Cognitive performance and associated factors among primary school children in artisanal and small-scale gold mining communities in northwestern Tanzania

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ABSTRACT

INTRODUCTION Cognitive performance deficit remains a major public health problem in developing countries. Emerging evidence from the literature suggests environmental exposure to chemical substances influences neurocognitive development in children. The study determined the prevalence of cognitive deficits and associated factors among primary school children aged 8–12 years in artisanal and small-scale gold mining (ASGM) communities where exposure to toxic chemical elements is common.

METHODS A cross-sectional school-based study was conducted in areas with and without artisanal and small-scale gold mining in northwestern Tanzania between 2017 and 2018. Primary school children aged 8–12 years were examined for their cognitive ability using the Parent Rating of Everyday Cognitive and Academic Abilities (PRECAA). Linear regression was done to evaluate factors associated with cognitive performance.

RESULTS A total of 865 primary school children were recruited from areas with (n=412) and without (n=453) ASGM activities with almost equal distribution of boys and girls (51% vs 49%). Mild deficits in memory, coordination, language, learning, cognitive, and academic performance were 6%, 23%, 26%, 35%, 36.9, and 32%, respectively, were found among the pupils. Number of teachers per school (β=0.08, 95% CI: 0.05–0.11), number of children per school (β= -0.001, 95% CI: -0.0010 – -0.0004), and water availability (β= -0.63, 95% CI: -0.88 – -0.385) were significantly associated with cognitive performance ($p<0.0001$).

CONCLUSIONS Cognitive performance deficits among school children in all domains evaluated are a salient yet public health issue in northwestern Tanzania. High memory skills deficits among pupils in ASGM compared to their counterparts in non-ASGM communities call for immediate public health intervention. Reliable sources of water, teacher–children ratio, and children's nutrition status (measured by body mass index), significantly affected cognitive performance among the pupils. Early screening and educational intervention that address learning difficulties and cognitive deficits among the affected children are needed.

INTRODUCTION

Cognitive disability due to developmental neurotoxicity has emerged as an area of public health concern to maternal health and child development[1]. Cognitive disorders affect millions of children worldwide[1-3]. Studies have shown that cognitive disorders affect 10–15% of all births, and the prevalence of these disorders is increasing[4-6]. Developmental neurotoxicity is any adverse effect of exposure to a toxic substance on the normal development of nervous system structures and/or functions as defined by Tsuji and Crofton[7]. Neurodevelopmental disabilities include autism spectrum disorders, attention-deficit hyperactivity disorder, dyslexia, sensory deficits, mental disability, and learning disabilities, among other cognitive deficits[1-3].

Although genetic factors have a role in cognitive deficits, the current increase in the reported prevalence cannot be explained. Genetic factors account for 30–40% of all cases of cognitive deficits[5,8,9]. Research suggests that another cause of cognitive deficit is exposure to environmental chemicals. Evidence published to date supports the contention that environmental chemicals contribute significantly to cognitive deficits worldwide[10]. It is of interest and a driving motivation in addressing cognitive deficits due to increased exposure to environmental hazards such as toxic chemical elements due to different anthropogenic activities[1,3,5,6].

Toxic chemicals have become part and parcel of our daily lives, and cognitive deficits have been associated with several environmental contaminants, including heavy metals, anticonvulsant pharmaceuticals, organochlorine pesticides, polychlorinated biphenyls, toluene, and tetrachloroethylene. These contaminants have been shown to alter the developing brain and contribute to a rise in the prevalence of neurodevelopmental disorders[1,7,8]. Over the last decade, the number of confirmed developmental neurotoxicants that have been associated with impaired cognitive performance has doubled[1,7]. Evidence from the literature suggests that there are more than 200 chemicals that have been reported to cause brain injury in humans. In contrast, animal laboratory studies have indicated more than 1000 chemicals in use are neurotoxic[1,11]. Mercury, lead, arsenic, and other heavy metals have been shown to have neurotoxic effects and have raised concern in developing countries such as Tanzania, Ghana, Zimbabwe, and among others, following the escalation of artisanal and small-scale gold mining (ASGM) activities[10]. Many low- and middle-income countries (LMICs) have seen an explosive development of ASGM activities[12]. In Tanzania, ASGM provides approximately 15 million people with a livelihood and accounts for about 10% of the gold produced in the country[12]. Individuals who live near artisanal and small-scale gold mining areas in Tanzania are exposed to mercury (introduced by human activities for gold amalgamation) and to arsenic, lead, and cadmium, which are the constituents of most gold ores[13].

Tanzania has a significant number of individuals and communities involved in gold mining. It is estimated that 100 million people depend on ASGM, and about 20 million people worldwide are active ASGM miners[12,14]. Tanzania has the second largest population directly involved in ASGM (more than 1.5 million) in Africa[12,15]. In Tanzania, these activities started in the Lake Victoria region in 1894 and increased greatly through 1974–1975. The anthropogenic activities associated with artisanal gold mining pose a major environmental and public health threat to miners and the surrounding communities through the introduction of contaminants into the environment from the mining process[13]. The mining process increases the concentrations of naturally occurring minerals. One of the main environmental and health hazards caused by artisanal mining is the widespread release of mercury as well as the environmental exposure to arsenic, lead, and cadmium[13]. Although some metallic ions (e.g. copper, manganese, iron, and zinc) play key roles in human physiology, most toxic metals such as arsenic, mercury, lead, and cadmium are unnecessary and hazardous to humans even at the lowest trace levels[16]. Such toxic metals have been documented to cause adverse reproductive outcomes, neurological disorders, and developmental neurotoxicity in children[17].

The number of people either directly or indirectly employed in this sector continues to increase due to the increase in gold prices and also because of the limited number of other livelihood options in many rural areas of Tanzania[18]. Studies have shown that these activities are conducted haphazardly without regard to environmental, occupational, or community exposures[13,19]. Thus, individuals in ASGM communities may be exposed to toxic levels of arsenic and mercury through the water they drink, the food they eat, the soil that their food is grown in, and the air they breathe[12, 13,19-21].

Several studies have reported high levels of arsenic and mercury in urine, breast milk, blood, hair, and nail samples of individuals living in ASGM areas in Tanzania, and in fish samples obtained from lakes in these areas[19,20,22,23]. This is a public health concern; as such, exposure may impair cognitive performance and, in turn, may affect the absorption of important nutrients, which have been reported to have a direct impact on the cognitive development of the children[10,21,24]. It is of more concern that a significant number of people involved in ASGM are women of reproductive age, which is estimated to be 30–40% of women of reproductive age[12]. This increases the likelihood of exposure to these contaminants in fetuses and young children, and such exposure could be associated with impaired cognitive performance in children[10,25]. Recently, Nyanza et al.[10] reported significant neurodevelopmental deficits of up to 31% among infants prenatally exposed to toxic chemical elements in ASGM communities in northwestern Tanzania[10].

This study aims to compare cognitive performance and identify its associated factors among primary school children (aged 8–12 years) who live in areas with and without ASGM activities in mining or non-mining communities in north-western Tanzania.

METHODS

Study design and study settings

This cross-sectional school-based study was conducted in the Geita District, located in the Geita Region in northwestern Tanzania. According to the 2012 National Population and Housing Census, Geita District had a population of 807619

(400475 males and 407144 females) and children aged <18 years were 473006[26]. Except for the ASGM activities, most of the socioeconomic and sociodemographic activities in the recruited communities are similar to those detailed elsewhere[22]. School-aged children between 8–12 years were recruited from their purposively selected respective primary schools in Geita District, in northwestern Tanzania, during 2017–2018.

Study population and sampling strategy

The sample size was determined using the Whitley and Ball[27] formula, which used a 40% proportion of exposure to occupational and environmental substances and a marginal error of 10%. Three primary school children who consented to participate were excluded for medical reasons. The study intended to exclude school-aged children with recognized mental health disorders and those with congenital anomalies to avoid misinterpretation of results; however, there were no school-aged children with such cases. A total of 865 pupils were recruited to participate in this study (i.e. 412 from ASGM areas and 453 from non-ASGM areas. The class attendance registers were used as a sampling frame using alphabetically arranged names.

Six primary schools located in ASGM communities (Nyarugusu, Ziwani, Zahanati, Buziba, Iseni, and Mwenge) were selected to participate in the study. Systematic random sampling was used to recruit pupils attending classes using a class register. Four primary schools from communities in areas without ASGM activities (Ikandilo, Nyaruyeye, Nyawilimilwa, and Nyamilyango) were recruited to participate in the study. A structured questionnaire with closed and open-ended questions was administered to selected pupils from each school. The questionnaire was pre-tested in Chato District before actual data collection to assess the suitability of the questionnaire with regard to duration, language, appropriateness, content, validity, and question comprehensibility. A standardized checklist was used to capture some of the required details on nutritional status, cognitive performance, number of students at the school, and individual pupil performance based on average scores obtained during previous examinations.

Data collection procedure and data collection

Observations of the pupils everyday cognitive abilities were conducted by the class teachers, as individual children spend most of the daytime, five days a week, at their respective schools. Cognitive performance was evaluated in 6 domains (memory, coordination, language, learning, cognition, and academic ability). The procedure for data collection involved the use of structured questionnaires to collect sociodemographic characteristics of the children and anthropometric measurements (e.g. sex, age, weight, and height) as well as environmental factors, human resource factors, and the availability of potable water sources at schools.

Cognitive performance was measured in two aspects: 1) using class performance at the school level; and 2) using proxy measures and a questionnaire on cognitive performance adopted from parents' rating of everyday cognitive abilities among low birthweight children[28]. The prevalence of low birth weight in Geita is reported to be around 19.8%[23]. The Parent Rating of Everyday Cognitive and Academic Abilities (PRECAA) was developed and validated to assess the cognitive functioning of children aged 6–16 years and has been explained elsewhere[28]. The PRECAA had excellent internal consistency with an overall coefficient alpha of 0.98 and a person correlation for test-retest reliability ranging from 0.68 to 0.94[28]. In ASGM areas and most of the rural areas in Tanzania, school-aged children spend most of the time with their teachers rather than their parents. Children have to walk to and from their respective schools and spend the entire day with their teachers rather than their parents. Further, the 81 items of the PRECAA are intended to assess cognitive abilities, coordination, learning behavior, and academic skills[28], which are well covered in the school context by teachers where children spend most of their time.

Six complementary index subscales were used to measure cognitive performance that is important to achievement and is sensitive to specific learning disabilities. The comprehensive rating scales were available to allow teachers to rate the pupils on a daily basis cognitive performance skills, namely: memory skills, coordination skills, language skills, learning skills, cognitive skills, and academic skills. The PRECAA tool has a total of 81 responses excluding anthropometric measurements, where the number of items per domain were: memory 25, language 20, academic skills 16, coordination 14, cognitive function 11, and learning abilities 9. It should be noted that some items were used on more than one subscale. All responses for assessments were scored on a 5-point scale: whereby response number one describes how the child is good, 1 = 'not at all like this child' to 5 = 'extremely like this child', indicating that the behavior signals a serious problem. The Academic Skills subscale (e.g. reading, drawing) is also scored on a 5-point scale that ranges from 1 = 'superior ability' to 5 = 'very poor ability'. A comparison group of children living in areas without a history of ASGM activities was used to explore standard scores during the study. In addition, pupils body mass index (BMI, kg/m^2) as a measure of nutritional status was measured from weight and height. Two measurements were conducted for each parameter, and an average was calculated.

Data management and analysis

Data cleaning and analysis were done using Stata version 15.0 Stata Corp LP®. Categorical variables were summarized using frequencies and proportions. A choice to use means was made as the variables were normally distributed. Comparison of the sociodemographic characteristics of the participants from the mining and non-mining sites was

Table 1. Distribution of primary school children aged 8–12 years and respective teachers in selected schools in Geita (N=865)

Name of school	Number of children per school	Number of teachers per school	Children per teacher*
Nyarugusu	1451	28	52
Ziwani	1171	26	45
Zahanati	2377	41	58
Nyaruyeye	1236	14	88
Ikandilo	374	10	37
Buziba	1428	24	60
Iseni	600	12	50
Mwenge	2400	22	109
Nyawilimilwa	978	20	49
Nyamilyango	1092	22	50

*Recommended children per teacher in Tanzania: 50.

done using chi-squared tests for categorical variables and t-tests for continuous variables. Cognitive performance was determined on each of the six domains of the PRECAA (memory, coordination. language, learning, cognition, and academic performance). Cut-off Z-scores were used to classify school-aged children's cognitive performance compared to the unexposed normal population in non-ASGM communities as documented elsewhere10. A pupil's cognitive performance was categorized to have severe cognitive deficits (for those with a Z-score of less than < -2, mild cognitive deficits (for those with a Z-score ≥ -2 and < -1), and normal performance (for those with a Z-score of ≥ -1).

In addition to academic skills, academic performance assessment was also triangulated with the pupils' academic scores at their schools. The Z-scores were treated as continuous variables, and hence a t-test was used. To evaluate the nutrition status of the school-aged children, the percentile was compared with standards set by WHO BMI norms, which were further classified as underweight for <5.0 percentile, normal BMI for 5.0–84.9 percentile, and overweight for ≥85.0 percentile. Linear regression was done to evaluate factors that are associated with the average score. Variables found significant at crude analysis were put in the final model to adjust for confounders. The strength

Table 2. General characteristics of participating pupils aged 8–12 years and respective teachers in selected schools in Geita (N=865)

Characteristics	Total n (%)	Mining sites n (%)	Non-mining sites n (%)	p
Total	865 (100)	412 (47)	453 (52)	
Sex				0.491*
Boys	443 (51)	206 (50)	237 (52)	
Girls	422 (49)	206 (50)	216 (48)	
Age (year), mean (SD)				
Overall	10.7 (1.1)	10.9 (1.0)	10.5 (1.1)	<0.0001**
Boys	10.8 (1.1)	11.1 (1.1)	10.6 (1.2)	
Girls	10.6 (1.1)	10.7 (1.0)	10.4 (1.1)	
Availability of potable water sources at school premises				<0.0001*
Yes	517 (60)	307 (75)	210 (46)	
No	348 (40)	105 (25)	243 (54)	
Number of teachers, mean (SD)	20 (9)	25 (9)	15 (4)	<0.0001**
Number of pupils, mean (SD)	1336 (612)	1507 (622)	1180 (562)	<0.0001**
Body mass index (N=854)				
Underweight	171 (20)	84 (21)	90 (20)	<0.0001*
Normal	581 (68)	240 (59)	344 (77)	
Overweight	94 (11)	81(20)	15 (3)	

*Chi-squared test. **t-test.

of association was expressed with their 95% confidence intervals. Independent variables with $p<0.05$ in multivariable analysis were considered statistically significantly associated with the outcomes of interest. Age and sex were not found significant in crude analysis and, hence, were not included in the final model.

RESULTS

Overview of the selected schools according to clusters

This study involved 865 pupils aged 8–12 years (48% from ASGM communities, and 52% from non-ASGM communities), 443 boys and 422 girls. Pupils were recruited from the government schools in Geita District. More details on the sampled pupils per school and respective teachers are summarized in Table 1.

There was an almost equal distribution of boys and girls (51% vs 49%). The overall mean age of the participants was 10.7 (SD=1.1) years. The mean number of teachers per school was 20 (SD=9), while the mean number of pupils per school was 1336 (SD=612) (Table 2). The ASGM and non-ASGM communities were different in the general characteristics, including mean age of the pupils, potable water source from which pupils collected water for school use, number of teachers, number of pupils, and BMI ($p<0.05$). The schools were not different in the children's sex distribution ($p>0.05$) (Table 2).

Summary of the magnitude of impaired cognitive performance in selected communities

The deficits of cognitive performance among pupils were as follows: 6% (n=51) mild memory deficits, 23% (n=200) mild coordination deficits, 26% (n=225) mild language deficits, 35% (n=306) mild learning deficits, 0.5% (n=4) severe cognitive deficits while 36.9% (n=319) mild cognitive deficits, 1% (n=9) severe academic deficits, and 32% (n=277) mild academic deficits. Participants from the ASGM and non-ASGM communities were different in all the elements of cognitive deficit functions evaluated ($p<0.05$) (Table 3).

After adjusting for other factors, number of teachers per school (β=0.08, 95% CI: 0.05–0.11), number of pupils per school (β= -0.001, 95% CI: -0.0010 – -0.0004), and potable water availability at school (β= -0.63, 95% CI: -0.88 – -0.385)

Table 3. The magnitude of impaired cognitive performance among participating pupils aged 8–12 years in selected schools in Geita (N=865)

Variable	Total n (%)	Mining sites n (%)	Non-mining sites n (%)	p
Memory				0.005
Mild	51 (6.0)	34 (8.0)	17 (4.0)	
Normal	814 (94.0)	378 (92.0)	436 (96.0)	
Coordination				<0.0001
Mild	200 (23.0)	48 (12.0)	152 (34.0)	
Normal	665 (77.0)	364 (88.0)	301 (66.0)	
Language				<0.0001
Mild	225 (26.0)	81 (20.0)	144 (32.0)	
Normal	640 (74.0)	331 (80.0)	309 (69.0)	
Learning				<0.0001
Mild	306 (35.0)	86 (21.0)	220 (49.0)	
Normal	559 (65.0)	326 (79.0)	233 (51.0)	
Cognition				<0.0001
Severe	4 (0.50)	-	4 (1.0)	
Mild	319 (36.9)	102 (25.0)	217 (48.0)	
Normal	542 (62.7)	310 (75.0)	232 (51.0)	
Academic				0.0007
Severe	9 (1.0)	3 (0.70)	6 (1.3)	
Mild	277 (32.0)	110 (27.0)	167 (37.0)	
Normal	577 (67.0)	299 (73.0)	280 (62.0)	
Average, mean (SD)*	51.8 (17.6)	50.7 (19)	52.8 (16.2)	0.09

*The average refers to ...

Table 4. Linear regression crude and adjusted factors associated with cognitive performance among participating pupils aged 8–12 years in selected schools in Geita (N=865)

Factor	β (95% CI)	p	Adjusted β (95% CI)	p
Teachers and children per school				
Teachers	0.05 (0.04–0.07)	<0.0001	0.08 (0.05–0.11)	<0.0001
Children	0.00 (0.00–0.00)	0.013	-0.001 (-0.001 – -0.0004)	<0.0001
Availability of potable water sources at school premises				
Yes ®				
No	-0.80 (-1.050 – -0.557)	<0.0001	-0.63 (-0.881 – -0.385)	<0.0001
Mining status				
Mining site ®				
Non-mining site	-0.97 (-1.211 – -0.733)	<0.0001	-0.20 (-0.528–0.123)	0.223
Body mass index				
Underweight ®				
Normal	-0.20 (-3.173–2.768)	0.894	-1.9 (-4.8–1.0)	0.196
Overweight	-7.10 (-11.468 – -2.722)	0.002	-3.8 (-8.2–0.6)	0.09

® Reference categories.

were significantly associated with cognitive performance ($p<0.0001$) while ASGM status was not (Table 4).

DISCUSSION

Cognitive deficits status

This study involved 865 primary school children aged 8–12 years from 10 public primary schools in Geita District to assess the magnitude of impaired cognitive performance. The current study compared two communities, one with a history of ASGM activities and one without a history of such activities. The findings of this study indicate mild deficits in memory, language, learning, cognitive, and academic performance at 6%, 26%, 35%, 36.9, and 32%, respectively. Also, severe deficits were found regarding cognitive and academic performance by 0.5%, and 1%, respectively.

The current prevalence in some of the cognitive performance domains (language, learning, cognitive, and academic) is quite high among the studied school children in Geita compared to the general population of cognitive deficits of 10%[29]. This calls for attention to examine the underlying factors and improvise rehabilitation measures among the disadvantaged groups. Looking at learning deficits alone, the general cutoff, as documented elsewhere of 12.8%[29], is far below the current situation (35%). This implies that in all the domains, the primary school children in the Geita district are not performing well compared to other children in the world[29]. According to a study done in Taiwan, children with mild cognitive disorders were more likely to develop mental health problems in later life compared to their counterparts with normal cognitive performance[30].

Therefore, mild deficits documented in this study should be monitored carefully as they may result in severe forms of such deficits in adulthood, if intervention measures are not taken seriously. The current study indicates significant results regarding memory deficits among school-aged children in mining communities (8%) compared to non-mining communities (4%) ($p=0.005$). The effects of ASGM activities on cognitive performance have been explained in different studies affecting children worldwide[1,12,18]. This cognitive disability has been directly linked to developmental neurotoxicity which has emerged as an area of public health concern to maternal health and child development[18]. Research suggests that another cause of cognitive deficits, especially memory loss, has been directly linked to environmental chemicals such as mercury[10].

Studies conducted in Ghana and Zimbabwe highlighted the evidence that could potentiate cognitive deficits among communities exposed to toxic chemical elements[6-8]. The findings are also consistent with the results reported elsewhere that, even at low doses, chemicals such as mercury, lead, arsenic, cadmium, and their compounds can cross the placenta barrier and damage the developing fetus which in turn results in impaired cognitive performance in young children[9-11]. There is a need to examine how and why there is memory loss among the mining communities and to understand etiological causes to develop strong intervention means. It is also important to examine why school-aged children in ASGM communities perform better in the academic domain despite impaired memory function.

Contribution of sex and age differences with respect to cognitive performance

Even though other studies have indicated biological differences in cognitive performance in different populations between girls and boys[31], the current study did not find any significant difference in cognitive performance across all the domains studied (memory, language, learning, coordination, cognition, and academic domains) (p=0.491) by sex and age[29]. Sex and age have not been significantly mentioned to play a role in such deficits also in other studies[5,8,30].

Availability of potable water and pupils' cognitive performance

The current findings indicate a significant association between the availability of potable water sources at the school and general cognitive performance (p<0.0001) in both mining and non-mining communities. Several factors explain this finding: 1) school-aged children might be spending more time looking for water for different school uses and as a result less time is spent on academic activities; and 2) the water that is found in other premises away from the school might be contaminated by chemicals[3,13] and/or water-borne agents such as coliforms[16]; as a result school-aged children might be spending more time seeking medical care in addition to academic matters[17]. Studies have indicated the relationship between lack of clean and safe water supply with helminth infection which is associated with poor nutrition status and lower hemoglobin level[32]. In Tanzania, the availability of potable water at school has been reported to influence the improvement of adolescent girls' cognitive ability[33]. Studies among Philippines children aged 7–18 years, indicated helminth infection affects hemoglobin and nutrition status, which in turn affects cognitive performance[32]. There is a need to strengthen and increase water sources at the school level to minimize the need to search for water for school-aged children during class hours. Based on the study findings, further detailed epidemiological studies are needed, focusing on the relationship between the availability of water sources and academic performance.

Teacher–pupil ratio and cognitive performance

In different areas in Tanzania, the integral role that teachers play in providing a quality education for school-aged children and helping them achieve their academic goals has been recognized and stated[30]. The lack of a sufficient number of teachers may decrease the academic status of children[30,33]. According to the Ministry of Education standards, most of the primary schools in Geita District had an inadequate number of teachers per number of children, where a single teacher is expected to manage between 45 to 50 school-aged children.

The quality of the teachers and the level of motivation of these teachers were not assessed in this study. Some studies have suggested policies and initiatives to raise teachers' motivation levels to improve academic performance in Tanzania[30]. Of interest was that most of the schools in mining communities had enough teachers compared to the area with no mining activities. The current study's findings indicate a statistically significant contribution of an adequate number of teachers to pupils' performance. This might create disparities in cognitive performance in communities where the teacher–pupil ratio is inadequate compared to non-mining communities.

The factors that influence the large number of teachers allocated to mining areas were not assessed in this study. The findings indicate that 50% of the primary schools in Geita District had an insufficient number of teachers for the number of pupils according to the government's minimum requirements (50 pupils per teacher), highlighting the need for more human resource distribution in the district.

Nutritional status with respect to cognitive performance

The results from this study have shown a significant association between the nutritional status of the children and cognitive performance in the study area. The findings are supported by similar studies on the relationship between nutrition and cognitive performance among children, this is according to the study done in 1993 and 1999 in Philippines[34]. Poor nutritional status has been reported to be associated with impaired cognitive performance and may affect social and emotional development[6,17]. For instance, a carbohydrate deficiency can result in dizziness and mental confusion, whereas vitamins, magnesium, manganese, and minerals are important substances in brain function[6,17]. Also, iron deficiency anemia and folic acid deficiency have been reported to be associated with cognitive decline among adolescent girls[33].

It was reported that deficiency of some minerals, such as calcium, leads to failure to obtain adequate amounts of energy and other essential body elements that may lead to poor cognitive performance[13,17]. The findings have also been evidenced by other studies elsewhere that show stunting and children's cognitive development[16,17] are associated with inadequate uptake of essential nutrients. In this study, overweight was inversely related to cognitive performance (β= -3.8, 95% CI: -8.2–0.6). Pupils who were overweight had lower performance in cognitive ability. Similar findings have been reported elsewhere in the USA[32]. The epidemiological approach to nutritional issues is crucial and should be incorporated as a one-health approach aiming to improve the whole population's health.

The current findings on cognitive deficits call for adequate attention in the screening and treatment of biomarkers of cognitive deficits. This is vital as evidence from other studies has indicated that children with cognitive deficits have a greater risk of developing emotional problems later in life. It is important to learn that '*... learning disabilities are not a prescription for failure. With the right kinds of instructions, guidance, and support, there are no limits to what individuals with learning disabilities can achieve*'[35]. It is a higher need, therefore, for the Regional and Council Health management teams in the affected areas to consider developing a policy and/or regulations that will guide cognitive screening and rehabilitation in respective communities.

The present study is limited in a way that it was a school-based study and did not recruit school aged children from residents and/or homes. We may have missed some of the school children in the same age group due to absenteeism associated with being sick or any other family issues.

Strengths and limitations

The current study provides baseline data on the cognitive performance of school-aged children and associated factors in the targeted areas. This information is vital for developing a plan to improve pupils academic performance in ASGM areas in Tanzania and other areas with similar challenges. Our data supports the call for mitigation measures for promoting early stimulation among children and other health promotion strategies in ASGM areas, provided there is strong evidence for cognitive deficits. This study has several limitations. First, this was a school-based study and did not recruit pupils from residents and/or homes. Some of the school children in the same age group might have been missed due to absenteeism associated with being sick or other family issues. Secondly, we did not determine individual children's blood levels for toxic chemical elements. The exposure risk is based on ecological assessment, which could have either overestimated or underestimated the actual risk. However, human biomonitoring studies in northern Tanzania have revealed elevated prenatal levels of mercury (up to 72 μg/L), arsenic (up to 213 μg/L), cadmium (up to 1.5 μg/L), and lead (up to 145 μg/L) among pregnant women living in ASGM areas, which potentially could cause adverse developmental outcomes in early and later fetal life[10,22,23,36]. Similarly, evidence from ASGM in northwestern Tanzania has indicated individuals residing in such areas are continuously exposed to toxic chemical elements such as mercury, arsenic, lead, and cadmium via the water they drink, the soil from which they grow plants, the air they breathe, and from plants they eat[12,13,15,19,22]. The findings of this study cannot be generalized to all age groups of primary school-aged children in the district studied.

CONCLUSIONS

Participants from the ASGM and non-ASGM sites were different in all the elements of cognitive functions deficits (memory, language, learning, cognitive, academic) evaluated. Memory skills among school children in ASGM were significantly impaired compared to their counterparts in non-ASGM communities. School children residing in ASGM areas performed better in the academic domain than non-ASGM areas. Teacher–pupil ratio per school, the nutrition status of the individual children, assessed by BMI, and the availability of potable water sources at a school premise significantly affected pupils' cognitive performance. The use of screening tools for cognitive ability, such as the PRECAA, could provide information for early educational intervention that addresses learning difficulties and cognitive deficits among the affected children.

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DATA AVAILABILITY
The data supporting this research are available from the authors on reasonable request.

AUTHORS' CONTRIBUTIONS
Study conceptualization: ECN, JM and NK. Study design: ECN. Supervision of data collection, statistical analysis and interpretation of results: all authors. Assisting with writing of manuscript: ECN. Finalizing the manuscript: JM and NK. All authors read and approved the final version of the manuscript.

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