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RISK MANAGEMENT OF MANGANESE (Mn) CONTAMINATION IN DRINKING WATER SOURCES

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ABSTRACT

Manganese (Mn) is a heavy metal that naturally exists in the environment and can contaminate drinking water sources through anthropogenic activities, particularly in agricultural areas. Long-term exposure to Mn levels above safe limits can lead to neurological disorders in humans. This study aims to analyze the risk management of manganese contamination in drinking water sources in Langkat District, North Sumatra. A cross-sectional study was conducted on 8 samples of well water and 209 respondents. Data collection included water sampling and neurological symptom assessment using the Q18 questionnaire. Risk analysis was carried out based on concentration exposure, body weight, and daily water intake to calculate the Risk Quotien (RQ). Manganese concentrations in water ranged from 0.991 mg/L–2.809 mg/L, exceeding the Indonesian Ministry of Health threshold of 0.1 mg/L. Six respondents experienced numbness, and four experienced palpitations. Risk management analysis showed a safe body weight at 36.26–141.81 kg, the safe length of residence ranged at 23.01–58.72 years, and safe Mn concentration at 0.62–2.78 mg/L. This study provides important scientific evidence for developing risk management strategies for manganese contamination in drinking water to prevent neurological issues in Langkat Regency. Recommendations were given to improve water quality monitoring and community health education.

Keywords: dringking water; langkat; manganese; neurological disorders; risk management; q18

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INTRODUCTION

Manganese (Mn) is a naturally occurring heavy metal and the fifth most abundant metal in the Earth's crust, following iron (Fe), aluminum (Al), copper (Cu), and zinc (Zn), accounting for approximately 0.1% of the Earth's mass (Azhari et al., 2017). The increasing demand for manganese, driven by industrial and agricultural applications, has raised concerns regarding its potential as an environmental contaminant. Globally, around 300–400 million tons of hazardous waste, including heavy metals, are discharged into water bodies each year (Jandieri et al., 2020).The presence of manganese in water sources, particularly groundwater, is often a result of both natural geological processes and anthropogenic activities such as industrial discharge, mining operations, and the excessive use of chemical fertilizers and fungicides (Prabowo et al., 2021; Joode et al., 2019). Studies in the United States have found manganese in 68–70% of groundwater systems, indicating its widespread distribution due to the natural abundance of manganese in rocks and soils (Environmental Protection Agency, 2020; Minnesota Department of Health, 2016).

Manganese is widely used in agriculture, primarily in the form of manganese sulfate ($MnSO_4$), an essential component of micronutrient fertilizers for crops such as rice, soybeans, maize, and sugarcane (Fauzi, 2021). However, overuse or mismanagement of such fertilizers, particularly in developing countries, has been linked to elevated manganese levels in groundwater, especially in rural areas where agriculture is intensive and regulations are limited (Husnain et al., 2016; Widowati et al., 2022). Studies in Costa Rica, for example, have

shown that households located near large-scale banana plantations exhibited significantly higher concentrations of Mn in drinking water, with values reaching 500 mg/L in some samples (Joode et al., 2019).Prolonged exposure to high levels of manganese in drinking water can lead to a range of adverse health outcomes, including neurological effects resembling Parkinson's disease (Lucchini et al., 2017), hepatotoxicity, and cognitive impairments in children (Kullar et al., 2019; Sakizadeh & Mirzaei, 2016). According to the United States Environmental Protection Agency (US EPA), the acceptable limit for manganese in drinking water is 0.05 mg/L, while the Indonesian Ministry of Health sets the maximum allowable concentration at 0.1 mg/L (Permenkes No. 2, 2023).

In Indonesia, the risk of manganese contamination is particularly high in agricultural regions such as Langkat Regency, North Sumatra, which ranks third in the province for agricultural land area (BPS Sumatera Utara, 2021). Preliminary surveys conducted in this region revealed manganese concentrations in groundwater ranging from 0.187 mg/L to 0.260 mg/L—exceeding national drinking water quality standards. Moreover, anecdotal reports from residents include symptoms such as numbness, tingling, and palpitations, which may be linked to chronic manganese exposure.Given the increasing concern over manganese-related health risks, especially in rural agricultural communities, it is critical to implement risk management strategies that reduce exposure. Such strategies should consider factors such as individual body weight, exposure duration and frequency, and environmental concentrations (Pahruddin, 2017). These efforts align with the Sustainable Development Goals (SDGs), particularly Goal 6, which emphasizes the importance of clean water and sanitation for all (WHO & UNICEF, 2021).this study aims to analyze manganese concentrations in household well water in agricultural areas of Langkat Regency and to evaluate the associated health risks to local residents. The findings will inform effective risk management approaches to ensure water safety and protect public health.

METHOD

This study applied an analytical approach with a cross-sectional design to examine the association between manganese (Mn) concentrations in drinking water sources and neurological disorders among residents in Langkat Regency, North Sumatra. Data collection involved both primary and secondary sources. Primary data included community characteristics, well characteristics, manganese concentrations in water samples, and neurological symptoms, while secondary data were obtained from relevant government agencies, such as demographic statistics and administrative maps.The study was conducted from January to March 2025 in purposively selected villages within Langkat Regency, chosen based on the largest agricultural land areas. Respondents were selected through purposive sampling with inclusion criteria: individuals aged 19 years or older, residents living in the area for at least three months, and those using well water as their primary source of drinking water.Primary data on neurological function were collected using the German version of the Q18 neurotoxic symptoms questionnaire, validated by Ihrig et al. (2001), which consists of 18 items measuring memory, mood, sensory disturbances, and cognitive function. A cut-off score of ≥5 affirmative responses for males and ≥6 for females was used to indicate potential neurotoxic symptoms. In addition, observations were conducted using the ARKL form to assess water intake, body weight, physical activity, and duration of residence.

Manganese exposure through drinking water was estimated using an oral intake formula that considers the concentration of Mn in water, daily intake volume, exposure frequency and duration, body weight, and average exposure time. The resulting intake value (mg/kg/day) was then used to calculate the Risk Quotient (RQ) by dividing it by the reference dose (RfD) set by the U.S. EPA. An RQ greater than 1 indicates a potential health risk from chronic manganese exposure. To manage this risk, strategies such as reducing manganese concentration in water, limiting exposure duration, or decreasing daily intake volume may be

implemented.Data entry and analysis were performed using statistical software. Univariate analysis was used to describe respondent and well characteristics. Bivariate analysis using simple logistic regression tested associations between independent variables (e.g., age, weight, water consumption, manganese concentration) and neurological symptoms. Multivariate analysis was performed using multiple linear regression, including variables with a p-value ≤0.25 from bivariate tests to identify dominant predictors.

RESULT

Analysis bivariate done with statistical tests simple logistic regression which aims For know and test connection between the independent variables (community characteristics and Mn concentration in wells) and the dependent variable (complaints of nervous disorders) .

Table 4
Analysis Results Bivariate Connection Characteristics of Society with Complaint Disturbance Nerve Function .

Variables	*p-value*	CI 95%		Coef
		Lower	*Upper*	
Age	0 , 0 0 1	14,729	22,445	18,587
Weight	0 , 001	-17,519	-8,349	-12,934
Length of Stay	0 , 0 0 1	17,233	24,002	20,628
Amount Water Consumption	0 , 001	0.33	0.504	0.419
Blood pressure	0 , 0 01	8,169	13,723	10,946
Concentration	0.001	242,173	429,409	335,791

Based on results analysis regression involving 209 respondents , there is connection significant between age and score disturbance nerves . Analysis results show mark p-value of 0.001 or more small from value α = 0.05. This is indicates that there is connection between age with disturbance nerves . Relationship weight with complaint disturbance function nerve show mark p-value of 0.013 or more small from value α = 0.05. This is indicates that there is connection between weight with disturbance nerves , increasingly tall the respondent 's weight , increasingly big possibility they experience disturbance nerves . Analysis results long term relationship with complaint disturbance function nerve show mark p-value of 0.001 or more small from value α = 0.05. This is indicates that there is connection between length of stay with disturbance nerve .

Analysis results connection amount water consumption with complaint disturbance function nerve show mark p-value of 0.001 or more small from value α = 0.05. This is indicates that there is connection between amount water consumption with disturbance nerves . Analysis results connection pressure blood with complaint disturbance function nerve show mark p-value of 0.001 or more small from value α = 0.05. This is indicates that there is connection between pressure blood with disturbance nerves . Analysis results connection Mn concentration in the well with complaint disturbance function nerve respondents who consume the water show mark p-value of 0.001 or more small from value α = 0.05. This is indicates that there is connection between Mn concentration with disturbance nerve .

Table 2.
Bivariate Analysis Results of the Relationship Between Community Characteristics and Concentration with Risk Question Scores.

Variabel	p-value	CI 95%		Koef
		Lower	Upper	
Age	0,001	14,729	22,445	18,587
Weight	0,001	-17,519	-8,349	-12,934
Length of Stay	0,001	17,233	24,002	20,628
Amount Water Consumption	0,001	0,33	0,504	0,419
Blood pressure	0,001	8,169	13.723	10,946

Based on the bivariate logistic regression analysis results presented in Table 2, several community characteristics were found to be significantly associated with the risk question scores, which serve as a proxy for the likelihood of experiencing nervous system disturbances. All examined variables demonstrated statistically significant associations, as indicated by p-values less than 0.05, suggesting that these factors may influence the risk of neurological complaints.Age exhibited a positive association with the risk scores (p = 0.001), with a coefficient of 18.587 and a 95% confidence interval (CI) ranging from 14.729 to 22.445. This indicates that as age increases, the likelihood of reporting nervous system disturbances also increases, aligning with existing literature that associates aging with heightened vulnerability to neurological issues. Weight showed a negative association (p = 0.001), with a coefficient of -12.934 and a 95% CI between -17.519 and -8.349. This suggests that higher body weight may be linked to a decreased risk of nervous system complaints, though the underlying mechanisms warrant further investigation. Length of Stay in the community was positively associated with risk scores (p = 0.001), with a coefficient of 20.628 and a 95% CI from 17.233 to 24.002. This implies that prolonged residence in the area may increase exposure to environmental factors contributing to neurological disturbances.Amount of Water Consumption also demonstrated a positive relationship (p = 0.001), with a coefficient of 0.419 and a 95% CI between 0.33 and 0.504. This finding may reflect increased ingestion of potential contaminants present in the water supply, necessitating further environmental assessments. Blood Pressure was positively associated with risk scores (p = 0.001), with a coefficient of 10.946 and a 95% CI ranging from 8.169 to 13.723. Elevated blood pressure may serve as both a marker and a mediator of increased risk for nervous system disturbances.

In summary, the analysis identifies age, length of stay, water consumption, and blood pressure as factors positively associated with increased risk scores for nervous system disturbances, while higher body weight appears to be inversely related. These findings underscore the importance of considering both individual and environmental factors in assessing neurological health risks within communities

DISCUSSION

Based on the characteristics of the population using well water as their drinking source in Langkat Regency, the majority of respondents are in the adult age group, with 85.6% aged between 25 and 64 years. The elderly group (≥65 years) only accounted for 7.7% of the respondents, while young adults (19-24 years) comprised 6.7%. These findings suggest that the majority of the population involved in this study are in their active and productive years. This aligns with previous research indicating that adults are more vulnerable to health issues influenced by environmental factors, including exposure to heavy metals (Damurgier, 2020).In terms of education, most respondents (50.2%) have completed senior high school, followed by 19.6% holding bachelor's degrees.

This reflects that the population in Langkat Regency has relatively good access to education. Higher education levels are generally associated with better health literacy, enabling individuals to better understand health risks, including the potential hazards of heavy metal exposure. However, approximately 7.2% of individuals have no formal schooling, highlighting a gap in health information dissemination. Consequently, improving health literacy is essential to ensure that the population understands the risks of heavy metal exposure, such as manganese (Mn) toxicity (Eni, 2023)The majority of respondents are engaged in farming (32.5%), with a significant proportion working as entrepreneurs (24%) or homemakers (11.5%). Farming as the predominant occupation indicates that most of the population depends on agriculture as their primary livelihood. Agricultural activities are often linked to environmental exposures that can impact health, including exposure to contaminated water (Järup, 2003).

Regarding income, most respondents have low to middle-range earnings, with more than 40% earning between IDR 1,000,000 and IDR 2,500,000. This suggests income inequality, which may affect access to healthcare services and overall quality of life. Research by Avanceña et al. (2021) revealed that low income exacerbates health disparities, a phenomenon also observed in this study.Regarding nutritional status, the majority of respondents (58.4%) fall within the normal weight category (45-65 kg), although a significant proportion is overweight (24.9%). A smaller percentage (11%) is underweight. These findings highlight concerns regarding nutritional health, which can affect neurological functions. Both underweight and obesity have substantial implications for metabolic disturbances, which influence the nervous system (Pirozzi et al., 2024).The analysis of water consumption habits reveals that nearly half of the respondents consume less than two liters of water per day (47.8%), while the remaining 52.3% consume more than two liters per day. The high water consumption observed among farmers, who often carry 2-liter water bottles while working, suggests that their daily activities lead to increased hydration needs. However, consuming contaminated water with heavy metals can pose significant health risks, including neurological damage (Latif et al., 2025).

The importance of managing water quality is reflected in the analysis of well water as a drinking source, which showed manganese (Mn) concentrations well above the acceptable standards. The highest concentration reached 2.809 mg/L, while the lowest was 0.991 mg/L, clearly indicating that the water quality in the area poses a health risk. Despite the high levels of contamination, the community remains unaware of the presence of heavy metals in their water, continuing to consume it, thus potentially increasing the risk of neurological disorders, particularly manganism, due to the bioaccumulation of manganese (Mn) in the body (Harischandra et al., 2019).The prevalent symptoms of neurological disorders, notably excessive fatigue, can be attributed to excessive manganese exposure. Oxidative stress induced by manganese affects the central and peripheral nervous systems, often manifesting in symptoms such as fatigue (Bansal et al., 2025). The tremor symptoms reported by only 12.4% of respondents indicate that, while some neurological symptoms are evident, the impact on motor function remains relatively limited. This finding is consistent with previous studies showing that exposure to heavy metals can lead to mild to moderate neurological symptoms (Okelberry et al., 2024).

Regarding the relationship between demographic characteristics and neurological complaints, the analysis revealed that age, body weight, length of residence, water consumption, and blood pressure were significantly associated with neurological complaints. Older age was found to increase the likelihood of neurological disorders, supporting findings by (Dumurgier & Tzourio,2020), which suggest that aging increases susceptibility to neurological damage. Furthermore, low body weight was inversely related to neurological complaints, aligning with research by (Pirozzi et al, 2024) that links low body weight to deficiencies in essential nutrients, which negatively affect neurological function.The duration of residence in contaminated areas was also found to correlate with neurological symptoms. Long-term exposure to heavy metals through contaminated drinking water exacerbates the risk of neurological disorders (Järup, 2003). High water consumption, while influenced by farmers' daily activities, also indicates ongoing exposure to hazardous substances, further exacerbating the risk of neurological damage (Latif et al., 2025).

High blood pressure, found in 69.9% of respondents, was also significantly linked to neurological disorders. Studies by (Hung et al,2024) have demonstrated that hypertension increases the risk of nervous system dysfunction, including cognitive decline and cerebrovascular diseases, which corroborates the findings of this study.Overall, the multivariate analysis confirmed that body weight, water consumption, and manganese concentration in drinking water significantly correlate with neurological dysfunction. This

emphasizes the importance of managing water quality, controlling heavy metal exposure, and improving lifestyle and dietary habits to enhance the neurological health of the population in Langkat Regency.

CONCLUSION

This study provides compelling evidence of a statistically significant relationship between prolonged exposure to manganese (Mn) in groundwater and the manifestation of neurological dysfunctions among residents of Langkat Regency. Multivariate logistic regression analysis identified key sociodemographic and environmental determinants namely age, body weight, duration of residence, daily water consumption, blood pressure, and Mn concentration in drinking water as predictors of increased neurological complaints, particularly symptoms such as chronic fatigue and reduced neuromuscular coordination.The findings underscore the multifactorial nature of environmentally induced neurotoxicity, where chronic exposure to heavy metals, exacerbated by physiological vulnerabilities and socio-economic disparities, culminates in measurable neurobehavioral impairments. Notably, the elevated Mn levels ranging from 0.991 mg/L to 2.809 mg/L far exceed internationally recommended thresholds and represent a critical environmental health hazard.

REFERENCES

Avanceña, A. L. V., DeLuca, E. K., Iott, B., Mauri, A., Miller, N., Eisenberg, D., & Hutton, D. W. (2021). Income and income inequality are a matter of life and death. American Journal of Public Health, 111(8), 1404–1408. https://doi.org/10.2105/AJPH.2021.306301

Bansal, A. S., Seton, K. A., & Brooks, J. C. W. (2025). Cognitive dysfunction in myalgic encephalomyelitis / chronic fatigue syndrome. [Journal Name if available], 1–21.

Damurgier, J., & Tzourio, C. (2020). Epidemiology of neurological diseases in older adults. Revue Neurologique, 176(9), 642–648. https://doi.org/10.1016/j.neurol.2020.01.356

Eni. (2023). Pengaruh tingkat pendidikan dan tingkat kesehatan terhadap produktivitas tenaga kerja di Kabupaten/Kota Se-Provinsi Lampung tahun 2017–2021 dalam perspektif ekonomi. Angewandte Chemie International Edition, 6(11), 951–952.

Fauzi, W. (2021). Studi mineralisasi mangan dan mineral bijih ikutannya pada daerah Paludda Kabupaten Barru Provinsi Sulawesi Selatan. Pharmacognosy Magazine, 75(17), 399–405.

Harischandra, D. S., Ghaisas, S., Zenitsky, G., Jin, H., Kanthasamy, A., Anantharam, V., & Kanthasamy, A. G. (2019). Manganese-induced neurotoxicity: New insights into the triad of protein misfolding, mitochondrial impairment, and neuroinflammation. Frontiers in Neuroscience, 13(JUN), 1–19. https://doi.org/10.3389/fnins.2019.00654

Hung, T. H., Chen, V. C. H., Chuang, Y. C., Hsu, Y. H., Wu, W. C., Tsai, Y. H., McIntyre, R. S., & Weng, J. C. (2024). Investigating the effect of hypertension on vascular cognitive impairment by using the resting-state functional connectome. Scientific Reports, 14(1), 1–15. https://doi.org/10.1038/s41598-024-54996-9

Husnain, Kasno, A., & Rochayati, S. (2016). Pengelolaan hara dan teknologi pemupukan mendukung swasembada pangan di Indonesia. Jurnal Sumberdaya Lahan, 10(1), 25–36.

Ihrig, A., Triebig, G., & Dietz, M. C. (2001). Evaluation of a modified German version of the Q16 questionnaire for neurotoxic symptoms in workers exposed to solvents. Occupational and Environmental Medicine, 58(1), 19–23. https://doi.org/10.1136/oem.58.1.19

Jandieri, G., Sakhvadze, D., & Raphava, A. (2020). Manganese biomining from manganese-bearing industrial wastes of Georgia. Journal of The Institution of Engineers (India): Series D, 101(2), 303–316. https://doi.org/10.1007/s40033-020-00235-0

Järup, L. (2003). Hazards of heavy metal contamination. British Medical Bulletin, 68(1), 167–182. https://doi.org/10.1093/bmb/ldg032

Joode, B. van W. de, Barbeau, B., Bouchard, M. F., Mora, A. M., Skytt, Å., Cordoba, L., Quesada, R., Lundh, T., Lindh, C. H., & Mergler, D. (2019). Manganese concentrations in drinking water from villages near banana plantations with aerial mancozeb spraying in Costa Rica: Results from the Infants' Environmental Health Study (ISA). Environmental Pollution, 215, 247–257.

Kullar, S. S., Shao, K., Surette, C., Foucher, D., Mergler, D., Cormier, P., Bellinger, D. C., Barbeau, B., Sauvé, S., & Bouchard, M. F. (2019). A benchmark concentration analysis for manganese in drinking water and IQ deficits in children. Environment International, 130(May), 104889. https://doi.org/10.1016/j.envint.2019.05.083

Latif, M., Nasim, I., Ahmad, M., Nawaz, R., Tahir, A., Irshad, M. A., Al-Mutairi, A. A., Irfan, A., Al-Hussain, S. A., & Zaki, M. E. A. (2025). Human health risk assessment of drinking water using heavy metal pollution index: A GIS-based investigation in mega city. Applied Water Science, 15(1), 1–19. https://doi.org/10.1007/s13201-024-02341-w

Lucchini, R., Placidi, D., Cagna, G., Fedrighi, C., Oppini, M., Peli, M., & Zoni, S. (2017). Manganese and developmental neurotoxicity. Advances in Neurobiology, 18, 13–34. https://doi.org/10.1007/978-3-319-60189-2_2

Okelberry, T., Lyons, K. E., & Pahwa, R. (2024). Updates in essential tremor. Parkinsonism and Related Disorders, 122(March), 106086. https://doi.org/10.1016/j.parkreldis.2024.106086

Pahruddin, M. (2017). Risiko pajanan logam berat pada air sungai. Jurnal Kesehatan Lingkungan: Jurnal dan Aplikasi Teknik Kesehatan Lingkungan, 14(2), 525–532. https://doi.org/10.31964/jkl.v14i2.47

Pirozzi, C., Opallo, N., Del Piano, F., Melini, S., & Lama, A. (2024). Body and mind: How obesity triggers neuropsychiatric and neurodegenerative disorders. Frontiers in Psychiatry, 15(January), 1–5. https://doi.org/10.3389/fpsyt.2024.1524555

Prabowo, R., Bambang, A. N., & Sudarno. (2021). Water quality index of well water in the converted agricultural land. Jurnal Pendidikan IPA Indonesia, 10(4), 560–570. https://doi.org/10.15294/jpii.v10i4.31790

Sakizadeh, M., & Mirzaei, R. (2016). Health risk assessment of Fe, Mn, Cu, Cr in drinking water in some wells and springs of Shush and Andimeshk, Khuzestan Province, Southern Iran. Iranian Journal of Toxicology, 10(2), 29–35. https://doi.org/10.32598/ijt.10.2.336.1

U.S. EPA. (2002). Drinking water health advisory for manganese. U.S. Environmental Protection Agency, Office of Water, Washington, DC. https://www.epa.gov/sites/default/files/2014-09/documents/support_cc1_magnese_dwreport_0.pdf

WHO & UNICEF. (2021). WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene. https://washdata.org/

Widowati, L. R., Hartatik, W., Setyorini, D., & Trisnawati, Y. (2022). Pupuk organik dibuatnya mudah, hasil tanam melimpah (I. Mutaqien & E. Kustanti, Eds.; 1st ed.). Kementerian Pertanian Republik Indonesia.