MEASURING THE EFFECTS OF MINING ON PERU'S PUBLIC HEALTH: IS THE APURIMAC REGION PREPARED TO ASSESS HEAVY METAL EXPOSURE?

by

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EXECUTIVE SUMMARY

Peru's Ministry of Health has approached Duke University because it seeks help with evaluating whether heavy metals exposure (in mining regions) is associated with adverse health outcomes.

To aid in this effort, I have proposed a new framework for health monitoring that incorporates new clinical assessment tools and diagnostic tests to begin evaluating whether heavy metals exposure (in mining regions) is associated with human health outcomes. This framework is proposed as a pilot program to be tested in Apurimac by Peru's Ministry of Health (MOH), following the completion of their current presidential election.

Tools developed will evaluate exposure to five heavy metals: lead, arsenic, cadmium, selenium, and mercury. The information generated is anticipated to provide the MOH the ability to identify exposures to environmental hazards and health risks in Apurimac and the possibility of introducing a national surveillance program that identifies environmental health risk factors in other mining regions of Peru. Addition, we expect improved ability to identify public health needs, evaluate program costs, diagnose and treat patients suffering from heavy metal exposure, and increased transparency and awareness of environmental risk factors.

The first section of this report provides an overview of the economic contributions that mining makes to the Peruvian economy, the environmental hazards that stem from mining metals, the potential health risk due to heavy metal exposure, and the inability of the Peruvian healthcare infrastructure for linking public health to environmental exposure. It also emphasizes the need to adapt new population health management practices to regions with unique needs based on industry presence, i.e. mining, and likely environmental hazards.

The second section provides background and context. It explains how humans can be exposed to heavy metals and what the toxic effects are for each respective exposure pathway and heavy metal. It also explains how copper, gold, and silver mining is a source of exposure to lead, arsenic, cadmium, selenium and mercury. It also reviews historical case studies of heavy metal exposure near mining sites in Peru. This section also provides an overview of the Apurimac Region's formal and informal mining industry, its demographic and social characteristics, its daunting epidemiology, and its inability to meet public health needs with its current healthcare infrastructure.

The third section explains the goals of the pilot program proposed by this paper. It lists explicit objectives for enabling Peru's MOH and Apurimac's health agency the ability to link population health to environmental exposure. Secondary objectives are defined to help evaluate program efficiency, effectiveness, and scalability. The S.M.A.R.T. Goals framework is recommended for

refining pilot program objectives. Several challenges are acknowledged and listed for consideration during goal formulation.

The fourth section is an overview of methods and materials used to illustrate the various aspects involved in implementing the proposed population health surveillance program. It describes four phases for project rollout, a new clinical procedure, a unique patient and health provider survey tool for environmental exposure data collection, laboratory analysis protocols, and data storage and reporting instructions. This section also discusses limitations regarding data collection and analysis specifically related to literacy, language barriers, and biases.

The fifth section of the report describes the anticipated outcomes from the pilot study, referencing the ability to integrate clinical protocols at the National and Regional levels, with newly gained clinical capacity to link public health to environmental risk factors. For example, this section proposes new clinical diagnosis codes, i.e. ICD-10--"Lead", for associating morbidity and mortality with an environmental exposure to a heavy metal. This section also expands on the benefits of meeting the pilot's secondary goals.

The sixth section dives into the uncertainty of success associated with the execution of such a novel approach to integrate both population health management and environmental health. It cautions against implementing the recommendation brought forth in this report without proper examination from the national and regional health agencies and other pertinent stakeholders.

Peru's mining economy is, and will remain, a going concern and threat to human health because it's expected to continue for several years into the future. However, by providing political support for the health surveillance pilot program proposed in this report, regional health agencies should be able to identify environmental health hazards and protect the communities they are responsible for. Eventually, the outcomes from the pilot program should be used to identify how the environments in regions with a large mining footprint are impacting human health. Creating a near real-time population health surveillance platform for Peru's MOH would be an accomplishment not seen even in the most developed economies or health systems. For the sake of Peru's reported 5.86 million people who are said to be dependents of mining sector employees, I strongly encourage Peru's Ministry of Health to carefully consider my recommendations and move forward with them.

This report makes several key points and recommendations:

- Peru is a mining country and a global leader of metal mining and production

- Heavy metals are toxic to humans and exposure could be hazardous to human health
- Peru's MOH does not report morbidity or mortality that is attributed to environmental health issues or exposures, i.e. heavy metals
- Peru's MOH, and the Apurimac Region, does not currently have the infrastructure to link environmental exposures to public health outcomes
- New approaches to outpatient clinical assessment and diagnostics can help tease out symptoms (morbidity) or deaths (mortality) attributed to heavy metal exposure
- Successful implementation of innovative population health surveillance program has the potential to be replicated and scaled in other mining regions of Peru, impacting public health at a national level

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INTRODUCTION

At the end of 2014 Peru was estimated to have a population of roughly 31 million people and a Gross Domestic Product (GDP) of nearly $203 billion USD (WorldBank, 2016). The mining industry in Peru was estimated to generate as much as 14% of the country's GDP and is expected to see annual growth of 6.3% in 2015 and 12.1% in 2016 (Ernest & Young, 2015).

Peru is a global competitor in the metals mining industry. It is a regarded as a top producer not only regionally in South America, but also internationally. Its mining exports totaled $20.4 billion USD (52%) of the county's total exports in 2014 (Oriz Rios, 2014). Peru main exports are to China (28%), Switzerland (13%), Canada (11%), and the United States (6%); it mainly exports copper (42.3%, gold (33%), lead (7.4%), and zinc (7.4%) (Ortiz Rios R. , 2016).

2014 : POSICIÓN DEL PERÚ EN EL RANKING MUNDIAL DE PRODUCCIÓN MINERA
PLACE OF PERU IN THE WORLDWIDE RANKING OF MINING PRODUCTION

PRODUCTO / *PRODUCT*	LATINOAMÉRICA / *LATIN AMERICA*	MUNDO / *WORLD*
Zinc / *Zinc*	1	3
Estaño / *Tin*	1	3
Plomo / *Lead*	1	4
Oro / *Gold*	1	7
Cobre / *Copper*	2	3
Plata / *Silver*	2	3
Molibdeno / *Molybdenum*	2	4
Selenio / *Selenium*	2	9
Cadmio / *Cadmium*	2	8
Roca Fosfórica / *Phosphoric Rock*	2	12

Source: Peru's Ministry of Energy and Mines (Oriz Rios, 2014)

It's reported that Peru's mining sector directly employed 195,631 people in 2014 and indirectly provided opportunities for an estimated 1,748,000 people, but over 5.86 million people are estimated to be dependents of mining sector employees (Oriz Rios, 2014).

Peru's stable economy, sound credit rating from three of the major rating agencies (Standard & Poor's, Fitch, and Moody's), favorable investment policies, and immense untapped mineral wealth makes the country a prime target for foreign investment (Ernest & Young, 2015).

Source: Peru This Week, 2010 (Laguna, 2010)

Peru is expected to receive approximately $64 billion in direct investment for mining construction, exploitation, and exploration over the next 5 years (Oriz Rios, 2014). The principle countries investing in Peru's mining industry over the next five year are China (35%), the United States (16%), and Canada (14%). The majority of the $64 billion is earmarked for copper mining, and 26% overall is expected to be invested in Apurimac (Ortiz Rios R. M., 2015).

Mining Impacts on the Environment

Mining sites of industrial metals are notorious for creating dust, noise, traffic, erosion, changes to the landscape, and displacement of flora and wildlife in the geography they operate in (Arbogast & et al., 2011). According to the US Department of the Interior, US Geological Survey, one of the most prevalent forms of copper mineral extraction is by using an 'open-pit' method (Long & Singer, 2001). Open-pit mining involves excavating the surface of the ground for the purpose of removing rock or minerals from the earth by their extraction from an open pit or borrow (GreatMining, n.d.). Worth noting is that mining in Peru is responsible for a large proportion of their environmental conflicts. In 2011, nearly 75% of the environmental conflicts were related to mining activities (PWC, 2013).

Source: Latin American Bureau, 2012
(Low, Peru: Espinar Conflict Back From The Brink, 2012)

Mining Impacts on Human Health

The byproducts generated from mining copper, gold, silver, and zinc can become hazardous to human health if they become bioaccessible, bioavailable, bioconcentrate, or bioaccumulate. The physical and chemical properties of arsenic, cadmium, lead, selenium, and mercury indicate that environmental exposure will likely originate from air, water, soil, and food (US EPA, Estimaion Progam Interfac (EPI) Suite Physical Chemical Properties, v4.11, 2012). A table describing physical and chemical properties of the five heavy metals can be found in the appendix section of this report under **Appendix A**.

For example, the physical and chemical properties of elemental mercury indicate it has a lower boiling point (356.6° C) than gold (2,807° C) (Bentor, 2016). The drastic difference in boiling point makes separating gold-mercury amalgam very easy and effective. However, as a result of burning the amalgam, mercury vapor is released into the atmosphere where it can persist for up to two years, or deposited into aquatic bodies via wet or dry deposition where it can persist for up to 10 years (EC, 2007). If elemental mercury reaches aquatic bodies of water, it can be transformed into methylmercury by anaerobic bacteria and potentially accumulate in humans due to its movement up the aquatic food chain (USDOE, 2014).

Risk to human health from arsenic, lead, cadmium, selenium, and mercury exist due to the toxic effects of each respective chemical and the high probability of exposure that results from formal and informal mining operations. Health effects from the five heavy metals vary from death due to acute exposure to cough, headaches, and diarrhea due to chronic exposure (Goyer, 2004) / (Gerberding, 2003).

Integrating Environmental Exposure Assessment in the Health System

The potential exposure to byproducts from mining in Peru motivated the Peru MOH to engage Duke University for assistance in developing a National Plan for Heavy Metal Exposure. Presently, Peru's MOH does not systematically capture or report environmental risk factors impacting population health. Regions such as Apurimac, and those with a large mining presence, are in desperate need of tools, programs, and policies that Regional health systems can implement and use to understand how heavy metal exposures are contributing to morbidity and mortality. This project proposes a pilot system to aid in risk characterization of contaminants integrated into ongoing health monitoring. The goal of the system is to help identify risk mitigation solutions to preserve, protect and improve public health.

BACKGROUD

Mining in Peru

Mining production in Peru is expected to increase over the next few years, generating double digit growth figures for the sector. Copper, gold and silver are among the metals that are anticipated to aid Peru in its growth (Oriz Rios, 2014). Peru's place among the top mineral producers in the world is quite impressive considering it's developed only a small fraction of the country's proven mineral wealth. Only 1.36% of the territory is developed for mining exploration and exploitation; this is a small fraction of Peru's mineral reserves considering that 13.6% of the country is subject to mining concessions (Ernest & Young, 2015).

According to Peru's MEM, nearly all of its major metals produced experienced growth in 2015; with some metals having sustained growth figures for a period of a few years. The table below gives an account of how much production has changed since 2006.

Año	Cobre	Oro	Zinc	Plata	Plomo	Hierro	Estaño
	TMF	OzF	TMF	OzF	TMF	TMF	TMF
2006	1,048,472	6,521,008	1,203,364	111,584,354	313,332	4,861,155	38,470
2007	1,190,274	5,473,211	1,444,361	112,574,629	329,165	5,185,254	39,019
2008	1,267,867	5,782,971	1,602,597	118,505,446	345,109	5,243,278	39,037
2009	1,276,249	5,915,567	1,512,931	126,118,017	302,459	4,418,768	37,503
2010	1,247,184	5,275,436	1,470,450	117,043,695	261,990	6,042,644	33,848
2011	1,235,345	5,343,028	1,256,383	109,918,981	230,199	7,010,938	28,882
2012	1,298,761	5,193,782	1,281,282	111,912,160	249,236	6,684,539	26,105
2013	1,375,641	5,023,793	1,351,273	118,130,938	266,472	6,680,659	23,668
2014	1,377,642	4,504,224	1,315,475	121,148,743	277,294	7,192,592	23,105
2015*	**1,700,814**	**4,662,863**	**1,421,513**	**131,885,896**	**315,784**	**7,320,807**	**19,511**

TMF = Fine Metric Ton, OzF = Fine Ounce, Source: Peru's Ministry of Energy and Mines (Ortiz Rios R. M., 2015)

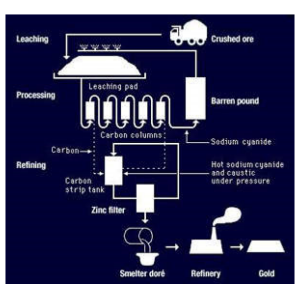
Three metal groups that are of particular relevance to our report are copper, gold, and silver. The mining processes associated with exploration, extraction, and processing have their own unique characteristics and interactions with the environment.

Copper Mining - Copper mining can have negative environmental consequences because of the byproducts associated with the extraction and concentration process. Heavy metals such as arsenic, cadmium, and lead, typically found together at mining sites and can be harmful to human health even in very small amounts (Hesperian, 2014). Selenium is another heavy metal byproduct of copper mining and found in concentrations that range from 10% to 40% (George, 2003).

Copper concentration in Peru involves a process known as Froth Flotation (MINEM, 2016). Froth Flotation involves the use of air, water and chemicals and yields a copper concentration of roughly 30% before it moves on to the next step in its purification process (Calcutt, 2001). The copper extraction and purification process also produces precious metals such as gold, silver, and zinc (Ayres, Ayres, & Rade, 2003); these metals are also known to have their own processes for purification and typically found with arsenic, cadmium, lead, and mercury (Hesperian, 2014).

Gold and Silver Mining – Gold and silver mining in our Region of focus has historically been performed mainly as illegal small-scale, ‘artisanal’, mining. A major problem with illegal gold mining is the lack of environmental safeguards and controls in the extraction and purification processes. Artisanal gold mining in Peru involves the intense use of elemental mercury during the gold extraction (smelting) process (Low, Artisanal and small-scale mining in Peru: a blessing or a curse?, 2012). Smelting, or amalgam burning, in artisanal gold mining is generally done in uncontrolled conditions, and as such is a major contributor to anthropogenic mercury emissions at a regional level; in some cases up to 50% of the mercury found in the atmosphere (de Lacerda, 2003).

Large-scale gold and silver mining has just recently began to take place in Apurimac. Large-scale gold mining involves a process of concentration called leaching. Leaching is done in an open setting and uses chemicals that pass through layered mountains of crushed permeable rock in order to detach the gold from the ore and allow it to flow down to an embankment, where it is then collected for further purification (Estefani, 2013). As with artisanal gold mining, mercury is used in large scale mines to further separate and purify gold.



Source: Artinaid, 2013 (Estefani, 2013)

Another major environmental problem with gold mining is toxic mine drainage of sulfuric acid, arsenic and copper into aquatic systems such as lakes, rivers and streams (Rastogi, 2010).

Heavy Metal Exposure and Toxicity

In order for one of the heavy metals of concern to be a hazard to human health they must meet certain exposure assessment criteria. First, be bioaccessible, which refers to amount of naturally available metal that actually interacts with an organism and is likely accessible for absorption; be bioavailable, refers to the extent that a bioaccessible metal sorbs onto, into, or across living membranes of organisms, measured as a fraction of the total quantity of metal the organism is exposed to during a given period of time and under distinct conditions; bioconcentrate, referring to the net accumulation of metal in an organism derived from direct uptake from water, for example through gills or other external sources; or bioaccumulative, meaning the net accumulation of a metal in a tissue, organ, or organism of interest that stems from all exposure sources, including diet or dermal exposures (Anderson & et al., 2007).

Despite the likelihood of environmental exposure to heavy metals from air, water, soil, sediment, and food sources, the possibility of potential routes of human exposure for the five heavy metals varies depending on environmental conditions. Conditions such as temperature, atmospheric pressure, humidity, precipitation, organic matter content in soil and sediment, pH, wind, atmospheric deposition, other chemicals and reactions, trophic systems and uptake from biota, bioavailability in aquatic systems, and professional occupation can all influence human exposure to heavy metals (Anderson & et al., 2007).

With respect to our five metals of concern, the traditional and most common potential routes of human exposure to arsenic, lead, cadmium, selenium, and mercury is via oral ingestion via food, water used for cooking and drinking, hand-to-mouth contact, inhalation of dust in the atmosphere, gas vapors released during occupational practices, and dermal contact (Goyer, 2004) / (Risher & et al., 2003).

The health hazards of heavy metal exposure observed in clinical studies vary between metals and studies, but indicate adverse health effects if humans are exposed to enough of the chemical (Tchounwou & et al., 2012). Factors such as dose-response relationships, exposure periods, route of exposure, life stage of the organism, the uptake, distribution, storage, metabolism, and elimination process in organism, pharmacokinetics with other chemicals, and the adverse outcome pathways of a chemical in an organism can have tremendous influence on the development and severity of diseases (Anderson & et al., 2007).

A table listing the metal specific health effects by exposure can be found in the Appendix section of this report under **Appendix B**.

THE APURIMAC REGION

Apurimac is one of Peru's twenty-five regions. It encompasses 20,896 km^2 of land mass and is divided into seven provinces and further segmented into eighty-one districts (MINSA, Indicadores Basicos 2014, 2015). As of the end of 2014, the population in Apurimac was approximately 456,700 people, (~1.47% of Peru's population). Approximately 94% of the population is under age 65 (MINSA, Estadistica: Informaction Por Departamento Y Distrito, 2015), and 61% of the population lives in a rural area. Additionally, most of the Region's inhabitants lives in the north-western part of the Region (MINSA, Indicadores Basicos 2014, 2015). Geographically,– Apurimac is located in the Andes Mountains (*Sierra*) with an average elevation of roughly 10,284 feet (ElevationMap, 2016). It is characterized as a cold, rainy region of Peru with an average annual precipitation of 43.9 inches and average annual temperatures of 57.4° F (14.1° C) (INEI, Medio Ambiente, 2015).

Source: AlumbraUnaPhoto, 2016 (AUF, 2016)

People living in Apurimac are poor. 87% of residential dwellings have exterior walls made from adobe, some 72% have dirt floors, 85% have access to a public utility in the home, 87% are connected to electricity, 38% have a sewage utility inside the home while 26% use a latrine, and only 15% utilize gas for cooking inside the home (INEI, Sociales, 2016).

Health statistics from Apurimac indicate high burden. The Region has the 3rd highest mortality rate in the country (6.8 per 1,000 population); it has the 2nd lowest life expectancy (70.2 years); it has the highest rate of extreme poverty (21.3% with another 12.6% living under "regular" poverty conditions); it has the 3rd highest rate of chronic child malnutrition; and an income per capita that is 32.5% below national averages (INEI, Sociales, 2016).

Mining in Apurimac

The Region of Apurimac has not historically been a major contributor to Peru's formal mining economy. According to a December 2015 report from Peru's MEM, Apurimac was on track to close the year out with a 0.4% contribution the country's total copper production and a 1.6% contribution to Peru's total gold output (Ortiz Rios R. M., 2015). All other production of metals in the Region, including zinc, silver, and lead were negligible.

A December 2015 year-end report from Peru's MEM reported that 73,924 fine ounces of gold and 53,074 fine ounces of silver had been produced in Apurimac (Ortiz Rios R. M., 2015). The same report indicated that Apurimac had produced about 1.6% of Peru's gold; a huge leap considering they produced 0% of Peru's gold in the prior year. Silver had yet to reach any meaningful contribution in 2015.

Despite Apurimac's lack of formal mineral contributions, it has had an informal mining sector for some time. Illegal small-scale 'artisanal' gold mining has taken place throughout the region (DIRESA, 2011). Formalizing the illegal gold mining that happens in Apurimac has recently been underway with President Ollanta Humala push to control artisanal mining in the Region (Grabski, 2012)

However, mining in the Region has not come without quarrel and social unrest. The Las Bambas Copper mine, projected to be the 4th largest in the world, has been an ongoing controversy. Protesters have been demanding the mining company employ and train local works, concentrate the copper ore outside of the local town due to environmental concerns, allocate 10% of profits to local public works projects, and fairly compensate families that were relocated to accommodate the construction of the mine (BBC, 2015).

Going forward, mining in Apurimac is expected to contribute a substantial portion of the country's copper production and exportation. Apurimac will be receiving approximately $20 billion USD in mining investments over the next 5-years, with the Las Bambas Mine Company receiving half of the investment (Oriz Rios, 2014). Gold, silver, and molybdenum mining construction and exploration in Apurimac are also receiving meaningful investments; it's only a matter of time until they also begin to make substantial contributions to Peru's mining sector.

Apurimac's Epidemiological Profile

An area such as Apurimac, with is high rural population, cold and rainy climate, poor economy, and humbling social characteristics is slated to have its fair share of health challenges. A review of the Region's published public health reports did not mention, cite, or indicate that any morbidity or mortality in the region is attributed to environmental hazards associated with mining or heavy metals. National and Regional reports fail to link population health outcomes with environmental exposures and risk factors that are specific to heavy metals.

Illnesses that may be caused by heavy metal exposure are not teased out of the traditional morbidity or mortality categories. The current epidemiological reports communicate what and how many cases of a reported illness or death the Region experienced in a defined period of time, but they do not report why individuals in Apurimac are suffering or dying.

Source: DIRESA Apurimac, 2015 (DIRESA, 2011) Source: Hospital Abancay, 2014 (Apac Robles & et al., 2014)

With respect to mortality in the Region, Influenza and Pneumonia are the principle causes of death; in 2013 Apurimac attributed 16.3% of deaths to Influenza and Pneumonia compared to 14.0% for the rest of Peru (INEI, Indicadores de Genero, 2015) / (MINSA, Informacion Por Departamento Y Distrito, 2016). Apurimac's weekly epidemiological publications report the number of cases of such illnesses as Malaria, Leishmaniosis, Dengue, HIV, diabetes, types cancer, pneumonias, respiratory ailments, and pesticide poisonings among others.

Cause of Death	Apurimac	Peru
Influenza & Pneumonia	16.3%	14.0%
Tumors / Neoplasia	12.9%	18.6%
Accidents (non-transport)	10.3%	7.7%
Other Bacterial Illnesses	6.6%	7.2%
Ischemic Heart Disease	2.8%	5.2%
Cerebrovascular Illnesses	4.0%	4.8%
Other forms of Heart Illnesses	4.7%	3.9%
Respiratory Illnesses	2.0%	3.8%
Illnesses of the Liver	5.2%	3.5%
Transportation Accidents	3.9%	2.8%
Renal Failure	3.8%	3.5%
Hypertensive Illnesses	3.5%	3.1%

Source: MINSA (MINSA, Informacion Por Departamento Y Distrito, 2016) / (INEI, Indicadores de Genero, 2015)

Morbidity in the Region is captured and reported both by acute settings such as hospitals as well as outpatient clinics and health posts.

Once again the categories that are described by the reports fail to link the illnesses to a source. For example, Influenza and Pneumonia is the leading cause of hospital based morbidity for men in Apurimac, but there is no indication of what was the cause or contributor of influenza, i.e. communicable disease, weaken immune system or anemia, environmental exposure to chemicals, metals, weather, or indoor air pollution from cook stoves, etc.…

Morbidity - Hospital Based	Apurimac (Men) 2014	Apurimac (Women) 2014
Pregnancy, Maternal, Childbirth, and Fetal Complications	3.7%	13.6%
Influenza & Pneumonia	9.2%	3.0%
Pregnancy ended in Abortion	-	6.5%
Gallbladder & Pancreas Complications	2.2%	3.0%
Urinary System Illnesses	1.3%	2.8%
Complications of the Appendix	5.2%	2.2%
Infections of the Skin	3.4%	0.9%
Intestinal Illnesses	3.3%	1.9%

Morbidity – Non-Hospital Based	Apurimac (Men) 2014	Apurimac (Women) 2014
Oral Cavity & Salivary Glands Illnesses	24.4%	23.3%
Respiratory System Illnesses	22.9%	19.3%
Malnutrition	5.2%	3.4%
Esophagus, Stomach & Duodenum Illnesses	2.2%	3.0%
Dorsopathies	3.8%	3.9%
Intestinal Illnesses	3.7%	2.7%
Anemia	3.8%	2.5%

Source: MINSA, 2015 (MINSA, Estadistica: Informaction Por Departamento Y Distrito, 2015)

Evidence to Heavy Metals in Children and Adults - To emphasize the importance of linking environmental risk factors to population health outcomes, a literature review was conducted to search for previous studies on mining in Apurimac, signs of exposures to heavy metals, and environmental risk factors cited by the Region's health system as contributors to morbidity or mortality. The search yielded only two prior reports that were specific to the Apurimac Region.

The first report cited many studies that found high levels of lead in children and adults in several "hotspot" areas of Peru, but only one study cited in the report identified subjects in three different areas of Apurimac that demonstrated elevated levels of lead in the blood (Larson, 2014). The study estimated a "low, mid, and high" base case for the health effects associated with the increased levels of blood lead. The result was varying degrees of impaired intelligence for children measured in terms of IQ; ranging from a loss of 11-26 points of IQ among children <5 in Apurimac. As for adults health effects, the same report estimated between 11 and 23 cardiovascular deaths stemming from lead exposure.

The second report reviewed referenced elevated blood lead, urine cadmium, arsenic and mercury levels in two districts near the Las Bambas Copper mining site before the exploitation phase began in 2006 (Astete, Gastanaga, & et al., 2010). Also highlighted in the second study were causes that drove residents from the two districts to seek medical attention from the local health outpost. Among the reasons for visiting a health provider were: family violence, respiratory problems, diarrhea, anxiety, depression, alcohol abuse, personality disorder, drug abuse, psychoses, teen pregnancy, accidents due to alcohol abuse, diarrhea in children, occupational injuries from agricultural workers, childhood malnutrition, and gastrointestinal problems.

Of note is that none of the two reports that I came across made a direct association between the type of environmental exposure people had and the ultimate health effect, i.e. symptoms, diagnosis, morbidity, mortality. Providing further evidence for the need to innovate and improve on current health system tools and services.

The Significance of Our Health Infrastructure Assessment – Based on the all the information we've gathered from the various sources that are included in this report, we can begin to connect the dots. Peru mining industry will only get bigger, so human health concerns will persists. Under Peru's current health system, surveillance and evaluation of the impacts of mining on public health is not possible. Therefore, Peru lacks the ability to mitigate potential environmental risk factors affecting human health.

Specifically, Apurimac is facing challenges tied to political and economic conflicts, geographical and social obstacles, environmental exposures from legal and illegal mining, and an underequipped population health management and delivery model.

The MOH and Apurimac's health system must adopt new healthcare frameworks to accommodate Region specific risk factors, such as those stemming from gold and copper mining. Linking population health outcomes to risk factors that are attributed to mining activities is currently a major challenge, but one that must be tackled considering not only the historical existence of mining in the Region, but also the future presence of large-scale mining in Apurimac.

Peru's MOH and Apurimac's population health challenges offer my Master's Project a unique opportunity to innovate on current health delivery models and help assess, report, and mitigate risk factors from toxic metal exposure in communities impacted by the mining industry.

OBJECTIVES

The goal of the Master's Project, and the recommendations contained within it, is to provide a set of clinical frameworks and diagnostic procedures that can be used to link public health to environmental risk factors for regions with a presence of mining activity. Additional project scoping for unforeseen circumstances, 'on the ground' assessments of the Region and its healthcare infrastructure, and additional stakeholder engagement is also recommended to ensure the highest probability of success for the pilot program we are proposing in this Master's Project.

Objectives:

Epidemiological Surveillance – In order to know if the mining industry is in fact posing serious health risk to the general population and residents of Apurimac, we must be able to identify, quantify, rank, and report how much each respective heavy metal is impacting morbidity and mortality in the Region.

- **Identify** – Our recommendations should enable a quick, clinically relevant, and practical way for diagnosing patients who visit the health system with illnesses that may be attributed to heavy metal toxicity from one of the five metals of concern: arsenic, cadmium, lead, selenium, and mercury.

- **Quantify** – As new clinical and non-clinical patient data is aggregated by Apurimac's health system, statistical analysis should begin to provide insight into the likely sources that are responsible for driving visits to the health system. Identification of likely environmental risk factors, if any, should begin to unfold; allowing the MOH to track and understand the impact of heavy metals on public health, but more specifically to causes of morbidity and mortality in the Region.

- **Rank** – Reducing the number of adverse health outcomes that stem from environmental risk factors should be facilitated by the identification of specific metals found in patients visiting the health system, the amount of cases and their associated number of morbidity and mortality categories they impact in terms of ICD-9/10 classifications, and the geographic locations where patients are coming from.

- **Report** – Incorporating environmental indicators into the existing published regional epidemiological reports raises awareness as to the number of cases that are being seen by healthcare providers. Associating the morbidity or mortality with an environmental exposure in the publication will help the various stokeholds understand the impact of environmental risk factors.

  For example, if a patient that was diagnosed with 'Oral Cavity & Salivary Glands Illnesses' had the following: blood and urine labs drawn because his questionnaire indicated possible environmental exposures to heavy metals, plus when assessed by a healthcare provider his symptoms appeared to resemble Burton's line (deposition of lead sulfide at the interface of the teeth and gums (Nogue & Culla, 2006)), and the resulting labs demonstrated elevated blood lead levels. Then his diagnosis should say 'Oral Cavity & Salivary Glands Illnesses-Lead' and not just 'Oral Cavity & Salivary Glands Illnesses'.

In addition to these surveillance activities, other benefits that would be obtained from deploying the recommendations contained within this Master's Project include:

- Establish new metrics for measuring the need for environmental health related services based on utilization and case-mix-index

- Establishing a baseline for fixed operating costs, variable expenses driven by patient volumes and utilization, and one-time capital equipment requirements or costs

- Understanding the health services requirements of specific districts and provinces in Apurimac in order to appropriate resources based on public health needs

- Establish and refine a framework for linking public health to environmental risk factors that can be employed in other mining regions of Peru

SMART Goals Framework

Each section in both the *Epidemiological Goals* and *Additional Program Objectives* is subject to the SMART Goals framework. The adoption of SMART (Specific, Measurable, Attainable, Relevant, Time-bound) Goals is a helpful framework for this project to be more inclusive of principle stakeholders affected by the SMART Goals process and outcomes. Stakeholders include healthcare workers, regulatory agencies, public administrators, private sector employers, patients, equipment suppliers, vendors, or financiers, to name a few. Components of SMART are (MIT, n.d.):

- ✓ <u>Specific</u> – what is the goal of each initiative (who, what, where, why)
- ✓ <u>Measurable</u> – metrics that will be used to evaluate progress or completion of the goals
- ✓ <u>Attainable</u> – are the goals realistic given the resources and constraints
- ✓ <u>Relevant</u> – are the individual goals aligned with the overall objective of the program
- ✓ <u>Time-bound</u> – realistic timelines and milestones for progress given the complexity of individual and collective initiatives

SMART Goals should be drafted and revised by the team in charge of implementing the recommendations of this Master's Project.

SMART Goals Framework to achieve an Epidemiological Goal: An Example

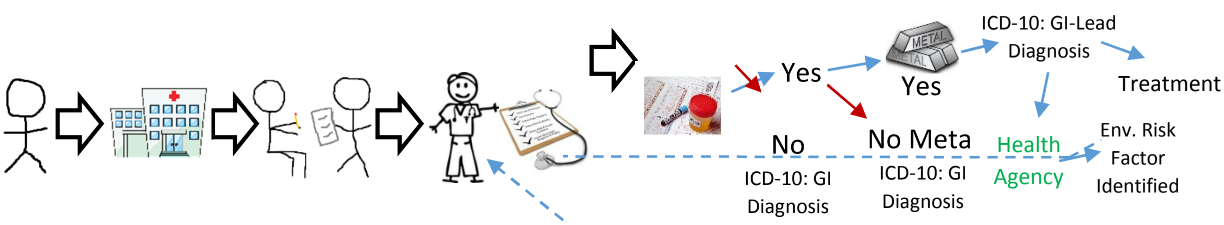
- ❖ **SPECIFIC**: The goal is identifying patients that visit the health system and appear to meet criteria of heavy metal toxicity (arsenic, cadmium, lead, selenium or mercury) within the first few minutes of a patient encounter or triage.

- ❖ **MEASURABEL**: Screening patients into two category that indicate either 'likely environmental exposure' or 'not likely suffering from illness related to heavy metal toxicity'.
- ❖ **ATTAINABLE**: Upon registration at the health system or clinic, patients will complete new intake questionnaires that help identify potential environmental risk factors (examples of the forms in the METHODS AND MATERIALS section of this report). Health

providers will also be given clinically credible questionnaires and guidelines to help determine if patient symptoms are likely associated with environmental exposure to the five toxic metals of concern (examples of the forms in the METHODS AND MATERIALS section of this report).

❖ **RELEVANT**: The new patient-focused environmental questionnaire and the provider-focused Heavy Metal-Focused Review of Systems and Related Diagnosis form will assist in determining if additional clinical test or diagnostic test are merited to verify metal exposure, type of metal exposure, severity of toxicity, and the potential for further health effects.

❖ **TIME-BOUND**: Diagnosis of patient illness (morbidity) or mortality should be completed within the initial patient encounter, unless the health facility is not equipped to run sophisticated diagnostic tests or diagnose complex or acute case. Attributing a patient's illness to an environmental cause should be achievable during the initial patient encounter based on both the patient-identified risk factors and the provider assessment. However, attributing a patient's illness to an environmental exposure may be delayed depending on a mired of factors that may include: clinical resources available for diagnostics test, turn-around time of diagnostics test, or available supplies to name a few. Despite any unforeseen barriers to diagnosing a patient and attributing morbidity or mortality to environmental exposure, the expected time involved to meet the specific goal of should not take more than 5 to 10 minutes per initial patient encounter. A patient-flow chart may be helpful to visually illustrate a time-bound process from start to finish.



❖ **STAKEHOLDERS**: Clinical healthcare works such as laboratory techs, nurses, doctors, quality control staff, social workers, patient registration staff, data analyst, medical supply vendors, patients, patient family members, Regional health agency administrators (DIRESA Apurimac), and any other person or function that can impact the outcome of the specific goal

Potential Challenges Facing Our Objectives - Potential obstacles that may arise in pursuit of executing the recommendations contained in this Master's Project include but are not limited to:

- Limited financial resources for personnel, equipment, or supplies
- Lack of skilled personnel with program / project management
- Limited or absent clinical capacity to perform health assessment or diagnostic tests
- Political pressure, corruption, social conflicts, lobby groups, trade / union pressures
- Siloed agencies, lack of cooperation, collaboration, or agency accountability
- Cultural resistance from healthcare works, administrators, suppliers, or patients
- Resistance to new workflow processes and framework integration
- Technology limitations, data capture and processing, and scalability limitations
- Regulatory hurdles, requirements, and timelines
- Resource appropriating funneled to more emergent initiatives
- Size of potentially impacted population not large enough (cost > benefits)
- Health literacy and literacy of patients
- Availability of language translators
- Data collected is limited by a health providers discretion to diagnose / screen for metals

METHODS AND MATERIALS

To assess if and how much environmental contributors are influencing human health we must first have information to analyze, interpret, and draw key insights. The lack of current data linking environmental exposure to health outcomes has prompted me to create new patient-focused forms that seek to understand the environmental conditions patient's experience, as well as health provider-focused guidelines that assist in screening patients with symptoms possibly related to heavy metal toxicity.

The intended results should produce the necessary data required to conduct statistical analysis and identify Region specific environmental risk factors that are detrimental to human health.

I. Project Rollout

Phase One: Partnerships between Peru's MOH, Apruimac's Direccion Regional De Salud, Hospital Regional Guillermo Diaz De La Vega-Abancay, and the urgent care, outpatient and health outpost clinic system.

Leadership from Hospital Regional Guillermo Diaz De La Vega-Abancay the urgent care, outpatient and health outpost clinic system, Direccion Regional De Salud-Apruimac, and Peru's MOH will meet to work together to refine project goals, plan out the incorperation of the heavy metal screening and survalience program. At the conclusion of thier meetings, they will have agreed on the most optimal meathod for the health system to accomplish the phases outlined below, including but not limited to; stakeholder education on heavy metals and project role out, optimal incorperation of screening material and data gathering into staff worksflow, measurment and feedback regarding exucution of project, and feedback regarding data gathered from poject.

Phase Two: Stakeholder Education of the Hospital Regional Guillermo Diaz De La Vega-Abancay and the urgent care, outpatient and health outpost clinic system

Stakeholders; clerks, health educators, nursing assistance, nurses, nurse practitioners, physician assistants, and doctors will attend a two day workshop sponsored and led by Minesterio De Salud-Centro Nacional De Salud Ocupacional Y Protection Del Ambiente Para La Salud (Censopas) focused on heavy metals.

Day one: Dedicated to providing education regarding natural environmental sources, occupational sources, risk factors for exposures, symptoms and physical exam findings related to acute and chronic toxicity of heavy metals, guidelines for how to screen and diagnose heavy metal poisoning, and appropriate blood and urine sample collection for screening and diagnosis. The lectures will be led by a multidisciplinary group of nurses, physician, toxicologist, and public health professional that have advanced clinical experience and knowledge on heavy metals.

Day two: The second day will have three objectives:

1) Review materials and concepts from the first day with a built time blocks for questions and answers.

2) Introduction of our surveillance and screening project that will be incorporated into the urgent care clinics, primary care clinics and health outposts. The stakeholders will be divided by caregiver role, where each manager will inform the employees of their new particular workflow and the methods for new data collected.

3) Feedback will be gathered from the stakeholders regarding usefulness of heavy metal education and feedback eliciting ideas for incorporating the screening and surveillance tools into the workflow (see **Appendix D**: Form A and Form B)

Phase Three: Workflow feedback analysis and incorporation into a new workflow redesign.

Feedback will be summarized and presented to project leadership, including the Chief Medical Officer (CMO) and outpatient leadership. The clinic leadership team will meet and incorporate the feedback from employees into the previously designed workflow. Once the leadership agrees on a final optimal workflow, each manager will hold their own meetings with their team to re-educate their staff on the redesigned workflow that incorporates their feedback. This will help to encourage stakeholder participation and enthusiasm in the project. The turnaround time between Phase Two and Phase Three should be no more than two months.

Phase Four: Patients and community member awareness and education

Hospital Regional Guillermo Diaz De La Vega-Abancay and its the urgent care, outpatient and health outpost clinics will hold weekly weekend workshops for one month targeting community members. The MOH-Censopas will provide the materials for the workshops. The workshops will emphasize environmental and occupational sources of heavy metals, risk factors for exposures to heavy metals, and common symptoms related to heavy metal exposures. The workshops will also be used to announce the heavy metal screening and survalience program and changes in intake they should expect when in contact with the healthcare system at any one of the urgent care clinics, outpatient and health outpost clinic system with the Hospital Regional Guillermo Diaz De La Vega-Abancay.

II. Shared Costs for Data Collection

A. Data collection

Urgent Care clinics, Primary Care Outpatient clinics and Health Outpost affiliated with the Hospital Regional Guillermo Diaz De La Vega-Abancay will receive support from the Peru's MOH for laboratory screening tests for six months as a pilot to estimate long term costs of project.

The support from the MOH will include:

- Clinical supplies: gloves, blood viles, syringes, urine speciment containers, hazardous waste disposal containers.
- Laboratory support: Reimburstment of shipping and laboratory costs for associated only with arsenic, lead, mercury, cadmium, selenium blood and urine tests.
- Epidemiologic analysis: The MOH will analyse the data gethered and send reports to the clinic systems and Apurimac's Direccion Regional De Salud agency.

Support will exclude financial support for staff/employee salaries, costs associated with the storing of new Hospital Regional Guillermo Diaz De La Vega-Abancay, costs of disposal of additional waste generated from screening.

The intent of the project is not to add additional financial and resource strain on the health system. However, a shared partnership of financial costs to both the local health system and federal government is a way of ensuring equal investment in population health and minimize resource abuse from both the local system and federal government. The six month pilot will be used to generate estimates of the financial and human resources needed to adopt the heavy metal screening and diagnostic effort on a larger scale.

B. Data collection

A) <u>At every patient encounter</u>, a medical attendent who's role it is to collect pertinent medical information will also incorperate the attached heavy metal screening and survelinece forms (see **Appendix D**: Form A and Form B). Each form will have unique patient indetifiers: Medical Record Number, First and Last name, Date of Birth, Sex, District and Provence of residence. Form A will be filled out by the medical attendent as part of their initial patient assessment. Form A and uncompleted forms B will then be passed on to the provider: physicain, nurse practitioner, physicain assistant.

The new patient questionnaire (Form A) is aimed at identifying characteristics that could possibly be contributing to symptoms associated with heavy metal toxicity will help to pre-screen patients, and provide additional information to healthcare providers for improved diagnosis. The newly generated data from the patient questionnaire will be helpful as it is intended to be paired with the final diagnosis and help reveal whether an environmental exposure is linked to the assigned diagnosis. Each patient encounter should require the *Patient-Focused Environmental Exposure Questionnaire* (Form A) be completed and kept with the patient's record.

Patient-focused forms will capture environmental exposure to heavy metals from three main exposure routes: inhalation, dermal, and oral ingestion. Categories that are represented in these patient intake questions include air quality, dietary sources, water sources and uses, occupational functions and hazards, living conditions, social behaviors, and geographical characteristics. Supplemental materials are provided in **Appendix E** to help guide the medical attendant and patient with completing Form A.

B) <u>The provider will then review the heavy metal screening questionaire (Form A) and will then fill out the provider focused resource questionaire (Form B) during the medical encounter.</u> If the providers decides to screen or diagnose a heavy metal intoxication, they will then check the appropriate laboratory studies associated with the visit and send it off to a laboratory that can at minimum do items listed in part C below (can be an existing laboratory that currenly services Apruimac or another).

Some laboratory or diagnostic test that are appropriate for determining heavy metal toxicity or exposure include blood test, urine tests, hair test, finger nail clippings test (US EPA, Framework for Metals Risk Assessment, 2007).

To complement the Provider-focused training in environmental exposure and toxicology, I've created a Provider-Focused *HEAVY METAL-FOCUSED Review of Systems and Related Diagnosis* tool (Form B) that should help to identify common and unique symptoms of heavy metal toxicity. See **Appendix D**. Supplemental materials meant are provided in **Appendix E** to help guide the health provider with completing Form A. Additionally, a list of health effects specific to each heavy metal of concern (arsenic, cadmium, lead, selenium, and mercury) is located in the **Appendix A**, and may be used as supplemental materials.

C) The laboratory will:

1) Record patient demographics, and information from Form A and Form B
2) Process the laboratory test ordered by the physician
3) Record the laboratory results associated with that encounter
4) Make a copy of Forms A and Form B and send the forms back to the provider through their standard form of data sharing
5) The laboratory will send the clinics and providers monthly updates of evolving incidence rates of heavy metal exposure and intoxication as confirmed by laboraty data sorted by: region/county, occupation, age, gender. The analysis should include the top three demographic associations, environmental expsores as seen in form A, and illnessness/morbidity seen in Form B.

Each health system is resposibile for the storing of their own data and reports sent from the laboratory and MOH.

III. Limitations to Data Collection

Literacy:

Their will be inharent limitations to completing the forms based in the health literacy and literacy of the patient. Often times, patients from poor and rural communities may not be able to answer some of the basic demographic questions regarding spelling of name, date of birth or age. Furthermore, the patients ability to express their clinical symptoms in a way that link them to known medical terminology my skew the translation of what the patient expresses and what is interpreted/recorded by assitant and providers. This will ultimetly lead to holes in the data that may lead to a patient being counted more then once, and may over or under estimate the true number of individuals who screen positive or negative for heavy metal intoxciation.

Language Barriers:

Language traslation from English to the native laguages of many indiginous communities may not be exact. Their may not be exact tranlations for symptoms such as, numbness or paralysis. Furthermore, their may be limitation of providers and healthcare workers who can communicate with their patients in their native languages. This will impact the completenss of the form.

Bias:

Selection bias: Patient who are able to reach a medical outpost or travel to clinics will limit the number of potential patients who could be screened. Patients who can be seen in clinics may be limited to patients who: can take time away from work, have transportation, who are physical able to travel, and patients who are without severe forms of dementia and can answer the questions appropriately.

Additionally, acute and chronic heavy metal poisoning often have symptoms with varying degrees of overlap with one another. Symptoms of heavy metal poisonings also overlap with many autoimmune diseases, inflammatory conditions, sequelae of cancers and infections illnesses. Despite the overlap in symptoms, there are some very unique and rare physical exam findings and symptoms of acute and or chronic heavy metal poisoning that should prompt a provider to send laboratory confirmation for particular heavy metal agents. However, selection of which patients get screened for heavy metal exposure via laboratory test is up to the discretion of the health provider.

Sampling Bias: The awareness campaign and information regarding the exposure risk factors and signs and symptoms may prompt a those who were present for the workshops to seek medical attention and use key verbage that may prompt a provider to send out laboratory confirmation.

Resource Limitations:

Urgent care clinics, primary care clinics and clinic outpost may be limited in times, staff, interpreters, supplies and time to administer the screening tool (forms).

EXPECTED RESULTS

A) Meeting The Pilot Program's Primary Objectives

The goal of the Master's Project is to provide a set of clinical frameworks that can be integrated into Peru Ministry of Health's outpatient clinical protocols and delivery system to link public health to environmental risk factors for regions with a presence of mining activity.

The anticipated results of successfully implanting the new health assessment tools should, in a short period of time, begin to produce new health information and records that could be aggregated, reviewed, analyzed, and interpreted for effective population heath management.

The new datasets of patient information, which would include environmental exposures and potential risk factors (described by Form A and Form B), could be used to link environmental hazards with public health outcomes, i.e. ICD-10 codes and categories. Thereby allowing National or Regional health agencies to identify, quantify, and rank not only environmental risk factors and the illnesses they produce (morbidity and mortality), but also enable key insights as to potential risk mitigation strategies that could help drive down the incidence of adverse health outcomes that stem from environmental exposures to heavy metals.

Distinct ICD-10 codes should be used, added or created to account for environmental induced illness. For example, ICD-10: ‘Oral Cavity & Salivary Glands Illnesses-Lead’ and not just ‘Oral Cavity & Salivary Glands Illnesses’.

B) Meeting The Pilot Programs Other Goals

1.) Surveillance at Scale

National or Regional Surveillance Programs or health policies that require environmental assessments at every healthcare access point can be created to scale monitoring efforts and reduce environmental or occupational exposure to toxic byproducts for one of Peru’s largest economic industries. By using the Apurimac pilot as a testing ground for how effective and resource intense an ongoing surveillance program can be, stewards of Peru’s public health can estimate and budget how much similar programs would cost if implemented in other mining regions of Peru.

2.) Resources for Areas of High Need

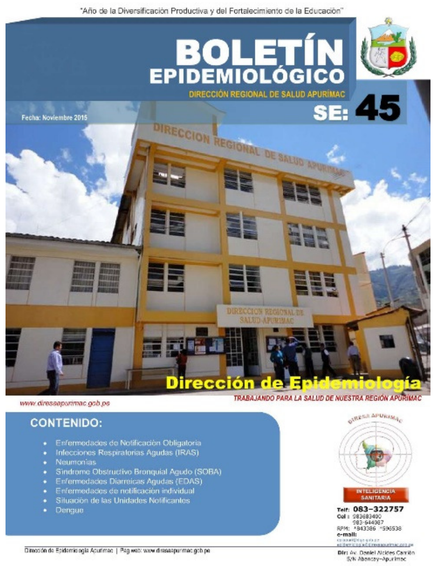
By identifying and publishing what regions, provinces, and districts and which heavy metals are driving the preponderance of illness, Peru’s MOH can begin to appropriate resources to areas of high need and begin to formulate Region specific risk-reduction strategies. Furthermore, by identifying what areas are driving the most utilization of health services as a result of heavy metal exposure, local or regional governments can petition to have private industry pay for health services or illness induced disabilities. Taxes can be levied and collected to help pay for ongoing health surveillance and treatments.

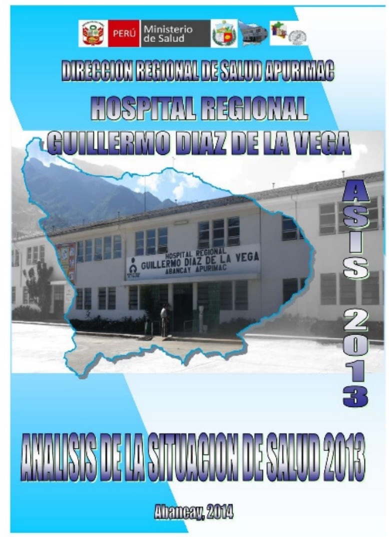
3.) Improved Patient Care

A key outcome not yet discussed is the ability to more accurately diagnose what illness a patient may be suffering from, potentially attribute that to an environmental toxin, and recommend a course of treatment that may be more effective in improving a patient’s condition that if the environmental toxic was not identified.

4.) Transparency and Awareness

Incorporating the new health data into the existing epidemiological reports (i.e. *Boletin Epidemiologico* or *Analysis De La Situacion De Salud 20xx*) that are published weekly, monthly, and even annual can increase awareness, promote better health behaviors, and increase accountability of potentially responsible contributors of environmental pollutants. Example of current reports where the new information can be published are shown below.





Source: DIRESA Apurimac, 2015 (DIRESA, 2011)   Source: Hospital Abancay, 2014 (Apac Robles & et al., 2014)

Adding a classification that indicates environmental exposure will help various stakeholders understand the impact the heavy metals are having on population health (morbidity and mortality).

For example, if a patient that was diagnosed with 'Oral Cavity & Salivary Glands Illnesses' had the following: blood and urine labs drawn because his questionnaire indicated possible environmental exposures to heavy metals, plus when assessed by a healthcare provider his symptoms appeared to resemble Burton's line (deposition of lead sulfide at the interface of the teeth and gums (Nogue & Culla, 2006)), and the resulting labs demonstrated elevated blood lead levels. Then his diagnosis should say 'Oral Cavity & Salivary Glands Illnesses-Lead' and not just 'Oral Cavity & Salivary Glands Illnesses'.

DISCUSSION

Through the proposed pilot program referenced in this report, we are attempting to innovate in the areas of epidemiology and environmental health risk assessment. Our Master's Project's attempt to link environmental exposures to public health outcomes by integrating with the national and regional healthcare delivery system, is a novel approach to public and environmental health. An online search and review of healthcare delivery systems, both national and international, did not yield comparable public health surveillance programs that tie or attempt to tie environmental exposures from heavy metals to morbidity or mortality.

Without hindsight we cannot discuss the effectiveness or significance of the recommendations contained in this Master's Project. However, the *Expected Results* are powerful in the sense that if we do meet our *Objectives*, then we could potentially be impacting the way public health is carried out in a country with nearly 31 million inhabitants and in a country where 5.86 million people are dependents of the mining sector (Oriz Rios, 2014).

In an idea situation all of the goals outlined in the *Objectives* section above would be met in the most efficacious manner, with the least amount of resources consumed, in the shortest amount of time possible, and delivery the biggest positive impact possible to public health. Nevertheless, without knowing what challenges may be faced by our program's recommendations or the implementation process, the expected outcomes listed below are reasonable expectations under manageable conditions.

Before this Master's Project is actually employed by Peru's MOH, it should be scrutinized and analyzed for sensibility, practicality, and implementability. It should be reviewed by a committee of clinical and non-clinical personnel, health agency staff and administrators, environmental agency personnel, program managers, Regional elected officials, residents of Apurimac, and any other relevant stakeholder, person, program or agency affected by my proposal.

CONCLUSION

As I move to conclude this Master's Project, it is without hesitation that I continue to believe that individuals and communities that live in regions of the world where, as a result of industrial practice or economic pursuit, are exposed to potentially harmful environmental exposures, should be protected by governmental agencies and appointed stewards of public and environmental health.

The reason for my pursuit of this Master's Project is to provide the Ministry of Health of Peru, and the Regional health agencies of Apurimac, the clinical frameworks and tools that should enable the healthcare delivery system to innovate how it assesses illness and provides care. The ability to link environmental exposure, specifically from heavy metals, to public health outcomes, specifically morbidity and mortality, would be an unprecedented innovation not only in public health but also in areas of environmental health and risk assessment.

By understanding that Peru's unwavering commitment to domestic exploration, exploitation, production, and exportation of metals, we can comprehend that the need to understand, manage, and mitigate potential environmental hazards is a critically important task. One that requires political will, innovative, and tailored healthcare solution that center around key environmental risk factors and their impact on public health. One that creates collaboration and cooperation between governmental agencies, private industry, and the general public.

If we are successful in creating and implementing a healthcare delivery based surveillance program, then we may accomplish something that not even the most developed economies, or the most advanced public health agencies have. A near real-time data collection, health monitoring, and risk mitigation platform that truly can save lives and disability-adjusted life years.

I strongly encourage Peru's Ministry of Health, the Region of Apurimac, and the appointed health agencies who are entrusted and responsible for ensuring the safety and well-being, not only of the 15,000 people that are reported to work in Apurimac's mining industry, but also the 457,000 people who live in the Region, to carefully consider my recommendations and move forward with them.

I look forward to seeing my recommendations implemented in some form and welcome any invitation to help Peru's Ministry of Health in any way that I can as a Duke trained Leader of Consequence.

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BIBLIOGRAPHY

References

Anderson, K., & et al. (2007). *Framework for Metals Risk Assessment.* Washington, DC: US Environmental Protection Agency: Office of the Science Advisor. Retrieved from https://www.epa.gov/risk/framework-metals-risk-assessment

Apac Robles, M., & et al. (2014). *Hospital Regional Guillermo Diaz De La Vega-Abancay: Analisis De La Situacion De Salud 2013.* Abancay: Ministerio de Salud: Direccion Regional De Salud Apurimac. Retrieved from http://hospitalabancaygdv.gob.pe/portal/index.php/estadisticas/publicaciones

Arbogast, B. F., & et al. (2011). *Development of Industrial Minerals in Colorado.* US Department of the Interior, USGS. Reston, Virginia: USGS. Retrieved from http://pubs.usgs.gov/circ/1368/C1368.pdf

Astete, J., Gastanaga, M., & et al. (2010). Comunicable Diseases, Mental Health and Exposure to Environmental Pollutants in Population Living Near Las Bambas Mining Project Before Exploitation Phase, Peru 2006. *Revista Peruana de Medicina Experimental y Salud Publica, 24*(4), 512-519.

AUF. (2016). *Occaralla Annex*. Retrieved from Alumbra Un Futuro: http://www.alumbraunfuturo.es/index.en.html

Ayres, R. U., Ayres, L. W., & Rade, I. (2003). *The Life Cycle of Copper, Its Co-Products and Byproducts.* Springer Science Business Media. doi:10.1007/978-94-017-3379-3

BBC. (2015, September 29). *Peru ani-mining protest sees deadly clashes*. Retrieved from BBC News: http://www.bbc.com/news/world-latin-america-34389803

Bentor, Y. (2016, April 27). *Periodic Table: Gold*. Retrieved from Chemical Elements: http://www.chemicalelements.com/elements/au.html

Calcutt, V. (2001, August). *Introduction to Copper: Mining & Extraction*. Retrieved from Copper Development Associates Inc.: http://www.copper.org/publications/newsletters/innovations/2001/08/intro_mae.html

CDC. (2013, September 30). *Lead*. Retrieved from Center for Disease Control and Prevention: http://www.cdc.gov/niosh/topics/lead/health.html

CDC. (2014, March 26). *Toxic Substances Portal-Selenium*. Retrieved from Agency for Toxic Substances & Disease Registry: http://www.atsdr.cdc.gov/toxfaqs/TF.asp?id=152&tid=28

CDC. (2015, March 12). *Toxic Subsances Portal - Arsenic*. (C. f. Sciences, Producer) Retrieved from Agency for Toxic Substances & Disease Registry: http://www.atsdr.cdc.gov/toxfaqs/TF.asp?id=19&tid=3

CDC. (2015, March 12). *Toxic Substances Portal - Cadmium*. Retrieved from Agency for Toxic Substances & Disease Registry: http://www.atsdr.cdc.gov/toxfaqs/TF.asp?id=47&tid=15

CDC. (2015, March 12). *Toxic Subtances Portal-Mercury*. Retrieved from Agency for Toxic Substances & Disease Registry: http://www.atsdr.cdc.gov/toxfaqs/TF.asp?id=113&tid=24

Chawla, M., & Sundriyal, D. (2012, September 6). Burton's Line. *The New England Journal of Medicine, 367*(10), 367-937. doi:DOI: 10.1056/NEJMicm1108354

de Lacerda, L. (2003, January). Updating global HG emissions from small-scale gold mining and assessing its environmental impacts. *Environmental Geology, 43*(3), 308-314. doi:10.1007/s00254-002-0627-7

Dinis, M., & Fiuza, A. (2011). Expsoure Assessment to Heavy Metals in the Environment: Measures to Eliminate or Reduce The Exposure to Critical Receptors. In M. D. Dinis, & A. Fiuza, *Environmental Heavy Metal Pollution and Effects on Child Mental Development: Risk Assesment and Prevention Strategies* (pp. 27-50). Springer Science & Business Media. doi:10.1007/978-94-007-0253-0_2

DIRESA. (2011). *Boletin Epidemiologico*. Retrieved from Direccion Regional de Salud Apurimac: http://diresaapurimac.gob.pe/diresa/index.php/en/normas#

EC. (2007, May 24). *Science For Environment Policy-DG Environment News Alert Service: Mercury Accumulation and Persistence in River Ecosystems*. Retrieved from European Commission: http://ec.europa.eu/environment/integration/research/newsalert/pdf/66na4_en.pdf

ElevationMap. (2016). *Elevation Search*. Retrieved from Elevation Map: Worldwide Elevations: http://elevationmap.net/jr-los-celajes-217-andahuaylas-peru?latlngs=(-13.6616515,-73.3767641)

EPA. (2016, February 23). *Selenium Compsounds*. Retrieved from US Environmental Protection Agency: https://www3.epa.gov/airtoxics/hlthef/selenium.html

Ernest & Young. (2015). *Peru's mining & metals investment guide 2015/2016.* ProInversion. Lima, Peru: Ernest & Young / Ministry of Foregin Affairs Peru. Retrieved from http://www.investinperu.pe/modulos/JER/PlantillaStandard.aspx?are=1&prf=0&jer=7885&sec=48

Estefani, G. (2013, April). *Lixiviacion por Montones para obtener oro*. Retrieved from Artinaid: http://www.artinaid.com/2013/04/lixiviacion-por-montones-para-obtener-oro/

George, M. W. (2003). *USGS Minerals Yearbook: Selenium and Tellurium.* USGS. USGS. Retrieved from http://minerals.usgs.gov/minerals/pubs/commodity/selenium/selenmyb03.pdf

Gerberding, J. L. (2003). *Toxicological Profile for Selenium.* Division of Toxicology / Toxicology Information Branch. Atlanta, Georgia: US Department of Health and Human Services: Agency for Toxic Substances and Disease Registry.

Goyer, R. (2004). *Issue Paper on The Human Health Effects of Metals.* Lexington, MA: US Environmental Protection Agency: Risk Assessment Forum. Retrieved from https://www.epa.gov/osa/issue-paper-human-health-effects-metals

Grabski, T. (2012, December 13). *Apurimac region to be Peru's new mining center-report*. Retrieved from BNamericas: http://www.bnamericas.com/en/news/mining/apurimac-region-to-be-perus-new-mining-center-report

GreatMining. (n.d.). *Open Pit Mining*. Retrieved April 12, 2016, from GreatMining: http://www.mine-engineer.com/mining/open_pit.htm

Hesperian. (2014). *Heavy Meals*. Retrieved from Hesperian Health Guides: http://en.hesperian.org/hhg/A_Community_Guide_to_Environmental_Health:Heavy_Metals:_Mining_and_Health

INEI. (2015). *Indicadores de Genero*. Retrieved from Instituto Nacional De Estadistica E Informatica: https://www.inei.gob.pe/estadisticas/indice-tematico/brechas-de-genero-7913/

INEI. (2015). *Medio Ambiente*. Retrieved from Instituto Nacional De Estadistica E Informatica: https://www.inei.gob.pe/estadisticas/indice-tematico/medio-ambiente/

INEI. (2016). *Sociales*. Retrieved from Instituto Nacional De Estadistica E Informatica: https://www.inei.gob.pe/estadisticas/indice-tematico/sociales/

Laguna, O. M. (2010, June 9). *Taxing mining profits in Peru: Will government renew the voluntary system?* Retrieved from PeruThisWeek.com: http://archive.peruthisweek.com/features-1420-politics-taxing-mining-profits-peru-will-government-renew-voluntary-system-

Larson, B. (2014). *An Economic Assessment of Environmental Health Risk in Apurimac, Peru.* World Bank. Bjorn Larsen: Environmental Economist.

Long, K. R., & Singer, D. A. (2001). *USGS Publications Warehouse.* Tuscon, AZ: USGS. Retrieved from USGS.gov: http://pubs.usgs.gov/of/2001/0218/pdf/of01-218.pdf

Low, P. (2012). *Artisanal and small-scale mining in Peru: a blessing or a curse?* London, UK: Peru Support Group. Retrieved from http://www.perusupportgroup.org.uk/files/fckUserFiles/file/Artisanal%20and%20Small-scale%20Gold%20Mining%20in%20Peru.pdf

Low, P. (2012, November 14). *Peru: Espinar Conflict Back From The Brink*. Retrieved from Latin American Bureau.org: http://lab.org.uk/espinar-bringing-conflict-back-from-the-brink

Martin, S., & Griswold, W. (2009, March). Human Health Effects of Heavy Metals. *Environmental Scient and Technology Briefs for Citizens*(15), 1-6.

MINEM. (2016, January). *Reporte Anual: Produccion Minera 2015 - Cobre*. Retrieved from Peru Ministerio de Energia y Minas: http://www.minem.gob.pe/_estadistica.php?idSector=1&idEstadistica=9288

MINSA. (2015). *Estadistica: Informaction Por Departamento Y Distrito*. Retrieved from Peru Ministerio de Salud: http://www.minsa.gob.pe/estadisticas/estadisticas/Poblacion/PoblacionMarcos.asp?03

MINSA. (2015). *Indicadores Basicos 2014*. Retrieved from Ministerio de Salud: http://www.dge.gob.pe/portal/index.php?option=com_content&view=article&id=606&Itemid=204

MINSA. (2016). *Informacion Por Departamento Y Distrito*. Retrieved from Peru's Ministerio de Salud: http://www.minsa.gob.pe/index.asp?op=6

MIT. (n.d.). *Performance Development*. Retrieved April 16, 2016, from Massachuesetts Institute of Technology: Human Resources: http://hrweb.mit.edu/performance-development/goal-setting-developmental-planning/smart-goals

Nogue, S., & Culla, A. (2006, May 18). Burton's Line. *The New England Journal of Medicine, 354*(20), E21. doi:10.1056/NEJMicm050064

Oriz Rios, R. (2014). *Peru 2014 Anuario Minero Reporte Estadistico.* Direccion de Promocion Minera. Lima, Peru: Ministerio de Energia y Minas. Retrieved from http://www.minem.gob.pe/_publicacion.php?idSector=1&idPublicacion=501

Ortiz Rios, R. (2016, January). *Publicacion: Boltin Estadistico de Mineria 2016*. Retrieved from Peru Ministerio de Energia y Minas: http://www.minem.gob.pe/minem/archivos/file/Mineria/PUBLICACIONES/VARIABLES/2016/ENERO.pdf

Ortiz Rios, R. M. (2015, December). *Publicacion: Boletines Estadisticos de Mineria 2015*. Retrieved from Peru Ministerio De Energia Y Minas: http://www.minem.gob.pe/_publicacion.php?idSector=1&idPublicacion=511

PWC. (2013). *2013 Mining Industry: Doing Business in Peru.* Lima, Peru: PricewaterhouseCoopers. Retrieved from https://www.pwc.com/pe/es/doing-business/assets/pwc-doing-business-mining-espanol.pdf

Rastogi, N. S. (2010, September 21). *Production of gold has many negative environmental effects*. Retrieved from The Washington Post: http://www.washingtonpost.com/wp-dyn/content/article/2010/09/20/AR2010092004730.html

Risher, J., & et al. (2003). *Toxicological Profile for Selenium.* Agency for Toxic Substances and Disease Registry. Atlanta, GA: US Department of Health and Human Services. Retrieved from http://www.atsdr.cdc.gov/toxprofiles/tp92.pdf

StanfordMed. (2016). *The Hand in Diagnosis*. Retrieved from Stanford Medicine: http://stanfordmedicine25.stanford.edu/the25/hand.html

Tchounwou, P. B., & et al. (2012, Apirl 24). Heavy Metals Toxicity and the Environment. *Molecular, Cliniacal and Environmental Toxicology, 101*, 133-164. doi:10.1007/978-3-7643-8340-4_6

US EPA. (2007). *Framework for Metals Risk Assessment.* Washington, DC: US EPA. Retrieved from https://www.epa.gov/risk/framework-metals-risk-assessment

US EPA. (2012). *Estimaion Progam Interfac (EPI) Suite Physical Chemical Properties, v4.11.* US Environmental Protection Agency: Office of Pollution Prevention and Toxic and Syracuse Research Corporation (SRC).

USDOE. (2014, July 1). *Multiple Species of Bacteria Convert Elemental Mercur to Toxic Methylmercury*. Retrieved from US Department of Energy: Office of Science: http://science.energy.gov/ber/highlights/2014/ber-2014-07-l/

WorldBank. (2016). *Peru*. Retrieved February 16, 2016, from WorldBank.org: http://www.worldbank.org/en/country/peru

APPENDIX

APPENDIX A

Physical-Chemical Properties of Lead, Arsenic, Selenium, Cadmium, and Mercury

Metal / MW	VP @ mm Hg, 25° C	Melting Point	Boiling Point	Henry's Law Constant	Log Koa	Log Kow	Log Koc	BCF	Level III Fugacity Model
Arsenic (As) / 77.95 g/mol	1.14E+004	188.3℃	473.4℃	0.002246 atm-m^3/mole	-0.82	0.68	0.59	1.164	Air 56.8%, Water 42.6%, Soil 0.51%, Sediment 0.102%
Cadmium (Cd) / 112.41 g/mol	8.98E-018	321℃	765℃	1.082E023 atm-m^3/mole	-0.071	-0.07	-0.061	0.926	Air 36.6%, Water 53.8%, Soil 9.45%, Sediment 0.128%
Lead (Pb) / 207.20 g/mol	7.28E-011	327.5℃	485.4℃	2.072E-015 atm-m^3/mole	0.729	0.73	0.633	1.095	Air 33.1%, Water 58.3%, Soil 8.44%, Sediment 0.148%
Selenium (Se) / 80.98 g/mol	6.67E+003	194.1℃	483.9℃	9.946E-004 atm-m^3/mole	0.640	0.24	0.208	0.978	Air 6.01%, Water 85.9%, Soil 7.85%, Sediment 0.205%
Mercury (Hg) / 200.59 g/mol	1.9E-005	-38.8℃	356.6℃	1.891E-009 atm-m^3/mole	0.619	0.62	0.538	1.047	Air 55.7%, Water 42.3%, Soil 1.85%, Sediment 0.101%

Source: EPA EPI Suite, v4.11, 2012 (US EPA, Estimaion Progam Interfac (EPI) Suite Physical Chemical Properties, v4.11, 2012)

APPENDIX B

Health Specific Effects from Arsenic (Inorganic)

Route of Exposure	Dose	Effect	Reference
Oral Ingestion	300 mg single dose	Fatal to an adult	(Goyer, 2004)
Oral Ingestion	0.04 mg/kg/day single or high dose for weeks or months	Gastrointestinal effects-stomach pains, diarrhea, hematological effects such as anemia, leucopenia, peripheral neuropathy, and cardiovascular effects	(Goyer, 2004)
Inhalation or oral	0.01 mg/kg/day or higher for a period of 3 to 5 years	Diffuse, spotted hyper-pigmentation of skin, if continued for years can produce skin lesions or skin cancer Liver disease-abnormal porphyry metabolism Lung cancer from chronic inhalation	(Goyer, 2004)
Oral	10 µg/L in drinking water	Cancer of the urinary bladder, lung, liver, and kidney	(Goyer, 2004)
Oral Ingestion	Low-level exposure	Vomiting, Nausea, reduced formation of red and white blood cells, damage to blood vessels, irregular heart rhythm, and a sensation of "pins and needles" in the hands and feet	(Martin & Griswold, 2009)
Oral Ingestion or breathing	Low-level Long-Term exposure	Blackening of the skin and the look of small warts or corns on the torso, soles, or palms	(Martin & Griswold, 2009)
Dermal Contact		Redness or swelling	(CDC, Toxic Subsances Portal - Arsenic, 2015)
-	Long-term exposure in children	Lower IQ score Exposure in womb and early childhood may raise mortality in young adults	(CDC, Toxic Subsances Portal - Arsenic, 2015)
Oral Ingestion or Inhalation		Injury to pregnant women or their unborn babies, however studies not conclusive	(CDC, Toxic Subsances

		Animals studies show that large dose cause illness in pregnant females, may cause low birth weight, fetal malformations, and possibly fetal death Arsenic crosses the placenta and has been found in fetal tissues Found at low levels in breast milk	Portal - Arsenic, 2015)
	Not Specified	Mees Lines, a.k.a. Aldrich or Reynold's Lines: White lines across finger nails	(StanfordMed, 2016)

Health Specific Effects from Lead

Route of Exposure	Dose	Effect	Reference
Not Specified	Child Development & Infants	Impairment of motor function and cognitive development Anemia	(Goyer, 2004)
Not Specified	Chronic High-Level in Older Children	Anemia and nervous system effects; reduced motor function and cognitive function and seizures, coma, and death with very high levels (> 80 µg/dL).	(Goyer, 2004)
Not Specified	Greater than 40 µg/dL (Adults Blood levels)	Impaired heme synthesis chronic kidney disease (blood levels above 60 µg/dL) Lethargy and deficiency of cognitive function (sustained blood levels > 80 µg/dL	(Goyer, 2004)
Not Specified	30-40 µg/Dl	Blood pressure effects	(Goyer, 2004)
Not Specified, but cite air, dust, and soil as exposure pathways	High-Levels	Vomiting, diarrhea, convulsions, coma or death	(Dinis & Fiuza, 2011)
Not Specified, but cite air, dust, and soil as exposure pathways	Chronic or Low-Levels	Neurodevelopment effects in children Anemia, brain and nervous system damage Cardiovascular, renal, gastrointestinal, hematological, and reproductive effects In adults inorganic lead doesn't cross the blood-brain barrier, but barrier is less developed in children	(Dinis & Fiuza, 2011)
Inhalation, Oral Ingestion	High-Levels Short-Period	Abdominal pain, constipated, fatigued, headaches, irritable, loss of appetite,	(CDC, Lead, 2013)

		memory loss, pain or tingling in the hands and/or feet, weakness Very high exposure may be fatal	
No Specified	Low-Levels Fetal Development (pregnancy)	Lead can cross the placental barrier and damage a developing fetus nervous system Miscarriages, stillbirths, and infertility in men and women	(CDC, Lead, 2013)
Not Specified	Long-Term Exposure	Abdominal pain, constipated, depressed, distracted, forgetful, irritable, nauseous Elevated blood pressure, heart attack, kidney disease, and reduced fertility	(CDC, Lead, 2013)
Not Specified	Chronic	Burton's Line: bluish line around the gums of the mouth > colicky stomach pain. No change in bowel or bladder function	(Chawla & Sundriyal, 2012)

Health Specific Effects from Cadmium

Route of Exposure	Dose	Effect	Reference
Inhalation	High Exposure to Fumes	Acute bronchitis or chronic disease- emphysema or pulmonary fibrosis and lung cancer	(Goyer, 2004)
Oral (Rice or Cigarette Smoking)	Low Dose Chronic Exposure Over Several Years	Kidney tubular dysfunction and osteoporosis in vulnerable populations (elderly women with iron deficiency)	(Goyer, 2004)
Inhalation	Chronic	Possible lung cancer, but none observed from oral ingestion only	(Goyer, 2004)
Oral Ingestion	High Levels	Severely irritates the stomach, causing vomiting and diarrhea	(Martin & Griswold, 2009)
Oral Ingestion	Long-Term Low Level Exposure	Known human carcinogen, Buildups up in the kidneys, potential kidney disease, fragile bones, and lung damage	(Martin & Griswold, 2009)
Dermal		Skin ulcers, sever redness, swelling of the skin	(Martin & Griswold, 2009)
Not Specified	Long-Term	Damage to the liver, kidney circulatory and nerve tissues, as well as skin irritation	(Martin & Griswold, 2009)
Oral Ingestion	Low Exposure	Animal test have shown cardiovascular disease	(Dinis & Fiuza, 2011)

Oral Ingestion	Acute Exposure	Salivation, hard to breath, nausea, vomiting, anemia, kidney failure, and diarrhea	(Dinis & Fiuza, 2011)
Inhalation (dust or smoke)	Not Specified	Dry throat, headaches, chest pains, coughing, increased uneasiness and bronchial complications	(Dinis & Fiuza, 2011)
Not Specified	Child Development	Young people may absorb more cadmium than adults Young people are more vulnerable than adults to a loss of bone and decreased bone strength from exposure	(CDC, Toxic Substances Portal - Cadmium, 2015)
Not Specified	High Levels during Fetal Development (pregnancy)	Behavior and leaning effects Lower body weight and affects skeleton in the developing young	(CDC, Toxic Substances Portal - Cadmium, 2015)

Health Specific Effects from Selenium

Route of Exposure	Dose	Effect	Reference
Oral Ingestion	High-Level Short-Term	Nausea, vomiting, diarrhea	(Martin & Griswold, 2009)
Oral Ingestion	Chronic High-Level	Selenosis; brittle nails, hair loss, and neurological irregularities	(Martin & Griswold, 2009)
Inhalation	Brief High-Levels	Bronchitis, respiratory tract irritation, trouble breathing, and stomach pains	(Martin & Griswold, 2009)
Inhalation	Long-Term	Respiratory irritation, bronchial spams, and coughing	(Martin & Griswold, 2009)
Oral Ingestion	High-Levels Short-Term	Nausea, vomiting, diarrhea	(CDC, Toxic Substances Portal-Selenium, 2014)
Not Specified	High-Levels	Animal studies displayed affects in sperm production and female reproductive cycle	(CDC, Toxic Substances Portal-Selenium, 2014)
Inhalation (Dust)	Not Specified	Acute: irritation of the mucous membranes in the nose and throat, causes cough, nosebleeds, dyspnea, bronchial spasms, bronchitis, and chemical pneumonia	(EPA, 2016)

		Acute: Gastrointestinal effects include vomiting and nausea; cardiovascular effects; neurological effects like headaches and malaise; eyes irritation	
Oral Ingestion	Not Specified	Pulmonary edema and lung lesions; cardiovascular effects and tachycardia; gastrointestinal effects like nausea, vomiting, diarrhea, and abdominal pain; liver effects; neurological effects like aches, irritability, chills, and tremors	(EPA, 2016)
Oral Ingestion	Chronic High-Levels in food and water	Skin discoloration, pathological deformation and hair loss, nail loss, extreme tooth decay and discoloration, garlic odor in breath and urine, lack of mental alertness, and listlessness	(EPA, 2016)

Health Specific Effects from Mercury (elemental, inorganic, and organic)

Route of Exposure	Dose	Effect	Reference
Inhalation	Vapor	Kidney and nervous system Crosses the blood-brain barrier; causes tremor, psychiatric disturbances, and altered behavior (generally not reversible and no mechanism for rapid removal from the brain) Renal toxicity results in glomerulonephritis, then progresses to renal failure	(Goyer, 2004)
Oral Ingestion (Dietary (aquatic food systems)	Developing Fetus (pregnancy)	Target organ is the brain Most susceptible population is the fetus; methyl mercury readily crosses the placenta and affects the developing brain	(Goyer, 2004)
Oral Ingestion	Child Development Low-Levels	Compromised development of motor and language skills during neonatal life and early childhood	(Goyer, 2004)
Oral Ingestions	Child Development / Developing Fetal (pregnancy)	Sever cognitive effects, including paresthesia, blindness, deafness Fetal death and abortion	(Goyer, 2004)

	Large Exposures		
Oral Ingestion	High Levels	Possible permanently damage to kidneys, brain, and developing fetuses Effects on brain may result in shyness, tremors, irritability, and change in vision or hearing, or memory issues	(Martin & Griswold, 2009)
Inhalation	Short-Term High-Levels Vapor	Damage to lungs, vomiting, nausea, diarrhea, elevated blood pressure or heart rate, skin rashes, and eye irritation	(Martin & Griswold, 2009)
Oral Ingestion / Inhalation	Not Specified	Possible human carcinogen Nervous system susceptible to all forms of mercury	(Martin & Griswold, 2009)
Inhalation	Vapor	Nervous system is susceptible to all forms of mercury Methylmercury and metallic mercury more harmful than other forms of mercury b/c stays in the brain	(CDC, Toxic Subtances Portal-Mercury, 2015)
Inhalation	High-Levels Exposures	Inorganic, metallic or organic mercury can forever damage the brain, kidneys, and developing fetus Effects on brain functioning may lead to irritability, shyness, tremors, changes in vision or hearing, and memory problems	(CDC, Toxic Subtances Portal-Mercury, 2015)
Inhalation	Short-Term High-Level Exposure to Vapor	Metallic mercury: Lung damage, nausea, vomiting, diarrhea, elevated blood pressure or heart rate, skin rashes, eye irritation	(CDC, Toxic Subtances Portal-Mercury, 2015)
Not Specified	Child Development / Fetal Development (pregnancy)	Young children more sensitive than adults; could develop problems of nervous system, digestive system, and damage kidnies Mercury passes through mother’s body to the fetus and may accumulate; may cause brain damage, mental retardation, incoordination, blindness, seizures, inability to speak Also pass to a nursing infant through breast milk	(CDC, Toxic Subtances Portal-Mercury, 2015)

APPENDIX C

Regulatory Limits for Arsenic, Lead, Cadmium, Selenium and Mercury

Regulatory limits for **Arsenic**:

- EPA: 0.01 parts per million (ppm) in drinking water (Martin & Griswold, 2009)
- OSHA: 10 micrograms per cubic meter of workplace air ($\mu g/m^3$) of workplace air for 8 hour shifts & 40 hour work weeks (Martin & Griswold, 2009)

Regulatory limits for **Lead**:

- EPA: 15 parts per billion (ppb) in drinking water (Martin & Griswold, 2009)
- EPA: 15 micrograms per cubic meter of air ($\mu g/m^3$) (Martin & Griswold, 2009)

Regulatory limits for **Cadmium**:

- EPA: 0.005 parts per million (ppm) in drinking water (Martin & Griswold, 2009)
- OSHA: 5 micrograms per cubic meter of workplace air ($\mu g/m^3$) of workplace air for 8 hour shifts & 40 hour work weeks (Martin & Griswold, 2009)

Regulatory limits for **Selenium**:

- EPA: 0.1 parts per million (ppm) in drinking water (Martin & Griswold, 2009)
- OSHA: 0.01 milligrams per cubic meter of workplace air (mg/m^3) of workplace air for 8 hour shifts & 40 hour work weeks (Martin & Griswold, 2009)

Regulatory limits for **Organic Mercury** and **Methylmercury**:

- EPA: 2 parts per billion (ppb) in drinking water (Martin & Griswold, 2009)
- EPA: 1 parts of methylmercury in a million parts of seafood (Martin & Griswold, 2009)
- OSHA: 1 milligram of organic mercury per cubic meter (mg/m^3) of workplace air
- OSHA: 0.05 milligrams per cubic meter (mg/m^3) of metallic mercury vapor for 8-hour shifts and 40 hour work week (Martin & Griswold, 2009)

APPENDIX D

Form A: PATIENT-FOCUSED ENVIRONMENTAL EXPOSURE QUESTIONNAIRE

Medical Record Number:	Patient Name (First, Last, Middle)
Date of Birth (MM/DD/YYYY)	District and Provence of Residents
Sex: Male or Female	DNI

<u>Heavy Metal Exposure Surveillance History</u>

How many times have you been screened for heavy metal exposure in the last 5 years?

() O () 1 () 2 () 3 () 4 () 5 () More than 5 times () Unsure

How many times have you been screen using laboratory test for heavy metal exposure/intoxication?

() O () 1 () 2 () 3 () 4 () 5 () More than 5 times () Unsure

Have you ever tested <u>positive</u> for heavy metal exposure by laboratory tests: () Yes () No () Unsure

Have you ever been hospitalized for heavy metal intoxication in the past: () Yes () No () Unsure

<u>Please read demographic categories and check ANY and ALL of the associated exposures that are associated with that category.</u>

Primary Occupation/Source of Income:

() Gold Mine Worker () Copper Mine Worker () Rice Farmer () Pesticide Sprayer () Fisherman () Other

Secondary Occupation/Source of Income:

() Gold Mine Worker () Copper Mine Worker () Rice Farmer () Pesticide Sprayer () Fisherman
() Other please specify

Occupational Safety Equipment Used at Workplace:

() Masks () Gloves () Whole body suite () Rubber boots () Masks () Suit () Goggles no Nose

() Goggles with nose () Plain cloths () Other: please specify () None

Living Environment:

() Brick or Cement Home () Rock Home () Adobe/Brick Home () Other home (please specify):

() Dirt floors () Title floors () Cement floor () Gas stove () Indoor cooking stove

Drinking Water Sources

() Connected Utility: Faucet () Well Water () Lake Water () River Water () Bottled water ()

Water Uses

Do you wash clothes using: () River water () Lake water () Connected Utility

Main source of protein

() Fish/aquatic animals () Meat from Cows () Meat from goats () Meat from pigs

() Meat from other animals: Please specify

Form B: HEAVY METAL-FOCUSED Review of Systems and Related Diagnosis

Medical Record Number:	Patient Name (First, Last, Middle)
Date of Birth (MM/DD/YYYY), AGE	District and Provence of Residents
Sex: Male or Female	DNI

<u>Pertinent Positive Review of Systems:</u>

Gastrointestinal

() Abdominal pain () Anorexia () Profuse Watery Diarrhea () Hematochezia () Melena () Jaundice
() Nausea () Vomiting () Excessive Salivation () Metallic Taste () Black-Blue Line at Gum Margin
() Garlic Breath

Respiratory

() Shortness of breath () Dry Cough () Productive Cough () Hemoptysis () Dyspnea on excretion
() Wheezing

Neurologic:

() Numbness and tingling () Generalized Weakness () Ascending Weakness () Paralysis () Confusion
() Headache () Loss of Consciousness () Tremor () Ataxia () Forgetfulness () Vertigo () Seizures
() Hallucinations () Memory Loss

Dermatologic:

() Palmar Keratosis () Solar Keratosis () Nail Discoloration () Brittle Nails

() White Spots/Longitudinal Nail Streaks () Alopecia () Rash

<u>After Care Visit Diagnosis</u>

Gastrointestinal/Renal

() Nausea/Vomiting () Profuse Watery Diarrhea () Hemorrhagic Gastroenteritis () Hepatitis
() Acute Renal Failure () Acute on Chronic Renal Failure () Chronic Kidney Disease

Respiratory

() Acute Bronchitis () COPD w/wo exacerbation () Asthma w/wo Exacerbation () Pulmonary Fibrosis () Pulmonary Edema () Acute Hypoxic Respiratory Failure () chemical pneumonitis

Neurologic:

() Polyneuropathy () Pure Motor Neuron Neuropathy () Ascending Neuropathy () Paralysis () Altered Mental Status () Encephalopathy () Encephalitis () Headache () Loss of Consciousness () Tremor () Ataxia () Vertigo () Seizures () Delirium () Memory Loss () Depression

Dermatologic:

() Palmar Keratosis () Solar Keratosis () Brittle Nails () Alopecia () Rash

() Burton's Lines/Lead Gum Lines () Mees' lines/Leukonychia Striata

Systemic

() Distributive shock () Cardiogenic Shock () Hypovolemic Shock

() Disseminated Intravascular Coagulopathy

<u>Laboratory Studies Associated with Visit:</u>

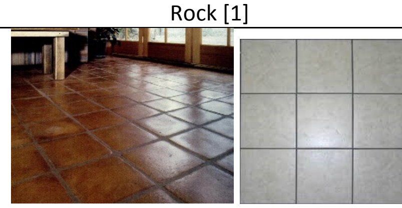
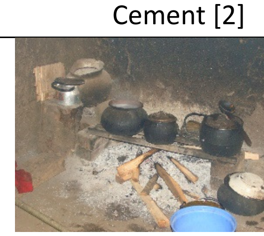
Arsenic: () Blood () Urine **Selenium** () Blood () Urine **Lead:** () Blood () Urine

Mercury: () Blood () Urine **Cadmium:** () Blood () Urine

APPENDIX E

Form A Supplemental Materials:

PATIENT-FOCUSED ENVIRONMENTAL EXPOSURE QUESTIONNAIRE

Occupational Functions & Hazards Occupation (mining, farming, fishing)	 Artisanal [0]  Artisanal Gold / Silver [1]  Large-Scale / Copper [3]	 Faming [4]	 Fishing [5]
Occupation Focus	 Gold [0]  Copper [1]	 Rice Farming [2]  Vegetable Farming [3]  Pesticide Spayer [4]	 Underwater Fishing [5]  Above Water Fishing [6]
Occupational Safety Equipment Used	 Mask [0]  Gloves [1]  Uniform [2]	 Gloves [3]  Boots [4]  Mask [5]  Suit [6]	 Goggles No Nose [7]  Goggles w/Nose [8]
Living Conditions Type of Dwelling	 Brick or Cement [0]	 Rock [1]	 Adobe / Adobe Brick [2]
Type of Floors in Dwelling (dirt, cement)	 Dirt [0]	 Tile [1]	 Cement [2]
Type of stove used for cooking (gas, cook stove, wood)	 Gas Stove [0]	 Indoor Oven / Cook Stove [1]	 Indoor Cook Stove [2]

Water Source & Uses Faucet, well, river, lake, or bottled	 Connected Utility [0]	 Well Water [1]	 Lake [2]	 River [3]	 Bottle [4]
Type of Bathroom Facility	 Outside [0]	 Inside Home [1]		 Septic Tank [2]	
Laundry (Wash and Dry)	 Outside Drying [0]	 River Washing [1]		 Lake Washing [2]	
SOCIAL BEHAVIORS Cigarette Smoker (yes or no) & Alcohol Use	 Smoker [0]	 Non-Smoker [1]	 Cerveza [2]	 Moonshine [3]	 Liquor [4]
Dietary Sources Meat, Fish, Vegetable, Grains, Bread	 Fish / Aquatic [0]	 Meat [1]	 Vegetables [2]	 Rice / Grains [3]	 Breads [4]

Form B Supplemental Materials:

PROVIDER-FOCUSED: HEAVY METAL-FOCUSED Review of Systems and Related Diagnosis