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Examining carcinogenic and noncarcinogenic health risks related to arsenic exposure in Ethiopia: A longitudinal study

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ABSTRACT

Background: The carcinogenic properties of arsenic make it one of the most hazardous chemicals globally. Nevertheless, the exact level of human exposure to arsenic and the associated risks of cancer and non-cancer effects through different pathways in Ethiopia are still uncertain.
Objective: The primary aim of this study was to evaluate the risk of both cancer and non-cancer outcomes among children and adults who have been exposed to arsenic through drinking water in the Adami Tulu Jido Kombolcha district of Ethiopia.
Methods: For this study, a longitudinal study design was employed. A total of 45 groundwater sources were sampled using the census sampling method. The concentrations of total arsenic were measured using Agilent 7900 series inductively coupled plasma mass spectrometry. Carcinogenic and noncarcinogenic risk assessments were conducted by calculating lifetime cancer risk and hazard quotients. Microsoft Office Excel was utilized to calculate human health risk indices, and descriptive statistical analysis were performed using SPSS software.
Results: Our findings revealed that during the dry season, the mean arsenic concentration in the groundwater samples was 11.15 ± 9.38 μg/L, while during the rainy season, it was 10.67 ± 8.16 μg/L. The total cancer risk for children, resulting from oral ingestion and skin contact, was 1.15×10^{-2} and 1.07×10^{-2} during the dry and rainy seasons, respectively. For adults, the total cancer risk from oral ingestion and skin contact during the dry and rainy seasons was 4.95×10^{-3} and 4.59×10^{-3}, respectively. Furthermore, the total hazard quotients for children via oral ingestion and skin absorption were 25.9 and 24.0 during the dry and rainy seasons, respectively. For adults, the total hazard quotients from ingestion and dermal contact during the dry and rainy seasons were 11 and 10, respectively.
Conclusions: The findings indicate that the risks of cancer and non-cancer effects resulting from arsenic exposure through ingestion and dermal exposure were found to exceed the acceptable thresholds in both seasons. These results emphasize the urgent need for focused attention on the study population in the study area due to the high likelihood of experiencing adverse health outcomes.

1. Introduction

Arsenic is a known carcinogen and one of the most dangerous chemicals in the world [1]. According to the ATSDR 2017 ranking, arsenic is the most toxic metalloid [2]. Likewise, the EPA, WHO, and IARC have also classified arsenic as a class I known human carcinogen [3–5]. Arsenic is a known human carcinogen that can harm human health even at low concentrations [6]. As a result, prolonged consumption of As, even at a low concentration, causes lung, bladder, liver, kidney, and skin cancers [7]. A population consuming high levels of As

Abbreviations: ABS, Absorption factor; AT, Average time; CDI, Chronic daily ingestion; CF, Conversion factor; CSF, Cancer slope factor; CR, Cancer risk; ED, Exposure duration; EF, Exposure frequency; ET, Exposure time; HQ, Hazard quotient; ILCR, Incremental lifetime cancer risk; Kp, Dermal permeability coefficient; RfD, Reference dose; SA, Skin surface area available for contact; TCR, Total cancer risk; THQ, Total hazard quotient; USEPA, Agency United States Environmental Protection Agency.

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in drinking water observed increased mortality from several internal cancers (lung, bladder, liver, and kidney) and a higher incidence of skin cancer [8]. Moreover, the WHO estimates that with long-term exposure, one in ten people who drink water containing 500 μg/l could eventually die due to arsenic-related lung, bladder, and skin cancer [4].

Apart from cancer, As causes a variety of adverse non-carcinogenic effects, including cardiovascular diseases [9–13], hypertension [14–16], respiratory [9], neurological [9,10,12], liver and kidney disorders [10,17], diabetes mellitus type 2 [9,11,18,19], mental disorders [9], hearing loss [9], memory loss [20–22], fetal loss and premature delivery [19,21], low birth weight [23], black foot disease [24,25], anemia [26–28], and male infertility [29], have been strongly linked to chronic exposure to arsenic at low concentrations. Likewise, exposure to arsenic in drinking water is known to cause peripheral neuropathy as well as hearing, visual, somatosensory, and other disorders in humans [30]. Arsenic can cross the placental barrier and harm the developing fetus [31]. Pregnant women who are exposed to drinking water contaminated with arsenic for long periods of time have a greater risk of miscarriage, premature birth, preterm birth in utero, and exposure in infancy [19,21]. Arsenic is also known to have cytotoxic and genotoxic effects in humans [32,33]. Arsenic toxicity also inactivates approximately 200 enzymes, particularly those engaged in DNA synthesis and repair and cellular energy pathways [27]. Therefore, arsenic is becoming a major public health concern worldwide due to its impact on human health [34].

The long-term effects of arsenic represent a serious health problem in developing countries, with limited research on its health effects, a lack of regular water quality monitoring, and the absence of water treatment technology to remove arsenic in affected areas. Several studies have shown that exposure to As, even at very low concentrations, is highly toxic to humans [35]. Therefore, arsenic is among the most important environmental toxins and pollutants worldwide, especially in developing countries. Arsenic contamination is undoubtedly a problem in many developing countries. However, the true extent of the problem, particularly in Africa, has yet to be fully understood or studied in depth. This is attributed to the limited research on arsenic. Likewise, the extent of arsenic exposure and its effects on human health have not been adequately studied in Ethiopia. Thus, arsenic remains a serious knowledge gap and needs more attention. Indeed, there are no published studies on the health risks associated with arsenic exposure in Ethiopia, particularly in the study area.

Therefore, this study aimed to assess the carcinogenic and noncarcinogenic risks of residents exposed to arsenic through ingestion and dermal contact in dry and rainy seasons in Adami Tulu Jido Kombolicha district, Ethiopia. The findings of this study provide important information that can help policymakers establish strong laws, policies, and strategies and take appropriate measures and interventions to protect the population in the study area and Ethiopia.

2. Materials and methods

2.1. Description of the study area

This study was conducted in Adami Tulu Jido Kombolicha District, East Shoa Zone, Oromia Region, Ethiopia. The district is located 115 km from Adama, the province's capital city, and 160 km from the capital city of Addis Ababa. The study area has a latitude and longitude of 7°56'N and 38°43'E, respectively, and the altitude ranges from 1500 to 2000 m above sea level [36]. The study area is bordered by the Arsi zone in the east, the Southern Nation and Nationalities People in the west, the Dugda Bora district in the north, and the Arsi Negele district in the south. Batu town is the district's capital city [37]. The study area is surrounded by Lake Ziway and predominantly consists of volcanic rocks associated with the rift system and sediments of different ages. Lake Ziway is fed primarily by the Meki and Ketar Rivers and drained to Lake Abijata through the Bulbula River. The lake provides water for domestic use for the rapidly expanding human population in Ziway City and surrounding areas and shares the same water table with key groundwater aquifers [38,39]. The main source of water supply in the study area is groundwater, which is supplementary to surface water for both urban and rural residents [37]. Furthermore, the area is an industrial zone; various fertilizers and chemicals used in horticulture, floriculture, and other industrial activities are directly released into the environment and Lake Ziway [40] (Fig. 1).

2.2. Study design and study periods

A prospective longitudinal study design was employed for this study. In addition, a laboratory-based study was conducted to determine the As content in the groundwater. During two seasons, we repeatedly collected samples from 45 groundwater sources: the dry season (winter) from June 5th to 9th, 2022, and the rainy season (summer) from September 25th to 29th, 2022.

2.3. Sample size determination

The census sampling method was used to collect water samples from groundwater sources in the study area to assess the magnitude of arsenic exposure and associated health risks. All public and private wells in the study area were included in the longitudinal study in both the dry season (winter) and the rainy season (summer). In two cycles, during the dry and rainy seasons, water samples were repeatedly taken from 27 deep wells, 11 shallow wells, and seven hand-dug wells. During the first cycle, 45 groundwater samples were collected from June 5–9, 2022. Likewise, in the second cycle from September 25th to 29th, 2022, 45 groundwater samples were taken from previously selected water sources. A total of 90 groundwater samples were collected from deep, shallow, and hand-dug wells.

2.4. Sample collection and storage

Water samples were collected from all public and private wells for this study. A total of 90 groundwater samples (27 deep wells, 11 shallow wells, and seven hand-dug wells) were taken during the dry and rainy seasons. After several pumpings (15 to 20 times), the samples were collected to remove standing water and impurities. A tightly capped 100-ml polyethylene bottle treated with HNO_3 and distilled water was used for sample collection. Before sampling, each container was washed with 2 % nitric acid and rinsed with deionized water [41]. Sample bottles were properly labeled prior to collection at each sampling site. Immediately after collection, samples were stored in freezers at 4 °C in the field and transported to the Ethiopian Public Health Institute laboratory with a cold box. Samples were stored in a freezer at −20 °C until analysis. Global positioning data was obtained from all sampling sites using a portable Garmin GPS device to locate the sampling positions (Fig. 2).

2.5. Sample preparation, processing, and analysis

The frozen water samples were thawed at room temperature for sample preparation. Then, 2 ml of concentrated nitric acid (70 % Sigma-Aldrich) per 100 ml of sample water was added to acidify the samples. The acidified water samples were filtered using 0.2 μm syringe filters, and 14 ml of the filtered water sample was added to a Falcon tube. Finally, the digested water samples were refrigerated at 4 °C before analysis [41]. Similarly, a blank was prepared for the water samples using the same procedures but without a water sample for quality control. Total As concentrations in groundwater samples were determined using Agilent 7900 series inductively coupled plasma-mass spectrometry (ICP-MS) at the Ethiopian Food and Drug Authority Laboratory. The calibration curve was constructed by analyzing various concentrations of standard solutions.

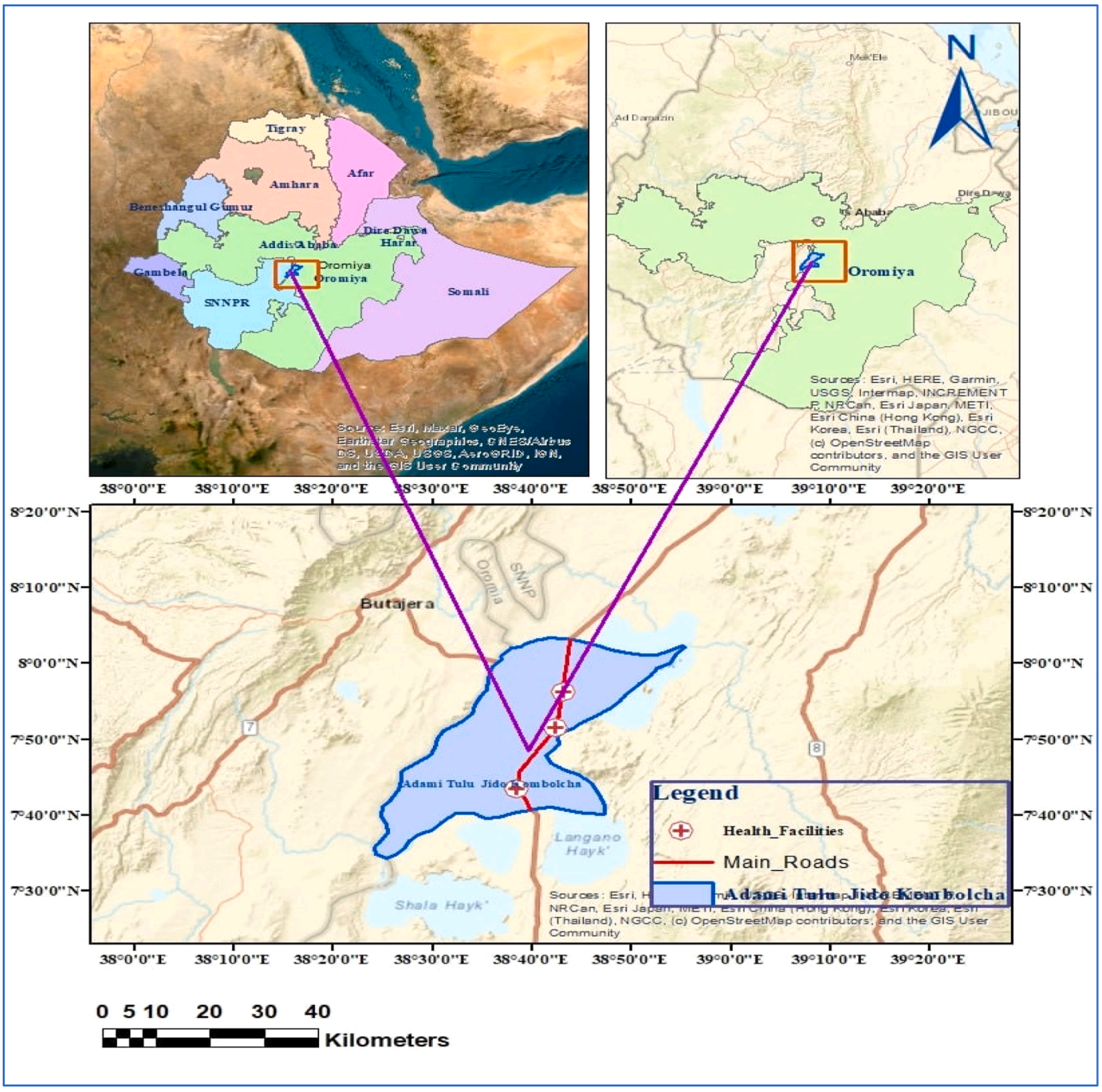

Fig. 1. Location map of the study area.

2.6. Chemicals and reagents

Analytical grade Ar (99.999 %), nitric acid (70 %) (Sigma-Aldrich, USA), and hydrochloric acid (37 %) (Sigma-Aldrich, USA) were used in the study. All working solutions were prepared in 0.5 % HNO3 using high-purity deionized water.

2.7. Statistical analysis

In this study, the human health risk assessment indices were calculated using Microsoft Office Excel, version 2022. Furthermore, statistical analyses such as mean and standard deviation were performed using SPSS software version 27 (IBM Corporation, USA).

2.8. Quality control and assurance

Background contamination was monitored using blank samples. The manufacturer's operating procedure was strictly followed during the analysis. All glassware used during the analysis was cleaned by soaking in 10 % HNO3 overnight and rinsing several times with distilled water. Then, the bottles were dried and sealed at room temperature before use. Analytical accuracy and precision were monitored throughout the laboratory analysis. Analyzing the blank samples in each batch ensured the accuracy of the analytical results. The accuracy of the measurements was assessed by calculating the yields of the certified reference materials. Standard reference solutions with a known arsenic concentration (spiked solution) were used as control samples to check the accuracy of the measurements. A control sample was tested after each batch of ten

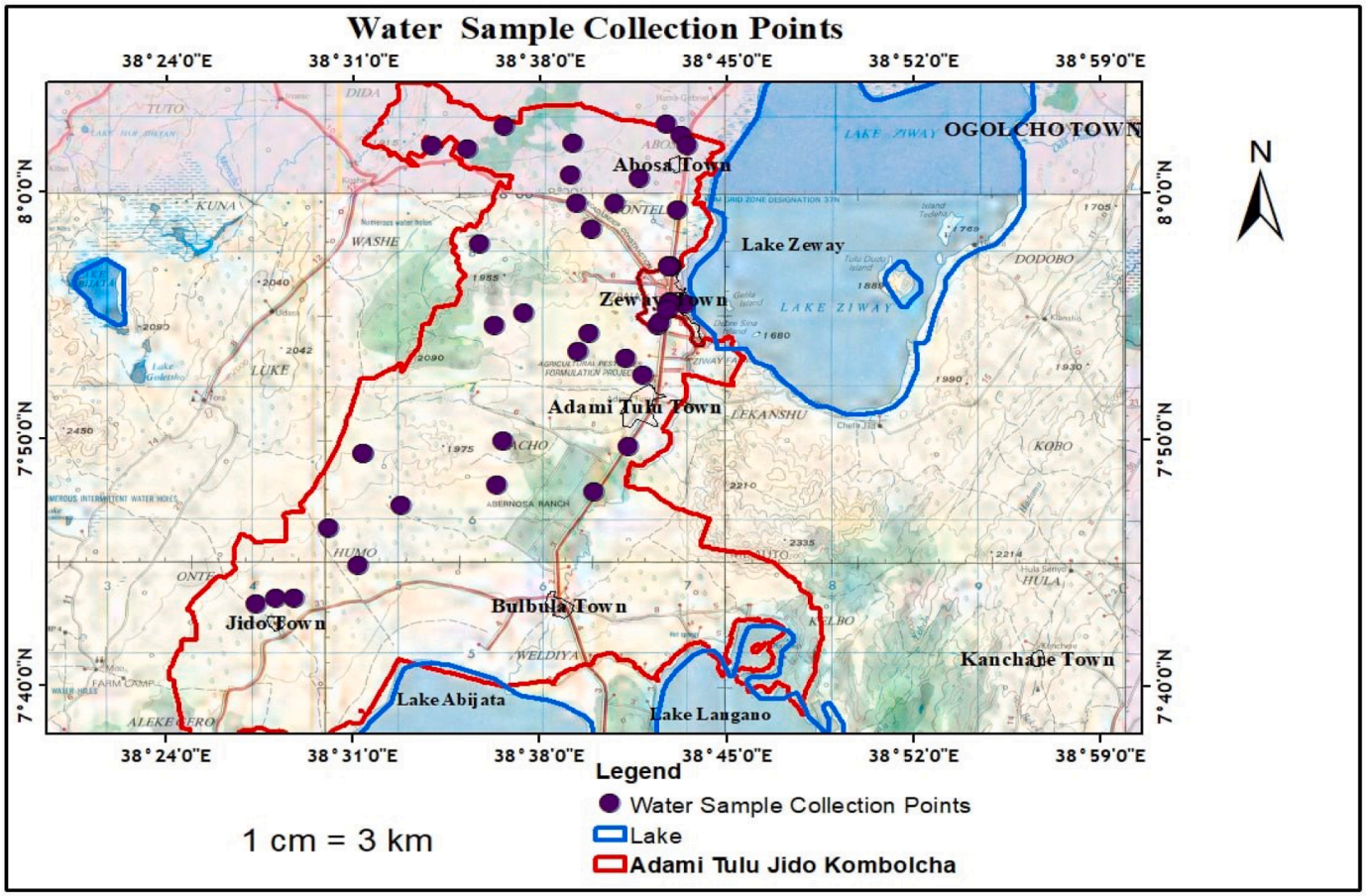

Fig. 2. Water sample collection points (sampling stations).

samples to verify the accuracy of the analysis. The recovery rate was 111.3 %. The acceptable recovery rate was between 80 % and 120 %, and the results of the samples tested were within the acceptable ranges [42].

2.9. Human health risk assessment

Human health risk assessment assesses the extent, type, and likelihood of adverse health effects on individuals exposed to chemicals in polluted environmental media [43]. Currently, human health risk assessment is one of the best approaches to studying the potential risk of human exposure to heavy metals. It provides vital information for public health researchers and policymakers to minimize the risk among the affected population [44]. The health risk assessment of each pollutant is generally carried out based on a risk assessment level and categorized as carcinogenic or noncarcinogenic risks [45]. The USEPA has developed a methodology for evaluating the carcinogenic and noncarcinogenic effects attributed to heavy metals [46]. In this study, a human health risk assessment was conducted based on the USEPA methodology. The USEPA methodology is often used to assess the risk of metal exposure through different exposure routes [47].

In this study, the carcinogenic and non-carcinogenic risks from ingestion and dermal contact with groundwater during the dry and wet seasons were evaluated using a protocol established by USEPA [46]. The carcinogenic risk was determined using the reference dose and cancer slope factor [49–51], while the noncarcinogenic risk was assessed using the chronic daily intake and reference dose [47]. Furthermore, the total non-carcinogenic risk was computed as the sum of HQ_{der} and HQ_{ing}. Thus, the chronic daily intake (Eqs. 1 and 2), the cancer risk (CR) (Eqs. 4–6), and the noncarcinogenic hazard quotient (HQ) (Eqs. 7 and 8) were used to assess the risks to human health. The target groups of this study were children and adults.

2.9.1. Exposure assessment

EPA defines exposure assessment as a technique for measuring the level, frequency, and length of human exposure to a substance or estimating future exposure to a substance that has not yet been released into the environment [49]. The two main routes of exposure considered in this study were ingestion (drinking) and skin contact (dishwashing and bathing). The exposure assessment aimed to estimate the extent to which the population in the study area was exposed to As through ingestion and dermal contact with As-contaminated water. Therefore, the chronic daily intake was calculated from groundwater intake and skin contact using Eqs. (1) and (2), respectively [46,52].

$$CDI_{ing} = \frac{CW \times IR \times ABS \times EF \times ED}{BW \times AT} \quad (1)$$

$$CDI_{der} = \frac{CW \times SA \times Kp \times ABS \times ET \times EF \times ED \times CF}{BW \times AT} \quad (2)$$

Where; CD_{Iing} and CD_{der} represent the chronic daily intake via drinking and skin absorption (mg/kg/day), respectively. CW is As concentration (μg/L); IR is the average daily water consumption (L/day) (2 liter/day for adults; 1 liter/day for children); the EF corrospondes to the frequency of exposure (365 days/year); ED is the duration of exposure (70 years for adults and 10 years for children); BW refers to average body weight (15 kg for children; 70 kg for adults); AT is the averaging duration (365 days/year x 70 years for an adult; 365, days/year x 10 years for a child); SA is the surface area of the skin exposed to water (18,000 cm^2 for adults; 6600 cm^2 for children); Kp is the dermal permeability

coefficient in water (cm/h) and 0.001 for As; ET is the exposure time (0.58 h/day for adults; 1 h/day for children) and CF is the unit conversion factor (0.001 L/cm^3) [5,41,52–56] (Table 1).

2.9.2. Carcinogenic risk

Cancer risk is the increasing likelihood that a person will develop cancer over their lifetime after exposure to a potential carcinogen [61]. A person's potential lifetime risk of exposure to cancer is calculated by multiplying chronic daily intake by the cancer slope factor [49,54]. The cancer risk (CR) and total cancer risk (TCR) for As exposure via oral ingestion and skin absorption were calculated using Eqs. (4–6). The USEPA has suggested an acceptable or tolerable cancer risk range for arsenic as 10^{-6} to 10^{-4} [52,62,63]. This indicates that a risk between 1 in 10,000 and 1 in 1,000,000 is acceptable. However, a lifetime cancer risk of less than 1×10^{-6} is considered negligible, and the risk of cancer can be neglected. In contrast, an ILCR of more than 1×10^{-4} is considered harmful, and the risk of cancer is problematic [52]. Cancer risk was calculated using Eqs. 3–6 [49–51].

$$CR = CDI \times CSF \quad (3)$$

$$CR_{ing} = CDI_{ing} \times CSF_{ing} \text{ cancer risk for ingestion} \quad (4)$$

$$CR_{derm} = CDI_{derm} \times CSF_{derm} \text{ cancer risk for dermal contact} \quad (5)$$

$$TCR = CR_{ing} + CR_{derm} \quad \text{cumulative cancer risk} \quad (6)$$

where; CDI corresponds to the chronic daily intake of carcinogens via ingestion and skin absorption (mg/kg/day) and CSF stands for cancer slope factor (mg/kg/day). The cumulative cancer risk from different exposure routes was calculated using Eq. (6). The acceptable or tolerable range for lifetime carcinogenic risks for regulatory purposes was 10^{-6} to 10^{-4} [52,62,63]. Cancer risk lower than 1.0×10^{-6} is considered negligible, while $> 1.0 \times 10^{-4}$ is unacceptable, and risk levels ranging from 1.0×10^{-6} to 1.0×10^{-4} are considered acceptable [64].

2.9.3. Noncarcinogenic risk

This study measured the noncarcinogenic health risks associated with oral ingestion and skin absorption of arsenic in groundwater during the dry and wet seasons. Non-cancer health risk was estimated using the hazard quotient (HQ) equation developed by the USEPA [48,49]. HQ is the ratio of the calculated mean daily arsenic intake to the oral reference dose of arsenic [47]. The hazard quotient does not predict the exact health outcomes for the exposed populations but indicates the risk associated with pollutant exposure [65]. If the HQ is found to be > 1, there might be a concern for noncarcinogenic health risks, and when the HQ is < 1, there is no potential noncarcinogenic health risk [5,65,66]. The higher the HQ value, the greater the risk to the exposed population. The hazard quotient of As exposure via oral ingestion and skin adsorption was calculated using Eqs. (7) and (8), respectively. In addition, the total hazard quotient (THQ) from the combined exposure routes was calculated using the Eq. (9).

$$HQ_{ing} = CDI_{ing}/RfD_{ing} \text{ noncancer risk for ingestion} \quad (7)$$

$$HQ_{derm} = CDI_{derm}/RfD_{derm} \text{ noncancer risk for dermal contact} \quad (8)$$

Table 1
The constant values are used for estimating the risk of arsenic exposure.

Parameters		As	References
RfD	Ing.	0.0003	[56,57]
	Der.	0.000123	[57,58]
CSF		1.5	[56,59]
ABS		0.01	[60]
Kp		0.001	[41,46,52]

RfD (mg/kg/day), while CSF (mg/kg/day) and ABS (unitless).

$$THQ = HQ_{ing} + HQ_{derm} \text{ cumulative noncancer risk} \quad (9)$$

where; HQ=noncancer hazard quotient, THQ=the total hazard quotients, and RfD stands for chronic oral reference dose expressed as mg/kg/day [62].

3. Results and discussion

3.1. Levels of arsenic in groundwater sources

In this study, arsenic concentrations in groundwater sources (shallow and deep wells) were measured in dry and rainy sessions to determine arsenic levels and their carcinogenic and noncarcinogenic effects on the study population. The study results showed that elevated arsenic concentrations (> 10 μg/L) were found in 42.2 % and 48.8 % of the total analyzed water samples for the dry and rainy seasons, respectively. The concentration in the groundwater samples was in the range of 0.22–40 and 1.02–29 μg/L, with an average concentration of 11.15 ± 9.38 and 10.67 ± 8.16 μg/L, respectively, during the dry and rainy seasons. The overall mean difference between arsenic measurements in the dry and wet seasons (dry minus wet) was 0.48 μg/L, with an average percent difference of 4.3 %. The mean concentration of arsenic in drinking water in this study is higher than the current standards set by the WHO, USEPA, and Ethiopia, which are 10 μg/L, indicating high levels of As in the study area. The results of this study are consistent with the studies conducted in the Rift Valley areas of Ethiopia [67]. However, the study results are lower than those reported for drinking water from Ethiopia [67], India [68], Bangladesh [69], Nepal [70,71], Vietnam [72], and the USA [73], but higher than the reported values reported in Ethiopia [41]. According to the findings from a previous study, ingestion of As, even at a low concentration (0.002 mg/l) over a long period, caused arsenic-induced skin, lung, bladder, liver, and kidney cancer [7]. Furthermore, in addition to cancer, As also causes a number of noncarcinogenic risks, including cardiovascular diseases, hypertension, diabetes, liver and kidney disorders, anemia, and neurological and mental disorders [74]. Thus, chronic exposure to high concentrations of arsenic in the study area is strongly linked with cancer and noncancer risks, and special attention should be taken to protect the residents from further risks.

3.2. Human health risk assessment

3.2.1. Chronic daily intake

Chronic daily intake (CDI) was calculated for children and adults separately for oral and dermal intake of As from groundwater during the dry and rainy seasons. The higher the average daily exposure dose, the higher the risk [75]. The CDI values for children during the dry and rainy seasons were 7.66×10^{-3} and 7.11×10^{-3} mg/kg/day, respectively, while the CDI values for adults during the dry and rainy seasons were 3.28×10^{-3} and 3.04×10^{-3} mg/kg/day, respectively. Regarding the calculated mean CDI values for dermal exposure, the CDI_{der} for children for dry and wet seasons were 4.90×10^{-5} and 4.69×10^{-5} mg/kg/day, while the CDI through dermal contact for adults for dry and rainy seasons were 1.66×10^{-5} and 2.38×10^{-5} mg/kg/day, respectively. The results of this study showed that children have a higher rate of CDI than adults, which is similar to the findings from Bangladesh [76].

Furthermore, the CDI through oral exposure was higher than the CDI from skin absorption in both study groups due to the permeability of skin in the water, which may limit the absorption of arsenic into the skin compared to oral intake, and similar results have been reported from Ethiopia and Malaysia [41,77]. Additionally, absorption of As through skin contact depends on the surface of the body that comes into contact with groundwater arsenic. Overall, the mean chronic daily intake of As via oral ingestion and skin contact during the dry and rainy seasons is

higher in children than in adults, and the results are consistent with those of another study [60]. Therefore, it is important to note that human exposure to arsenic through ingestion is a significant pathway for arsenic exposure, and these findings align with the study conducted in Iran [60].

3.2.2. Carcinogenic risk analysis

3.2.2.1. Cancer risk from ingestion. In this study, the lifetime risk of cancer (LCR) in children and adults from oral ingestion in drinking water during the dry season was 1.15×10^{-2} and 4.92×10^{-3}, respectively, which was above the unacceptable risk ($\geq$ 10–4). Likewise, the LCR for children and adults from oral ingestion in drinking water during the rainy season had an unacceptably high risk (1.06×10^{-2} and 4.57×10^{-3}, respectively). For cancer risk, LCR values between 1.0×10^{-6} and 1.0×10^{-4} are acceptable [52,62,63]. Therefore, in this study, the risk of cancer in children and adults was unacceptably high during the dry and rainy seasons, which was above the unacceptable risk ($\geq 10^{-4}$). Furthermore, in this study, the risk of cancer in children was higher than in adults in both the dry and rainy seasons. Thus, the study's result was consistent with Niknejad et al.'s findings [77]. This is attributed to the fact that children's vulnerability compared to adults is attributed to their underdeveloped organ systems and limited ability to metabolize dangerous chemicals at a young age [79]. Overall, the risk of cancer from oral ingestion was higher than that caused by dermal exposure for both children and adults, and the results of this study are consistent with other studies conducted in China and Romania [75,80] (Figs. 3–8).

3.2.2.2. Cancer risk from dermal absorption. The LCR for arsenic for children through dermal contact in drinking water during the dry and wet seasons was 7.35×10^{-5} and 7.04×10^{-5}, respectively, which was above the unacceptable risk level ($\geq 10^{-4}$). Likewise, the LCR for adults through dermal contact in the dry and rainy seasons was unacceptably high (2.49×10^{-5} and 2.38×10^{-5}), respectively. Thus, we found that the CR values for As via dermal contact among children and adults were above acceptable levels. Similarly, apart from the cancer risk from ingestion, we found that the cancer risk for children through dermal contact was higher than that of adults, suggesting that the risk of cancer was higher in children than in adults. Therefore, the results of this study were consistent with other studies conducted in Malaysia [77]. This is attributed to children having a much larger surface area relative to their body weight than adults, which can introduce more toxic substances into the body through skin absorption [81].

3.2.2.3. Total cancer risk from ingestion and dermal exposure. The total cancer risk (TCR) in children from ingestion and dermal contact during the dry and wet seasons was 1.15×10^{-2} and 1.07×10^{-2}, respectively. In contrast, the TCR for adults from ingestion and dermal contact during dry and rainy seasons was 4.95×10^{-3} and 4.59×10^{-3}, respectively. Therefore, the TCR for children and adults through oral ingestion and skin contact was unacceptable and higher than the acceptable risk ($>10^{-4}$) during the dry and wet seasons. These findings indicate that the study population is at risk of developing cancer due to exposure to As, whether through ingestion or skin contact. Interestingly, the cancer risk for oral ingestion was consistently higher than that for skin absorption in both the dry and rainy seasons in both groups. Thus, the oral route was the most common risk factor for cancer, and the results of this study were consistent with other studies [77,82,83].

Moreover, the result of the study revealed that the TCR from the combined exposure routes was higher in children than in adults during the dry and rainy seasons. As a result, the risk of cancer in children is significantly higher than that in adults in both seasons. This has been attributed to the fact that children are more exposed to pollutants and susceptible to diseases or cancers than adults. Also, children drink more water, consume more food, have a greater body surface area-to-weight ratio than adults, and have lower toxin elimination rates. Moreover, children's immune systems, organs, and tissues continue to develop or grow [60,81]. The results of this study were consistent with those of other studies conducted in Nigeria, Iran, and Malaysia [45,60,77,78].

3.2.3. Noncarcinogenic risk analysis

3.2.3.1. Noncancer risk from ingestion. The results of the study showed that the hazard quotients (HQ) among children via the oral ingestion route during the dry and rainy seasons were 25.5 and 23.7, respectively, while the HQ for adults from the ingestion route during the dry and rainy seasons was 11.8 and 10.29, respectively. Thus, the HQ values for oral ingestion for both children and adults exceeded 1 in both the dry and rainy seasons. Overall, the result of the study revealed that ingestion is the main contributor or risk factor for the noncarcinogenic risk. This implies that the non-cancer health risks from oral ingestion are critical for both study groups (children and adults), as the calculated hazard quotient (HQ) values were greater than 1 (>1). Furthermore, the noncarcinogenic risk analysis from ingestion showed that HQ values for dry and wet seasons were higher in children than adults. The results of this study are consistent with those of another study [78].

3.2.3.2. Noncarcinogenic health risk from dermal absorption. The hazard

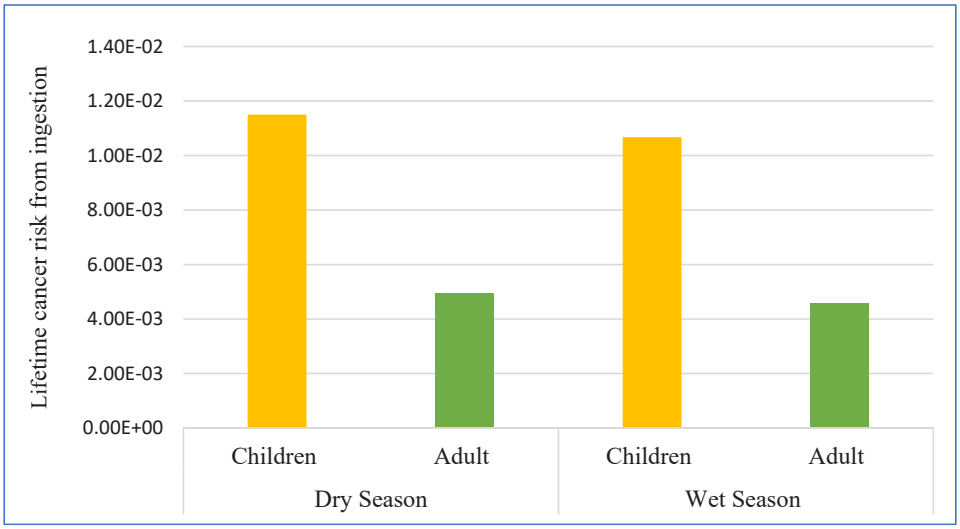

Fig. 3. Lifetime cancer risk from ingestion among children and adults in dry and wet seasons in Adami Tulu Jido Kombolcha District, 2022.

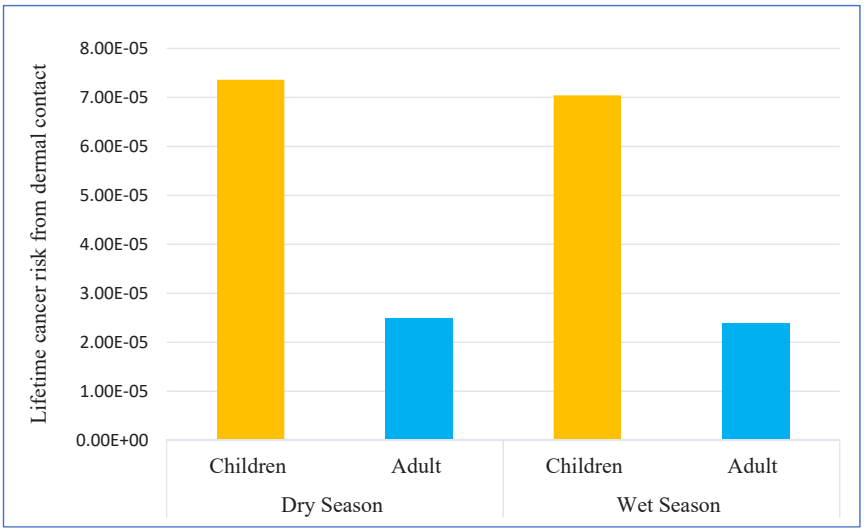

Fig. 4. Lifetime cancer risk from dermal contact among the study population during dry and rainy seasons in Adami Tulu Jido Kombolcha District, 2022.

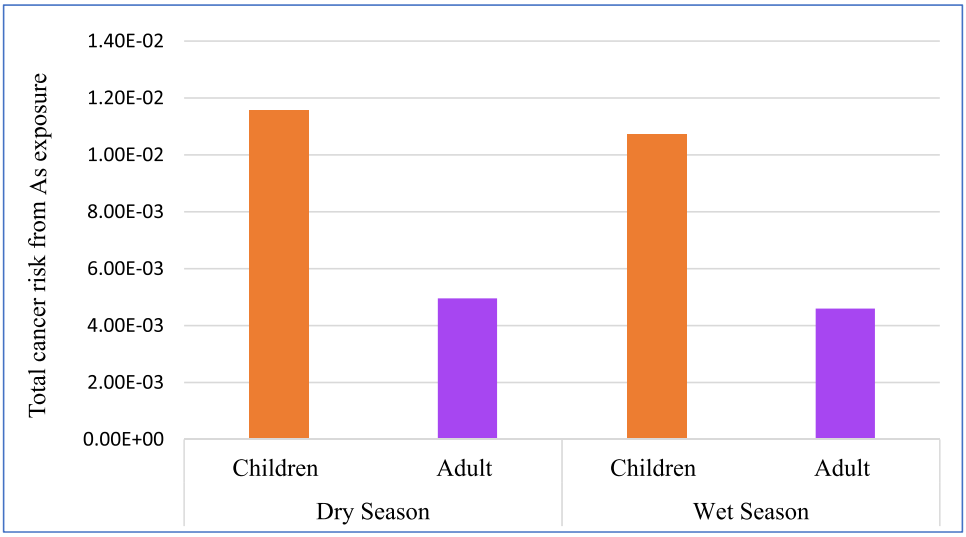

Fig. 5. Cancer risk from the combined routes of exposure among the study population during dry and wet seasons in Adami Tulu Jido Kombolcha District, 2022.

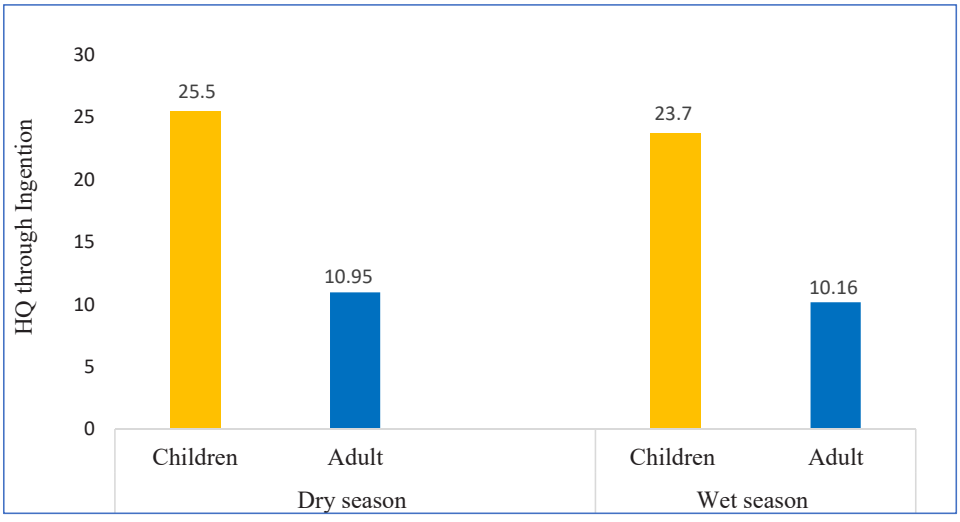

Fig. 6. Noncancer risk from ingestion among the study population in dry and wet seasons in Adami Tulu Jido Kombolcha District, 2022.

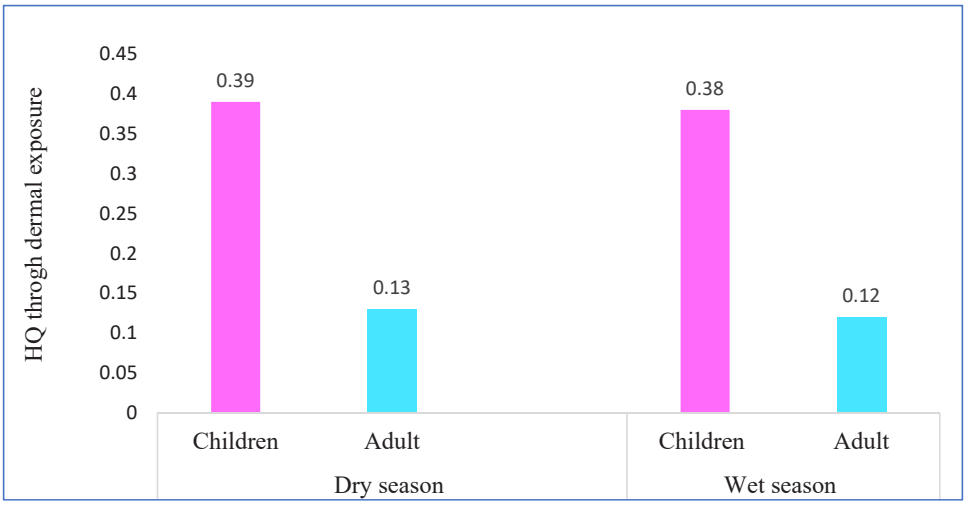

Fig. 7. Noncancer risk from dermal contact among the study population in dry and wet seasons in Adami Tulu Jido Kombolcha District, 2022.

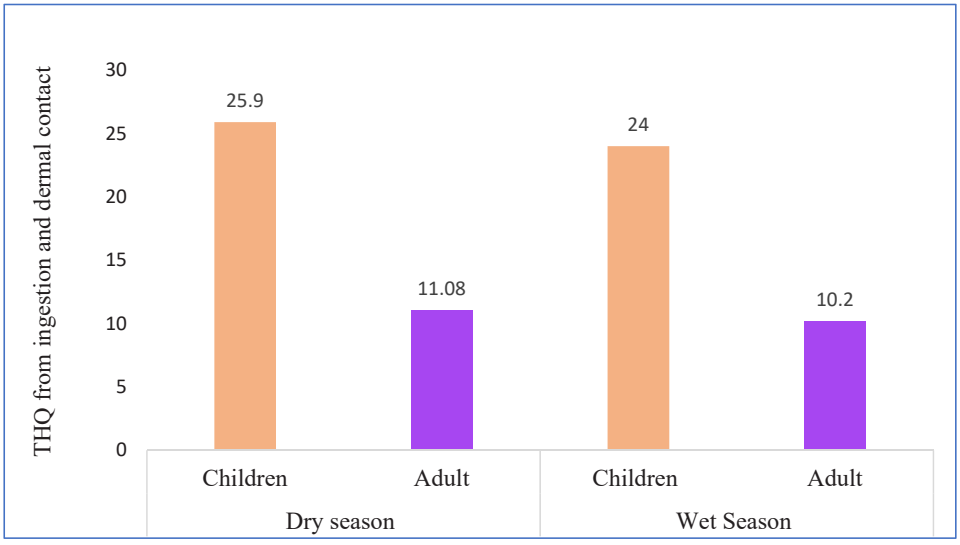

Fig. 8. Noncancer risk from the combined routes of exposure in the study population during the dry and rainy seasons in Adami Tulu Jido Kombolcha District, 2022.

quotients (HQ) from the dermal contact route for children in the dry and wet seasons were 0.39 and 0.38, respectively, while the HQ for adults from the dermal contact route during the dry and rainy seasons were 0.13 and 0.12, respectively. The calculated hazard quotient value is less than one (< 1), meaning that there is no chance of a non-carcinogenic risk for the study groups from arsenic exposure through skin contact during the dry and wet seasons. In this study, dermal contact was not a risk factor for noncarcinogenic risk in either children or adults, and the results of this study are consistent with previous studies conducted in Iran and Peru [60,84].

3.2.3.3. Total hazard quotients from ingestion and dermal absorption. The THQs for children for oral ingestion and skin absorption routes were 25.9 and 24.0, respectively, during the dry and rainy seasons, while for adults, the THQs for oral ingestion and skin contact were 11.0 and 10.2, respectively, during the dry and rainy seasons.

The total hazard quotients (THQs) for oral ingestion and skin absorption routes for children during the dry and rainy seasons were 25.9 and 24.0, respectively, while the THQs for oral ingestion and skin contact in adults during the dry and wet seasons were 11.0 and 10.2, respectively. The result of the total potential noncarcinogenic risk (THQ) value for children and adults is critical in both seasons since the calculated hazard quotient values were greater than one (>1). In this study, the hazard quotient findings indicated that the oral ingestion route had higher HQ values than the dermal route. Therefore, the ingestion route was the predominant route for noncancer risks, and the results of this study were consistent with other studies conducted in China and Pakistan [82,83,85]. Similar to the carcinogenic risk, the cumulative noncarcinogenic risk of arsenic for children for combined exposure routes is significantly higher than that for adults. Therefore, the results of this study were consistent with other studies conducted in Ethiopia, China, Iran, Bangladesh, and Malaysia [75–78]. This is attributed to the fact that arsenic exposure during the first years of life is a critical period, which significantly increases health risks later in life, including morbidity and mortality from arsenic-induced cancers [86]. Therefore, it is crucial to prevent arsenic exposure during early life among the study population in the study area.

Overall, we found high cancer and non-cancer risks from arsenic exposure through both ingestion and dermal absorption in both seasons in the study area. This study shows that to deal with the high risks of cancer and noncancer caused by arsenic exposure, research, practice, and policy should take a broad, multidisciplinary approach that looks at both short and long-term effects. Therefore, by combining rigorous research, effective practices, and informed policies, it is possible to

address the complex challenges associated with both carcinogenic and noncarcinogenic health risks of arsenic exposure. This integrated strategy can lead to more effective prevention, management, and mitigation of arsenic-related health issues. Also, collaboration between researchers, practitioners, and policymakers will be essential for developing holistic and impactful solutions.

3.3. Strengths and limitations of the study

The strength of this study was assessing cancer and noncancer risks through various exposure routes among adults and children based on the USEPA human risk assessment methodology. Also, compare the cancer and noncancer risks via different routes in different seasons to see if there is a seasonal variation. Lastly, we measured the total arsenic concentration in water samples using the latest ICP-MS Agilent 7900 series apparatus with an adequate sample size. However, the only limitation of the study was that using the USEPA human risk assessment method has limitations. Risk assessments involve making various assumptions, and the validity of the results depends on the accuracy of these assumptions. If assumptions are incorrect or outdated, the risk assessment may not accurately reflect the real situation. Risk assessments often use default values or assume average sensitivity, which may not adequately account for the variability in susceptibility among individuals. For instance, using United States skin surface area estimates in the dermal exposure route calculations may overestimate or underestimate the risk to adults and children in other countries.

4. Conclusions

This study determined the concentration of arsenic in all groundwater sources found in the study area and the health risk status among the study population. The study's findings showed that the mean concentration of arsenic in drinking water in this study is higher than the current seated WHO, USEPA, and Ethiopian standards. The study concluded that most groundwater sources in the study area are unsafe for human consumption due to high concentrations of arsenic. The incremental lifetime cancer risk caused by all pathways among children and adults in both dry and rainy seasons was higher than 10^{-6} and unacceptable. Likewise, the total hazard quotient values for oral ingestion and dermal absorption among children and adults during the dry and rainy seasons were > 1.0, indicating a potentially noncarcinogenic risk to residents. Regarding health risks associated with exposure, oral ingestion was the predominant route for carcinogenic and noncarcinogenic risks among the study population in the study area, followed by dermal contact. The carcinogenic and noncarcinogenic risks from oral ingestion and skin absorption are significantly higher among children compared to adults. Thus, the study found that children are the most vulnerable or sensitive group compared to adults for both carcinogenic and noncarcinogenic risks for all routes of exposure. Overall, this study indicates a high likelihood of cancer and noncancer risks among the residents in the study area, warranting special attention, particularly for children.

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Author statement

The authors declare that this research was carried out by all of us, and we all agreed to its publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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