & Boamah, D. (2012). X-ray Fluorescence (XRF) analysis of soil heavy metal pollution from an industrial area in Kumasi, Ghana. Soil and Sediment Contamination: An International Journal, 21(8), 1006-1021. doi:10.1080/15320383.2012.712073

Komárek, M., Ettler, V., Chrastný, V., & Mihaljevič, M. (2008). Lead isotopes in environmental sciences: A review. Environment International, 34(4), 562-577. doi:10.1016/j.envint.2007.10.005

Landrigan, P. J., Gehlbach, S. H., Rosenblum, B. F., Shoults, J. M., Robert, P., Candelaria, M., . . . Sanders, J. F. (1975). Epidemic lead absorption near an ore smelter. New England Journal of Medicine, 292(3), 123-129. doi:10.1056/nejm197501162920302

Lanphear, B. P., Hornung, R., Khoury, J., Yolton, K., Baghurst, P., Bellinger, D. C., . . . Roberts, R. (2005). Low-level environmental lead exposure and children’s intellectual function:

An international pooled analysis. Environmental Health Perspectives, 113(7), 894-899. doi:10.1289/ehp.7688

Lanphear, B. P., Matte, T. D., Rogers, J., Clickner, R. P., Dietz, B., Bornschein, R. L., . . . Jacobs, D. E. (1998). The contribution of lead-contaminated house dust and residential soil to children's blood lead levels. Environmental Research, 79(1), 51-68.

Lindsay, W. L. (1979). Chemical equilibria in soils. New York: Wiley.

Lu, Y., Gong, Z., Zhang, G., & Burghardt, W. (2003). Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing, China. Geoderma, 115(1-2), 101-111. doi:10.1016/s0016-7061(03)00079-x

Magrisso, S., Belkin, S., & Erel, Y. (2009). Lead bioavailability in soil and soil components. water, air, and soil pollution, 202(1-4), 315-323. doi:10.1007/s11270-009-9978-y

Malcoe, L. H., Lynch, R. A., Kegler, M. C., & Skaggs, V. J. (2002). Lead sources, behaviors, and socioeconomic factors in relation to blood lead of native American and white children: A community-based assessment of a former mining area. Environmental Health Perspectives, 110(S2), 221-231.

Martin, A. J. (1946). Summarized statistics of production of lead and zinc in the Tri-state (Missouri-Kansas-Oklahoma) mining district. Washington, D.C.: U.S. Dept. of the Interior, Bureau of Mines.

Matera, V., Laboudigue, A., Thomas, P., Tellier, S., Astruc, M., & Hécho, I. L. (2003). A methodological approach for the identification of arsenic bearing phases in polluted soils. Environmental Pollution, 126(1), 51-64. doi:10.1016/s0269-7491(03)00146-5

Mcclure, L. F., Niles, J. K., & Kaufman, H. W. (2016). Blood lead levels in young children: US, 2009-2015. The Journal of Pediatrics, 175, 173-181. doi:10.1016/j.jpeds.2016.05.005

McLean, J. E., & Bledsoe, B. E. (1992). Behavior of metals in soils. Washington, DC: Technology Innovation Office, Office of Solid Waste and Emergency Response.

Mielke, H. W., & Heneghan, J. B. (1991). Selected Chemical and Physical Properties of Soils and Gut Physiological Processes that Influence Lead Bioavailability. Chemical Speciation & Bioavailability, 3(3-4), 129-134. doi:10.1080/09542299.1991.11083164

Mielke, H. W., Gonzales, C. R., Powell, E., Jartun, M., & Mielke, P. W. (2007). Nonlinear association between soil lead and blood lead of children in metropolitan New Orleans, Louisiana: 2000-2005. Science of The Total Environment, 388(1-3), 43-53.

Miller, J. E., & Korenman, S. (1994). Poverty and children's nutritional status in the United States. American Journal of Epidemiology, 140(3), 233-243. doi:10.1093/oxfordjournals.aje.a117242

Merriam, D. F. (2011). Advances in the science and technology of finding and producing oil in Kansas: A critique. Kansas Geological Survey.

Nriagu, J. O. (1974). Lead orthophosphates. I. Solubility and hydrolysis of secondary lead orthophosphate. Inorganic Chemistry, 11(10), 2499-2503. doi:10.1021/ic50116a041

Nziguheba, G., & Smolders, E. (2008). Inputs of trace elements in agricultural soils via phosphate fertilizers in European countries. Science of The Total Environment, 390(1), 53-57. doi:10.1016/j.scitotenv.2007.09.031

O'reilly, S., & Hochella, M. F. (2003). Lead sorption efficiencies of natural and synthetic Mn and Fe-oxides. Geochimica Et Cosmochimica Acta, 67(23), 4471-4487. doi:10.1016/s0016-7037(03)00413-7

Oulhote, Y., Bot, B. L., Poupon, J., Lucas, J., Mandin, C., Etchevers, A., . . . Glorennec, P. (2011). Identification of sources of lead exposure in French children by lead isotope analysis: A cross-sectional study. Environmental Health, 10(1).

Patterson, C., Ericson, J., Manea-Krichten, M., & Shirahata, H. (1991). Natural skeletal levels of lead in Homo sapiens sapiens uncontaminated by technological lead. Science of The Total Environment, 107, 205-236. doi:10.1016/0048-9697(91)90260-l

Pendall, R., Theodos, B., & Hildner, K. (2014). Why high-poverty neighborhoods persist. Urban Affairs Review, 52(1), 33-65. doi:10.1177/1078087414563178

Rabinowitz, M. B. (2005). Lead isotopes in soils near five historic American lead smelters and refineries. Science of The Total Environment, 346(1-3), 138-148. doi:10.1016/j.scitotenv.2004.11.021

Rabito, F. A., Kocak, M., Werthmann, D. W., Tylavsky, F. A., Palmer, C. D., & Parsons, P. J. (2014). Changes in low levels of lead over the course of pregnancy and the association with birth outcomes. Reproductive Toxicology, 50, 138-144. doi:10.1016/j.reprotox.2014.10.006

Rautiu, R., Brush, S., & Thornton, I. (2001). Lead exposure to humans and other organisms. In Lead: The Facts. Surrey, UK: Ian Allan Printing.

Reimann, C., Flem, B., Fabian, K., Birke, M., Ladenberger, A., Demetriades, A., . . . Négrel, P. (2012). Lead and lead isotopes in agricultural soils of Europe - The continental perspective. Applied Geochemistry, 27(3), 532-542. doi:10.1016/j.apgeochem.2011.12.012

Rogan, W. J., & Ware, J. H. (2003). Exposure to lead in children: How low is low enough? New England Journal of Medicine, 348(16), 1515-1516. doi:10.1056/nejmp030025

Sajadi, S. A. (2011). A comparative investigation of lead sulfate and lead oxide sulfate study of morphology and thermal decomposition. American Journal of Analytical Chemistry, 02(02), 206-211. doi:10.4236/ajac.2011.22024

Salminen, R., Plant, J. A., & Reeder, S. (2005). Geochemical atlas of Europe. Part 1, Background information, methodology and maps. Espoo, Finland: Geological Survey of Finland.

Sauvé, S., Mcbride, M., & Hendershot, W. (1998). Soil Solution Speciation of Lead(II): Effects of Organic Matter and pH. Soil Science Society of America Journal, 62(3), 618. doi:10.2136/sssaj1998.03615995006200030010x

SCHER (Scientific Committee on Health and Environmental Risks). Opinion on Voluntary Risk Assessment Report on Lead and Lead Compounds. European Commission.

Schneyer, J., & Pell, M. (2016, June 09). Millions of American kids are going untested for lead poisoning. Retrieved from https://www.reuters.com/investigates/special-report/lead-poisoning-testing-gaps/

Schwartz, J. (1994). Low-level lead exposure and children's IQ: A meta-analysis and search for a threshold. Environmental Research, 65(1), 42-55. doi:10.1006/enrs.1994.1020

Shen, F., Li, Y., Zhang, M., Awasthi, M. K., Ali, A., Li, R., . . . Zhang, Z. (2016). Atmospheric Deposition-Carried Zn and Cd from a Zinc Smelter and Their Effects on Soil Microflora as Revealed by 16S rDNA. Scientific Reports, 6(1). doi:10.1038/srep39148

Shirahata, H., Elias, R., Patterson, C., & Koide, M. (1980). Chronological variations in concentrations and isotopic compositions of anthropogenic atmospheric lead in sediments of a remote subalpine pond. Geochimica Et Cosmochimica Acta, 44(2), 149-162. doi:10.1016/0016-7037(80)90127-1

Simonetti, A., Gariépy, C., & Carignan, J. (2000). Pb and Sr isotopic compositions of snowpack from Quebec, Canada: Inferences on the sources and deposition budgets of atmospheric heavy metals. Geochimica Et Cosmochimica Acta, 64(1), 5-20. doi:10.1016/s0016-7037(99)00207-0

Stroh, E., Lundh, T., Oudin, A., Skerfving, S., & Strömberg, U. (2009). Geographical patterns in blood lead in relation to industrial emissions and traffic in Swedish children, 1978-2007. BMC Public Health, 9(1).

Sturges, W. T., & Barrie, L. A. (1987). Lead 206/207 isotope ratios in the atmosphere of North America as tracers of US and Canadian emissions. Nature, 329(6135), 144-146. doi:10.1038/329144a0

Thompson, B. (2016, June 22). KDHE outlines lead exposure investigation in Saline County. Retrieved from http://www.khi.org/news/article/kdhe-outlines-lead-exposure-investigation-in-saline-county

Traina, S. J., & Laperche, V. (1999). Contaminant bioavailability in soils, sediments, and aquatic environments. Proceedings of the National Academy of Sciences, 96(7), 3365-3371. doi:10.1073/pnas.96.7.3365

U.S. EPA (U.S. Environmental Protection Agency). (2013) Integrated science assessment for lead [EPA Report]. Research Triangle Park, NC.

USDA (U.S. Department of Agriculture). (1987) History of Kansas Soil Survey . Compiled by Barker, W. Washington, D.C.

USGS (U.S. Geological Survey). (2013) Occurrence and Variability of Mining-Related Lead and Zinc in the Spring River Floodplain and Tributary Flood Plains, Cherokee County, Kansas, 2009–11. Reston, VA.

WHO (World Health Organization) (1997) Lead. In International programme on chemical safety. Geneva.

Wixson, B. G., & Davies, B. E. (1993). Lead in soil: Recommended guidelines. Northwood: Science Reviews.

Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. ISRN Ecology, 2011, 1-20. doi:10.5402/2011/402647

Yang, J. Y., Yang, X. E., He, Z. L., Chen, G. C., Shentu, J. L., & Li, T. Q. (2004). Adsorption-desorption characteristics of lead in variable charge soils. Journal of Environmental Science and Health, Part A, 39(8), 1949-1967. doi:10.1081/ese-120039367

Yao, Q., Wang, X., Jian, H., Chen, H., & Yu, Z. (2015). Characterization of the particle size fraction associated with heavy metals in suspended sediments of the Yellow River. International Journal of Environmental Research and Public Health, 12(12), 6725-6744. doi:10.3390/ijerph120606725

Appendix A - Fieldwork Summary

Table A-1: Fieldwork summary.

Sample #	Age of House	Remodel Year	Sample Details	County	City	Zipcode
1A	1938		FY	Barton	Great Bend	67530
1B			DZ			
2A	1920		FY- Left facing	Barton	Great Bend	67530
2B			FY - Right facing			
2C			BY - ALL			
2D			DZ - Left			
2E			DZ - Right			
3A	1920		G	Barton	Great Bend	67530
3B			Near Washing Machine			
4A	1920	1996	BY - ALL	Barton	Great Bend	67530
4B			DZ - Top layer			
4C			DZ - 6 inches down			
5A	1914		FY- All	Barton	Great Bend	67530
5B			DZ in FY near painted over brick			
5C			BY - ALL			
6A	1920	1994	FY - ALL	Barton	Great Bend	67530
7A	1951	2002	FY - ALL	Barton	Great Bend	67530
8A	1920	2001	FY - close to road	Barton	Great Bend	67530
8B			FY - close to house			
9A	1900	1998	FY - close to road	Barton	Great Bend	67530
9B			FY - close to house			
10A	1940		FY - ALL	Barton	Great Bend	67530
11A	1950	1994	FY - ALL	Barton	Great Bend	67530
11B			SY - ALL			
12A	1953		FY - Right facing	Barton	Great Bend	67530
12B			FY - Left facing			

13A	1930		BY - by wood boat	Barton	Great Bend	67530
13B			BY - by house			
14A	1957	1994	FY - close to house	Barton	Great Bend	67530
14B			FY - closer to road			
14C			BY - ALL			
15A	1935	2001	DZ - near neighbors garage	Barton	Great Bend	67530
15B			G- Near DZ, tomatoes			
16A	1900	1995	FY - close to house	Barton	Great Bend	67530
16B			FY - close to road			
17A	1940		FY - close to road, tree left :)	Barton	Great Bend	67530
17B			FY - close to road, tree right :(			
18A	1941	2006	FY - left	Barton	Great Bend	67530
18B			SY - ALL			
19A	1930	1999	FY - close to road (Left)	Barton	Great Bend	67530
19B			FY - close to road (right)			
19C			FY - close to house			
20A	1910		FY - close to road	Barton	Great Bend	67530
20B			FY - close to house			
20C			FY - rose garden			
H-1A	1974		G - stunted tomatoes	Ellis	Hays	67601
H-1C			SY			
H-2A	1950		FY - close to road	Ellis	Hays	67601
H-2B			FY - next to house			
H-3A	1978		DZ	Ellis	Hays	67601
H-3B			FY - near road			
H-4A	1976		BY - by fence (tested negative)	Ellis	Hays	67601
H-4B			By - all (including near AC unit)			
H-4C			BY - near shed			
H-4D			FY - ALL			
H-5A	1959		FY - ALL	Ellis	Hays	67601
H-6A	1978		FY - ALL	Ellis	Hays	67601
H-7A	1980		FY - ALL	Ellis	Hays	67601
H-7B			Dz - corner of the house			
H-8A			Park	Ellis	Hays	67601
H-9A	1977		BY- Right side of maple tree	Ellis	Hays	67601
H-9B			BY - Left side of maple tree			
H-9D			FY - ALL			

H-10	1961	FY -ALL	Ellis	Hays	67601
H-11A	1935	G- tomato plants healthy	Ellis	Hays	67601
H-11B		G - tomato plants stunted			
H-11D		SY - plants to make a garden			
H-12A	1946	DZ- top layer	Ellis	Hays	67601
H-12B		DZ - deeper			
H-12C		FY - ALL			
H-13A	1950	DZ- top layer	Ellis	Hays	67601
H-13B		DZ- deeper			
H-13C		FY - ALL			
H-14A	1945	DZ - deeper	Ellis	Hays	67601
H-14B		DZ - Top layer			
H-14C		FY - ALL			
H-15A	1957	FY - ALL	Ellis	Hays	67601
H-15B		DZ - top (hard to dig)			
H-16A	1918	FY - ALL	Ellis	Hays	67601
H-17A	1920	DZ - top	Ellis	Hays	67601
H-17B		FY - ALL			
H-18A	1920	FY - ALL	Ellis	Hays	67601
H-19A	1920	FY - ALL	Ellis	Hays	67601
H-19B		DZ - deeper			
H-20A	1951	FY - close to road	Ellis	Hays	67601
H-20B		FY - close to house			

Appendix B - Mapping Variables

Table B-1: Number of oil wells in all counties from 2010-2013. KGS data.

NAME	OWell_2010	OWell_2011	OWell_2012	OWell_2013
Allen	2034	2050	2125	2322
Anderson	1626	1493	1696	1830
Atchison	0	0	0	0
Barber	1062	1165	1278	1396
Barton	1823	1852	1900	1956
Bourbon	556	485	548	605
Brown	0	0	1	4
Butler	1312	1340	1361	1365
Chase	75	75	75	73
Chautauqua	1167	1193	1256	1319
Cherokee	0	0	0	0
Cheyenne	30	29	28	38
Clark	137	121	135	141
Clay	10	11	10	5
Cloud	0	0	0	0
Coffey	958	1029	1135	1242
Comanche	259	267	278	342
Cowley	682	711	724	728
Crawford	549	557	655	665
Decatur	176	187	186	190
Dickinson	31	30	29	29
Doniphan	0	0	0	0
Douglas	407	399	419	440
Edwards	280	277	265	289
Elk	242	245	267	255
Ellis	2374	2443	2516	2606
Ellsworth	306	316	323	329
Finney	506	504	515	478
Ford	78	92	119	139
Franklin	1709	1802	1878	2012
Geary	10	10	9	8
Gove	333	352	386	421
Graham	918	968	1000	1037
Grant	64	60	62	62
Gray	43	46	64	74
Greeley	43	41	42	41
Greenwood	1388	1431	1438	1429

Hamilton	0	0	0	2
Harper	501	509	537	609
Harvey	114	116	114	115
Haskell	457	443	447	465
Hodgeman	235	257	285	297
Jackson	3	3	4	5
Jefferson	56	68	62	81
Jewell	0	0	0	0
Johnson	640	720	790	910
Kearny	121	101	98	100
Kingman	761	746	722	786
Kiowa	267	275	284	302
Labette	108	88	125	140
Lane	373	385	422	444
Leavenworth	203	202	210	211
Lincoln	0	0	0	0
Linn	882	875	961	1001
Logan	166	201	229	250
Lyon	39	40	41	39
Marion	365	344	351	364
Marshall	0	0	0	0
McPherson	617	605	608	604
Meade	161	159	185	172
Miami	2225	2269	2336	2314
Mitchell	0	0	0	0
Montgomery	1113	1185	1251	1371
Morris	85	81	80	83
Morton	186	178	160	148
Nemaha	23	22	24	25
Neosho	622	690	752	792
Ness	1014	1063	1098	1144
Norton	111	127	131	147
Osage	5	4	4	4
Osborne	112	120	128	133
Ottawa	0	0	0	0
Pawnee	141	157	169	177
Phillips	302	313	332	341
Pottawatomie	3	3	4	4
Pratt	533	535	539	545
Rawlins	134	120	123	149
Reno	400	402	404	411

Republic	0	0	0	0
Rice	845	950	966	988
Riley	31	31	31	31
Rooks	1520	1566	1606	1655
Rush	195	210	225	241
Russell	1886	1894	1933	1950
Saline	101	102	112	115
Scott	167	189	214	247
Sedgwick	127	126	127	131
Seward	250	239	256	247
Shawnee	0	0	0	0
Sheridan	109	106	115	123
Sherman	6	5	5	8
Smith	0	0	0	0
Stafford	1157	1169	1193	1215
Stanton	86	87	92	95
Stevens	140	150	144	149
Sumner	504	527	542	551
Thomas	106	125	142	163
Trego	557	573	596	633
Wabaunsee	31	32	37	34
Wallace	25	28	31	33
Washington	0	0	0	0
Wichita	13	14	32	50
Wilson	1146	1195	1251	1276
Woodson	2841	2938	3176	3406
Wyandotte	0	0	0	0

Table B-2: Poverty percentage per county. Census data.

NAME	Pov2010	Pov2011	Pov2012	Pov2013
Allen	26.4	27.7	28.16	26.4
Anderson	21.7	21.2	22.56	21
Atchison	20	21.1	22.15	22.22
Barber	19.4	18.3	16.26	18.32
Barton	20.1	22.6	22.48	20.31
Bourbon	25.7	30.36	31.37	30.14
Brown	27.1	24.5	25.67	22.67
Butler	12	14.1	13.18	14.18

Chase	18.8	17.5	16.87	17.95
Chautauqua	25.2	29.5	29.57	25.83
Cherokee	28.2	26.5	27.45	27.72
Cheyenne	18.8	18.7	16.94	18.28
Clark	14.3	17.1	17.25	15.6
Clay	17.3	18	16.73	17.42
Cloud	19.1	19.1	19.52	17.18
Coffey	12.7	14.7	13.82	13.45
Comanche	13.8	14.4	14.57	15.93
Cowley	21.9	24.6	25.01	23.69
Crawford	26.8	27.3	27.29	24.37
Decatur	20.3	20	20.88	20.77
Dickinson	16.6	17.5	16.57	16.21
Doniphan	17.4	19.6	18.18	18.9
Douglas	13.8	13.7	17.11	15.16
Edwards	19.2	19.8	19.29	17.54
Elk	29.2	25.7	29.64	32.35
Ellis	13.4	15.6	13.74	13.67
Ellsworth	15.2	15.4	14.87	13.76
Finney	21.3	24.3	21.45	22.67
Ford	20.6	19.5	22.3	18.61
Franklin	16.6	21.2	19.48	19.48
Geary	15.7	26.3	25.08	24.22
Gove	18.8	17	16.28	14.99
Graham	17.8	16.2	16.63	18.59
Grant	16.7	17.9	17.68	17.19
Gray	12.7	12.8	12.83	13.58
Greeley	17	14.6	14.29	13.4
Greenwood	25.6	24.1	24.31	23.04
Hamilton	20	21.1	18.29	20.46
Harper	22.4	23.1	21.4	21.36
Harvey	13.1	18.5	16.38	15.15
Haskell	17.7	16.7	16.74	17.24
Hodgeman	14.9	14.3	12.78	13.75
Jackson	16	15.9	14.5	15.08
Jefferson	12.5	13.4	14.14	14.27
Jewell	18.6	20.4	19.75	20.22
Johnson	7.7	8.4	8.16	7
Kearny	18.2	19.5	18.6	19.18
Kingman	17.5	18	18.57	17.6
Kiowa	20	20	16.73	14.27

Labette	25.1	30.4	26.48	26.56
Lane	15.2	14.9	15.92	14.36
Leavenworth	12.7	14.3	13.86	13.72
Lincoln	18.4	21.1	19.7	19.87
Linn	21.9	22.9	22.32	21.48
Logan	15.3	16.1	14.36	13.66
Lyon	22.4	24.5	23.06	23.15
Marion	14	17	16.02	16.16
Marshall	16.9	17	15.78	14.7
McPherson	11.9	12.4	11.67	11.65
Meade	14.6	14.2	13.78	14.29
Miami	11.9	12.4	13.4	12.65
Mitchell	15.2	17.2	16.32	14.77
Montgomery	26.2	26	27.97	24.97
Morris	16.8	16.8	17.18	19.57
Morton	18.9	20.7	18.82	18.25
Nemaha	12.6	11.3	10.85	11
Neosho	23.7	26.5	26.6	29.84
Ness	15.4	17.6	14.2	14.72
Norton	18	17.3	15.89	16.86
Osage	17.3	16.6	15.89	16.56
Osborne	22	21.7	23.02	23.11
Ottawa	13.1	14.4	14.46	12.91
Pawnee	17.8	17.9	17.98	18.63
Phillips	16.3	16.8	18.2	18.3
Pottawatomie	11.6	12.9	13.16	12.2
Pratt	17	18.2	17.83	16.32
Rawlins	18.9	15.5	18.63	16.56
Reno	20.8	18.5	19.3	20.16
Republic	16.5	19.3	19.7	20.49
Rice	18	20.6	19.57	18.41
Riley	17.7	16.5	19.09	17.44
Rooks	19.2	16.8	17.28	18.58
Rush	22.2	19.3	18.09	18.99
Russell	21.4	21.3	21.21	23.91
Saline	28.3	22	21.67	19.8
Scott	14	13.5	14.27	12.81
Sedgwick	20.4	21.3	23.06	22.06
Seward	22.4	21.8	23.4	25.31
Shawnee	26	20.3	24.27	22.21
Sheridan	19.8	19.4	13.01	16.5

Sherman	25.6	24.9	23.47	24.14
Smith	19.2	20.1	17.75	17.73
Stafford	21.4	19.7	21.04	20.19
Stanton	18.2	20.7	16.89	19.28
Stevens	18.7	16.7	15.39	15.56
Sumner	16.4	19	18.59	18.18
Thomas	12.3	13.5	13.46	13.14
Trego	15.7	13.9	15.5	13.14
Wabaunsee	13.4	12.5	13.06	13.17
Wallace	15.8	16.4	12.84	16.67
Washington	15.8	16	14.42	14.99
Wichita	21.6	20.5	18.58	17.58
Wilson	24.5	24.5	25.79	28.36
Woodson	28.1	27.7	29.88	30.16
Wyandotte	34.7	39.7	34.63	38.33

Table B-3: % of homes built pre-1978 gathered from each county. Population numbers from 2010 census.

NAME	% Built Pre-1978	Pop2010
Allen	76.59	14385
Anderson	74.07	8110
Atchison	79.45	16774
Barber	87.67	5307
Barton	87.11	28205
Bourbon	75.54	15379
Brown	81.87	10724
Butler	53.68	59484
Chase	76.68	3030
Chautauqua	81.06	4359
Cherokee	77.38	22605
Cheyenne	89.71	3165
Clark	90.95	2390
Clay	84.62	8822
Cloud	90.37	10268
Coffey	64.5	8865
Comanche	90.16	1967
Cowley	82.83	36291
Crawford	77.69	38242
Decatur	90.14	3472
Dickinson	80.02	19344

Doniphan	77.06	8249
Douglas	44.96	99962
Edwards	90.87	3449
Elk	81.33	3261
Ellis	70.38	27507
Ellsworth	84.52	6525
Finney	67.21	40523
Ford	75.43	32458
Franklin	66.12	24784
Geary	59.99	27947
Gove	86.48	3068
Graham	89.46	2946
Grant	77.06	7909
Gray	68.27	5904
Greeley	86.32	1534
Greenwood	83.66	7673
Hamilton	88.31	2670
Harper	86.44	6536
Harvey	72.56	32869
Haskell	83.56	4307
Hodgeman	85.68	2085
Jackson	65.35	12657
Jefferson	56.73	18426
Jewell	88.84	3791
Johnson	42.42	451479
Kearny	72.04	4531
Kingman	78.21	8673
Kiowa	66.43	3278
Labette	79.46	22835
Lane	88.17	2155
Leavenworth	49.34	68691
Lincoln	88.7	3578
Linn	50.07	9570
Logan	85.9	3046
Lyon	75.09	35935
Marion	80.52	29554
Marshall	80.76	13361
McPherson	70.42	10965
Meade	86.79	4631
Miami	48.3	28351
Mitchell	88	6932

Montgomery	85.12	36254
Morris	77.72	6104
Morton	86.46	3496
Nemaha	70.78	10717
Neosho	85.25	16997
Ness	87.06	3454
Norton	85.17	5953
Osage	67.37	16712
Osborne	92.27	4452
Ottawa	78.22	6163
Pawnee	91.97	7233
Phillips	89.12	6001
Pottawatomie	50.57	18209
Pratt	72.72	9647
Rawlins	89.77	2966
Reno	84.1	64790
Republic	90.63	5835
Rice	88.25	10761
Riley	56.71	62852
Rooks	87.47	5685
Rush	90.7	3551
Russell	89.23	7370
Saline	77.44	53597
Scott	85.93	5120
Sedgwick	59.36	452869
Seward	81.41	22510
Shawnee	69.44	169871
Sheridan	82.09	2813
Sherman	87.77	6760
Smith	89.25	4536
Stafford	90.41	4789
Stanton	86.73	2406
Stevens	79.73	5463
Sumner	76.46	25946
Thomas	83.32	8180
Trego	86.21	3319
Wabaunsee	69.15	6885
Wallace	86.34	1749
Washington	84.77	6483
Wichita	90.84	2531
Wilson	84.18	10332

Woodson	83.05	3788
Wyandotte	83.22	157882

Appendix C - Particle Size

Table C-1: PSA of Great Bend samples 1A-5A. % cumulative volume.

Size (µm)	GB_1A	GB_1B	GB_2A	GB_2B	GB_2C	GB_2D	GB_2E	GB_3A	GB_3B	GB_4A	GB_4B	GB_4C	GB_5A
0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0114	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0129	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0147	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0167	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0189	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0215	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0244	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0278	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0315	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0358	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0407	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0463	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0526	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0597	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0679	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0771	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0876	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0995	0	0	0	0	0	0	0	0	0	0	0	0	0
0.113	0	0	0	0	0	0	0	0	0	0	0	0	0
0.128	0	0	0	0	0	0	0	0	0	0	0	0	0
0.146	0	0	0	0	0	0	0	0	0	0	0	0	0
0.166	0	0	0	0	0	0	0	0	0	0	0	0	0

0.188	0	0	0	0	0	0	0	0	0	0	0	0	0
0.214	0	0	0	0	0	0	0	0	0	0	0	0	0
0.243	0	0	0	0	0	0	0	0	0	0	0	0	0
0.276	0	0	0	0	0	0	0	0	0	0	0	0	0
0.314	0	0	0	0	0	0	0	0	0	0	0	0	0
0.357	0	0	0	0	0	0	0	0	0	0	0	0	0
0.405	0	0	0	0	0	0	0	0	0	0	0	0	0
0.46	0	0.15	0	0.1	0	0	0	0.08	0	0	0	0	0
0.523	0.21	0.7	0.13	0.51	0.18	0	0	0.39	0.11	0.25	0.24	0.08	0.18
0.594	0.72	1.77	0.5	1.34	0.59	0.16	0.06	0.99	0.42	0.78	0.78	0.32	0.57
0.675	1.52	3.3	1.13	2.54	1.22	0.46	0.22	1.84	0.95	1.57	1.6	0.74	1.15
0.767	2.51	5.09	1.94	3.95	1.98	0.88	0.47	2.82	1.64	2.51	2.59	1.3	1.84
0.872	3.56	6.9	2.82	5.37	2.77	1.36	0.79	3.8	2.4	3.48	3.62	1.92	2.55
0.991	4.58	8.59	3.69	6.69	3.52	1.86	1.14	4.71	3.16	4.39	4.61	2.54	3.21
1.13	5.54	10.15	4.52	7.89	4.23	2.36	1.49	5.54	3.89	5.24	5.55	3.15	3.83
1.28	6.49	11.66	5.36	9.06	4.93	2.88	1.85	6.36	4.62	6.09	6.49	3.77	4.45
1.45	7.51	13.24	6.28	10.31	5.68	3.46	2.24	7.23	5.39	7.01	7.5	4.45	5.12
1.65	8.66	14.97	7.34	11.72	6.51	4.13	2.67	8.21	6.25	8.06	8.65	5.22	5.89
1.88	9.96	16.88	8.57	13.33	7.44	4.91	3.15	9.31	7.2	9.25	9.95	6.1	6.77
2.13	11.41	18.95	9.97	15.14	8.47	5.8	3.68	10.52	8.24	10.57	11.38	7.09	7.76
2.42	12.99	21.14	11.54	17.13	9.58	6.8	4.26	11.83	9.36	12.01	12.93	8.19	8.85
2.75	14.7	23.43	13.26	19.28	10.76	7.9	4.9	13.22	10.56	13.54	14.57	9.39	10.03
3.12	16.52	25.81	15.14	21.59	12.01	9.11	5.61	14.69	11.85	15.16	16.29	10.69	11.29
3.55	18.45	28.27	17.17	24.05	13.34	10.43	6.4	16.25	13.24	16.86	18.09	12.1	12.64
4.03	20.49	30.81	19.34	26.64	14.74	11.86	7.29	17.9	14.74	18.63	19.97	13.61	14.07
4.58	22.62	33.42	21.64	29.35	16.22	13.4	8.28	19.63	16.36	20.47	21.91	15.22	15.58
5.21	24.82	36.08	24.03	32.14	17.76	15.04	9.37	21.44	18.1	22.36	23.91	16.92	17.17
5.92	27.07	38.76	26.48	34.98	19.34	16.75	10.57	23.31	19.96	24.28	25.96	18.68	18.82
6.72	29.33	41.42	28.96	37.82	20.95	18.53	11.89	25.22	21.93	26.21	28.04	20.49	20.51
7.64	31.59	44.04	31.43	40.64	22.58	20.36	13.33	27.16	24.01	28.13	30.15	22.33	22.23

8.68	33.83	46.59	33.86	43.41	24.21	22.23	14.9	29.12	26.19	30.04	32.28	24.2	23.98
9.86	36.04	49.07	36.25	46.13	25.84	24.14	16.62	31.1	28.48	31.94	34.44	26.09	25.74
11.2	38.24	51.47	38.59	48.81	27.48	26.09	18.5	33.11	30.88	33.85	36.65	28.01	27.53
12.7	40.46	53.82	40.91	51.48	29.15	28.1	20.57	35.16	33.41	35.8	38.92	29.98	29.36
14.5	42.72	56.14	43.23	54.17	30.87	30.19	22.85	37.26	36.09	37.82	41.27	32.02	31.25
16.4	45.07	58.47	45.6	56.92	32.66	32.37	25.36	39.44	38.94	39.96	43.71	34.17	33.23
18.7	47.54	60.84	48.05	59.75	34.56	34.65	28.12	41.7	41.97	42.25	46.26	36.45	35.32
21.2	50.15	63.28	50.61	62.68	36.59	37.05	31.12	44.05	45.17	44.73	48.92	38.9	37.55
24.1	52.92	65.79	53.29	65.69	38.77	39.55	34.35	46.48	48.54	47.41	51.68	41.52	39.93
27.4	55.84	68.35	56.1	68.77	41.1	42.14	37.77	48.98	52.05	50.3	54.52	44.32	42.46
31.1	58.89	70.92	59.01	71.87	43.56	44.78	41.33	51.54	55.66	53.38	57.41	47.29	45.13
35.3	62.01	73.46	62	74.94	46.14	47.43	44.97	54.14	59.31	56.63	60.31	50.41	47.92
40.1	65.15	75.93	65.03	77.94	48.8	50.04	48.61	56.76	62.95	59.99	63.17	53.64	50.81
45.6	68.25	78.3	68.05	80.83	51.52	52.57	52.2	59.39	66.51	63.41	65.93	56.94	53.77
51.8	71.26	80.55	71.02	83.58	54.26	54.99	55.68	62.01	69.94	66.82	68.56	60.26	56.78
58.9	74.14	82.69	73.9	86.19	57.01	57.3	59.02	64.61	73.18	70.15	71.03	63.56	59.81
66.9	76.86	84.73	76.66	88.65	59.76	59.51	62.21	67.18	76.2	73.34	73.33	66.8	62.85
76	79.42	86.67	79.27	90.95	62.51	61.64	65.25	69.71	78.97	76.34	75.47	69.94	65.88
86.4	81.82	88.51	81.71	93.06	65.25	63.73	68.15	72.18	81.46	79.11	77.46	72.96	68.87
98.1	84.07	90.23	83.96	94.95	67.97	65.82	70.91	74.58	83.67	81.62	79.31	75.84	71.81
111	86.18	91.8	85.99	96.57	70.66	67.95	73.53	76.87	85.62	83.84	81.02	78.56	74.67
127	88.15	93.2	87.79	97.87	73.3	70.16	76	79.03	87.33	85.78	82.6	81.13	77.43
144	89.98	94.42	89.36	98.84	75.87	72.51	78.32	81.04	88.83	87.46	84.06	83.55	80.07
163	91.66	95.47	90.73	99.48	78.38	75.04	80.5	82.92	90.17	88.91	85.43	85.83	82.59
186	93.18	96.37	91.92	99.83	80.85	77.79	82.55	84.7	91.39	90.19	86.73	87.98	84.98
211	94.53	97.14	92.98	99.96	83.31	80.76	84.49	86.43	92.53	91.35	88.02	90.01	87.24
240	95.73	97.81	93.95	99.99	85.78	83.9	86.35	88.18	93.61	92.46	89.34	91.9	89.36
272	96.78	98.4	94.86	99.99	88.27	87.13	88.18	89.99	94.65	93.55	90.73	93.65	91.33
310	97.68	98.91	95.74	99.99	90.74	90.3	90.01	91.86	95.64	94.66	92.2	95.23	93.13
352	98.44	99.34	96.58	99.99	93.12	93.23	91.85	93.75	96.58	95.78	93.73	96.62	94.75

400	99.05	99.66	97.38	99.99	95.3	95.74	93.69	95.57	97.45	96.87	95.26	97.78	96.18
454	99.51	99.85	98.11	99.99	97.15	97.69	95.46	97.19	98.22	97.87	96.7	98.7	97.4
516	99.81	99.96	98.74	99.99	98.55	99	97.06	98.48	98.87	98.72	97.95	99.36	98.38
586	99.97	100	99.25	99.99	99.46	99.67	98.38	99.38	99.37	99.36	98.92	99.77	99.11
666	100.01	100	99.61	99.99	99.88	99.97	99.32	99.88	99.7	99.77	99.57	99.95	99.57
756	100.01	100	99.85	99.99	99.96	99.97	99.86	100	99.89	99.96	99.91	100	99.82
859	100.01	100	99.96	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.94
976	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
1110	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
1260	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
1430	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
1630	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
1850	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
2100	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
2390	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
2710	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
3080	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97
3500	100.01	100	99.99	99.99	99.96	99.97	100	100	99.96	99.99	100.04	100	99.97

Table C-2: PSA for Great Bend samples 5B-12B. % cumulative volume.

Size (µm)	GB_5B	GB_5C	GB_6A	GB_7A	GB_8A	GB_8B	GB_9A	GB_9B	GB_10A	GB_11A	GB_11B	GB_12A	GB_12B
0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0114	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0129	0	0	0	0	0	0	0	0	0	0	0	0	0

0.0147	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0167	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0189	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0215	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0244	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0278	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0315	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0358	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0407	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0463	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0526	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0597	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0679	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0771	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0876	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0995	0	0	0	0	0	0	0	0	0	0	0	0	0
0.113	0	0	0	0	0	0	0	0	0	0	0	0	0
0.128	0	0	0	0	0	0	0	0	0	0	0	0	0
0.146	0	0	0	0	0	0	0	0	0	0	0	0	0
0.166	0	0	0	0	0	0	0	0	0	0	0	0	0
0.188	0	0	0	0	0	0	0	0	0	0	0	0	0
0.214	0	0	0	0	0	0	0	0	0	0	0	0	0
0.243	0	0	0	0	0	0	0	0	0	0	0	0	0
0.276	0	0	0	0	0	0	0	0	0	0	0	0	0
0.314	0	0	0	0	0	0	0	0	0	0	0	0	0
0.357	0	0	0	0	0	0	0	0	0	0	0	0	0
0.405	0	0	0	0	0	0	0	0	0	0	0	0	0
0.46	0	0.09	0	0.11	0	0	0	0	0	0	0	0	0
0.523	0.15	0.38	0	0.49	0	0.09	0	0.09	0.06	0.11	0.14	0.12	0
0.594	0.49	0.92	0.16	1.19	0.19	0.35	0.16	0.37	0.26	0.42	0.54	0.41	0.17

0.675	1.01	1.66	0.47	2.16	0.56	0.82	0.48	0.87	0.63	0.94	1.22	0.86	0.51
0.767	1.64	2.49	0.92	3.27	1.08	1.44	0.93	1.53	1.12	1.61	2.09	1.41	0.99
0.872	2.29	3.3	1.44	4.36	1.67	2.12	1.45	2.27	1.67	2.33	3.02	1.99	1.55
0.991	2.91	4.03	1.98	5.36	2.28	2.8	1.99	3.01	2.22	3.03	3.93	2.54	2.13
1.13	3.49	4.69	2.51	6.27	2.88	3.46	2.54	3.74	2.76	3.7	4.81	3.05	2.71
1.28	4.06	5.33	3.05	7.16	3.5	4.13	3.1	4.49	3.31	4.38	5.71	3.55	3.31
1.45	4.67	6	3.62	8.11	4.17	4.87	3.72	5.32	3.91	5.13	6.7	4.08	3.97
1.65	5.35	6.75	4.25	9.17	4.93	5.72	4.43	6.28	4.6	6.01	7.85	4.67	4.73
1.88	6.11	7.59	4.97	10.36	5.81	6.71	5.25	7.4	5.39	7.04	9.19	5.34	5.62
2.13	6.94	8.5	5.77	11.66	6.81	7.85	6.18	8.69	6.3	8.22	10.73	6.1	6.66
2.42	7.83	9.47	6.66	13.05	7.93	9.13	7.22	10.14	7.31	9.55	12.45	6.94	7.84
2.75	8.77	10.48	7.64	14.5	9.17	10.54	8.37	11.75	8.43	11.02	14.35	7.86	9.18
3.12	9.76	11.52	8.72	16	10.54	12.09	9.63	13.52	9.66	12.62	16.42	8.87	10.68
3.55	10.8	12.6	9.91	17.55	12.06	13.78	11	15.46	11	14.35	18.65	9.98	12.36
4.03	11.9	13.71	11.21	19.14	13.73	15.6	12.49	17.55	12.45	16.21	21.04	11.2	14.21
4.58	13.05	14.85	12.63	20.77	15.55	17.55	14.09	19.79	14	18.18	23.58	12.52	16.24
5.21	14.25	16.01	14.17	22.44	17.52	19.6	15.8	22.15	15.63	20.24	26.24	13.94	18.42
5.92	15.5	17.19	15.81	24.13	19.61	21.74	17.59	24.61	17.32	22.36	28.99	15.45	20.74
6.72	16.8	18.38	17.55	25.82	21.8	23.94	19.45	27.13	19.04	24.52	31.79	17.04	23.17
7.64	18.13	19.57	19.39	27.5	24.08	26.17	21.36	29.69	20.77	26.69	34.61	18.69	25.69
8.68	19.51	20.76	21.35	29.15	26.43	28.42	23.3	32.27	22.49	28.86	37.43	20.38	28.28
9.86	20.94	21.95	23.47	30.79	28.84	30.68	25.26	34.86	24.2	31.02	40.23	22.09	30.92
11.2	22.44	23.15	25.8	32.43	31.32	32.96	27.25	37.46	25.9	33.18	43.01	23.82	33.59
12.7	24.04	24.38	28.41	34.11	33.88	35.27	29.28	40.09	27.63	35.35	45.79	25.57	36.29
14.5	25.77	25.67	31.37	35.88	36.55	37.63	31.38	42.76	29.42	37.56	48.58	27.34	39.02
16.4	27.67	27.05	34.74	37.82	39.36	40.06	33.58	45.5	31.31	39.83	51.41	29.13	41.78
18.7	29.78	28.56	38.58	40.01	42.35	42.6	35.93	48.34	33.37	42.19	54.31	30.96	44.56
21.2	32.13	30.22	42.91	42.53	45.55	45.26	38.46	51.29	35.64	44.67	57.29	32.85	47.36
24.1	34.73	32.07	47.69	45.43	48.97	48.06	41.2	54.35	38.15	47.27	60.36	34.82	50.18
27.4	37.58	34.12	52.83	48.74	52.6	50.99	44.17	57.5	40.92	49.99	63.5	36.89	53

31.1	40.64	36.37	58.19	52.43	56.4	54.02	47.36	60.72	43.95	52.81	66.68	39.09	55.81
35.3	43.87	38.82	63.59	56.43	60.33	57.11	50.75	63.97	47.19	55.69	69.86	41.45	58.58
40.1	47.2	41.45	68.84	60.64	64.3	60.21	54.3	67.19	50.59	58.6	72.99	43.99	61.27
45.6	50.55	44.24	73.76	64.92	68.22	63.28	57.95	70.34	54.07	61.51	76.01	46.71	63.85
51.8	53.87	47.17	78.2	69.14	72.01	66.3	61.65	73.37	57.56	64.39	78.87	49.61	66.29
58.9	57.1	50.23	82.07	73.18	75.57	69.26	65.34	76.25	60.99	67.23	81.54	52.67	68.57
66.9	60.2	53.41	85.33	76.94	78.84	72.17	68.97	78.96	64.32	70.03	83.99	55.85	70.7
76	63.15	56.71	87.99	80.36	81.76	75.03	72.5	81.5	67.5	72.78	86.21	59.12	72.69
86.4	65.94	60.12	90.11	83.41	84.31	77.84	75.88	83.88	70.52	75.47	88.19	62.44	74.57
98.1	68.58	63.63	91.77	86.08	86.49	80.59	79.08	86.11	73.37	78.08	89.93	65.77	76.38
111	71.07	67.22	93.07	88.38	88.33	83.24	82.07	88.19	76.05	80.58	91.43	69.07	78.12
127	73.43	70.85	94.1	90.35	89.88	85.76	84.83	90.14	78.59	82.93	92.71	72.31	79.81
144	75.72	74.48	94.94	92.03	91.19	88.11	87.38	91.94	81.01	85.11	93.78	75.47	81.44
163	78	78.06	95.68	93.47	92.34	90.27	89.73	93.59	83.35	87.1	94.68	78.55	83.02
186	80.36	81.55	96.36	94.73	93.4	92.22	91.89	95.07	85.64	88.91	95.44	81.58	84.55
211	82.86	84.9	97.02	95.84	94.41	93.96	93.87	96.36	87.91	90.55	96.1	84.57	86.05
240	85.53	88.06	97.67	96.84	95.4	95.48	95.64	97.45	90.15	92.05	96.69	87.52	87.55
272	88.33	90.97	98.29	97.73	96.38	96.78	97.16	98.33	92.33	93.43	97.23	90.39	89.09
310	91.16	93.57	98.86	98.5	97.32	97.85	98.38	99.01	94.39	94.7	97.73	93.08	90.7
352	93.84	95.78	99.34	99.12	98.18	98.69	99.25	99.49	96.23	95.88	98.19	95.46	92.39
400	96.18	97.55	99.69	99.58	98.9	99.31	99.78	99.78	97.76	96.96	98.61	97.41	94.12
454	98.01	98.83	99.91	99.86	99.44	99.72	99.99	99.96	98.91	97.92	98.98	98.82	95.81
516	99.23	99.63	100.01	99.97	99.77	99.95	99.99	100.05	99.65	98.73	99.29	99.68	97.34
586	99.82	99.97	100.01	100	99.93	100.03	99.99	100.05	100.02	99.35	99.54	100	98.58
666	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	99.76	99.74	100	99.44
756	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	99.95	99.88	100	99.91
859	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
976	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
1110	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
1260	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01

1430	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
1630	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
1850	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
2100	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
2390	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
2710	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
3080	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01
3500	99.98	100.01	100.01	100	99.98	100.03	99.99	100.05	100.03	100.01	99.96	100	100.01

Table C-3: PSA for Great Bend samples 13A-19A. % cumulative volume.

Size (µm)	GB_13A	GB_13B	GB_14A	GB_14B	GB_14C	GB_15A	GB_15B	GB_16A	GB_17A	GB_17B	GB_18A	GB_18B	GB_19A
0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0114	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0129	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0147	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0167	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0189	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0215	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0244	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0278	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0315	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0358	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0407	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0463	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0526	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0597	0	0	0	0	0	0	0	0	0	0	0	0	0

0.0679	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0771	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0876	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0995	0	0	0	0	0	0	0	0	0	0	0	0	0
0.113	0	0	0	0	0	0	0	0	0	0	0	0	0
0.128	0	0	0	0	0	0	0	0	0	0	0	0	0
0.146	0	0	0	0	0	0	0	0	0	0	0	0	0
0.166	0	0	0	0	0	0	0	0	0	0	0	0	0
0.188	0	0	0	0	0	0	0	0	0	0	0	0	0
0.214	0	0	0	0	0	0	0	0	0	0	0	0	0
0.243	0	0	0	0	0	0	0	0	0	0	0	0	0
0.276	0	0	0	0	0	0	0	0	0	0	0	0	0
0.314	0	0	0	0	0	0	0	0	0	0	0	0	0
0.357	0	0	0	0	0	0	0	0	0	0	0	0	0
0.405	0	0	0	0	0	0	0	0	0	0	0	0	0
0.46	0	0	0	0	0.1	0.08	0	0	0	0	0.11	0.09	0
0.523	0.21	0.13	0.18	0.1	0.43	0.42	0.23	0.09	0.13	0.09	0.47	0.43	0.13
0.594	0.75	0.5	0.63	0.4	1.05	1.12	0.72	0.38	0.48	0.35	1.11	1.11	0.5
0.675	1.61	1.14	1.35	0.93	1.92	2.15	1.46	0.91	1.07	0.82	1.98	2.09	1.13
0.767	2.69	1.98	2.25	1.63	2.91	3.37	2.34	1.63	1.82	1.44	2.95	3.23	1.93
0.872	3.83	2.9	3.2	2.39	3.88	4.62	3.25	2.44	2.63	2.14	3.9	4.38	2.79
0.991	4.94	3.82	4.12	3.15	4.77	5.8	4.13	3.26	3.43	2.86	4.75	5.45	3.63
1.13	5.99	4.72	5	3.89	5.58	6.92	4.96	4.08	4.21	3.57	5.51	6.45	4.44
1.28	7.04	5.64	5.89	4.65	6.37	8.04	5.8	4.93	5	4.3	6.24	7.45	5.27
1.45	8.19	6.65	6.88	5.5	7.21	9.26	6.71	5.87	5.86	5.08	7	8.54	6.19
1.65	9.51	7.81	8.03	6.5	8.15	10.65	7.73	6.96	6.83	5.95	7.83	9.78	7.27
1.88	11.03	9.14	9.37	7.69	9.2	12.23	8.88	8.23	7.93	6.92	8.73	11.19	8.54
2.13	12.76	10.65	10.91	9.07	10.35	13.99	10.14	9.68	9.15	7.99	9.69	12.75	10
2.42	14.69	12.32	12.63	10.64	11.58	15.9	11.5	11.3	10.47	9.15	10.68	14.43	11.64
2.75	16.8	14.14	14.53	12.4	12.86	17.93	12.93	13.08	11.89	10.39	11.69	16.19	13.45

3.12	19.08	16.11	16.59	14.35	14.18	20.06	14.42	15.02	13.4	11.72	12.72	18.02	15.42
3.55	21.52	18.22	18.8	16.5	15.53	22.29	15.97	17.12	14.99	13.15	13.78	19.89	17.54
4.03	24.11	20.47	21.16	18.84	16.91	24.6	17.57	19.37	16.66	14.68	14.87	21.79	19.79
4.58	26.83	22.85	23.64	21.36	18.31	26.99	19.21	21.76	18.4	16.3	15.99	23.69	22.16
5.21	29.65	25.34	26.21	24.03	19.72	29.43	20.88	24.27	20.2	18.01	17.15	25.58	24.62
5.92	32.53	27.92	28.83	26.83	21.13	31.9	22.56	26.88	22.05	19.8	18.33	27.43	27.13
6.72	35.43	30.56	31.48	29.71	22.53	34.38	24.25	29.57	23.92	21.66	19.52	29.22	29.65
7.64	38.33	33.25	34.12	32.65	23.93	36.86	25.93	32.31	25.82	23.57	20.71	30.94	32.14
8.68	41.2	35.97	36.74	35.61	25.33	39.32	27.61	35.1	27.74	25.53	21.9	32.6	34.58
9.86	44.04	38.72	39.33	38.57	26.76	41.77	29.3	37.94	29.7	27.55	23.11	34.23	36.97
11.2	46.85	41.52	41.89	41.53	28.26	44.22	31.03	40.85	31.73	29.66	24.37	35.88	39.33
12.7	49.63	44.39	44.44	44.49	29.89	46.7	32.84	43.84	33.88	31.88	25.74	37.63	41.7
14.5	52.41	47.35	46.99	47.47	31.72	49.24	34.78	46.93	36.21	34.26	27.31	39.55	44.12
16.4	55.19	50.43	49.56	50.48	33.82	51.88	36.9	50.13	38.77	36.85	29.18	41.74	46.66
18.7	57.98	53.65	52.16	53.54	36.26	54.64	39.25	53.45	41.62	39.69	31.46	44.27	49.38
21.2	60.77	57	54.79	56.66	39.08	57.56	41.88	56.87	44.78	42.82	34.25	47.18	52.33
24.1	63.54	60.46	57.46	59.85	42.3	60.63	44.8	60.37	48.26	46.24	37.62	50.48	55.53
27.4	66.27	63.99	60.15	63.09	45.91	63.85	48.02	63.91	52.04	49.93	41.58	54.12	58.96
31.1	68.92	67.52	62.85	66.37	49.85	67.18	51.51	67.43	56.05	53.83	46.08	58	62.57
35.3	71.46	70.98	65.54	69.64	54.03	70.57	55.22	70.87	60.2	57.83	51.01	62	66.27
40.1	73.85	74.27	68.2	72.86	58.33	73.93	59.07	74.16	64.37	61.82	56.21	65.97	69.94
45.6	76.08	77.32	70.8	75.97	62.63	77.19	62.96	77.24	68.45	65.68	61.47	69.76	73.46
51.8	78.13	80.07	73.32	78.93	66.8	80.26	66.8	80.07	72.32	69.3	66.59	73.26	76.71
58.9	80	82.5	75.73	81.7	70.73	83.07	70.49	82.63	75.88	72.61	71.38	76.39	79.61
66.9	81.71	84.62	78.02	84.24	74.34	85.57	73.95	84.92	79.07	75.58	75.7	79.12	82.1
76	83.26	86.45	80.18	86.54	77.58	87.73	77.13	86.95	81.87	78.23	79.47	81.47	84.16
86.4	84.67	88.04	82.2	88.59	80.44	89.54	80	88.74	84.27	80.62	82.66	83.48	85.81
98.1	85.96	89.43	84.07	90.38	82.92	91.02	82.55	90.32	86.31	82.81	85.3	85.21	87.1
111	87.14	90.68	85.8	91.92	85.04	92.19	84.79	91.72	88.02	84.89	87.45	86.73	88.09
127	88.22	91.83	87.38	93.22	86.85	93.1	86.76	92.96	89.45	86.93	89.22	88.12	88.86

144	89.23	92.91	88.84	94.31	88.4	93.8	88.53	94.06	90.66	88.98	90.72	89.44	89.5
163	90.18	93.96	90.19	95.22	89.75	94.36	90.15	95.07	91.71	91.05	92.05	90.75	90.11
186	91.11	94.99	91.46	96	90.96	94.84	91.68	96.01	92.65	93.11	93.28	92.09	90.78
211	92.04	95.99	92.67	96.7	92.09	95.29	93.15	96.89	93.52	95.07	94.46	93.46	91.58
240	93	96.93	93.84	97.34	93.17	95.74	94.57	97.71	94.36	96.82	95.6	94.83	92.56
272	94.01	97.78	94.98	97.94	94.22	96.19	95.91	98.44	95.2	98.24	96.67	96.14	93.72
310	95.08	98.5	96.09	98.5	95.25	96.65	97.12	99.05	96.03	99.24	97.62	97.32	95.02
352	96.17	99.06	97.14	99	96.26	97.1	98.16	99.51	96.84	99.79	98.4	98.31	96.36
400	97.22	99.45	98.08	99.42	97.21	97.54	98.97	99.82	97.6	99.96	98.99	99.07	97.62
454	98.17	99.69	98.87	99.73	98.07	97.96	99.54	99.97	98.27	99.96	99.39	99.59	98.67
516	98.94	99.85	99.46	99.93	98.8	98.35	99.87	100.01	98.83	99.96	99.61	99.86	99.42
586	99.49	99.95	99.84	100.01	99.36	98.69	99.99	100.01	99.26	99.96	99.77	100	99.85
666	99.8	99.99	100	100.03	99.74	98.97	99.99	100.01	99.55	99.96	99.88	100.03	99.98
756	99.96	99.99	100.03	100.03	99.93	99.17	99.99	100.01	99.76	99.96	99.94	100.03	99.98
859	99.99	99.99	100.03	100.03	100	99.33	99.99	100.01	99.88	99.96	99.96	100.03	99.98
976	99.99	99.99	100.03	100.03	100	99.45	99.99	100.01	99.95	99.96	99.96	100.03	99.98
1110	99.99	99.99	100.03	100.03	100	99.55	99.99	100.01	99.98	99.96	99.96	100.03	99.98
1260	99.99	99.99	100.03	100.03	100	99.64	99.99	100.01	99.98	99.96	99.96	100.03	99.98
1430	99.99	99.99	100.03	100.03	100	99.73	99.99	100.01	99.98	99.96	99.96	100.03	99.98
1630	99.99	99.99	100.03	100.03	100	99.82	99.99	100.01	99.98	99.96	99.96	100.03	99.98
1850	99.99	99.99	100.03	100.03	100	99.9	99.99	100.01	99.98	99.96	99.96	100.03	99.98
2100	99.99	99.99	100.03	100.03	100	99.95	99.99	100.01	99.98	99.96	99.96	100.03	99.98
2390	99.99	99.99	100.03	100.03	100	99.99	99.99	100.01	99.98	99.96	99.96	100.03	99.98
2710	99.99	99.99	100.03	100.03	100	100.01	99.99	100.01	99.98	99.96	99.96	100.03	99.98
3080	99.99	99.99	100.03	100.03	100	100.01	99.99	100.01	99.98	99.96	99.96	100.03	99.98
3500	99.99	99.99	100.03	100.03	100	100.01	99.99	100.01	0				

Table C-4: PSA for Great Bend samples 19A- 20B. % cumulative volume.

Size (µm)	GB_19B	GB_19C	GB_20A	GB_20B
0.01	0	0	0	0
0.0114	0	0	0	0
0.0129	0	0	0	0
0.0147	0	0	0	0
0.0167	0	0	0	0
0.0189	0	0	0	0
0.0215	0	0	0	0
0.0244	0	0	0	0
0.0278	0	0	0	0
0.0315	0	0	0	0
0.0358	0	0	0	0
0.0407	0	0	0	0
0.0463	0	0	0	0
0.0526	0	0	0	0
0.0597	0	0	0	0
0.0679	0	0	0	0
0.0771	0	0	0	0
0.0876	0	0	0	0
0.0995	0	0	0	0
0.113	0	0	0	0
0.128	0	0	0	0
0.146	0	0	0	0
0.166	0	0	0	0
0.188	0	0	0	0
0.214	0	0	0	0
0.243	0	0	0	0
0.276	0	0	0	0

0.314	0	0	0	0
0.357	0	0	0	0
0.405	0	0	0	0
0.46	0	0	0	0
0.523	0.13	0.08	0.13	0.19
0.594	0.5	0.34	0.5	0.61
0.675	1.13	0.81	1.12	1.24
0.767	1.94	1.44	1.91	2
0.872	2.82	2.15	2.76	2.79
0.991	3.69	2.86	3.6	3.55
1.13	4.53	3.55	4.41	4.27
1.28	5.39	4.25	5.24	5.01
1.45	6.35	5	6.17	5.83
1.65	7.47	5.85	7.25	6.77
1.88	8.78	6.83	8.51	7.85
2.13	10.28	7.93	9.95	9.06
2.42	11.94	9.14	11.55	10.38
2.75	13.76	10.46	13.3	11.8
3.12	15.72	11.9	15.18	13.29
3.55	17.8	13.46	17.19	14.85
4.03	20	15.14	19.31	16.47
4.58	22.3	16.95	21.53	18.14
5.21	24.67	18.88	23.82	19.84
5.92	27.08	20.91	26.14	21.55
6.72	29.51	23.03	28.47	23.25
7.64	31.93	25.23	30.78	24.93
8.68	34.32	27.49	33.05	26.58
9.86	36.69	29.82	35.28	28.2
11.2	39.05	32.22	37.48	29.81
12.7	41.43	34.71	39.68	31.44

14.5	43.88	37.32	41.93	33.12
16.4	46.46	40.07	44.27	34.9
18.7	49.22	42.99	46.76	36.82
21.2	52.2	46.1	49.44	38.92
24.1	55.42	49.4	52.34	41.22
27.4	58.87	52.87	55.46	43.74
31.1	62.52	56.47	58.76	46.46
35.3	66.28	60.13	62.2	49.35
40.1	70.06	63.78	65.69	52.36
45.6	73.76	67.33	69.14	55.43
51.8	77.28	70.71	72.47	58.49
58.9	80.54	73.86	75.61	61.49
66.9	83.49	76.76	78.5	64.37
76	86.11	79.4	81.13	67.12
86.4	88.4	81.79	83.5	69.72
98.1	90.38	83.94	85.63	72.2
111	92.09	85.87	87.56	74.61
127	93.58	87.62	89.33	77
144	94.89	89.24	90.98	79.44
163	96.06	90.78	92.53	81.98
186	97.1	92.29	94	84.64
211	98.01	93.78	95.38	87.41
240	98.77	95.25	96.65	90.2
272	99.34	96.65	97.77	92.89
310	99.72	97.9	98.68	95.32
352	99.93	98.91	99.35	97.32
400	99.99	99.61	99.75	98.78
454	99.99	99.98	99.91	99.67
516	99.99	100.03	99.96	99.98
586	99.99	100.03	99.96	99.98

666	99.99	100.03	99.96	99.98
756	99.99	100.03	99.96	99.98
859	99.99	100.03	99.96	99.98
976	99.99	100.03	99.96	99.98
1110	99.99	100.03	99.96	99.98
1260	99.99	100.03	99.96	99.98
1430	99.99	100.03	99.96	99.98
1630	99.99	100.03	99.96	99.98
1850	99.99	100.03	99.96	99.98
2100	99.99	100.03	99.96	99.98
2390	99.99	100.03	99.96	99.98
2710	99.99	100.03	99.96	99.98
3080	99.99	100.03	99.96	99.98
3500				

Table C-5: PSA for Hays samples 1A- 7A. % cumulative volume.

Size (µm)	H_1A	H_1C	H_2A	H_2B	H_3A	H_3B	H_4A	H_4B	H_4C	H_4D	H_5A	H_6A	H_7A
0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0114	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0129	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0147	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0167	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0189	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0215	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0244	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0278	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0315	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0358	0	0	0	0	0	0	0	0	0	0	0	0	0

0.0407	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0463	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0526	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0597	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0679	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0771	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0876	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0995	0	0	0	0	0	0	0	0	0	0	0	0	0
0.113	0	0	0	0	0	0	0	0	0	0	0	0	0
0.128	0	0	0	0	0	0	0	0	0	0	0	0	0
0.146	0	0	0	0	0	0	0	0	0	0	0	0	0
0.166	0	0	0	0	0	0	0	0	0	0	0	0	0
0.188	0	0	0	0	0	0	0	0	0	0	0	0	0
0.214	0	0	0	0	0	0	0	0	0	0	0	0	0
0.243	0	0	0	0	0	0	0	0	0	0	0	0	0
0.276	0	0	0	0	0	0	0	0	0	0	0	0	0
0.314	0	0	0	0	0	0	0	0	0	0	0	0	0
0.357	0	0	0	0	0	0	0	0	0	0	0	0	0
0.405	0	0	0	0	0	0	0	0	0	0	0	0	0
0.46	0	0	0	0	0	0	0	0	0	0	0	0	0
0.523	0.13	0.13	0.22	0.16	0.18	0.29	0.15	0.29	0.15	0.12	0.13	0.16	0.24
0.594	0.47	0.51	0.77	0.62	0.69	0.98	0.6	0.95	0.56	0.46	0.51	0.61	0.85
0.675	1.02	1.16	1.64	1.4	1.54	2.07	1.37	1.97	1.24	1.05	1.17	1.37	1.83
0.767	1.71	2.01	2.73	2.4	2.63	3.42	2.38	3.22	2.11	1.83	2.03	2.34	3.06
0.872	2.46	2.94	3.9	3.48	3.81	4.84	3.48	4.53	3.05	2.69	2.98	3.39	4.37
0.991	3.21	3.87	5.04	4.55	4.97	6.22	4.58	5.8	3.98	3.55	3.93	4.43	5.64
1.13	3.94	4.78	6.13	5.6	6.09	7.54	5.65	7.01	4.88	4.39	4.84	5.44	6.86
1.28	4.69	5.72	7.24	6.68	7.23	8.89	6.73	8.21	5.79	5.25	5.75	6.47	8.09
1.45	5.51	6.75	8.45	7.87	8.47	10.37	7.91	9.5	6.77	6.18	6.72	7.59	9.43
1.65	6.43	7.93	9.82	9.23	9.88	12.06	9.24	10.93	7.87	7.22	7.8	8.87	10.95

1.88	7.46	9.29	11.37	10.79	11.48	13.99	10.76	12.53	9.11	8.39	9.01	10.33	12.67
2.13	8.59	10.82	13.09	12.54	13.26	16.15	12.46	14.28	10.48	9.67	10.35	11.96	14.59
2.42	9.8	12.5	14.95	14.45	15.19	18.49	14.32	16.14	11.96	11.05	11.81	13.73	16.67
2.75	11.07	14.33	16.92	16.5	17.25	20.98	16.33	18.1	13.53	12.51	13.38	15.63	18.88
3.12	12.38	16.29	18.98	18.67	19.42	23.6	18.48	20.15	15.18	14.05	15.06	17.65	21.2
3.55	13.73	18.38	21.13	20.96	21.69	26.33	20.77	22.28	16.91	15.67	16.85	19.78	23.63
4.03	15.12	20.59	23.35	23.35	24.06	29.15	23.2	24.48	18.72	17.37	18.76	22.02	26.15
4.58	16.53	22.92	25.63	25.82	26.51	32.04	25.75	26.75	20.6	19.14	20.79	24.36	28.75
5.21	17.96	25.34	27.95	28.35	29.03	34.97	28.41	29.07	22.53	20.97	22.93	26.78	31.4
5.92	19.4	27.82	30.29	30.92	31.58	37.91	31.14	31.42	24.49	22.84	25.16	29.26	34.08
6.72	20.84	30.34	32.62	33.5	34.15	40.82	33.91	33.77	26.47	24.72	27.46	31.77	36.76
7.64	22.27	32.87	34.93	36.08	36.71	43.69	36.7	36.1	28.45	26.59	29.82	34.29	39.42
8.68	23.7	35.39	37.2	38.64	39.26	46.51	39.48	38.4	30.41	28.44	32.22	36.8	42.04
9.86	25.14	37.91	39.43	41.19	41.8	49.28	42.26	40.66	32.35	30.28	34.65	39.29	44.62
11.2	26.6	40.43	41.65	43.76	44.34	52.03	45.05	42.9	34.29	32.13	37.12	41.77	47.17
12.7	28.11	42.99	43.89	46.39	46.93	54.8	47.9	45.16	36.26	34.03	39.63	44.25	49.72
14.5	29.69	45.62	46.21	49.14	49.6	57.63	50.86	47.47	38.32	36.07	42.22	46.76	52.31
16.4	31.38	48.37	48.67	52.06	52.41	60.57	53.99	49.9	40.54	38.33	44.91	49.34	54.98
18.7	33.21	51.29	51.33	55.2	55.4	63.66	57.34	52.52	43.01	40.92	47.75	52.02	57.77
21.2	35.21	54.41	54.25	58.61	58.62	66.92	60.96	55.39	45.84	43.92	50.78	54.85	60.73
24.1	37.39	57.75	57.47	62.28	62.08	70.35	64.85	58.56	49.12	47.4	54.03	57.87	63.88
27.4	39.76	61.31	60.97	66.19	65.76	73.92	68.98	62.05	52.91	51.38	57.52	61.09	67.23
31.1	42.3	65.06	64.72	70.25	69.62	77.57	73.27	65.84	57.22	55.8	61.24	64.49	70.74
35.3	44.98	68.92	68.62	74.34	73.57	81.21	77.59	69.88	61.99	60.56	65.17	68.05	74.36
40.1	47.75	72.8	72.54	78.31	77.49	84.72	81.8	74.06	67.09	65.48	69.25	71.69	77.99
45.6	50.55	76.58	76.34	82.03	81.25	87.99	85.74	78.24	72.32	70.36	73.39	75.33	81.53
51.8	53.32	80.14	79.88	85.37	84.72	90.91	89.28	82.26	77.44	74.99	77.51	78.87	84.85
58.9	55.99	83.37	83.05	88.27	87.8	93.4	92.32	85.97	82.2	79.18	81.5	82.2	87.85
66.9	58.5	86.2	85.78	90.72	90.43	95.42	94.8	89.25	86.37	82.8	85.27	85.25	90.45
76	60.83	88.59	88.05	92.76	92.59	96.98	96.71	92.02	89.81	85.78	88.74	87.96	92.6

86.4	62.95	90.53	89.89	94.46	94.32	98.11	98.09	94.26	92.45	88.12	91.84	90.31	94.31
98.1	64.88	92.07	91.35	95.88	95.67	98.89	99.01	95.99	94.32	89.87	94.49	92.32	95.61
111	66.65	93.27	92.51	97.07	96.72	99.39	99.56	97.27	95.51	91.14	96.64	94.02	96.56
127	68.32	94.22	93.44	98.06	97.56	99.69	99.85	98.19	96.18	92.04	98.25	95.47	97.25
144	69.97	95.01	94.22	98.85	98.25	99.86	99.98	98.85	96.51	92.72	99.31	96.71	97.75
163	71.72	95.72	94.92	99.43	98.83	99.95	100.01	99.32	96.67	93.29	99.88	97.78	98.13
186	73.68	96.41	95.58	99.8	99.3	99.97	100.01	99.65	96.8	93.86	100.01	98.67	98.45
211	75.96	97.1	96.22	99.96	99.65	99.99	100.01	99.86	96.96	94.51	100.01	99.35	98.73
240	78.64	97.77	96.84	99.99	99.86	100.01	100.01	99.97	97.24	95.27	100.01	99.8	98.97
272	81.72	98.4	97.43	99.99	99.95	100.01	100.01	100	97.64	96.13	100.01	100.01	99.17
310	85.12	98.94	97.96	99.99	99.97	100.01	100.01	100	98.13	97.05	100.01	100.01	99.32
352	88.67	99.37	98.42	99.99	99.97	100.01	100.01	100	98.67	97.95	100.01	100.01	99.45
400	92.11	99.66	98.81	99.99	99.97	100.01	100.01	100	99.18	98.74	100.01	100.01	99.57
454	95.14	99.87	99.17	99.99	99.97	100.01	100.01	100	99.59	99.34	100.01	100.01	99.67
516	97.5	99.98	99.46	99.99	99.97	100.01	100.01	100	99.86	99.72	100.01	100.01	99.76
586	99.04	100.04	99.7	99.99	99.97	100.01	100.01	100	99.99	99.92	100.01	100.01	99.84
666	99.72	100.04	99.86	99.99	99.97	100.01	100.01	100	100.01	100.01	100.01	100.01	99.91
756	99.97	100.04	99.94	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	99.96
859	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
976	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
1110	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
1260	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
1430	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
1630	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
1850	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
2100	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
2390	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
2710	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
3080	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100
3500	99.98	100.04	99.96	99.99	99.97	100.01	100.01	100	100.01	100.03	100.01	100.01	100

Table C-6: PSA for Hays samples 7B- 13B. % cumulative volume.

Size (µm)	H_7B	H_8A	H_9A	H_9B	H_9D	H_10A	H_11A	H_11B	H_11D	H_12B	H_12C	H_13A	H_13B
0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0114	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0129	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0147	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0167	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0189	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0215	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0244	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0278	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0315	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0358	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0407	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0463	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0526	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0597	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0679	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0771	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0876	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0995	0	0	0	0	0	0	0	0	0	0	0	0	0
0.113	0	0	0	0	0	0	0	0	0	0	0	0	0
0.128	0	0	0	0	0	0	0	0	0	0	0	0	0
0.146	0	0	0	0	0	0	0	0	0	0	0	0	0
0.166	0	0	0	0	0	0	0	0	0	0	0	0	0
0.188	0	0	0	0	0	0	0	0	0	0	0	0	0
0.214	0	0	0	0	0	0	0	0	0	0	0	0	0

0.243	0	0	0	0	0	0	0	0	0	0	0	0	0
0.276	0	0	0	0	0	0	0	0	0	0	0	0	0
0.314	0	0	0	0	0	0	0	0	0	0	0	0	0
0.357	0	0	0	0	0	0	0	0	0	0	0	0	0
0.405	0	0	0	0	0	0	0	0	0	0	0	0	0
0.46	0.08	0.05	0.17	0	0	0	0	0	0.1	0	0	0	0
0.523	0.5	0.3	0.71	0.18	0.2	0.12	0.11	0.24	0.49	0.16	0.13	0.12	0.14
0.594	1.42	0.8	1.68	0.7	0.75	0.48	0.46	0.81	1.28	0.61	0.52	0.48	0.57
0.675	2.81	1.51	2.98	1.57	1.66	1.12	1.07	1.7	2.42	1.38	1.19	1.12	1.31
0.767	4.5	2.33	4.42	2.68	2.82	1.97	1.88	2.79	3.75	2.39	2.07	1.98	2.28
0.872	6.26	3.15	5.8	3.87	4.06	2.91	2.77	3.93	5.09	3.5	3.04	2.95	3.36
0.991	7.95	3.89	7.02	5.04	5.26	3.85	3.66	5.02	6.33	4.61	4.01	3.94	4.45
1.13	9.55	4.56	8.1	6.17	6.42	4.76	4.54	6.05	7.48	5.7	4.95	4.93	5.52
1.28	11.17	5.21	9.14	7.34	7.61	5.69	5.45	7.1	8.63	6.81	5.92	5.95	6.62
1.45	12.93	5.91	10.26	8.66	8.94	6.71	6.46	8.26	9.87	8.02	6.99	7.06	7.81
1.65	14.93	6.69	11.53	10.21	10.51	7.89	7.64	9.61	11.28	9.39	8.21	8.31	9.15
1.88	17.2	7.57	12.97	12.03	12.36	9.26	9.01	11.18	12.88	10.94	9.62	9.72	10.66
2.13	19.71	8.54	14.55	14.12	14.48	10.82	10.58	12.96	14.65	12.66	11.21	11.28	12.32
2.42	22.41	9.57	16.23	16.44	16.84	12.56	12.33	14.93	16.55	14.53	12.96	12.97	14.11
2.75	25.26	10.65	17.98	18.96	19.41	14.47	14.24	17.06	18.54	16.54	14.85	14.77	16.01
3.12	28.22	11.76	19.77	21.66	22.16	16.54	16.32	19.33	20.61	18.67	16.88	16.69	18.01
3.55	31.26	12.9	21.6	24.51	25.05	18.77	18.56	21.73	22.74	20.93	19.05	18.74	20.12
4.03	34.37	14.07	23.47	27.49	28.07	21.15	20.95	24.24	24.92	23.3	21.35	20.91	22.35
4.58	37.52	15.28	25.38	30.58	31.18	23.68	23.48	26.85	27.15	25.78	23.77	23.2	24.69
5.21	40.67	16.52	27.32	33.74	34.34	26.33	26.13	29.52	29.41	28.35	26.29	25.6	27.13
5.92	43.8	17.79	29.3	36.93	37.51	29.07	28.86	32.23	31.68	30.97	28.89	28.09	29.65
6.72	46.87	19.09	31.31	40.11	40.66	31.87	31.64	34.94	33.95	33.62	31.53	30.65	32.24
7.64	49.86	20.43	33.35	43.26	43.76	34.71	34.43	37.63	36.2	36.27	34.2	33.25	34.87
8.68	52.76	21.81	35.43	46.35	46.79	37.57	37.21	40.28	38.44	38.91	36.88	35.87	37.53
9.86	55.58	23.25	37.56	49.38	49.74	40.44	39.97	42.88	40.67	41.54	39.57	38.5	40.22

11.2	58.34	24.76	39.75	52.35	52.62	43.33	42.72	45.45	42.92	44.17	42.29	41.15	42.95
12.7	61.06	26.37	42.02	55.27	55.44	46.25	45.47	48	45.23	46.84	45.05	43.83	45.74
14.5	63.77	28.1	44.39	58.16	58.21	49.22	48.25	50.56	47.64	49.59	47.87	46.57	48.62
16.4	66.5	29.97	46.87	61.02	60.96	52.26	51.1	53.16	50.19	52.47	50.78	49.41	51.64
18.7	69.27	32.01	49.47	63.87	63.72	55.39	54.05	55.83	52.93	55.52	53.8	52.38	54.84
21.2	72.09	34.22	52.18	66.72	66.52	58.62	57.13	58.58	55.89	58.76	56.94	55.53	58.25
24.1	74.95	36.61	54.98	69.57	69.38	61.95	60.35	61.42	59.07	62.2	60.2	58.86	61.88
27.4	77.83	39.17	57.85	72.41	72.33	65.37	63.69	64.32	62.44	65.8	63.56	62.36	65.72
31.1	80.7	41.88	60.75	75.22	75.37	68.84	67.11	67.26	65.96	69.48	66.97	65.99	69.7
35.3	83.52	44.71	63.64	77.98	78.5	72.31	70.54	70.18	69.53	73.15	70.38	69.66	73.72
40.1	86.24	47.61	66.48	80.64	81.69	75.7	73.89	73.03	73.06	76.7	73.71	73.26	77.66
45.6	88.79	50.53	69.24	83.16	84.89	78.94	77.08	75.75	76.43	80.01	76.9	76.68	81.38
51.8	91.12	53.41	71.9	85.5	88.03	81.95	80.04	78.29	79.55	82.99	79.87	79.82	84.75
58.9	93.18	56.2	74.45	87.62	91.01	84.67	82.71	80.62	82.33	85.58	82.57	82.6	87.68
66.9	94.93	58.85	76.89	89.49	93.71	87.07	85.06	82.71	84.73	87.76	84.97	84.98	90.12
76	96.36	61.32	79.21	91.1	96.02	89.15	87.08	84.57	86.75	89.55	87.04	86.96	92.06
86.4	97.46	63.57	81.39	92.45	97.83	90.93	88.78	86.23	88.42	90.99	88.78	88.57	93.54
98.1	98.27	65.58	83.4	93.56	99.09	92.44	90.19	87.7	89.79	92.14	90.2	89.86	94.63
111	98.82	67.34	85.2	94.44	99.81	93.72	91.34	89.02	90.92	93.05	91.32	90.88	95.41
127	99.17	68.85	86.78	95.13	100	94.8	92.28	90.21	91.89	93.77	92.17	91.68	95.98
144	99.37	70.18	88.15	95.66	100	95.73	93.06	91.29	92.76	94.35	92.82	92.31	96.42
163	99.48	71.43	89.36	96.09	100	96.53	93.73	92.29	93.58	94.86	93.35	92.82	96.81
186	99.57	72.76	90.49	96.47	100	97.22	94.32	93.22	94.41	95.36	93.83	93.25	97.19
211	99.66	74.34	91.64	96.85	100	97.81	94.87	94.09	95.26	95.89	94.32	93.65	97.58
240	99.76	76.35	92.88	97.26	100	98.3	95.39	94.92	96.14	96.47	94.88	94.05	97.98
272	99.84	78.89	94.23	97.73	100	98.7	95.91	95.72	97.03	97.11	95.53	94.49	98.37
310	99.92	81.98	95.65	98.24	100	99.01	96.43	96.5	97.87	97.78	96.27	94.99	98.74
352	99.98	85.49	97.04	98.76	100	99.25	96.98	97.25	98.62	98.43	97.07	95.55	99.08
400	100.01	89.17	98.26	99.23	100	99.45	97.56	97.97	99.21	99.01	97.87	96.15	99.38
454	100.01	92.68	99.18	99.6	100	99.62	98.16	98.63	99.61	99.47	98.6	96.77	99.62

516	100.01	95.67	99.75	99.85	100	99.76	98.75	99.19	99.84	99.78	99.2	97.38	99.81
586	100.01	97.9	99.97	99.96	100	99.89	99.27	99.61	99.95	99.95	99.62	97.95	99.93
666	100.01	99.27	100.02	99.98	100	99.99	99.67	99.86	99.98	99.99	99.87	98.46	100
756	100.01	99.85	100.02	99.98	100	100.03	99.91	99.96	99.98	99.99	99.98	98.89	100.03
859	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	99.23	100.03
976	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	99.47	100.03
1110	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	99.64	100.03
1260	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	99.77	100.03
1430	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	99.86	100.03
1630	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	99.93	100.03
1850	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	99.98	100.03
2100	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	100.01	100.03
2390	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	100.03	100.03
2710	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	100.03	100.03
3080	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	100.03	100.03
3500	100.01	100.02	100.02	99.98	100	100.03	100.01	99.98	99.98	99.99	100	100.03	100.03

Table C-7: PSA for Hays samples 13C- 20B. % cumulative volume.

Size (µm)	**H_13C**	**H_14A**	**H_14B**	**H_14C**	**H_15A**	**H_15B**	**H_16A**	**H_17A**	**H_17B**	**H_18A**	**H_19A**	**H_19B**	**H_20A**	**H_20B**
0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0114	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0129	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0147	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0167	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0189	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0215	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0244	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0278	0	0	0	0	0	0	0	0	0	0	0	0	0	0

0.0315	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0358	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0407	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0463	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0526	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0597	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0679	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0771	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0876	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0995	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.113	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.128	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.146	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.166	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.188	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.214	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.243	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.276	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.314	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.357	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.405	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.46	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.523	0.09	0.21	0.11	0.11	0.18	0.08	0.11	0.11	0	0	0.19	0.21	0.18	0.25
0.594	0.39	0.8	0.46	0.44	0.68	0.32	0.43	0.46	0.18	0.15	0.67	0.75	0.68	0.92
0.675	0.94	1.79	1.07	1.02	1.5	0.73	0.99	1.09	0.53	0.44	1.43	1.63	1.53	2.02
0.767	1.69	3.05	1.88	1.78	2.54	1.27	1.73	1.92	1.01	0.85	2.38	2.74	2.62	3.41
0.872	2.54	4.4	2.79	2.62	3.66	1.86	2.54	2.85	1.56	1.32	3.38	3.92	3.8	4.9
0.991	3.41	5.72	3.71	3.46	4.76	2.45	3.35	3.79	2.13	1.81	4.34	5.07	4.96	6.34
1.13	4.28	6.99	4.62	4.28	5.83	3.03	4.15	4.71	2.69	2.29	5.25	6.18	6.09	7.73
1.28	5.18	8.28	5.56	5.13	6.92	3.62	4.98	5.65	3.25	2.78	6.17	7.32	7.25	9.15

1.45	6.17	9.68	6.58	6.08	8.13	4.27	5.89	6.68	3.85	3.3	7.17	8.58	8.53	10.74
1.65	7.3	11.28	7.73	7.18	9.52	5.01	6.94	7.85	4.52	3.87	8.32	10.04	10	12.59
1.88	8.6	13.11	9.02	8.47	11.12	5.86	8.15	9.18	5.27	4.5	9.64	11.73	11.69	14.75
2.13	10.06	15.15	10.44	9.95	12.92	6.81	9.51	10.66	6.1	5.2	11.12	13.63	13.58	17.2
2.42	11.66	17.36	11.97	11.59	14.89	7.84	11.01	12.27	7.01	5.95	12.74	15.71	15.64	19.9
2.75	13.39	19.71	13.6	13.38	17	8.94	12.62	14.01	7.99	6.76	14.49	17.94	17.84	22.79
3.12	15.24	22.18	15.33	15.31	19.24	10.1	14.34	15.87	9.05	7.64	16.35	20.3	20.16	25.84
3.55	17.22	24.76	17.16	17.38	21.58	11.32	16.17	17.86	10.2	8.6	18.33	22.78	22.58	29.02
4.03	19.33	27.44	19.09	19.57	24.02	12.58	18.1	19.98	11.44	9.64	20.41	25.37	25.1	32.3
4.58	21.57	30.2	21.12	21.87	26.53	13.88	20.11	22.24	12.78	10.77	22.59	28.06	27.7	35.65
5.21	23.92	33.02	23.25	24.26	29.09	15.2	22.19	24.63	14.21	11.99	24.85	30.83	30.36	39.04
5.92	26.37	35.88	25.46	26.72	31.68	16.53	24.32	27.13	15.73	13.28	27.17	33.65	33.05	42.43
6.72	28.92	38.76	27.73	29.22	34.27	17.86	26.48	29.72	17.32	14.63	29.51	36.5	35.75	45.78
7.64	31.55	41.63	30.05	31.74	36.84	19.18	28.65	32.38	18.97	16.01	31.86	39.34	38.43	49.07
8.68	34.27	44.48	32.41	34.26	39.38	20.49	30.82	35.1	20.67	17.41	34.2	42.16	41.08	52.28
9.86	37.09	47.3	34.81	36.79	41.9	21.81	33	37.87	22.42	18.83	36.54	44.95	43.7	55.4
11.2	40.02	50.1	37.26	39.33	44.41	23.17	35.2	40.7	24.24	20.29	38.91	47.71	46.3	58.42
12.7	43.09	52.9	39.79	41.91	46.95	24.6	37.46	43.63	26.16	21.84	41.35	50.46	48.91	61.34
14.5	46.32	55.74	42.45	44.57	49.56	26.15	39.8	46.71	28.22	23.56	43.93	53.23	51.56	64.17
16.4	49.74	58.66	45.27	47.34	52.28	27.87	42.27	49.99	30.49	25.55	46.71	56.09	54.3	66.93
18.7	53.35	61.72	48.31	50.26	55.15	29.83	44.91	53.53	33.05	27.95	49.77	59.09	57.16	69.64
21.2	57.15	64.97	51.59	53.35	58.19	32.07	47.75	57.36	35.97	30.89	53.15	62.3	60.19	72.32
24.1	61.1	68.46	55.11	56.62	61.42	34.62	50.8	61.5	39.31	34.48	56.88	65.76	63.4	75.02
27.4	65.15	72.19	58.84	60.05	64.81	37.5	54.05	65.91	43.09	38.77	60.94	69.49	66.78	77.77
31.1	69.22	76.13	62.71	63.6	68.32	40.69	57.46	70.5	47.31	43.74	65.26	73.46	70.3	80.58
35.3	73.22	80.19	66.61	67.2	71.87	44.14	60.98	75.15	51.89	49.29	69.74	77.57	73.89	83.46
40.1	77.05	84.24	70.42	70.78	75.37	47.77	64.53	79.7	56.71	55.23	74.24	81.7	77.44	86.37
45.6	80.62	88.09	74.01	74.25	78.71	51.48	68.02	83.97	61.61	61.3	78.6	85.68	80.84	89.25
51.8	83.86	91.57	77.27	77.52	81.8	55.16	71.35	87.82	66.39	67.23	82.67	89.34	83.97	92
58.9	86.73	94.51	80.12	80.52	84.56	58.71	74.44	91.12	70.88	72.76	86.32	92.52	86.73	94.5

66.9	89.23	96.8	82.52	83.21	86.94	62.05	77.23	93.81	74.93	77.66	89.46	95.12	89.06	96.61
76	91.37	98.4	84.48	85.56	88.92	65.11	79.69	95.89	78.44	81.8	92.05	97.1	90.95	98.23
86.4	93.21	99.33	86.06	87.57	90.51	67.87	81.82	97.41	81.38	85.12	94.08	98.47	92.41	99.31
98.1	94.78	99.81	87.32	89.28	91.74	70.32	83.65	98.46	83.78	87.66	95.6	99.31	93.51	99.89
111	96.12	99.98	88.36	90.74	92.67	72.5	85.23	99.13	85.72	89.53	96.67	99.7	94.33	100.01
127	97.25	99.98	89.25	92.01	93.37	74.46	86.63	99.53	87.32	90.9	97.38	99.83	94.98	100.01
144	98.17	99.98	90.08	93.16	93.92	76.28	87.94	99.75	88.72	91.95	97.81	99.91	95.56	100.01
163	98.88	99.98	90.91	94.24	94.4	78.06	89.24	99.84	90.04	92.87	98.05	99.95	96.14	100.01
186	99.39	99.98	91.76	95.29	94.9	79.89	90.6	99.91	91.39	93.79	98.17	99.97	96.78	100.01
211	99.69	99.98	92.65	96.31	95.46	81.86	92.05	99.96	92.82	94.8	98.21	99.97	97.48	100.01
240	99.85	99.98	93.57	97.26	96.1	84.03	93.58	99.98	94.33	95.89	98.21	99.97	98.2	100.01
272	99.92	99.98	94.5	98.08	96.81	86.43	95.14	99.98	95.85	97.01	98.21	99.97	98.87	100.01
310	99.96	99.98	95.43	98.74	97.56	89.01	96.64	99.98	97.27	98.06	98.24	99.97	99.42	100.01
352	99.96	99.98	96.34	99.21	98.28	91.66	97.95	99.98	98.46	98.93	98.3	99.97	99.79	100.01
400	99.96	99.98	97.22	99.49	98.91	94.21	98.97	99.98	99.32	99.55	98.4	99.97	99.95	100.01
454	99.96	99.98	98.05	99.69	99.4	96.46	99.63	99.98	99.82	99.89	98.54	99.97	100	100.01
516	99.96	99.98	98.78	99.85	99.73	98.21	99.92	99.98	99.96	99.99	98.73	99.97	100	100.01
586	99.96	99.98	99.36	99.95	99.89	99.36	99.95	99.98	99.96	99.99	98.95	99.97	100	100.01
666	99.96	99.98	99.75	100	99.99	99.9	99.95	99.98	99.96	99.99	99.19	99.97	100	100.01
756	99.96	99.98	99.93	100	100.03	99.99	99.95	99.98	99.96	99.99	99.43	99.97	100	100.01
859	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.65	99.97	100	100.01
976	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.82	99.97	100	100.01
1110	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.93	99.97	100	100.01
1260	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01
1430	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01
1630	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01
1850	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01
2100	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01
2390	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01
2710	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01

3080	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01
3500	99.96	99.98	100	100	100.03	99.99	99.95	99.98	99.96	99.99	99.98	99.97	100	100.01

Appendix D - XRF Results

Table D-1: XRF results for Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni

Sample #	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni
1A	3294.52	44910.09	216459.08	907.16	2665.40	19677.52	56924.60	2713.02	53.39	97.32	419.64	21713.70	5.70	19.51
1B	2143.96	37339.51	182993.88	535.35	1883.17	16732.30	84827.97	2432.73	49.66	85.21	348.72	19925.06	6.16	23.59
2A	2506.00	41380.16	209823.24	723.13	2579.98	18047.97	42798.56	2451.67	78.71	112.05	430.87	19102.63	5.95	23.60
2B	1606.94	40064.84	207313.95	531.24	2035.58	19235.16	55045.43	2557.58	73.09	98.38	372.18	21059.35	6.08	18.20
2C	2113.40	35558.01	225347.56	1697.87	2611.97	18058.98	38242.54	2084.17	99.61	125.18	442.09	15915.17	6.27	16.95
2D	1004.46	36354.18	216386.42	1.06E+10	3040.34	17303.49	13449.38	3071.47	97.40	130.34	500.72	18127.73	8.87	27.05
2E	1.14E+07	3.55E+08	2.08E+09	5.51E+06	5.35E+07	1.61E+08	2.06E+08	3.57E+07	6.79E+05	1.28E+06	5.09E+06	1.36E+08	1.33E+05	4.84E+05
3A	960.58	33545.90	174600.24	1384.32	3506.51	15331.78	45649.26	2579.64	71.23	99.01	477.96	23504.00	8.10	27.56
3B	1642.14	41442.94	180795.65	524.81	2464.24	13502.27	54408.43	2933.57	78.32	115.68	494.50	22114.45	10.97	33.99
4A	1215.32	43772.86	223363.95	672.04	2029.59	19316.68	25574.12	2913.88	80.55	100.51	469.07	21517.21	6.34	24.78
4B	1325.77	37616.61	200661.88	996.89	3561.19	17127.96	29019.76	3293.95	65.03	116.73	451.38	18475.02	12.00	42.40
4C	595.03	43254.67	221279.00	649.08	1993.63	19942.85	27389.41	2841.25	70.47	106.94	467.24	22798.25	7.60	26.22
5A	649.31	37790.95	229689.95	548.89	2574.41	19977.44	18573.77	2308.93	112.87	119.64	421.32	18207.52	4.84	14.53
5B	403.42	36411.88	217993.63	645.03	2863.62	18237.08	26351.14	3139.10	61.47	128.77	407.63	18126.95	5.63	18.92
5C	1747.72	43579.72	226079.30	687.74	2516.05	20665.68	37942.11	2598.21	80.60	116.57	330.70	20222.39	4.97	20.50
6A	593.62	40798.42	227509.65	669.87	2383.23	20444.93	22172.81	2879.57	91.79	110.10	416.31	23080.89	8.11	22.99
7A	1220.49	44949.72	239995.86	671.68	2805.31	20443.83	23246.64	2842.06	85.82	102.96	455.07	22627.53	6.41	24.26
8A	396.57	39427.46	218265.88	557.67	2111.34	20099.69	20303.22	2412.13	108.65	175.55	463.26	18543.44	6.28	23.00
8B	1049.74	40429.03	222123.81	698.02	2273.83	20239.76	33705.85	2997.45	59.36	124.91	383.70	22557.09	6.15	23.49
9A	265.43	42434.79	227782.40	432.93	2040.53	19613.52	21150.89	2590.05	100.17	134.37	425.59	19083.24	5.92	22.91
9B	388.55	39495.51	223277.08	424.78	1959.54	20141.02	21960.77	2396.41	118.95	140.16	413.37	18516.72	5.44	21.80
10A	349.41	41251.67	237179.74	605.44	2009.66	20947.65	23598.32	2583.14	90.38	122.52	401.80	19172.68	5.40	19.23
11A	655.68	40544.25	225803.99	862.51	2198.65	20680.89	25063.68	2677.32	83.06	115.33	428.84	23429.43	5.96	23.04
11B	792.57	40641.31	228574.88	925.27	2178.53	20547.07	27928.35	2691.34	81.30	108.48	445.68	22651.17	5.86	22.36
12A	956.75	35983.24	218056.62	888.94	2798.70	18827.05	44576.04	2232.79	84.83	127.52	381.50	17203.35	5.65	16.74
12B	199.11	28281.65	196954.77	1540.51	3534.98	16535.97	45117.48	2075.50	79.57	116.97	365.00	16681.97	5.53	14.87
13A	1090.95	35856.46	209852.99	713.78	2299.11	18950.36	48887.54	2595.80	65.54	106.18	363.21	19442.87	5.92	17.87
13B	947.22	39230.99	221524.09	783.08	2138.20	19783.74	28817.85	2878.77	70.97	107.04	445.39	21964.10	6.92	25.12
14A	666.30	38001.99	214202.28	514.21	2075.36	19429.72	24743.58	2607.98	90.89	116.27	431.56	20079.43	6.40	23.31
14B	885.70	33407.49	214161.35	437.82	2484.47	19220.96	19914.99	2440.97	97.00	122.27	418.87	18839.82	5.08	16.44
14C	452.30	38192.81	216205.23	481.39	1867.72	18634.89	15545.30	2674.89	103.87	126.49	482.93	18144.31	5.65	16.41

15A	1138.88	44682.56	235383.62	1083.07	2245.53	21102.10	26803.86	3005.94	81.68	108.73	422.44	22188.74	5.19	20.33
15B	658.24	39934.08	215200.18	891.57	2094.08	19628.55	22655.35	2914.17	68.32	119.79	405.20	19160.02	6.18	22.34
16A	472.49	41375.27	230215.71	588.43	1909.88	21482.86	17852.08	2767.63	100.30	123.70	395.90	20042.68	5.25	19.42
16B	712.57	38748.22	219289.69	423.09	1997.08	19160.52	11854.30	2501.63	135.17	156.13	497.35	16311.12	5.27	22.78
17A	705.19	35291.91	203918.05	333.65	1593.12	16124.40	8948.00	2646.44	135.25	148.76	555.34	16443.29	6.43	24.73
17B	602.56	42388.92	243635.57	316.55	1615.10	18300.35	8072.29	3344.57	95.48	111.77	643.09	23132.64	7.66	31.05
18A	903.71	38670.85	236781.83	388.22	1833.02	19138.36	9869.55	2774.18	107.43	144.11	501.41	17041.02	5.17	16.91
18B	581.63	40005.54	223775.17	365.06	1799.51	19386.62	10509.25	2619.41	111.10	127.93	483.47	18244.48	5.37	18.03
19A	346.85	42076.86	238415.30	467.98	2139.70	20028.91	14371.79	2874.45	96.33	130.90	455.32	18932.12	4.99	19.07
19B	542.24	42437.81	239230.87	335.42	1750.69	20011.22	10115.98	2883.06	97.64	132.92	431.59	18351.10	5.12	18.58
19C	476.92	39401.72	233128.21	333.05	1627.78	18873.80	9044.12	2724.65	110.79	148.67	537.81	16590.73	5.54	20.39
20A	675.40	37707.88	224831.24	345.82	2003.50	18890.84	10223.19	2494.39	117.45	145.66	478.91	14324.46	4.36	15.87
20B	607.58	41608.10	229847.78	335.28	1713.82	20058.59	9558.79	2893.71	100.99	124.85	463.52	18909.78	6.09	22.56
20C	608.91	40331.25	230218.23	391.35	1818.13	18934.24	10862.08	2750.33	114.58	148.02	496.43	19073.91	5.31	20.78
H-1A	904.52	36548.49	192910.58	1181.96	2721.00	18564.05	33003.28	2567.69	86.55	119.94	498.28	19455.19	7.59	24.85
H-1C	522.81	41718.42	222068.49	814.10	1672.99	18938.28	21112.97	2861.42	109.02	121.97	569.86	21828.03	8.17	29.36
H-2A	750.72	41321.33	201506.10	233.31	1464.22	17330.18	20936.62	2695.82	122.66	131.45	523.63	20440.58	5.98	27.75
H-2B	500.97	45589.67	225505.35	263.18	1610.13	18994.13	14415.95	3124.49	91.12	106.36	481.75	24998.04	9.55	31.90
H-3A	826.32	40159.45	198830.54	293.25	1412.22	16840.92	28197.99	2951.84	81.15	111.53	443.39	20306.96	8.29	29.67
H-3B	997.42	47058.48	231490.49	341.10	1448.31	20451.61	24805.93	3093.17	80.96	106.15	440.53	24322.90	8.01	27.00
H-4A	810.14	35272.01	182077.39	309.47	1426.11	15104.37	29834.00	2502.19	122.78	141.24	466.35	16468.18	7.79	30.34
H-4B	1264.98	39858.58	193727.20	289.53	1522.96	16213.88	53068.73	2776.92	66.59	98.04	376.98	21258.72	8.09	29.26
H-4C	858.85	42931.15	216073.93	331.92	1461.73	17984.67	30814.97	2938.18	92.26	116.86	433.67	21032.03	7.49	28.70
H-4D	457.26	36868.09	194075.41	317.40	1797.19	16413.87	45349.94	2804.41	71.13	109.63	392.80	19414.70	7.15	25.93
H-5A	794.28	37784.51	194758.21	296.87	1569.15	17647.40	57183.28	2728.65	60.39	98.96	343.74	19264.58	7.11	22.66
H-6A	975.60	41316.86	207518.68	265.30	2346.07	17626.11	30831.20	2779.95	98.04	122.06	433.78	19968.47	8.26	25.73
H-7A	539.31	42485.07	205863.76	346.64	1971.05	18839.55	40402.94	2999.72	60.19	95.04	370.41	23676.83	7.91	27.11
H-7B	961.31	43791.54	205505.91	345.49	1902.67	18575.84	40758.61	3041.53	56.13	98.61	391.69	23914.06	8.27	31.26
H-8A	2363.74	30967.60	250863.04	242.59	2168.72	16384.19	9433.75	1087.99	125.89	121.43	453.06	9441.20	2.59	3.24
H-9A	571.62	37835.94	192262.31	262.35	2564.43	16894.09	17593.81	2768.92	98.58	120.59	479.28	24364.01	9.08	30.41
H-9B	357.51	43225.79	211997.63	249.85	2389.01	17230.84	15015.06	3202.41	90.82	100.82	468.37	27277.11	9.72	31.59
H-9D	489.28	44123.27	221440.11	284.02	2151.70	18875.98	25145.51	3004.57	74.77	102.85	423.39	24308.10	7.89	29.86
H-10	612.32	36123.38	187794.69	412.69	2361.08	16429.22	49873.98	2624.33	60.54	99.04	377.38	22246.83	7.35	25.69
H-11A	184.30	39836.04	215751.64	858.82	2092.06	19540.35	22414.19	2943.90	82.76	102.91	523.23	24068.03	7.39	24.51
H-11B	380.62	39779.87	210365.20	902.20	2126.09	19165.11	22946.66	2924.71	85.87	114.37	532.27	22319.26	7.21	27.40
H-11D	426.08	41548.84	219329.67	924.90	2032.52	19768.08	22948.27	3069.87	75.15	101.27	499.63	24116.89	6.22	22.53
H-12A	1556.54	40234.76	213260.21	2280.58	8128.48	22192.64	25708.79	2937.89	65.93	98.46	440.08	22381.69	7.54	24.53
H-12B	597.99	42896.46	218916.69	859.57	4500.81	20007.56	23315.96	2992.92	77.74	103.65	460.99	23124.67	8.43	30.03
H-12C	645.40	40947.37	216554.11	451.12	2239.39	21218.28	26178.56	2873.14	83.02	112.13	490.18	21233.82	7.15	25.56

H-13A	1627.32	40080.59	205343.39	1113.32	12392.18	21266.06	24075.10	2901.66	61.59	99.87	425.27	23097.11	8.74	32.44
H-13B	718.01	41762.98	211336.71	578.57	5967.36	19206.88	21990.79	3116.74	69.52	96.17	469.06	24121.20	8.52	30.26
H-13C	209.79	44957.97	224901.62	301.28	1548.37	19738.17	17171.04	3109.48	78.52	102.03	477.93	25342.91	8.59	29.14
H-14A	1235.91	37861.81	186089.47	533.96	5599.83	17874.08	17057.69	2746.35	120.78	140.43	482.58	18218.69	9.74	35.01
H-14B	682.96	43806.08	208595.37	768.76	5220.28	21921.48	20398.49	3159.53	77.51	98.32	429.75	25076.11	10.00	34.39
H-14C	501.12	39532.02	211852.82	553.14	1807.73	18568.98	18112.90	2991.65	93.83	125.02	489.26	21199.61	7.63	25.55
H-15A	663.60	43533.08	221675.77	419.41	1671.31	19499.67	25960.36	3099.83	75.49	103.13	508.23	23292.42	7.33	19.74
H-15B	577.00	39969.25	214726.37	551.95	2045.16	17680.90	32799.67	3062.51	79.68	103.75	471.15	23386.27	8.55	31.57
H-16A	715.50	38142.60	203862.90	465.54	1868.98	16829.83	19982.25	2828.42	107.99	168.77	511.10	18116.77	9.11	31.98
H-17A	435.83	43172.69	234544.49	467.82	1504.91	19769.23	14929.66	3417.04	73.16	105.53	519.66	20792.41	8.28	30.39
H-17B	676.75	38450.39	218998.11	786.66	1732.40	20138.46	31095.33	2965.25	71.03	116.43	473.03	18641.21	6.76	24.50
H-18	510.44	40736.18	231197.63	559.94	1518.13	19520.82	14460.72	3064.00	90.60	128.56	518.05	19451.20	7.72	24.70
H-19A	610.89	38183.70	223130.49	495.24	1502.21	18253.12	14130.35	2851.81	99.82	138.97	523.86	16411.58	6.55	21.81
H-19B	450.61	40071.44	225743.76	385.76	1806.01	18556.22	11323.32	3160.20	91.56	139.92	519.45	17848.25	8.35	27.49
H-20A	425.97	45767.17	213785.76	189.75	1309.94	18853.77	18602.61	3239.39	92.02	107.74	560.95	24780.08	6.55	21.81
H-20B	332.74	47249.00	227688.67	254.56	1351.72	19894.29	16137.51	3328.55	83.31	100.18	571.05	25254.76	8.35	27.49

Table D-2: XRF results for Cu, Zn, Ga, As, Pb (nitron), Pb, Th, Rb, U, Sr, Y, Zr, Nb, Mo, Rh

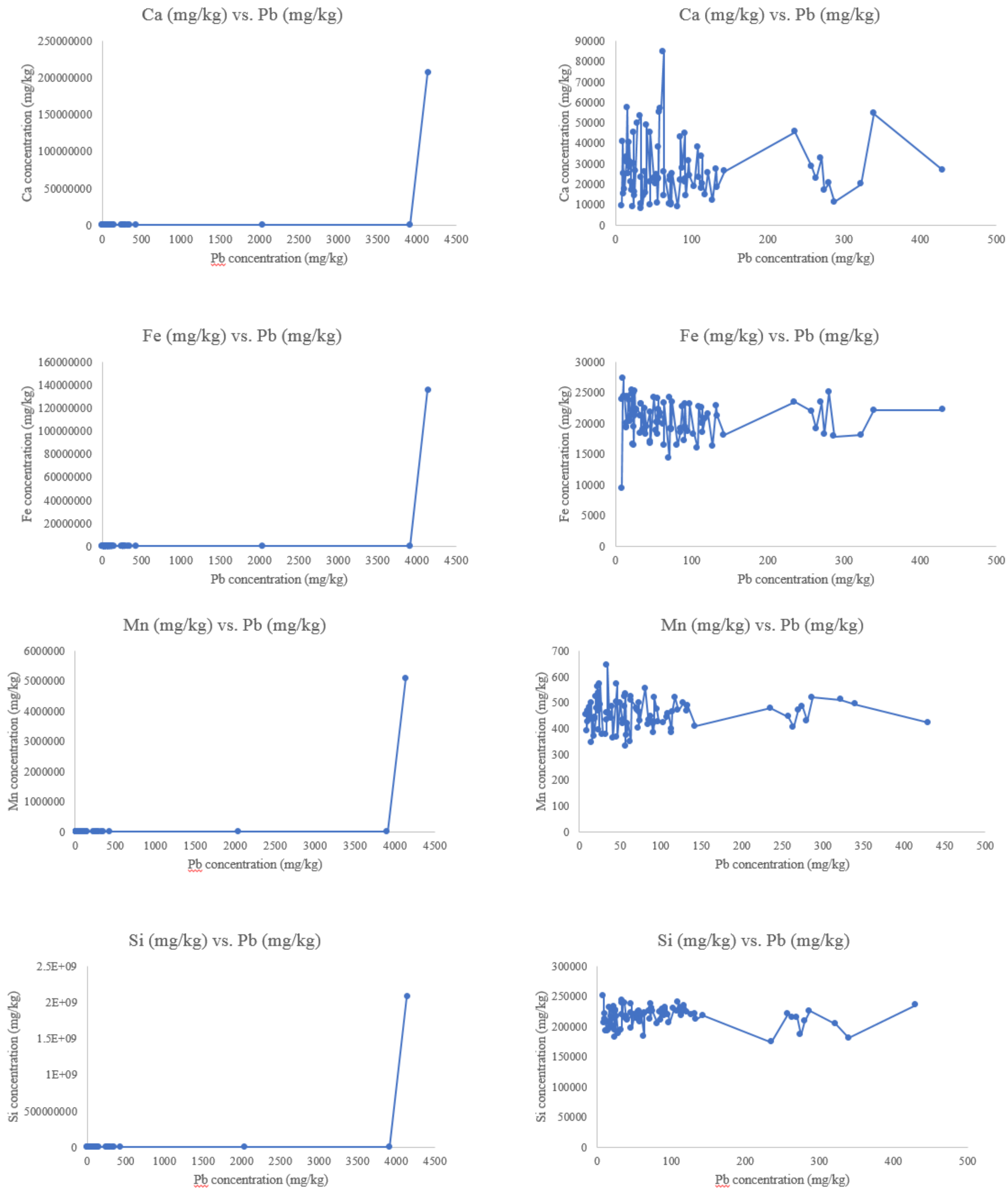
Sample #	Cu	Zn	Ga	As	Pb-Nitron	Pb	Th	Rb	U	Sr	Y	Zr	Nb	Mo	Rh
1A	13.58	124.31	12.49	32.31	8.57	18.18	7.05	89.06	1.11E+10	242.70	28.86	243.49	12.34	22.93	0.00
1B	14.45	95.97	14.62	35.06	9.40	19.04	7.32	89.79	3.15	335.26	31.49	266.93	10.79	24.60	0.00
2A	17.84	161.00	17.95	57.54	10.58	19.41	7.50	95.31	3.52	253.00	34.11	295.36	11.80	26.03	0.00
2B	14.15	119.84	13.28	34.82	10.76	19.11	7.08	87.58	4.62	251.63	30.20	243.91	12.25	22.93	0.00
2C	28.75	330.30	17.12	69.26	12.54	19.38	7.04	90.61	3.35	238.22	31.03	213.79	11.14	15.89	0.00
2D	147.89	1472.69	327.06	3478.94	14.76	4283.25	4.80	86.54	128.25	92.13	56.22	221.72	15.00	85.43	0.00
2E	2.99E+06	2.55E+06	1.39E+07	1.86E+08	1.48E+01	2.39E+08	2.90E+04	1.01E+06	3.06E+06	3.63E+06	9.18E+05	2.19E+06	1.74E+05	2.14E+06	0.00
3A	55.73	569.36	31.35	188.90	15.43	18.44	6.04	82.37	18.10	247.16	32.88	193.39	11.83	1.57	0.00
3B	59.29	497.72	41.39	230.69	16.44	56.27	6.28	81.19	21.55	330.99	36.95	238.26	11.93	6.34	0.00
4A	25.78	234.70	21.87	73.22	17.93	14.84	7.42	96.05	7.12	218.27	35.90	328.26	11.89	27.30	0.00
4B	189.06	717.23	789.67	10385.37	19.53	13727.18	3.60	96.96	252.28	226.99	83.58	249.02	17.72	172.25	0.00
4C	27.14	260.79	23.61	90.88	19.88	14.27	7.62	98.06	6.91	232.21	35.94	288.87	12.24	21.79	0.00
5A	20.36	205.69	17.44	63.63	20.29	17.96	7.66	102.46	4.30	172.44	30.84	236.93	11.13	15.63	0.00

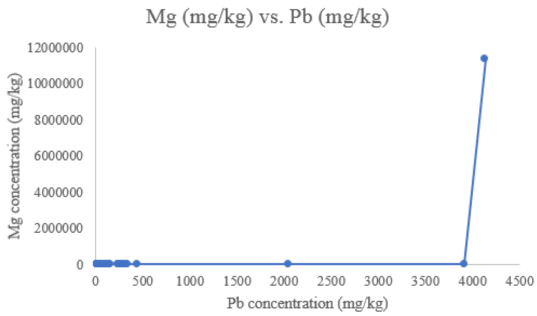
5B	60.69	779.36	21.71	91.68	22.10	14.14	6.84	90.55	5.43	182.49	29.77	253.46	12.12	13.86	0.00
5C	18.03	161.96	14.45	32.44	22.45	18.93	8.06	101.32	2.87	287.10	31.30	275.05	11.61	24.72	0.00
6A	21.84	207.82	18.24	62.33	23.39	19.25	8.09	105.83	4.04	235.04	32.66	265.14	11.52	21.53	0.00
7A	21.82	184.32	21.76	100.97	23.96	14.07	7.78	100.63	3.87	198.92	34.79	301.52	11.78	25.40	0.00
8A	23.41	226.30	20.04	71.45	24.16	15.76	8.08	104.19	3.90	208.03	32.99	280.84	11.58	22.26	0.00
8B	24.10	244.77	23.01	88.74	24.96	11.22	7.79	100.95	8.46	224.13	33.79	308.71	12.11	23.78	0.00
9A	17.81	149.45	20.41	81.53	25.51	15.79	8.19	105.32	4.69	198.15	33.71	274.19	12.09	21.29	0.00
9B	18.20	181.67	19.20	71.65	26.22	18.88	8.26	105.67	3.81	205.08	34.49	297.63	12.11	25.06	0.00
10A	13.30	119.47	17.93	63.78	28.62	16.35	7.83	100.02	1.87	203.21	33.90	305.47	12.31	26.72	0.00
11A	22.42	271.90	18.34	60.83	32.99	20.24	7.83	101.34	5.34	209.72	34.33	313.15	12.85	27.04	0.00
11B	18.69	187.08	16.47	54.37	33.40	18.39	7.27	94.45	4.74	208.15	31.50	258.58	12.27	17.60	0.00
12A	22.47	199.33	15.00	61.04	34.24	20.98	7.23	93.75	1.08E+10	229.26	29.16	213.83	11.03	13.55	0.00
12B	19.82	176.63	10.96	32.87	34.38	18.40	6.88	87.95	6.33E+09	246.58	26.38	218.38	10.75	18.76	0.00
13A	12.00	115.84	12.41	28.26	37.09	17.67	7.07	89.95	3.26	275.65	30.94	294.75	11.93	26.99	0.00
13B	31.97	359.40	37.51	208.85	38.94	47.87	7.59	100.36	18.33	195.21	37.45	291.39	12.62	12.61	0.00
14A	19.70	202.63	16.16	45.34	40.37	20.08	8.36	106.00	3.22	223.42	35.47	287.64	12.39	25.92	0.00
14B	16.05	183.59	13.17	34.16	41.20	18.55	7.93	103.93	2.43	180.56	31.42	259.36	11.66	22.84	0.00
14C	11.65	87.23	10.53	21.31	46.13	15.61	6.95	85.56	4.13	131.58	26.05	220.83	13.95	30.93	0.00
15A	23.77	260.35	55.70	474.50	46.14	213.82	7.05	97.96	31.75	136.76	36.63	219.24	11.86	7.39	0.00
15B	31.43	335.38	39.43	244.70	46.17	59.83	7.96	108.17	18.13	183.14	37.97	230.72	11.90	4.59	0.00
16A	13.69	107.93	19.09	74.78	50.51	17.19	8.22	107.32	3.47	163.45	32.93	260.87	11.82	18.41	0.00
16B	16.41	137.16	21.32	80.83	53.67	13.05	8.27	106.18	3.42	169.12	35.50	303.70	12.71	24.55	0.00
17A	23.89	137.99	18.86	82.35	54.34	20.21	7.77	100.89	3.77	162.58	35.81	330.20	13.02	29.40	0.00
17B	18.11	97.75	15.99	56.44	55.60	22.35	7.79	99.58	2.41	157.36	37.77	344.62	13.23	34.26	0.00
18A	14.69	143.00	13.28	34.07	56.19	18.16	7.77	100.36	3.00	154.50	32.91	313.61	12.67	28.67	0.00
18B	13.31	134.24	14.45	42.60	56.82	19.89	7.56	98.60	4.49	147.16	32.10	286.21	12.68	27.37	0.00
19A	13.49	87.46	12.58	23.18	56.87	16.77	7.84	100.95	4.11E+09	181.39	33.01	307.37	12.12	30.70	0.00
19B	10.25	77.02	12.16	17.78	58.16	15.32	8.23	105.88	4.28	174.29	34.00	332.70	11.93	36.84	0.00
19C	9.81	67.57	13.44	16.68	59.60	15.37	8.06	104.57	2.65	171.41	35.12	382.58	12.28	41.19	0.00
20A	10.53	126.22	14.34	37.97	63.08	19.27	7.69	100.06	2.12	156.66	31.07	266.69	12.01	23.66	0.00
20B	14.44	101.95	16.38	43.20	63.99	19.23	8.49	109.24	2.97	178.47	35.70	331.77	12.57	32.28	0.00
20C	13.99	114.24	15.51	42.52	64.02	19.71	7.83	102.50	3.08	173.05	35.68	317.39	12.72	30.24	0.00
H-1A	18.12	132.72	10.99	13.06	70.66	13.42	6.88	90.05	1.81	195.39	32.31	268.78	12.30	23.75	0.00
H-1C	20.40	163.12	16.56	33.87	71.93	19.71	7.76	101.13	4.10	175.47	35.12	301.04	12.73	24.21	0.00
H-2A	11.51	62.50	12.27	8.53	72.90	12.42	8.15	105.41	2.95	170.83	32.81	299.59	12.14	29.75	0.00
H-2B	24.27	293.08	14.79	14.45	73.43	15.00	8.53	108.93	1.92	162.63	36.47	320.45	12.59	30.33	0.00
H-3A	27.01	368.48	14.00	10.78	73.63	13.52	7.78	99.87	1.54E+10	185.29	34.62	339.54	12.58	33.58	0.00

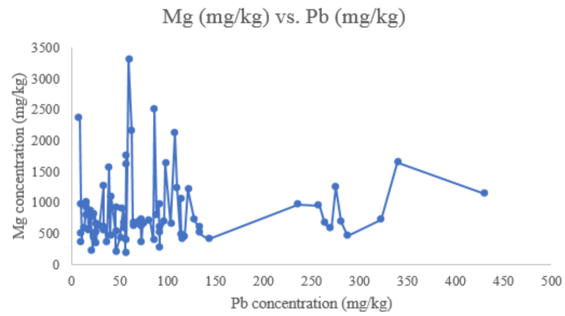
H-3B	11.35	59.31	12.58	10.24	74.73	13.17	7.98	102.37	5.10	172.36	35.03	330.75	12.83	30.40	0.00
H-4A	17.72	108.39	13.73	15.10	81.59	15.07	7.73	97.31	2.77	206.15	33.47	339.88	11.88	35.65	0.00
H-4B	16.92	102.42	13.70	18.20	85.28	15.86	7.47	94.63	2.87	210.39	33.63	314.70	11.09	30.37	0.00
H-4C	19.31	93.43	12.12	12.12	85.62	13.70	7.45	96.15	2.52	180.39	34.93	343.69	12.39	34.78	0.00
H-4D	16.38	116.36	11.91	14.83	88.00	14.59	7.26	94.09	3.95	193.31	32.15	292.11	11.30	29.19	0.00
H-5A	10.83	61.42	11.34	10.79	91.12	13.03	7.05	87.61	3.99	186.08	33.07	346.62	11.39	37.35	0.00
H-6A	12.49	71.38	12.36	10.11	91.59	12.91	7.74	97.41	3.78	168.58	33.81	304.84	12.80	27.26	0.00
H-7A	13.06	70.65	12.49	11.73	91.90	13.59	7.61	97.86	1.13	169.71	33.41	299.15	12.02	27.87	0.00
H-7B	27.20	98.75	14.04	9.69	92.29	13.61	8.00	101.54	2.65	172.62	34.75	311.73	12.03	29.42	0.00
H-8A	1.00	8.61	2.25	1.75	95.94	6.11	4.65	65.56	6.54	89.94	16.40	72.13	6.75	5.08	0.00
H-9A	20.97	88.01	11.78	8.84	97.59	12.17	7.52	98.08	1.63	150.54	32.12	252.73	12.56	19.98	0.00
H-9B	22.14	89.22	11.94	9.76	103.21	12.75	7.65	100.64	1.45	143.74	33.68	270.59	12.83	24.22	0.00
H-9D	12.59	66.27	12.95	8.88	107.99	12.90	7.97	101.62	1.94	166.65	35.57	345.03	12.34	35.88	0.00
H-10	20.45	126.51	13.48	23.37	109.70	16.95	7.42	96.21	4.02	184.15	34.32	283.54	11.95	23.73	0.00
H-11A	17.54	152.37	13.25	30.15	113.50	17.94	7.03	90.69	3.86	158.17	31.07	268.79	13.18	18.04	0.00
H-11B	19.88	159.84	17.60	50.57	113.60	17.72	7.74	100.18	3.83	179.84	34.79	283.24	12.58	21.92	0.00
H-11D	15.56	137.45	11.67	25.05	114.62	16.96	6.64	85.49	2.83	145.42	30.04	255.63	13.19	15.60	0.00
H-12A	18.53	199.99	13.66	21.77	117.87	16.61	7.55	95.78	2.03E+10	180.05	31.54	317.14	12.55	28.72	0.00
H-12B	19.24	156.02	14.38	20.96	121.56	16.74	8.19	103.85	1.78	190.64	34.49	326.90	12.16	32.31	0.00
H-12C	15.40	142.56	13.13	24.70	127.94	17.14	7.17	93.87	4.04	180.52	32.81	275.61	12.44	22.69	0.00
H-13A	27.08	309.20	21.82	74.14	132.64	16.72	7.66	100.83	9.43	170.72	35.99	287.36	11.84	20.10	0.00
H-13B	22.52	237.04	17.75	48.91	133.40	20.07	7.84	102.20	5.42	174.04	35.45	313.63	12.36	24.68	0.00
H-13C	16.16	91.04	12.40	20.51	142.83	16.09	7.44	93.40	4.19	141.87	31.39	295.19	13.60	35.01	0.00
H-14A	50.20	636.03	57.91	331.72	235.48	185.07	7.86	108.16	31.08	141.73	41.98	303.42	12.98	6.01	0.00
H-14B	55.18	691.67	56.57	326.65	257.74	201.75	7.61	105.09	32.30	142.57	41.31	282.73	12.67	2.00	0.00
H-14C	18.09	204.44	16.85	46.98	263.83	19.12	6.97	91.84	5.05	150.91	33.81	286.64	12.93	20.53	0.00
H-15A	13.98	179.39	15.83	66.12	270.10	17.65	6.13	78.57	7.77	122.39	27.45	214.76	13.28	17.67	0.00
H-15B	40.49	448.86	17.90	50.62	274.64	20.10	7.04	94.40	7.45	182.11	34.06	273.70	11.93	20.57	0.00
H-16A	40.78	534.92	49.47	302.49	280.34	135.19	7.33	98.78	27.11	137.59	40.98	300.40	12.88	6.35	0.00
H-17A	33.09	402.15	27.35	103.56	287.14	5.62	7.77	99.93	10.18	167.48	38.54	406.44	13.14	35.44	0.00
H-17B	18.47	173.70	18.12	60.59	322.30	17.85	7.14	92.46	5.37	195.01	36.42	348.99	12.58	30.84	0.00
H-18	22.06	218.22	17.62	59.26	339.54	18.58	7.08	91.80	3.65	165.81	33.79	335.00	12.74	28.10	0.00
H-19A	17.86	193.83	15.08	37.43	429.84	19.36	7.12	92.03	4.85	158.99	34.39	354.64	13.31	33.54	0.00
H-19B	46.05	687.28	42.33	217.62	2046.26	90.04	7.32	98.83	23.65	123.46	40.16	374.10	13.33	19.39	0.00
H-20A	17.86	193.83	15.08	37.43	3909.68	19.36	7.12	92.03	4.85	158.99	34.39	354.64	13.31	33.54	0.00
H-20B	46.05	687.28	42.33	217.62	4137.57	90.04	7.32	98.83	23.65	123.46	40.16	374.10	13.33	19.39	0.00

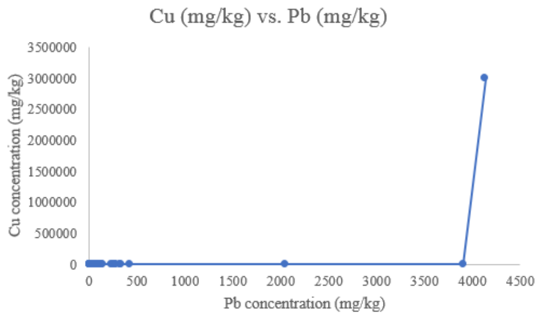
Appendix E - XRF Graphs

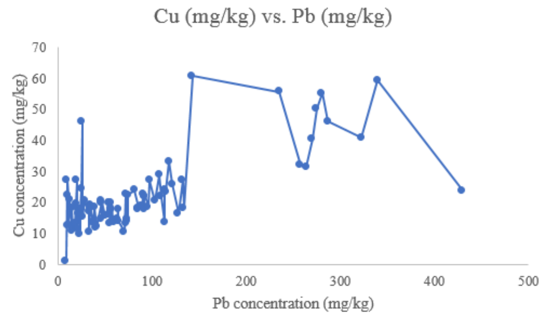
Figure 7-1: Graphs created from XRF data. Graphs on the right eliminate the highest three Pb concentrations.





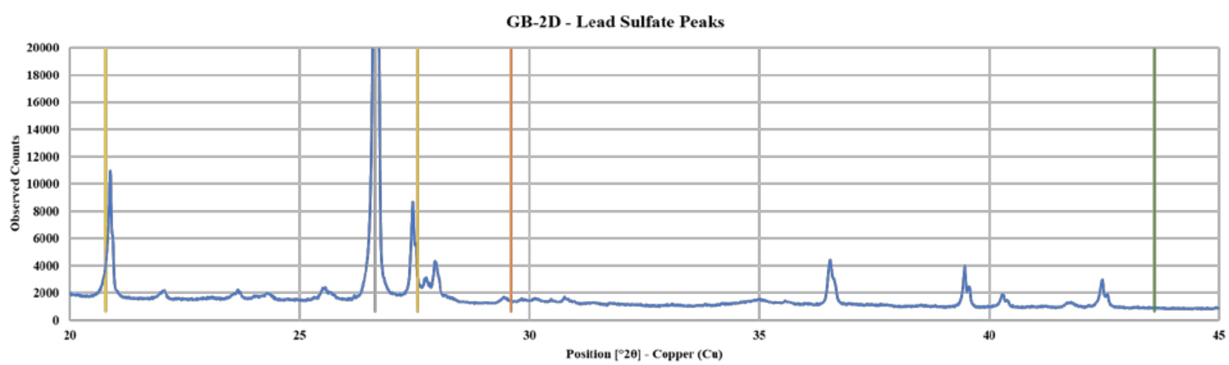


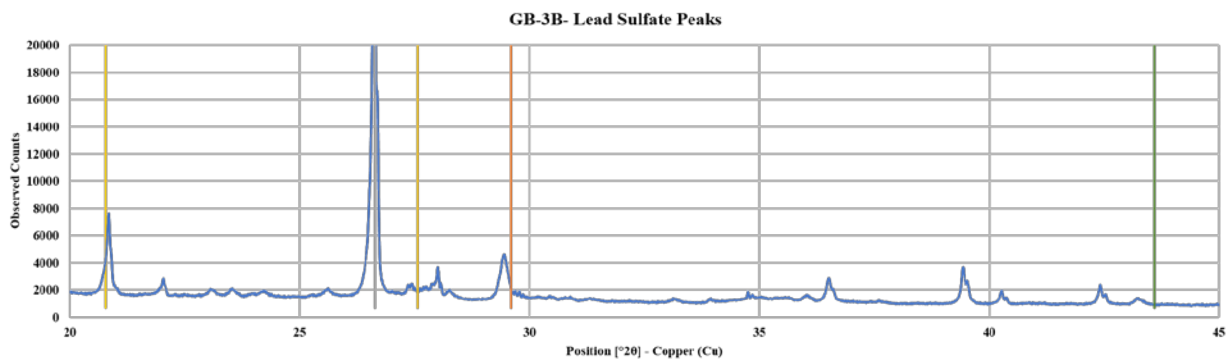


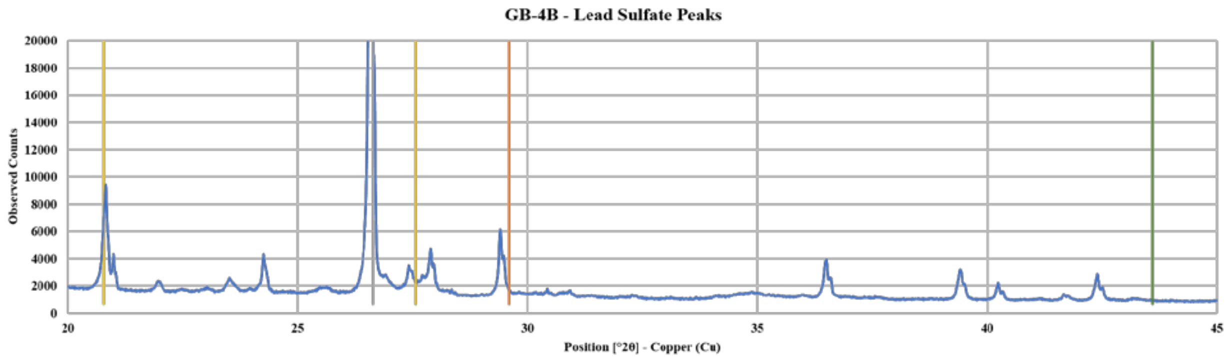


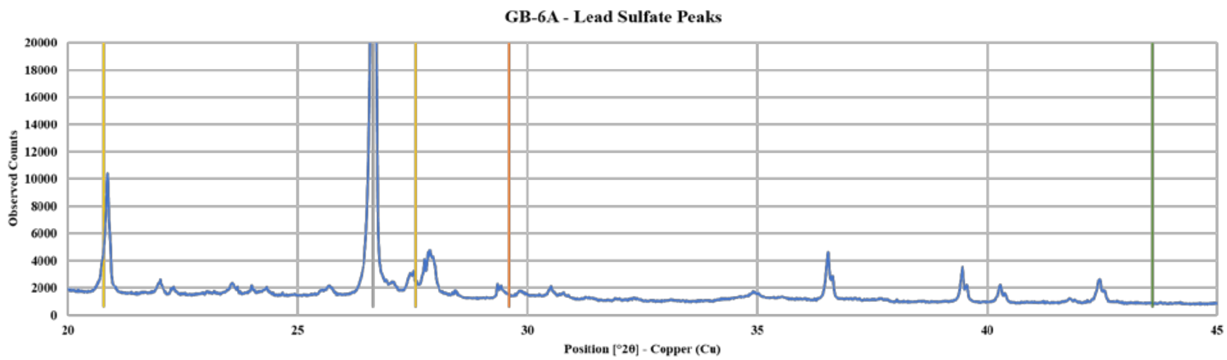
Appendix F - XRD Results

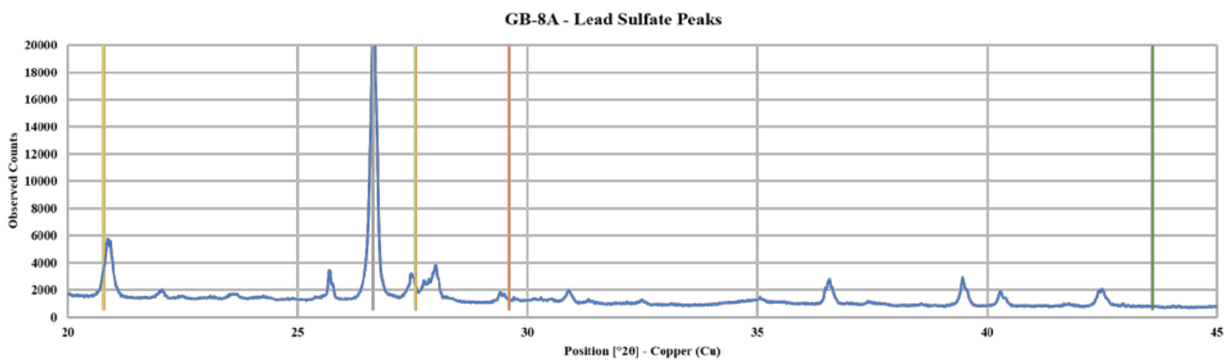
Figure 7-2: XRD results of 8 samples examined for sulfate peaks

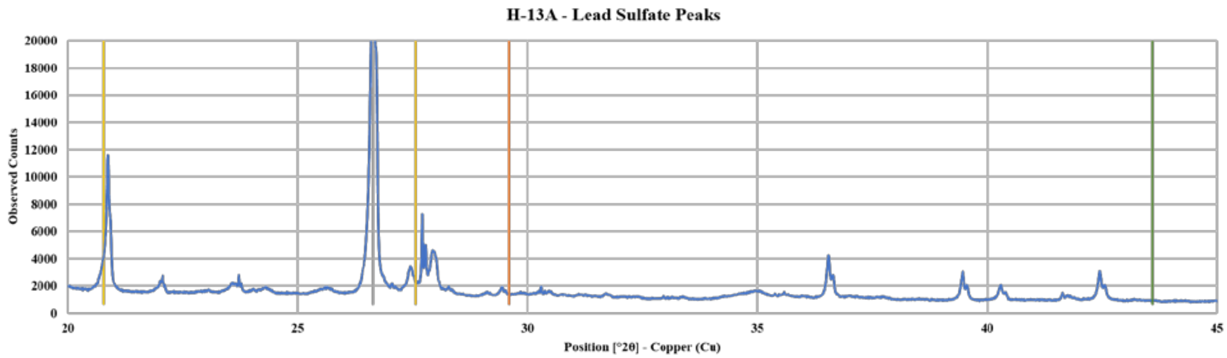


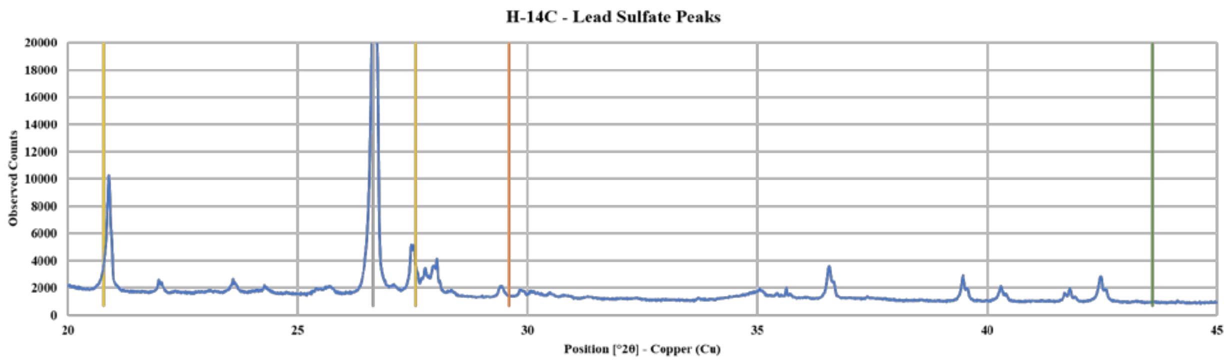


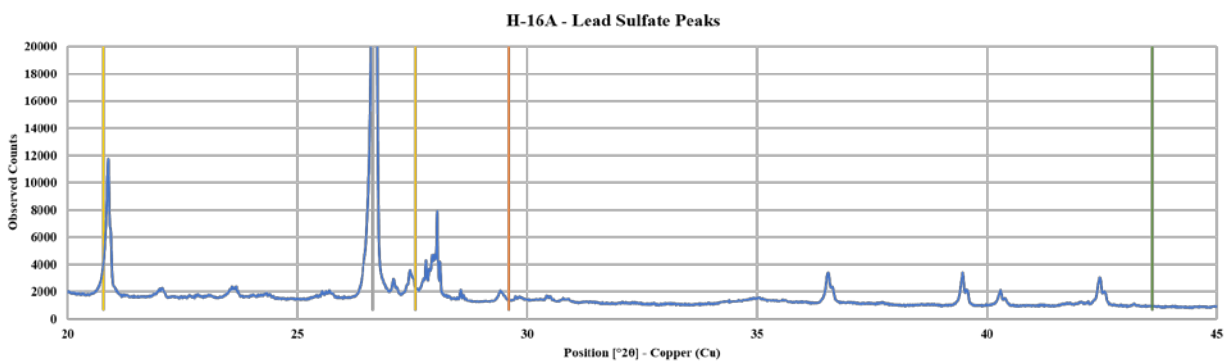

GB-4B - Lead Sulfate Peaks
Observed Counts
Position [°2θ] - Copper (Cu)


GB-6A - Lead Sulfate Peaks
Observed Counts
Position [°2θ] - Copper (Cu)


GB-8A - Lead Sulfate Peaks
Observed Counts
Position [°2θ] - Copper (Cu)


H-13A - Lead Sulfate Peaks
Observed Counts
Position [°2θ] - Copper (Cu)

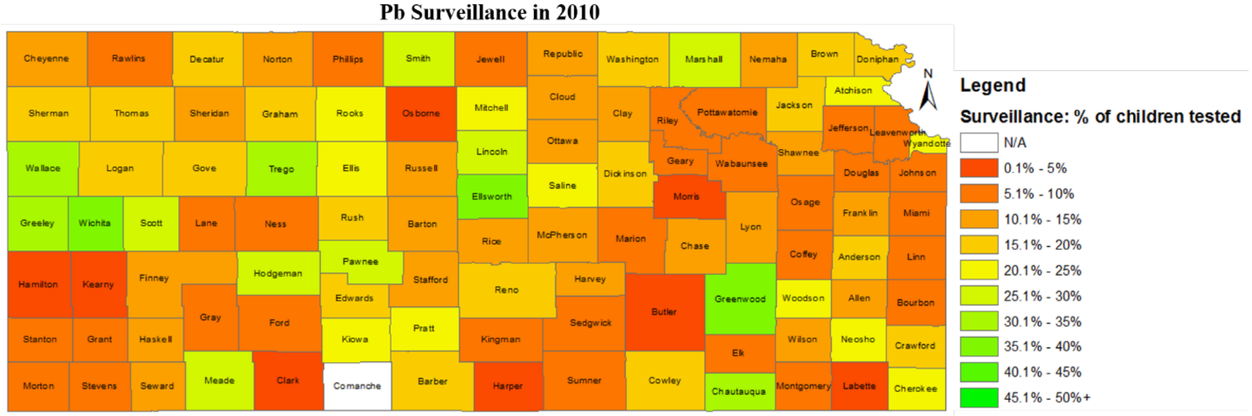

H-14C - Lead Sulfate Peaks
Observed Counts
Position [°2θ] - Copper (Cu)


H-16A - Lead Sulfate Peaks
Observed Counts
Position [°2θ] - Copper (Cu)

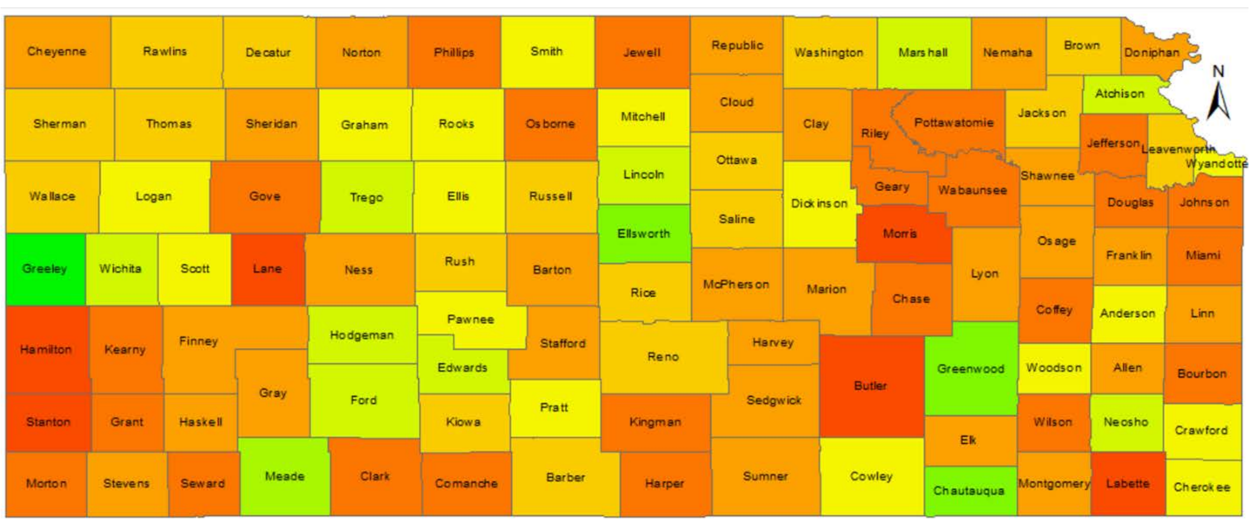
Appendix G - Surveillance Maps

Figure 7-3: Pb Surveillance 2010-2013.

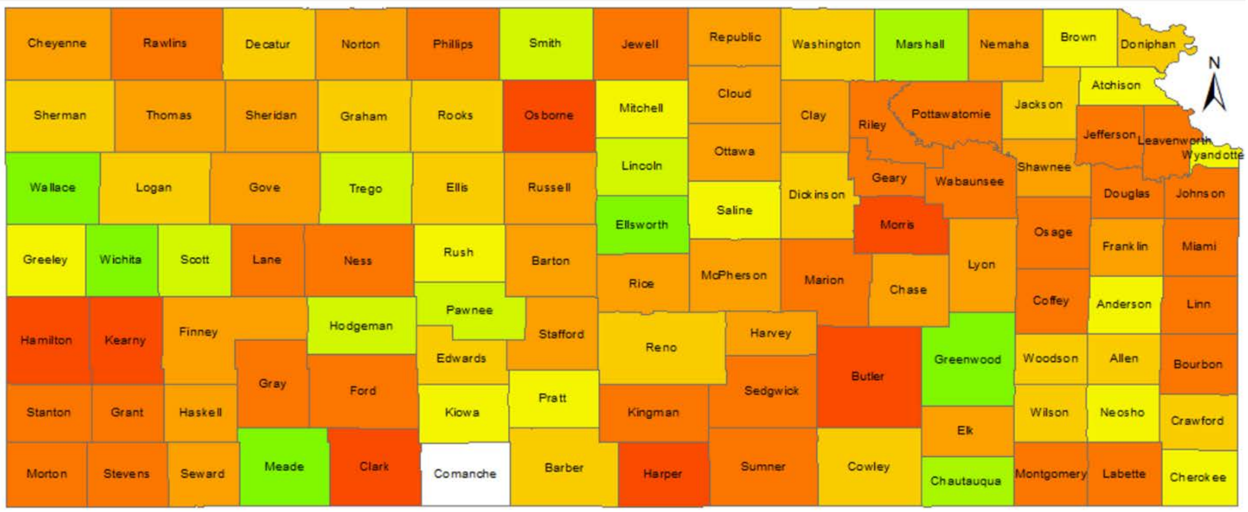
Pb Surveillance in 2010



Pb Surveillance in 2011



Pb Surveillance in 2012



Pb Surveillance in 2013