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Article

Environmental Lead Exposure and Adult Literacy in Myanmar: An Exploratory Study of Potential Associations at the Township Level

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Abstract: Environmental lead exposure is a population health concern in many low- and middle-income countries. Lead is found throughout Myanmar and prior to the 1940s, the country was the largest producer of lead worldwide. The aim of this study was to examine any potential association between lead mining and adult literacy rates at the level of the 330 townships in Myanmar. Townships were identified as lead or non-lead mining areas and 2015 census data were examined with association being identified using descriptive, analytical and spatial statistical methods. Overall, there does appear to be a significant relationship between lead mining activity and adult literacy levels ($P<0.05$) among townships with both low access [OR= 2.701 (1.136-6.421)] as well as townships with high access to safe sanitation [OR=18.40 (1.794-188.745)]. LISA cluster maps confirm these findings. This exploratory analysis is a first step in the examination of potential environmental lead exposure and its implications in Myanmar.

Keywords: lead exposure, adult literacy, global health, environmental health, Myanmar.

1. Introduction

Literacy, traditionally defined as proficiency in reading and writing, is an important determinant of health and can support an individual's functional role in society[1]. Adult literacy has been used as one marker of cognitive proficiency and intelligence[2], as well as being a facilitator of comprehension and reasoning[3]. Illiteracy in adult populations may be attributed to many variables, including limited access to educational institutions or opportunities due to low socioeconomic status[4,5]. Exposure to harmful environmental contaminants has also been adversely associated with cognitive function and literacy. Lead exposure specifically has been associated with negative outcomes related to neurological function, cognitive proficiency, intelligence quotient (IQ) and literacy[3].

The most common pathway of lead toxification is through inhalation of lead via the respiratory tract, but the heavy metal can also be absorbed in the gastrointestinal tract via ingestion[6]. Lead can then be redistributed to the skeletal system, where it may have a half-life of five to nineteen years[6,7]. The main anatomical target during lead absorption and toxification is the nervous system, which can lead to adverse neurological functions such as ataxia, coma, or even death[6]. Additional neurological impacts include reductions in attention span and levels of educational engagement, leading to a subsequent decrease in educational attainment[5]. Furthermore, heavy metals such as lead have high affinity and can bind N-methyl-D-aspartate receptors found in nerve cells, resulting in cognitive dysfunction due to reactive oxygen species[8].

There are no previous studies specifically looking at the cognitive outcome of adult literacy in relation to lead exposure at a population level. However, one previous study does conclude that

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people residing in lead mining communities have a higher exposure, and greater absorbance, of lead than populations residing in areas without lead mining activity[10]. This increase in lead absorption could be detrimental to human health and development, as prolonged exposure may result in the neurological impacts mentioned.

Myanmar (previously known as Burma), is a country with a large mining industry and great potential for further mine development, as its lands are rich with jade, oil and metals[13,14]. Lead has great historical significance in the country. Prior to the Second World War, Myanmar was the world's largest producer of lead, providing a significant source of economic activity[14]. Today, following recent political and economic reform, many lead mines in Myanmar are developed through foreign investment as well as Myanmar's Ministry of Mines[14]. However, it is recognized that private investors, small-scale artisan extraction, and informal or undocumented groups also conduct lead mining. Despite the potential economic benefits, there are many negative human health implications of lead toxification, particularly regarding impacts upon human brain development and neurological function[3,4,6]. To date there is no research evidence available related to the level of environmental contamination or the potential health effects of lead exposure for populations in Myanmar. However, studies conducted on Burmese refugee populations in the United States indicate that blood lead levels may be elevated in this population[43].

In this exploratory study, townships in Myanmar were categorized as "lead" or "non-lead" mining, and census data for adult literacy levels and socioeconomic levels were examined. Myanmar's country-wide adult literacy rate was reported as 89.5%, and this cognitive-related indicator has also been determined at the township level in the 2014 Myanmar Census[12]. This study specifically explored the relationship between lead exposure and adult literacy level, based on residency in townships of lead mining. This relationship may be modified by the level of affluence or poverty (measured by a basic sanitation indicator), so this was explored as an effect-modifying variable. As there is minimal research regarding the human health impact of lead mining in Myanmar, this study may reveal potential population-level health and mining exposure patterns that could be further investigated in future field-based studies.

2. Materials and Methods

The main research question for this study was whether adult literacy levels differed across lead mining and non-lead mining townships in Myanmar when taking into consideration access to safe sanitation as an indicator of affluence. To answer this question our research objectives were to screen and categorize the 330 townships in Myanmar as either lead-mining or non-lead-mining; to use the 2014 Myanmar Census data, to describe and map the adult literacy level, and level of access to safe sanitation (as a measure of poverty/affluence) at the township level in Myanmar; to statistically examine the relationship between lead exposure and Myanmar's adult literacy level at a township level, taking into consideration poverty/affluence as a potential effect modifying variable; to explore global and local tests of spatial autocorrelation to identify patterns of clustering; and to map and report the results to inform future studies.

We began by establishing a series of study hypotheses. First, that adult literacy levels will be lower in lead-mining townships than in townships without lead mining. It is assumed this relationship is due to the negative effect of lead exposure upon neurological and cognitive development of which adult literacy is a proxy measure; second, that poverty or affluence levels modify the relationship between lead mining exposure and adult literacy; third that access to safe sanitation is a proxy measure for poverty/affluence that has a relevant threshold in Myanmar, and finally fourth that townships with low adult literacy levels may cluster in similar locations to lead-mining townships.

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Data Collection:

Data for the outcome, adult literacy, and data for the development indicator (safe sanitation) was available in Myanmar's 2014 Census, which was undertaken by the Ministry of Immigration and Population, and supported by the United Nations Development Program (UNDP). Data collected from the country-wide census was accessed through the Myanmar Information Management Unit (MIMU). The 2014 Myanmar Census was the first census conducted in Myanmar since 1983, following the transition of Burma to Myanmar[12]. Receiving a vast amount of international support, the census results included over 50 million Burmese citizens. The adult literacy levels, and levels of access to safe sanitation as an indicator of socioeconomic status were collected at a township level.

Locations of lead deposits in Myanmar are well documented and tend to be concentrated in specific areas including the Shan State and the Kayah State[14]. Lead mining takes place at large and small scales in the country and there are no complete and current maps of lead mining activity in Myanmar. The specific location of lead mining sites, and thus the lead mining townships, were identified using three sources of information. First, coordinates for lead mines were recorded using yearly reports from the United States Geological Survey (USGS) for Myanmar. In addition, socio-economic analyses and occupational reports from MIMU were used to corroborate and add to the USGS records of lead mining activity. The mineralogy database Mindat was used to identify and confirm mining sites across Myanmar. It should be noted that these data comprehensively captured large and medium scale mining activities but it possible that very small-scale lead mines went undetected.

Study Population*:*

Myanmar has a population of approximately 51.5 million people located in 14 state regions, subdivided further into 330 townships[12]. As stated previously, Myanmar's lead mining development could have critical implications for human health and development particularly in lead mining areas. For instance, the Hpasaung Township in the Kayah State is known to have a large portion of its population working in lead mines. Citizens in this township have expressed concern about water pollution from lead mine development, indicating worry for adequate safety regulations[15]. Improper safety precautions in regions of lead mining development could not only provide a hazardous occupational exposure towards workers in the mining industry, but also could impact the surrounding township through lead dust or contamination of sediments and water sources.

Study Design:

The first portion of this exploratory cross-sectional study was a descriptive analysis. The descriptive analysis explored the prevalence of illiteracy and lead mining in Myanmar, and visually assessed patterns of distribution of adult literacy levels, access to safe sanitation, and lead mining. Basic descriptive tables were first created, followed by Geographic Information System (GIS) maps including the 330 townships using GeoDa mapping software (v1.12). Townships were identified as a lead mining township if there was a confirmed active lead mine, or if there had been a mine within the last 50 years, as lead has the ability to leech into soils and continuously contaminate the surrounding groundwater long after such mining sites close[16]. Townships were also considered as lead mining if there was an active lead mine within 15 kilometers of its borders, as research indicates that communities living several kilometers from lead mines still have a significant exposure to lead when compared to the general population[10]. The maps created through GeoDa provide a visual representation of adult literacy in Myanmar, as well as other variables considered within this study.

To assess the degree of patterning in the data, techniques of exploratory spatial data analysis were applied. First, a global indicator of spatial autocorrelation – Moran's I – was applied to the adult literacy, safe sanitation, and lead mining variables[17,18]. Spatial autocorrelation is a measure of how similar one value is to its neighboring values[19]. Moran's I is measured from negative one to positive one with values further from zero indicating decreasing spatial randomness, whereby a value of positive one indicates perfect clustering, and a value of negative one indicates perfect dispersion[19]. Although the Moran's I provides insight towards the global spatial patterns, this method is not able to identify cluster locations or the type of clustering. Local Indicators of Spatial Association (LISA) was applied to each of the three variables to identify the presence of localized clusters[20]. LISA is a spatial analytic tool adapted from the Moran's I and conducts spatial autocorrelation test statistics at a localized level for each unit of geography to identify statistically significant clusters. To verify the significance of the LISA cluster maps, 999 random Monte Carlo permutations were calculated. The LISA maps characterize five different types of spatial relationships: (1) High-High, indicating clustering of high values surrounded by high values; (2) High-Low, indicating high values surrounded by low values; (3) Low-Low, indicating clustering of low values surrounded by low values; (4) Low-High, indicating low values surrounded by high values; and (5) Not-Significant, indicating the absence of spatial autocorrelation[20].

To conduct global and local tests of spatial autocorrelation, a spatial weights matrix had to be specified[19,20]. The purpose of the spatial weights matrix is to identify the extent to which neighboring geographic units are associated with each other. This study utilized a first-order queen contiguity spatial weights matrix, whereby a geographic unit will only be affected by the immediately contiguous units sharing a common border or vertex.

Following the descriptive analysis, the relationship between lead exposure and adult literacy was assessed to determine whether there was a significant association, using the statistical program SPSS (v.24). The primary exposure was lead mining in Myanmar's townships, while the primary outcome was low adult literacy levels (Figure 1). Townships were categorized as having high adult literacy levels if over 89.1% of their adult population was literate. This was chosen as the cutoff for the dichotomy, as it included the upper two tertiles and had practical relevance. Effect modification by level of access to safe sanitation (as an indicator of development or poverty/affluence) was determined using the Mantel-Haenszel Chi-square test for homogeneity. Townships were categorized as having high access to safe sanitation if over 83.3% of their population had access to safe sanitation, also representing the upper two tertiles. The association between lead mining and adult literacy was assessed primarily through a one-tailed Chi-square test for independence, both for townships of low and high access to safe sanitation. However, if any cells during the statistical analysis had a sample under 5 townships, the Fisher's Exact test was used as an alternative calculation. Finally, assuming effect modification did exist, the stratum-specific odds ratio test was conducted with related confidence intervals. Through the use of descriptive, statistical and spatial analyses, the potential threat of lead mining towards cognitive development was identified.

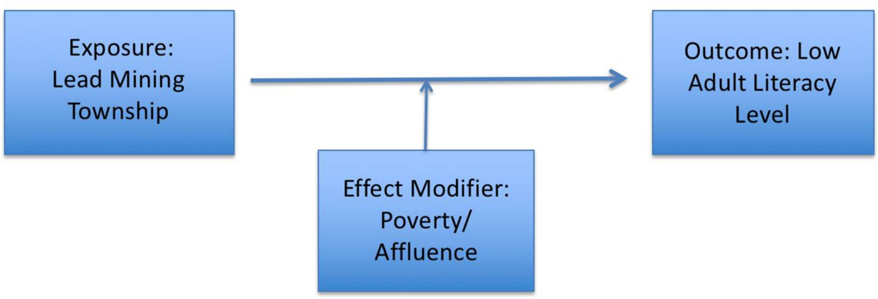

Figure 1: The causal pathway between the exposure (lead mining township) and outcome (adult literacy level) of interest, while taking into consideration poverty/affluence as a potential effect-modifying variable.

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3. Results

3.1 Demographic description

The demographic description of Myanmar's population (Table 1) indicates that there are discrepancies between Myanmar's townships in terms of both access to safe sanitation and adult literacy levels.

Table 1. Descriptive Characteristics of the Study Sample (Townships in Myanmar, n=330)

Descriptor	Townships in Myanmar n (%)
Lead Mine Development:	
Lead mining activity	29 (8.79%)
No lead mining activity	301 (91.21%)
Adult Literacy:	
High adult literacy level (>95% of township population)[1]	105 (31.82%)
Low adult literacy level (<95% of township population)	225 (68.18%)
Access to Safe Sanitation:	
Access for >90% of township population[2]	63 (19.09%)
Access for 70-90% of township population	148 (44.85%)
Access for <70% of township population	120 (36.6%)
Average and Range of Descriptors at the Township Level	**Percentage (%)**
Average adult literacy rate	85.56%
Range of adult literacy rates	11.5-99.2%
Average level of access to safe sanitation	71.42%
Range of access to safe sanitation	5.4-100.0%

[1] The United Nations Educational, Scientific and Cultural Organization (UNESCO) reported that there was a National Goal to achieve 95.0% adult literacy levels in Myanmar by 2010[22].

[2] The national strategy for the Government of Myanmar is to achieve 90% of the population having access to safe sanitation within the next 10 years[23].

For instance, there is a large range of access to safe sanitation in Myanmar (5.4-100.0%). It was reported that many urban centres have relatively high levels of access to safe sanitation, while many rural areas are not able to afford infrastructure for improved sanitation[18]. Similarly, the range of adult literacy levels among townships was large (11.5-99.2%). The Ayeyarwady State had the highest adult literacy rates (99.82%), while the Shan State had the lowest adult literacy rates (55.9%)[19]. Alongside the low adult literacy levels, the Shan State also had the majority of lead mining activity in Myanmar, with 17 lead mining townships. It is worth noting that the Shan State also had generally low levels of access to safe sanitation (average of 56.75%), indicating that it may be a state of low affluence or more limited development.

The demographic descriptions of adult literacy levels, access to safe sanitation, and lead mining are represented in Figure 2, while the LISA cluster maps for each of the respective variables are represented in Figure 3.

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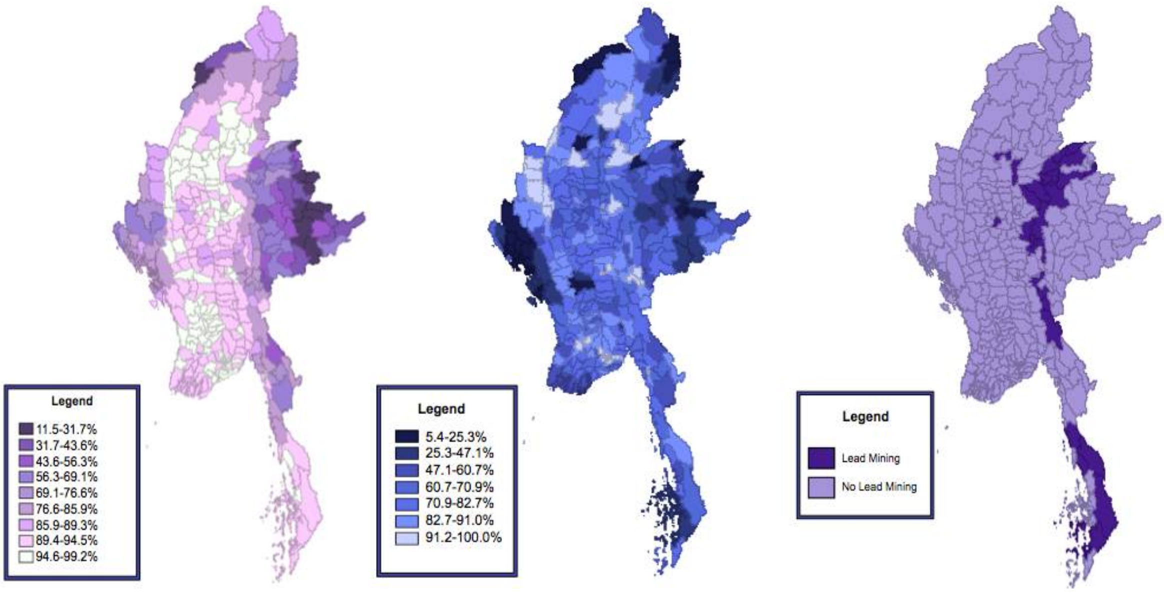

Figure 2a-c: *Descriptive maps of Myanmar visually representing adult literacy levels (2a-left), access to safe sanitation (2b- middle), and lead minng activity status (2c-right). * Both access to safe sanitation and adult literacy levels were mapped using natural breaks calculated through GeoDa, while the lead mining map represents dichotomous variables.*

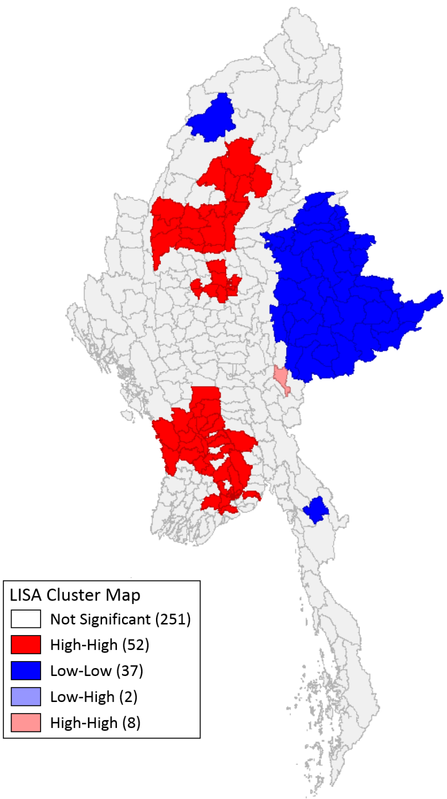

Figure 3a. *LISA Cluster Map of Adult Literacy at the Geographic Level of Myanmar Townships.*

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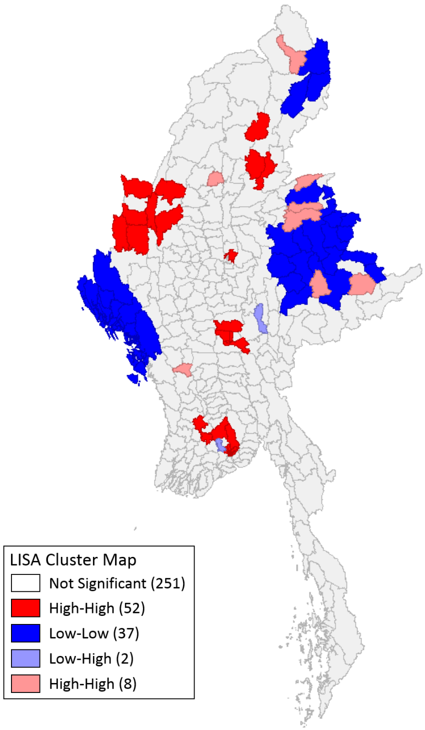

Figure 3b. *LISA Cluster Map of Access to Safe Sanitation at the Geographic Level of Myanmar Townships.*

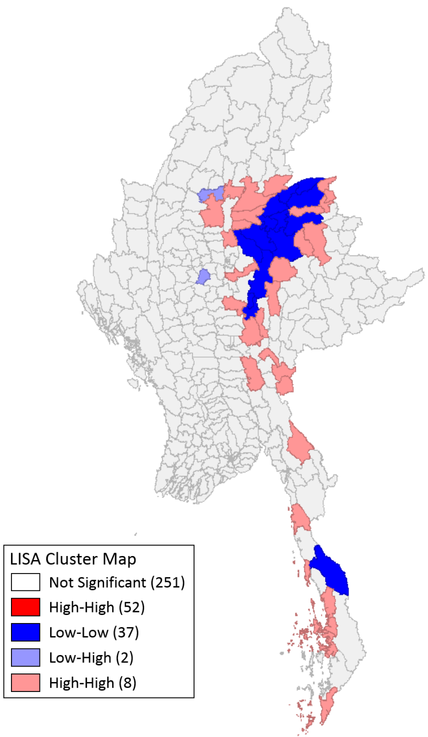

Figure 3c. *LISA Cluster Map of Lead Mining at the Geographic Level of Myanmar Townships*

3.2 Adult Literacy

When exploring the choropleth map of adult literacy in Figure 2a, it appears that there is a high concentration of low adult literacy townships in the Eastern regions of Myanmar, followed by smaller aggregations in the Western and Northern regions. Further analysis with the Moran's I also suggests a strong degree of positive spatial autocorrelation with a test statistic of 0.83. When exploring the LISA map of adult literacy in Figure 3a, it is apparent that there are statistically significant "Low-Low" clusters of low adult literacy predominantly in the Eastern and Western regions of Myanmar previously identified in the choropleth maps of Figure 2, and two distinct "High-High" clusters of high adult literacy in central Myanmar.

3.3 Access to Safe Sanitation

Similar the spatial patterns depicted by adult literacy rates, there appears to be a concentration of townships with low access to safe sanitation in most Eastern, Western, and Northern regions of Myanmar as depicted in Figure 2b. A Moran's I statistic of 0.53 suggests that access to safe sanitation exerts moderate positive spatial autocorrelation, albeit less than what was depicted with adult literacy. When exploring the LISA map of access to safe sanitation in Figure 3b, three "Low-Low" clusters of poor access to safe sanitation emerge in the areas identified by the choropleth maps, as well as 5-6 "High-High" clusters in central Myanmar.

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3.4 Lead Mining

The lead mining choropleth map depicted in Figure 2c differs from the previous two figures in that there appears to be a narrow ribbon of lead mining townships from central to southern Myanmar. The Moran's I statistic of 0.38 indicates a low degree of positive spatial autocorrelation and suggests that lead mining is relatively diffuse in Myanmar. The findings from the LISA cluster map in Figure 3c parallel that of the Moran's I since the LISA map uncovered two localized clusters of lead mining townships in central and southern Myanmar.

3.5 Cluster Location Comparisons

Based on the exploratory spatial data analysis, it reveals there is likely a spatial correlation between adult literacy and access to safe sanitation, based on the location of the statistically significant "Low-Low" cluster in Eastern Myanmar. In addition, it appears there could be a relationship between lead mining activity and low adult literacy levels due to overlapping geographic units depicted in the central-Myanmar clusters for both variables. These descriptive assessments were further investigated during the statistical analysis.

3.6 Lead Mining and Adult Literacy

According to the results (Table 2), there does appear to be a significant relationship between lead mining activity and adult literacy levels ($P<0.05$) among townships with high access and those with low access to safe sanitation as an indicator of relative affluence and development. The Fisher's Exact test was used for the relationship between lead mining and adult literacy in townships of high access to sanitation, as there were under 5 townships with high levels of access to improved sanitation that were also lead mining townships for both high and low adult literacy levels. The majority of lead mining townships also had low access to safe sanitation (86.2% of lead mining townships).

Table 2. Cross Tabulation of Lead Mining Activity and Adult Literacy in Myanmar's Townships, and the Effect of Access to Safe Sanitation on This Relationship (n=330).

Descriptor	Low Adult Literacy Level (≤89.1% of Population)	High Adult Literacy Level (>89.1% of Population)	P-Value
Lead Mining Development:			
Lead Mining	19 (5.76%)	10 (3.03%)	<0.01*
No Lead Mining	92 (27.88%)	209 (63.33%)	
Access to Safe Sanitation:			
High Proportion (>83.3% of Population)	18 (5.45%)	93 (28.18%)	<0.01*
Low Proportion (<83.3% of Population)	93 (28.18%)	126 (38.18%)	
Townships with High Access to Safe Sanitation (>83.3%):			
Lead Mining	3 (0.91%)	1 (0.30%)	0.013**
No Lead Mining	15 (4.55%)	92 (27.88%)	
Townships with Low Access to Safe Sanitation (<83.3%):			
Lead Mining	16 (4.85%)	9 (2.73%)	<0.05*
No Lead Mining	77 (23.33%)	117 (35.45%)	

*P-value from Chi-Square test (one-tailed), with significance indicated when P<0.05.
**P-value from Fisher's Exact Test (one-tailed) with significance indicated when P<0.05.

It was also concluded that access to safe sanitation interacted (was an effect modifier) in the relationship between lead mining and adult literacy levels. Both townships with low access to safe sanitation [OR= **2.701** (1.136-6.421)] as well as townships with high access to safe sanitation [OR=**18.40** (1.794-188.745)] appeared to have an increased risk of lower adult literacy levels in lead mining townships. These was a meaningful difference in the odds ratios of these two strata. Due to small cell sizes in the contingency tables, however, there were wide confidence intervals. Overall, the statistical tests seem to confirm the assumptions made in the geographic descriptive assessment, as lead mining activity appears associated with lower literacy levels at the township-level, with access to safe sanitation acting as an effect modifier on this relationship, but the statistical results have to be interpreted with caution.

4. Discussion

Lead mining activity in Myanmar tends to be localized in certain spatial areas, such as Kayah, Shan and Tanintharyi States, all regions of large lead deposits[13]. Spatial and statistical analyses reveal significant associations between lead mining and adult literacy at the township level, with differential risks in areas of low and high access to safe sanitation, our chosen development or affluence indicator. Many areas of low access to safe sanitation also had low levels of adult literacy, and we acknowledge the well-established relationship between poverty and adult literacy[20,22]. However, our findings indicate that citizens living in townships with high access to safe sanitation and lead mining activity may also be more at risk of having lower adult literacy than those in similar situations but in non-mining townships. Further exploration of this pattern is warranted particularly at community and individual levels. Do citizens in these townships have high lead levels in biological samples?

Myanmar citizens located in proximity to lead mines could be exposed to lead from contaminated soils, lead dust, or ingesting contaminated drinking water or food items[38-39]. As many people living in lead mining townships don't have adequate access to safe drinking water or sanitation, this could

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increase their consumption of lead due to contaminated water sources[15,19] while it is also possible that bottled water is used. Lower adult literacy levels in lead mining townships could be due to lead's ability to impact neurological functions[5]. It is expected that there is an increased exposure to environmental lead for children in lead mining townships. For instance, dust lead levels have been found to be significantly associated with blood lead levels in children whose specific behavioural and physiological characteristics make them particularly at risk for environmental exposures[23-24]. It is likely that Myanmar citizens located in lead mining townships could have increased lead toxification if exposed to lead from an early age. Additionally, it was reported in one study that children from low-income families are at a differential risk for being exposed to environmental lead, highlighting ongoing environmental injustices occurring today[25]. It is possible that lower-income families have resided near lead mining activities for a lack of a better option, demonstrating the relationship between lead mining activity and affluence. The collection and testing of biological specimens from residents in different townships could confirm or refute these ideas although currently there is limited opportunity to conduct these kinds of studies in Myanmar (personal communication, WHO-Myanmar Country Representative Dr. J. Luna, February 2, 2016).

Early exposure to environmental lead could have severe and long-lasting impacts upon cognitive function, causing cognitive impairment that lasts well into adulthood. It has been determined that along with hypochromic anemia and lead-caused encephalopathy, high lead exposure has also resulted in poorer school performance, a decreased IQ and hyperactivity[27]. Many studies have reported a positive association between lead exposure and encephalopathy[27-29]. Lead encephalopathy may abrupt neurological function, as it is associated with difficulties concentrating, behavioural problems, and restlessness. In more severe cases, it may cause confusion, difficulty in understanding, and deterioration of memory storage. Understandably, the occurrence of encephalopathy should be further explored, as alongside other cognitive dysfunction, it could have resulted in increased illiteracy rates found in Myanmar's lead mining townships.

As mentioned previously, many studies have looked at the association between lead exposure and reduced IQ[3,27,30-31]. It has been reported that alongside a lower IQ, high lead exposure can also impact emotional well being, aggression and anxiety[30]. These negative impacts on emotional health could contribute to poor performance in academic settings and potential illiteracy. Although adult literacy has not been used as an indicator of cognitive function in studies of lead exposure, there are studies indicating that IQ and memory are significantly associated with performance in adult literacy tests[32]. A reduction in IQ from lead toxification could therefore contribute to decreased adult literacy levels in lead mining townships.

Although children are arguably at a much greater risk of the acute and chronic impacts of environmental lead exposure, lead may also have direct detrimental consequences upon the cognitive functioning of adults. Therefore, it is also possible that short-term residents of lead mining townships in Myanmar could also have had neurological impacts decreasing literacy capability. For instance, lead accumulation in adults may result in increased brain lesions, and a subsequent decline in cognitive function[33]. This decrease in cognitive function could result in reduced verbal and visual memory, declining verbal learning and a decrease in actual brain size from cell death. In fact, epidemiological studies have indicated that lead exposure may increase the rate of cognitive decline in older populations, as increased blood lead concentrations were associated with lower scores on a mental status examination[34]. The neurodegenerative effects of lead exposure have also been studied, and it has been reported that increased lead exposure is significantly associated with Parkinson's Disease, amyotrophic lateral sclerosis, and potentially Alzheimer's Disease[35-37]. Therefore, it is possible that even individuals without early age exposure to lead could encounter cognitive deficits when moving to a lead mining township in Myanmar. This could reduce the literacy capability in Myanmar's adult population.

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This exploratory study fills an important gap in literature that could help inform future etiological studies about the negative health effects of lead exposure from mining development in Myanmar. As previous studies have not investigated lead mining in Myanmar, this is the first study to categorize and map Myanmar's townships as lead or non-lead mining. There has also been an absence of studies exploring lead's impact upon adult literacy as an indicator of cognitive function. Additionally, the 2014 Myanmar Census was the first undertaken in 30 years and provides extensive data for the majority of Myanmar's population. Along with other reports from MIMU, the USGS, and mineralogy databases, this study draws information from high-quality and current data sources. The study plan and results were discussed with public health stakeholders in Myanmar to ensure the appropriateness of the design, analysis and dissemination of findings. The World Health Organization (WHO) outlined that lead mining in lower-income countries, including Myanamr, is a grave concern because of possible adverse effects during brain development[17].

There are many strengths of the study, however there are also limitations important to consider. As mentioned, even though Myanmar's larger lead mining development areas are identified, it is possible that smaller-scale productions could go unnoticed. Small and independent operations may not necessarily report lead mining activity to Myanmar's government[13,15]. In addition, lead can travel in water, air and soil, and is present in leaded gasoline, paints and other products. We recognize that lead exposure could extend beyond the immediate zones around mining sites. This kind of more extended assessment of broader environmental exposure will not be possible to capture in this study and this limitation is recognized. Although adults readily absorb lead, or may have absorbed lead when they were children, direct measures of cognitive development among younger populations would have been an ideal addition to this study. Unfortunately, there are no township-specific data sets available for cognitive or neurological indicators for children in Myanmar. Lead exposure is cumulative and affects neurological function over time, so if adults had moved in and out of lead-mining areas this may represent a limitation to the study. Migration between townships was not available in the census data, and therefore could not be incorporated into the results. Moreover, there is a potential for ecological fallacy in this study, as data in the Census was not available at a finer-scale than at the township level. It is unlikely that information at the township level can account for individual citizen diversity within a township, however it is also worth noting that there are relatively large discrepancies between townships in relation to safe sanitation access and adult literacy. Therefore, although it is difficult to generalize populations within a township, many of these townships do have distinct differences. Given the limitations mentioned, and the inherent inability to measure all potential confounding variables, we propose this study as the first exploratory step in what might represent a longer program of research. The current study has successfully tested an approach to spatial and population health analysis that could be used to examine other potential environmental health concerns, particularly in areas where field study might be difficult. These kinds of studies, while inherently limited, represent starting points in examining potential health or illness threats. Results from this study are being used to advocate for further focused study in Myanmar.

5. Conclusions

With growing development of lead mining projects in Myanmar[13] and other low- and middle-income countries, these results signify the importance of further investigation and the implementation of safety measures to guard against harmful exposure. It is essential to test and regulate lead concentrations found in soil and water sources and to protect workers in lead mines to prevent lead poisoning and toxification[38]. Ongoing surveillance should be explored in current lead mining operations, while site-specific remediation plans should be implemented on inactive lead mining sites.

Overall, there was a significant relationship calculated between lead mining and adult literacy at the township level in Myanmar. Future studies should measure the extent of human and environmental lead accumulation in lead mining and neighbouring areas. Lead exposure, health and cognitive

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function research should be conducted at the individual level. In addition, further studies should investigate the role of lead exposure in the cognitive development of Myanmar's children.

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