



Outbreak Investigation of Manganese Toxicity Among Workers in a Selected Manganese Smelting Plant in Serenje District, Central Province, Zambia, 2022

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Abstract

Introduction: In September 2022, the Serenje district health office reported cases of lower limb weakness, difficulty walking, and impaired sexual function among workers at a manganese smelting plant. To investigate, we conducted a case-control study.

Methods: Cases were identified as individuals with confirmed neurological symptoms, elevated blood manganese levels, and neurologist-validated brain imaging reports. The study included 20 cases and 42 controls, selected at random but balanced for their duration of employment.

Results: Symptoms among cases included difficulty walking (90%), joint pain (90%), impaired sexual function (90%) and difficulty talking (75%). Blood manganese levels among cases were exceptionally elevated, exceeding 20 times the normal range (0.116 to 0.623 ppm), compared to the reference range (0.005-0.02 ppm). Each additional day of overtime worked per week was associated with a 2.40-fold increased risk (95% CI = 1.05-6.35) of developing manganese toxicity. Notably, individuals using respirators had a 93% lower risk of adverse outcomes compared to non-users (OR = 0.07, 95% CI 0.01-0.51).

Conclusion: Our study highlights the association between overtime work and manganese toxicity risk. To prevent future occurrences of heavy metal toxicity among industrial workers, we emphasize the need for enhanced monitoring, adherence to safety protocols, and vigilant toxic exposure surveillance.

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Introduction

Manganese (Mn) is a naturally occurring element that makes up approximately 0.1% of the earth's crust. It is the fifth most abundant metal found as oxides, carbonates, and silicates with pyrolusite [1]. The inorganic forms of Mn can be used in the production of steel, dry-cell batteries, glass, and fireworks. Chemical manufacturing of leather, fertilizers, and cosmetics also uses the inorganic forms of Mn. The inorganic forms of Mn can be found in fungicides, fuel-oil additives, smoke inhibitors, and medical imaging agents [2]. Additionally, Mn is a cofactor in enzymatic reactions in neurotransmitter synthesis and metabolism [3].

Exposure to Mn can be through food and water consumption, inhalation, and skin contact. Occupational exposure to Mn is mostly through inhalation of particles. Normal ranges of Mn levels in body fluids are 4–15 µg/L in blood, 1–8 µg/L in urine, and 0.4–0.85 µg/L in serum [1]. Excessive exposure can lead to a condition known as Manganism, with similar characteristics to Parkinson's disease. Both Manganism and Parkinson's disease have been shown to affect the basal ganglia. In its most severe form, Manganism is characterized by neurological symptoms due to damage to the globus pallidus and substantia nigra pars reticulata [4].

Beginning in September 2022, clusters of workers presented to nearby health facilities with neurological symptoms, including lower limb weakness, difficulty walking, and impaired sexual function. An outbreak investigation identified 18 symptomatic workers, with the index case diagnosed with manganese toxicity at the University Teaching Hospital in April 2022.

Subsequent occupational exposure assessment by the Occupational Health and Safety Institute detected elevated blood manganese levels among workers (0.116–0.623 ppm; reference: 0.005–0.02 ppm). Preliminary findings suggested inadequate local exhaust ventilation and inconsistent use of respiratory protective equipment. Therefore, this study aimed to investigate the possible risk factors of Manganese toxicity among the workers at the smelting plant.

Objectives

To investigate reports of manganese toxicity among mine workers at a manganese smelting plant in Serenje district that occurred in 2022.

Specific Objectives

- To describe the extent of the outbreak in Serenje district, 2022.
- To identify risk factors associated with Manganese toxicity among mine workers in a selected manganese smelting plant in Serenje district, 2022
- To provide evidence-based recommendations

Methods

Study Design

A case-control study with a 1:2 ratio was conducted to assess the risk factors associated with the Manganese toxicity among miners in the selected smelting plant in Serenje district.

Study Population

All workers employed at the selected Manganese smelting plant in 2022.

Case Definitions

- Suspected case definition – a manganese mine worker presenting with neurological symptoms such as lower limbs weakness and/or walking difficulties and/or impaired sexual function.
- Confirmed case – suspected case with a neurologist-validated brain imaging report confirming deposition on Manganese in the brain.
- Control: A manganese mine who is asymptomatic of any signs and symptoms after undergoing examination by a neurologist.

Inclusion and exclusion criteria

Inclusion

Employment at the plant in 2022

Exclusion

- Age >60 years
- History of head injury

Data Collection

Data was collected from health facility records in the study area and from UTH to identify cases and create

a line list. A structured questionnaire will be used to collect information on demographics, exposure factors, symptoms, and usage of personal protective equipment (PPE).

Sample Size Determination

A complete enumeration of all the suspected cases will be carried out to determine the sample size. For every case collected, two controls will be selected.

Data Analysis and Management

Data will be exported from the Kobo toolbox into R version 4.1.3, which will be used for data analysis. Means and standard deviations will be done for continuous variables while frequencies and percentages for categorical variables. Logistic regression at 95% confidence intervals will be used to assess the factors associated with the development of Manganese toxicity among miners.

Ethical Considerations

The proposal has been reviewed and approved by the Eres Research Converge Review Board. Permission to conduct the study has been obtained from the National Health Research Authority. Informed consent will be obtained from everyone who is to participate in the study. Data collected will be de-identified and maintained on an encrypted hard drive.

Results

A total of 62 participants were included in the study: 20 cases and 42 controls (Table 1). All participants in the study were male, with the age group 20-29 (60%) having the most participants. Seventy-seven per cent (77%) of the participants were married and had at least 1 child (29%). Most participants resided in Kanona area (84%), which is the area around the mine. Eighty-four per cent (84%) of participants had secondary education as the highest educational level and earned 2001 -3000 kwacha per month (71%). The mean age among cases was 29.5 years (range 25-33), and 5% aged 40-49 years, as shown in Figure 2.

Among the 62 participants (20 cases and 42 controls), cases had a longer median duration of employment compared to controls (5.0 years [IQR: 2.75–5.50] vs 2.5 years [IQR: 2.00–4.00], $p=0.009$). Similarly, cases had spent more time in their current section (median 4.0 years [IQR: 2.75–7.00]) than controls (2.0

years [IQR: 1.00–3.75], $p=0.002$). The distribution of work sections differed significantly ($p=0.007$), with a higher proportion of cases working in the deck (35% vs 12%) and raw material handling (35% vs 4.8%), while controls were more commonly found in tapping (33% vs 5%). Fewer cases had worked in other sections compared to controls (20% vs 48%, $p=0.037$).

Overtime frequency also differed, with 56% of cases reporting three overtime shifts per week compared to 11% of controls ($p=0.006$). Use of respirators was significantly lower among cases than controls (30% vs 76%, $p<0.001$), whereas surgical mask use was higher among cases (40% vs 12%, $p=0.019$). No significant differences were observed between cases and controls in hours per shift, workdays per week, overtime participation overall, safety training, or emergency training. From Figure 3, the earliest case was reported in December 2021 with a spike in September 2022. The last case was found during our data collection in March of 2023.

The multivariate analysis of factors associated with manganese toxicity among workers in the smelting plant revealed that working overtime for at least one hour per week was a significant risk factor (AOR = 2.40, 95% CI: 1.05-6.35, $p = 0.049$), suggesting that prolonged exposure increases the likelihood of toxicity. While several factors were significant in the bivariate analysis, including age group, duration of employment, working in other sections, and use of surgical masks, these associations were not maintained after adjusting for potential confounders. Notably, working in a section for at least one year showed a higher unadjusted odds ratio (UOR = 1.37, $p = 0.007$), but this association weakened in the adjusted model (AOR = 1.52, $p = 0.355$), indicating that other workplace factors may influence exposure risk.

The use of respirators was a strong protective factor, significantly reducing the odds of manganese toxicity (AOR = 0.07, 95% CI: 0.01-0.51, $p = 0.015$), highlighting the effectiveness of respiratory protective equipment in mitigating exposure. Conversely, surgical mask use, which was associated with increased toxicity in the unadjusted analysis (UOR = 4.93, $p = 0.016$), was not significant in the adjusted model (AOR = 1.03, $p = 0.982$), suggesting it offers limited protection against manganese exposure.

Discussion

The purpose of this study was to investigate the possible association between occupational risk factors and the development of manganese toxicity. The study population was workers in a selected manganese smelting plant located in Serenje district, Zambia. Additionally, this study aimed to understand the smelting process of manganese and understand the factors that led to a large delay in reporting manganese toxicity.

Symptoms most common among participants included chest pain and this is the cause of concern in the view that manganese dust exposure is through the respiratory system [5]. A study by Cowan et al. identified that acute manganese exposure leads to a condition known as metal fume fever which is characterised by upper respiratory tract irritation, flu-like symptoms and motor deficits [6]. These symptoms can be alleviated upon removal from exposure. During the early stages of progressive manganese toxicity, symptoms can include lower limb weakness, difficulty walking, headaches and difficulty talking, which were seen in most of the cases in the study. These symptoms are generally reversible if exposure is reduced or eliminated [6]. A combination of motor deficits and psychological disturbances is more common with chronic exposure [6]. Established movement disorders are more common in the late stages characterized by bradykinesia, gait disturbances, cock-walk, cogwheel rigidity and in worst cases, permanent and complete disability [6].

Wang et al. identified that chronic low-level occupational manganese exposure is more prevalent among smelters, welders, and dry-cell battery production workers which can lead to irreversible damage to neurological structures [7]. This study revealed that those in close contact with the raw materials in sections such as raw material handling have an increased risk of developing manganese toxicity. This is further established by the increased odds of developing manganese toxicity if one works in a section for a longer period. On the other hand, this study has revealed that having worked in a second section of the smelting plant reduces the risk of developing manganese toxicity. Prolonged exposure occurred in those who worked 3 days or more of overtime per week and overtime of any kind has an increased risk of developing manganese toxicity.

This study revealed that the use of respirators reduces the risk of developing manganese toxicity among workers in the selected manganese smelting plant. Marit et al. further establish that the use of respirators, irrespective of the type, reduces the risk of occupational dust among workers [8]. However, even in a situation when respirators are provided, most workers might not use them if they are uncomfortable, unpractical and when there is a low understanding of the risk being prevented [8].

Limitations

The study was without limitations, which included a small sample size. There was also the potential for recall bias in PPE reporting. There was also limited environmental monitoring during the peak exposure period.

Conclusion

This study has revealed the risk factors that increase the odds of workers in a manganese smelting plant developing manganese toxicity. These include working for prolonged periods in sections that handle the source material such as deck and raw material handling. The study has also shown that the use of PPE such as respirators reduces the risk of developing manganese toxicity.

This study has also shown symptoms commonly associated with manganese toxicity such as lower limb weakness, joint pains and impaired sexual function. The study has also shown that most controls complained of chest pains, and this might warrant further investigation due to the respiratory exposure route of manganese dust.

The study has also revealed a loophole in symptom identification among health facilities near the selected smelter in suspecting a case of manganese toxicity. Their study revealed that the yearly medical examinations of workers are not focused on manganese toxicity. A loophole in the licencing procedure was seen in the study as the mine has no obligation to report a change in the process such as introducing a new raw material such as manganese powder.

In conclusion, working in a manganese smelting plant has many risks apart from manganese exposure. It is therefore vital that proper PPE is used, and exposure is

reduced by proper ventilation systems and shuffling of workers between different sections of the plant.

7. Compensation for workers with severe symptoms of Manganese toxicity.

Recommendations

1. Medical examinations of workers at mine before they start work.
2. Training of hospital staff in areas around manganese smelting plants in early manganese toxicity symptoms and investigations to be carried out.
3. Improve surveillance of occupational incidents by integrating the work of different departments involved in occupational health.
4. Training of workers in the importance of using PPE such as respirators
5. Reduction in number of overtimes allowed per week.
6. Decentralization of different parties in the management of occupational incidents to the district level to encourage more coordination.

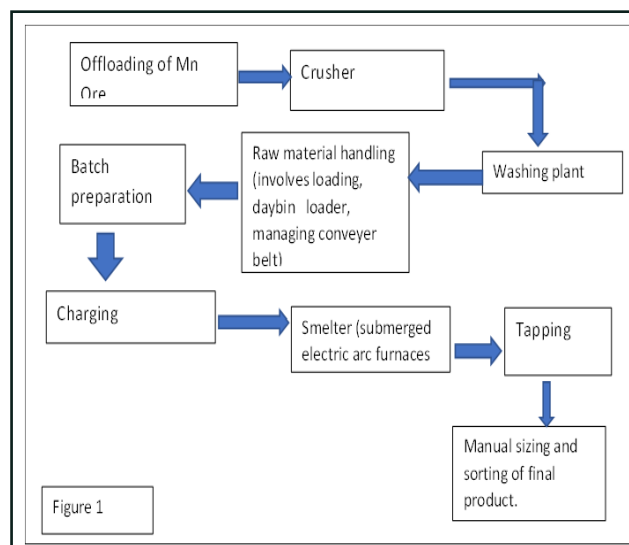


Figure 1: Processing procedure of manganese smelting plant in Serenje, 2022

Table 1: Demographic characteristics of participants in Manganese toxicity study in Serenje district, 2022.

Participants				
Variable	Total (N = 62)1	Case, N = 201	Control, N = 421	p-value2
Age (yrs.)	29.0 (25.0, 33.0)	29.5 (26.5, 33.5)	27.5 (25.0, 33.0)	0.7
Sex				
Male	62 (100%)	20 (100%)	42 (100%)	
Marital status				>0.999
Married	48 (77%)	16 (80%)	32 (76%)	
Single	14 (23%)	4 (20%)	10 (24%)	
Number of children				0.016
0	13 (21%)	3 (15%)	10 (24%)	
1	18 (29%)	3 (15%)	15 (36%)	
2	11 (18%)	3 (15%)	8 (19%)	
3	8 (13%)	6 (30%)	2 (4.8%)	
4	6 (9.7%)	4 (20%)	2 (4.8%)	
5	3 (4.8%)	0 (0%)	3 (7.1%)	
6	1 (1.6%)	1 (5.0%)	0 (0%)	
7	2 (3.2%)	0 (0%)	2 (4.8%)	
Religion				>0.999
Christian	61 (98%)	20 (100%)	41 (98%)	
Not religious	1 (1.6%)	0 (0%)	1 (2.4%)	
Residence				0.023
Kabwe	1 (1.6%)	1 (5.0%)	0 (0%)	

Kanona	52 (84%)	13 (65%)	39 (93%)	
Kundalila	4 (6.5%)	3 (15%)	1 (2.4%)	
Mafwasa	2 (3.2%)	1 (5.0%)	1 (2.4%)	
Mukando	1 (1.6%)	1 (5.0%)	0 (0%)	
Mwifumba	2 (3.2%)	1 (5.0%)	1 (2.4%)	
Monthly income				0.296
1001 - 2000	7 (11%)	3 (15%)	4 (9.5%)	
2001 - 3000	44 (71%)	16 (80%)	28 (67%)	
Less than 1000	1 (1.6%)	0 (0%)	1 (2.4%)	
More than 3000	10 (16%)	1 (5.0%)	9 (21%)	
Highest educational level				0.85
Primary school	7 (11%)	3 (15%)	4 (9.5%)	
Secondary school	52 (84%)	16 (80%)	36 (86%)	
Tertiary (university/college)	3 (4.8%)	1 (5.0%)	2 (4.8%)	
¹ Median (IQR); n (%)				
² Wilcoxon rank sum test; Fisher's exact test				

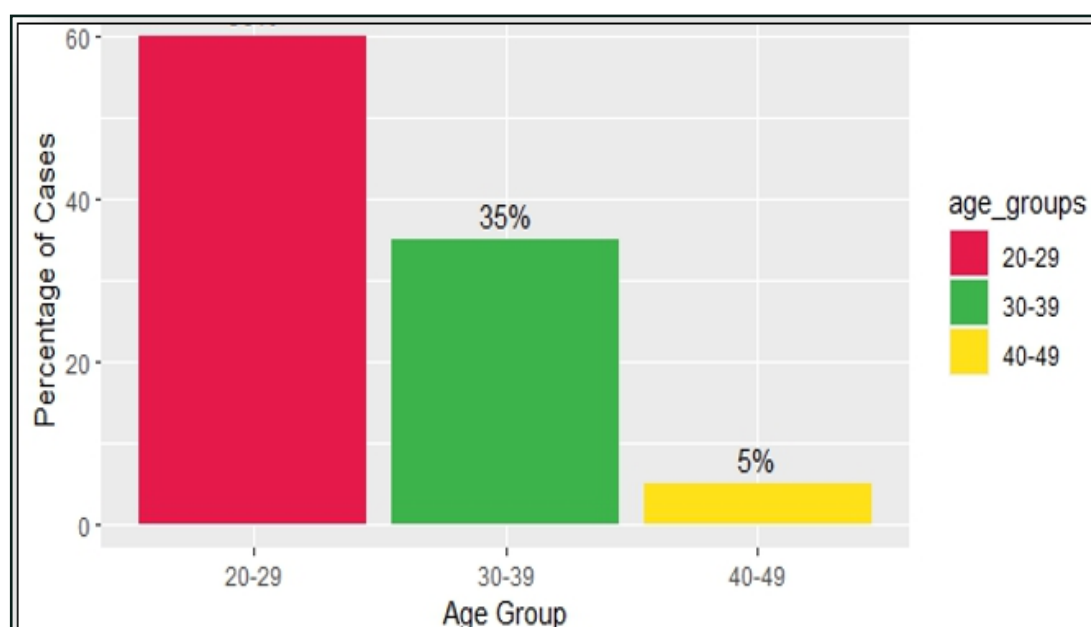


Figure 2: Distribution of age groups among cases in Manganese toxicity study in Serenje, 2022

Table 2: Descriptive Statistics of Participants in Manganese Toxicity study in a Selected Manganese smelting firm in Serenje district, 2022.

Participants				
Variable	Total (N = 62) ¹	Case, N = 201	Control, N = 421	p-value ²
Duration of employment (yrs.)	3.00 (2.00, 5.00)	5.00 (2.75, 5.50)	2.50 (2.00, 4.00)	0.009
Section of work				0.007
Batching	9 (15%)	3 (15%)	6 (14%)	
Chipping Yard	1 (1.6%)	0 (0%)	1 (2.4%)	
Coke crusher	1 (1.6%)	0 (0%)	1 (2.4%)	
Deck	12 (19%)	7 (35%)	5 (12%)	
Laboratory	1 (1.6%)	0 (0%)	1 (2.4%)	
Mechanical	8 (13%)	2 (10%)	6 (14%)	
Raw material handling	9 (15%)	7 (35%)	2 (4.8%)	
Safety	1 (1.6%)	0 (0%)	1 (2.4%)	
Stores	3 (4.8%)	0 (0%)	3 (7.1%)	
Tapping	15 (24%)	1 (5.0%)	14 (33%)	
Washing plant	2 (3.2%)	0 (0%)	2 (4.8%)	
Duration in section (yrs.)	2.71 (1.35, 4.00)	4.00 (2.75, 7.00)	2.00 (1.00, 3.75)	0.002
Worked in other section	24 (39%)	4 (20%)	20 (48%)	0.037
Hours per shift				>0.999
8	61 (98%)	20 (100%)	41 (98%)	
9	1 (1.6%)	0 (0%)	1 (2.4%)	
Workdays/week				0.491
5	1 (1.6%)	0 (0%)	1 (2.4%)	
6	58 (94%)	18 (90%)	40 (95%)	
7	3 (4.8%)	2 (10%)	1 (2.4%)	
Overtime	54 (87%)	19 (95%)	35 (83%)	0.258
Overtime /week				0.006
1	19 (36%)	3 (17%)	16 (46%)	
2	13 (25%)	3 (17%)	10 (29%)	
3	14 (26%)	10 (56%)	4 (11%)	
4	5 (9.4%)	1 (5.6%)	4 (11%)	
7	1 (1.9%)	1 (5.6%)	0 (0%)	
8	1 (1.9%)	0 (0%)	1 (2.9%)	
(Missing)	9	2	7	
Safety measures training	31 (50%)	10 (50%)	21 (50%)	>0.999
Emergency training	28 (45%)	9 (45%)	19 (45%)	0.986
Respirators	37 (61%)	6 (30%)	31 (76%)	<0.001
(Missing)	1	0	1	
Face shield	6 (9.8%)	4 (20%)	2 (4.9%)	0.084

(Missing)	1	0	1	
Surgical mask	13 (21%)	8 (40%)	5 (12%)	0.019
Cloth mask	3 (4.8%)	1 (5.0%)	2 (4.8%)	>0.999
1Median (IQR); n (%)				
2Wilcoxon rank sum test; Fisher's exact test; Pearson's Chi-squared test				

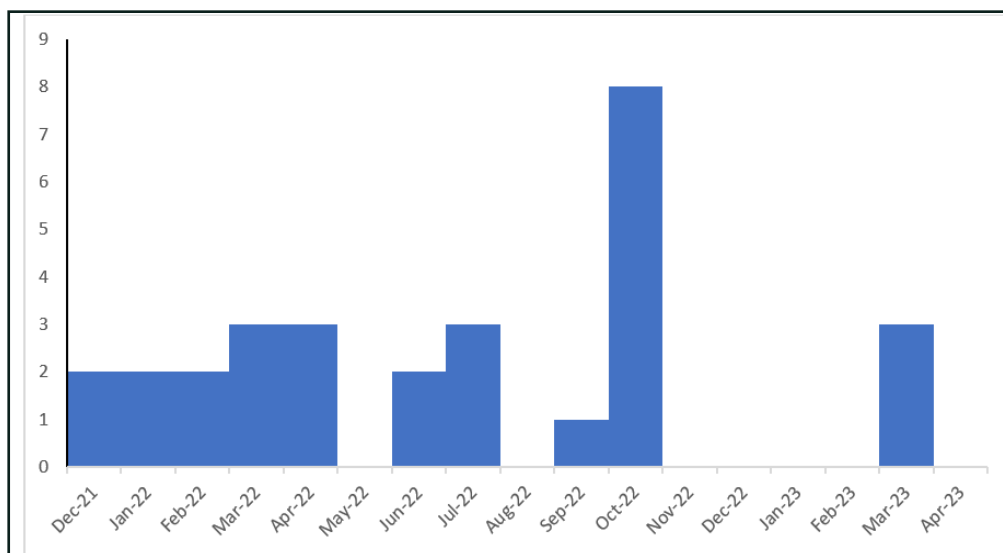


Figure 3: Epicurve of Suspected Manganese (Mn) toxicity among mine workers in a selected Manganese smelting plant in Serenje, 2022

Table 3: Multivariate analysis (unadjusted and adjusted odds ratios) of Manganese toxicity study in a selected Manganese smelting plant in Serenje, 2022

User Characteristics	Bivariate		Multivariate	
	UOR (95% CI)	p-Value	AOR (95%CI)	p-Value
Age group				
20-29	1 (Reference)		-	-
30-39	1.04 (0.33-3.25)	0.037*	-	-
40-49	1.04(0.09-12.6)	0.944	-	-
Duration of employment (yrs)				
0	1(Reference)		1(Reference)	
≥1	1.28(0.09-12.6)	0.025*	0.72(0.22-1.50)	0.48
Duration in section(yrs)				
0	1(Reference)		1(Reference)	
≥1	1.37(1.09-1.72)	0.007*	1.52(0.79-5.15)	0.355
Worked in other section				
No	1(Reference)		1(Reference)	
Yes	1.32(0.08-0.96)	0.043*	0.47(0.05-5.96)	0.529

Overtime per week (days)				
0	1(Reference)		1(Reference)	
≥1	1.42(0.92-2.18)	0.107	2.40(1.05-6.35)	0.049*
Respirators				
No	1(Reference)		1(Reference)	
Yes	0.14(0.04-0.46)	0.001*	0.07(0.01-0.51)	0.015*
Surgical Mask				
No	1(Reference)		1(Reference)	
Yes	4.93(1.35-17.95)	0.016*	1.03(0.10-11.5)	0.982
*Statistically significant at 5% level				

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