U.P.B. Sci. Bull., Series D, Vol. 87, Iss. 4, 2025 ISSN 1454-2358

# WATER QUALITY ASSESSMENT AND HUMAN HEALTH RISK EVALUATION: A STUDY FROM MOROCCO

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*This study addresses drinking water risk assessment in the context of groundwater contamination associated with mining activities in Morocco, with a focus on water quality impacts. Intensive human activities related to industrial and mining exploration in South-East region of Morocco have contributed to the release of toxic substances such as heavy metals into the soil migrated into the groundwater. The mining ores are located near residential areas which use groundwater as the on-site source of direct consumption of fresh water, without any prior water treatment. The groundwater samples (subject of the current study) were undertaken from 5 monitoring wells and the water quality analysis showed a presence of 15 metals, out of which 5 belonged to the carcinogenic group 1 and 2A (As, Cd, Cr, Ni and Pb), as per the IARC classification. In this study, we are evaluating the quality of the potable well water used by the residents (adults and children as main receptors) in the South-Eastern Morocco mining region against the National Legislation. Furthermore, drinking risk assessment considering the metal concentrations identified in the water wells was performed. The results achieved evidenced that the quality of the groundwater from the wells used for direct drinking water pose a high risk to human health, exceeding the WHO carcinogenic imposed limit ($10^{-6}$) and cumulative ($10^{-5}$).*

**Keywords**: Drinking risk assessment, groundwater contamination, Morocco mining, water quality

## 1. Introduction

Nowadays intensive groundwater exploitation was observed worldwide, impacting directly and indirectly the aquifer through different ways, such as: reducing soil permeability, lowering aquifer storage, contamination and presence of fractures due to groundwater subsidence [1]. Although the detrimental effects of excessive and unsustainable groundwater resource exploitation are evident worldwide, they are more persistent in developing or third-world nations [2].

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Additionally to the overexploitation, based on the Intergovernmental Panel on Climate Change (IPCC), climate change has affected the hydrological water cycle alteration globally leading to negative impacts in terms of societal and economical [3], [4]. Herein, understanding the effects of land use and aquifer vulnerability is an essential step in groundwater protection, especially since groundwater constitute the main reservoir of fresh water at the level of local communities and irrigation activities [5].

Based on the article of Ahmed et.al, Morocco has a substantial water supply reservoir compared to other northern Africa countries. Herein, 25% of groundwater resources are used for drinking supply, while 75% are used for the irrigation purposes [6].

Morocco's dependence on groundwater highlights serious socio-economic disparities. Rural communities, where the poverty rate exceeds 17.7% (national average: 11.7%), depend heavily on groundwater for subsistence agriculture and domestic use. Limited access to safe drinking water perpetuates health inequalities, with 22% of rural households lacking safe drinking water (compared to 6% in urban areas) [7]. In addition, smallholder farmers - often lacking the financial resources to adapt to water scarcity - face increased risks of livelihood loss, further marginalizing vulnerable populations.

The research is focused on fifteen (15) metal contaminants found in five (5) groundwater wells used frequently as fresh water supply, in the South-East mining region in Morocco. Furthermore, the area is known for intensively mining activity exploitation for its base metals (e.g. Al, Cu, Zn) and precious metals (e.g. Au, Ag), while other mines have been abandoned and the resulting tailing dams are disposed directly on soil leading to contaminant leaching from soil to the groundwater and soil acidification [7]. Heavy metals and metalloids with a carcinogenic potential (e.g. As, Cd, Cr, Ni and Pb) found in the mining area groundwater has become a serios human health threat in recent years [8]. Presence of heavy metals and metalloids can occur naturally due to the earth's crust composition through geological weathering, however the contamination of the groundwater occurs through the anthropogenic sources[9] as in the current case due to mining activities. Considering the physicochemical properties of metals, direct ingestion of soil, groundwater and food exposure pathways (EP) are the predominant EPs based on the chemical behavior of these contaminants [10]. Prolonged exposure to these contaminants can lead to health problems, e.g. arsenic (As) long-term exposure is associated with cardiovascular disease, neurotoxicity, diabetes, skin lesions and cancer [9], on the other side a number of epidemiological studies present significant health effects associated to low exposure to cadmium (Cd) leading to kidney, skeleton diseases and even cancer [11].

Considering these aspects, in the current research paper we aim to investigate the consequences on the groundwater resources quality of over-exploitation of the region by the mining activities and the risks posed to humans by prolonged exposure to polluted groundwater. An assessment on interlinking water pollution to possible human health risks was introduced by evaluation of carcinogenic and non-carcinogenic risks of the metal contaminants through a Human Health Risk Assessment (HHRA) using a tool developed within a PhD research thesis based on US EPA model developed within the University of Science and Technology POLITEHNICA of Bucharest, Faculty of Energy Engineering.

## 2. Moroccan legislation on drinking water

The regulation of drinking water quality in Morocco is governed by Decree No. 2-97-787 of February 4, 1998, which establishes water quality standards based on its intended [12]. This decree defines specific guidelines to ensure compliance with safety and health requirements. It outlines procedures and methodologies for water testing, sampling, and analysis, ensuring standardized assessment practices. Additionally, it introduces a water quality classification system, which categorizes water based on its physicochemical, biological, and bacteriological properties. The decree specifically regulates the quality of water intended for human consumption, including drinking water, water used in food preparation, packaging, and preservation, as well as water used for irrigation. These standards play a crucial role in maintaining public health and ensuring the sustainable management of water resources in Morocco.

In alignment with this decree, Moroccan Standard 03.7.001 [13] further specifies the criteria that drinking water must meet to be deemed safe for human consumption. This standard defines "*water for human consumption*" as any water intended for drinking, regardless of its production or distribution method, as well as water used in food processing and preservation. It establishes strict microbiological and chemical safety requirements, ensuring that drinking water is free from harmful microorganisms and toxic substances that could pose health risks. Furthermore, the standard emphasizes that water quality should be maintained at a level that ensures it is both safe and palatable under given circumstances. To achieve this, Moroccan authorities enforce physicochemical, biological, and bacteriological quality thresholds, ensuring that all water intended for human consumption complies with national safety regulations. The concentration limit of contaminants in the groundwater considering Morocco legislation and related concentration limits proposed by the World Health Organization (WHO) guidelines, are presented in the Table 1.

**Table 1**

Specifications of Human Consumption Water concentration limit considering Morocco legislation and WHO guidelines[4].

| Contaminants in groundwater | Arsenic (As) | Barium (Ba) | Cadmium (Cd) | Cyanides (CN) | Chromium (Cr) | Manganese (Mn) | Copper (Cu) | Mercury (Hg) | Lead (Pb) | Selenium (Se) | Boron (B) | Nickel (Ni) | Lithium (Li) | Zink (Zn) | Iron (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAV Morocco (*mg/L* ) | 0,01 | 0.7 | 0,003 | 0,07 | 0,05 | 0.05 | 2 | 0,001 | 0,01 | 0,01 | 0.3 | 0,02 | - | - | - |
| WHO guidelines (*mg/L*) | 0.01 | - | 0.005 | 0.05 | 0.025 | 0.05 | 2 | 0.001 | 0.005 | 0.02 | 1.5 | 0.02 | - | - | 0.2 |

MAV – Maximum allowable values.

## 3. Materials and methods

### 3.1. Sampling

Morocco has long been a country with a strong mining background, as evidenced by the traces of extraction throughout the country. The South-East region is characterised by a diversity of geological structures and natural resources (Fig. 1). For this reason, this region will be the focus of our study as it contains dozens of mines in Morocco.

The South-East region is strongly affected by the lack of water resources and the phenomenon of desertification. In addition, the water resources are composed of drainage water carried by fords and subterranean water distributed in several hydrogeological basins.

[4] Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on quality of water intended for human consumption https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32020L2184

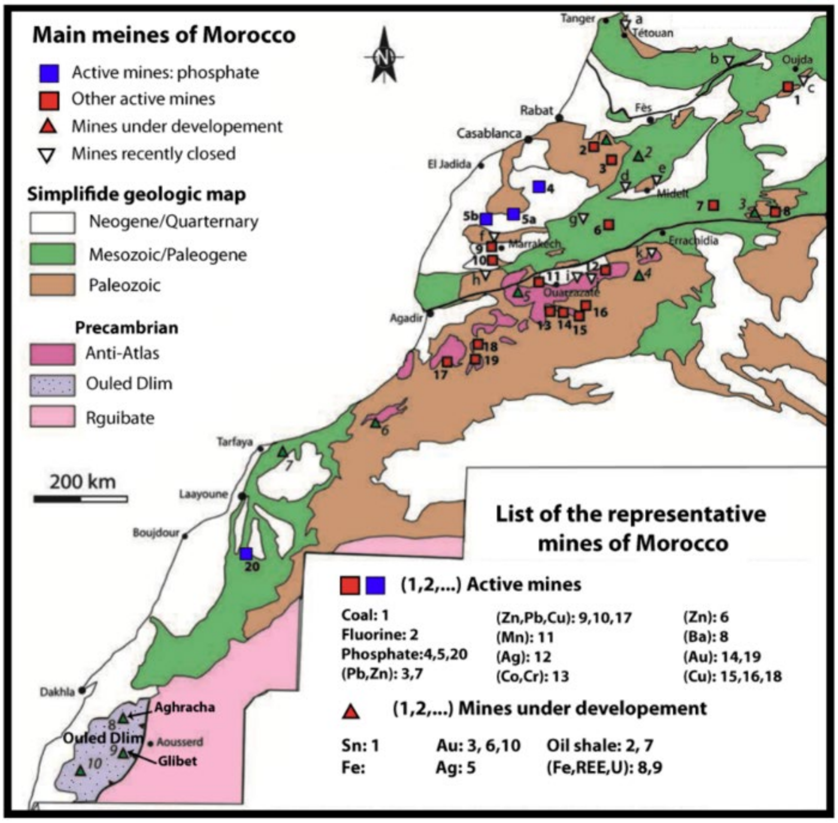



Fig. 1 Main mines of Morocco [14]

The study area has a population of 4,823 residents (2,356 male; 2,467 female) distributed across 481 households, with a growth rate of 2.8% and a population density of 6.68/km². The age structure reveals a significant youth demographic: 30.5% of residents are under 18 (1,522 children/adolescents), while 6.9% are aged 60+ (334 elderly), highlighting dependencies on reliable water for health and development.

These demographic factors contribute to increasing demand for water resources, particularly for domestic and agricultural needs. The social characteristics of the region highlight the importance of sustainable water management to ensure safe and equitable access.

To further understand drinking water contamination in the population zone close to mining activity, 5 drinking water samples were taken and analyzed. The localizations of the sampling points are presented in Fig. 2.

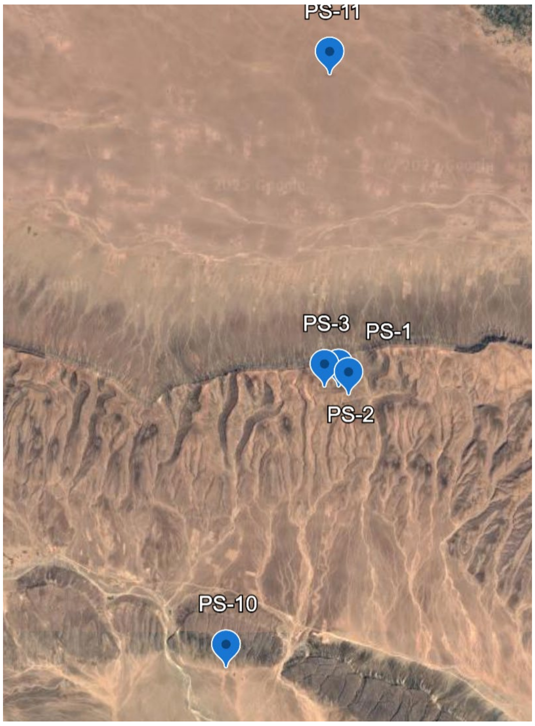



Fig. *2* Location of study samples

### 3.2. Assessment of groundwater quality in the South-East mining region, Morocco

In this study, a case analysis was conducted to evaluate the impact of mining activities on groundwater quality in the South-East mining region of Morocco. The area is characterized by extensive metal extraction, where both active and abandoned mining sites contribute to groundwater contamination. On the other side, the mining quarries activities are located near residential areas. It has been identified that residents located in the region are using directly fresh water from on-site groundwater-built wells. As part of the study, we have performed groundwater sampling analysis. The assessment focused on the physico-chemical properties of groundwater, as these parameters play a crucial role in determining water quality and usability. Key indicators such as pH, electrical conductivity, turbidity, alkalinity, hardness, nitrates, nitrites, ammonium, and chlorides were measured to determine potential changes in groundwater composition. In addition, the presence of fifteen (15) heavy metals and metalloids, including arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), lithium (Li), boron (B), barium (Ba), cyanides (Cn), manganese (Mn), mercury (Hg), selenium (Se) and iron (Fe) were analyzed to assess contamination levels. Out of the 15 heavy metals analyzed, 4 contaminants pose carcinogenic potential as per the IARC classification, such as: As, Cd, Cr VI, Ni and 1 contaminant is probable carcinogenic contaminant Pb [15].

The evaluation aimed to establish a link between mining-related activities and groundwater pollution, emphasizing the potential risks associated with the presence of carcinogenic and toxic elements in drinking water.

### 3.3. Human health risk assessment

In the current research study, human health risk assessment was performed considering heavy metals concentration from 5 groundwater wells by using a deterministic HHRA approach in line with the Moroccan legislation. Human health risk results were focused on quantification of risks and the toxicity of the chemicals using the guideline from Environmental Protection Agency from the United States guidelines (US EPA) mathematical model equations [10]. The software tool used in the current research is a Romanian tool developed within a PhD research thesis part of the University of Science and Technology POLITEHNICA of Bucharest, as part of the tool development consistently was elaborated a Technical Guideline [16]. Subsequently, during the years the HHRA tool was developed and updated to meet the Council of Europe Soil Monitoring Law requirements on contaminated sites management, which came into force on 29 September 2025.

Considering the current characteristics of the contaminants found and groundwater usage by residents, the current assessment is proposing to investigate *oral ingestion* exposure pathway considering **residential** scenario.

***Exposure assessment and risk results***

Morocco's legislative context on the health and environmental risk assessment, carcinogenic and non-carcinogenic risk was determined based on the U.S. EPA guideline on human health risk assessment [10].

The exposure assessment was done by calculating the Average Daily Dose (ADD) of direct groundwater ingestion exposure route for *children* and *adults* using a **residential scenario**.

The ADD was calculated for each contaminant concentration obtained from the sampling points of 5 phreatic monitoring wells. The ADD equation used in the research and included in the tool is represented by the Equation (1):

$$ADD_{ing}(mg\ kg^{-1}\ day^{-1}) = \frac{CS\ x\ IR\ x\ EF\ x\ ED}{BW\ x\ AT} \quad (1)$$

Where:

CS = Contaminant concentration in groundwater sample (*mg/L*); IR = Ingestion rate (adult - 2.5 *L/day*, child – 0.78 *L/day*)[17]; EF = exposure frequency (adult and child – 350 *days*); ED = exposure duration (adult 26 *years* and child – 6 *years*) [17]; BW = body weight (adult - 80 *kg,* child – 6 *kg*) [17]; AT = average exposure duration (adult - 28,470 *days,* child – 2,190 *days*)[18].
The non-carcinogenic risk was determined by calculating the Hazard Quotient (HQ) and the overall potential toxicity contaminants is expressed as Hazard Index (HI) for the direct groundwater ingestion EP, using the Equations (2) and (3).
According to the Agency for Toxic Substances and Disease Registry (ATSDR), the HQ must be compared with the value of 1. When the HQ < 1 it indicates no toxicological hazard effects will occur, however HQ > 1 the non-cancer threshold has been exceeded, possible toxic effects may occur and in depth toxicological analysis has to be performed [19].

$$HQ = \frac{ADD_{ing}}{RfD_{ing}} \quad \textbf{(2)}$$

$$HI = \sum HQ \quad \textbf{(3)}$$

Carcinogenic Risk (*Risk*) calculation for the ingestion EP was determined based on Equation (4):

$$Risk = ADD_{ing} \; x \; SF \quad \textbf{(4)}$$

Where:
RfD = reference dose ingestion for non-carcinogenic contaminants (*mg/kg-day*)$^{-1}$, SF = slope factor for carcinogenic contaminants (*mg/kg-day*)$^{-1}$. The RfD and SF parameters for each contaminant evaluated have been derived from the US EPA portal.

The Cumulative Risk (CR) and Total Hazard Index (THI) were calculated based on the equations (5) and (6) below:

$$CR = \sum_{i=1}^{n} Risk_i \quad (5)$$

$$THI = \sum_{i=1}^{n} HI_i \quad (6)$$

In this study, we have considered a set of input parameters for the assessment of health risks related to oral ingestion EP. In the case of agricultural scenario, the risk assessment was carried out considering a lifetime exposure for adults (78 years ) and children (6 years), based on the latest Agency for Toxic Substances and Disease Registry (ATSDR) report[18].

### 3.4. Analysis of the water physicochemical parameters

The study area comprised of 5 water wells from which samples were taken. The locations of the water wells are represented in Fig. 2. Sampling was carried out following guidelines for drinking water quality determined by the World Health Organization (WHO) 2017. The samples were correspondingly labelled, placed in a container with a temperature-control environment of 0 °C - 4 °C. The samples were sent to the laboratory accompanied by a form containing the necessary information on the origin, date and description.

The parameters pH, temperature, conductivity, turbidity, and dissolved oxygen were measured on-site using calibrated field instruments. Water samples were transported to the laboratory in insulated coolers under controlled conditions to ensure sample integrity, following standard preservation protocols.

Laboratory analyses were conducted in accordance with established analytical procedures compliant with national and international standards. The results were evaluated in comparison with Moroccan Standard 03.7.001 [13], which defines permissible limits for drinking water quality. These standards mandate the absence of hazardous microorganisms and harmful chemical contaminants while requiring water to be aesthetically acceptable (odorless, colorless, and palatable). Compliance with these criteria ensures the protection of public health and adherence to regulatory requirements. The water physicochemical values obtained for the analyzed chemical compounds cannot be disclosed due to confidentiality of data.

## 4. Results and Discussion

### 4.1 Quality of the drinking water extracted from the Wells

Evaluated groundwater samples show a mixed conformity pattern when assessed to Moroccan (NM 03.7.001) [13] drinking water standard. While heavy metals (Pb, Cd, Hg, As) were found below regulatory limits in both standards - indicating acceptable levels of metallic contamination - high concentrations of sulfates (>400 mg/L), chlorides (>750 mg/L), and dissolved oxygen (exceeding saturation thresholds) were detected above permitted limits. These physico-chemical anomalies suggest the possibility of saline intrusion or oxidative dissolution of mineral deposits in the aquifer system. In particular, bacteriological contamination (total coliforms, E. coli) still does not comply with the Moroccan standard, indicating that disinfection (e.g. by chlorination) is imperative.

### 4.2 Carcinogenic and non-carcinogenic human health risk results

Long term ingestion of contaminated groundwater can lead to adverse health problems. In the current article, carcinogenic and non-carcinogenic risk assessment due to ingestion exposure to contaminated groundwater has been investigated following US EPA guideline, based on the metals identified (As, Ba, B, Cd, Cn, Cr, Mn, Cu, Hg, Pb, Se, Ni).

Based on the IARC classification, 5 metal compounds were identified to be carcinogenic out of the total 15 metals investigated in the phreatic water samples. The identified carcinogenic metals were evaluated in terms of risks derived from the direct consumption of drinking water. The carcinogenic metals identified are: As, Cd, Cr VI, Ni which belong to group 1 (carcinogenic to humans) of risk and Pb group 2A (probably carcinogenic to humans) [20]. The average individual carcinogenic risk (CR) based on each metal (represented in Fig. 3) has shown that the highest risk is given by Cd (CR = 1.50 x $10^{-4}$ adult receptor and CR = 9.97 x $10^{-2}$ child receptor) while the lowest concern is given by Pb (CR = 1.70 x $10^{-7}$ adult receptor and CR = 8.48 x $10^{-7}$ child receptor)

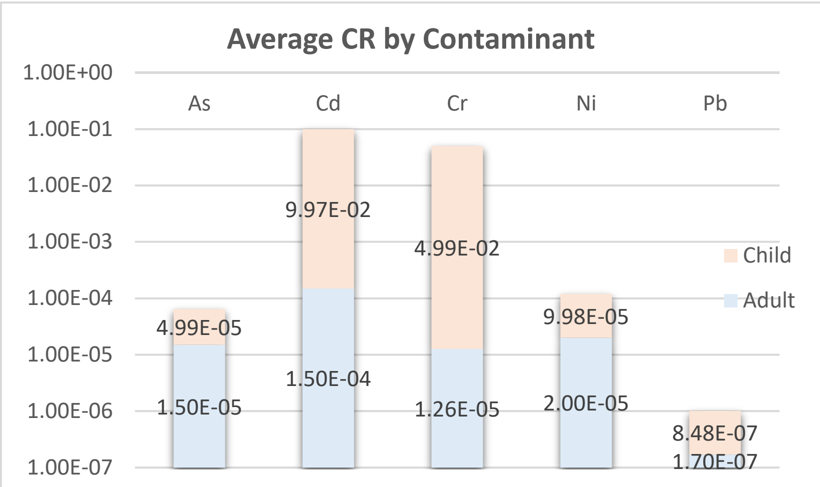



Fig. *3* Average individual CR represented by each carcinogenic metal identified.

The results of HI, Risk per investigated groundwater wells (PC01, PC02, PC03, PC04 and PC05) and related Cumulative risks are presented in in Table 2.

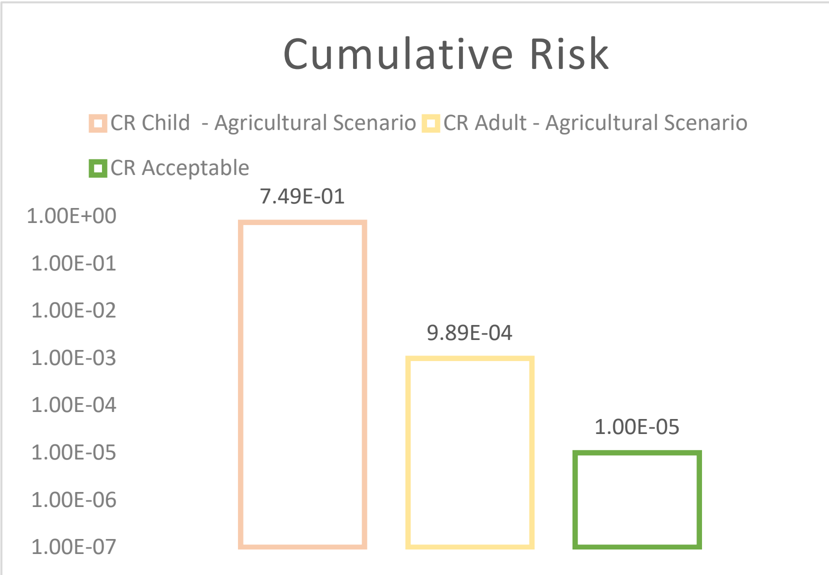
**Table 2**

**Hazard index and Risk results identified within the 5 monitoring wells investigated, considering the residential scenario.**

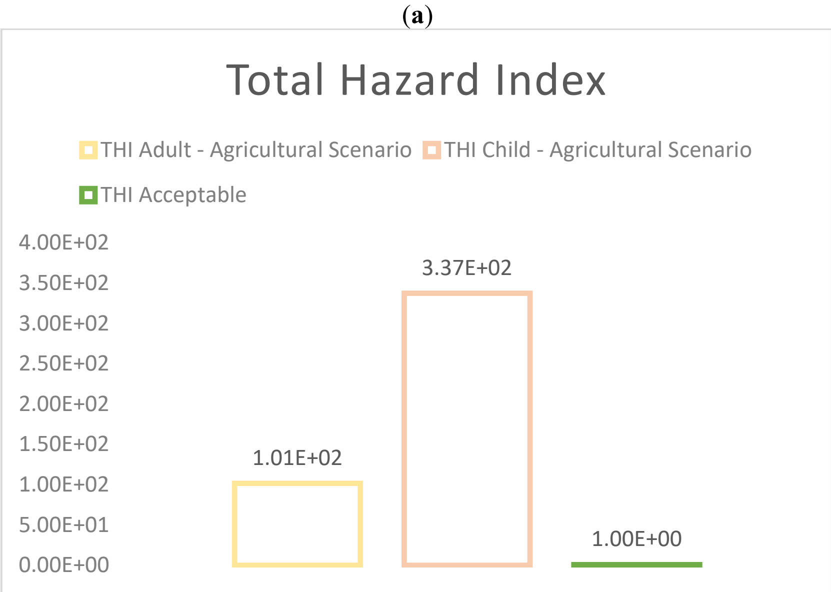
| | Receptor | PC 01 | PC 02 | PC 03 | PC 04 | PC 05 | Cumulative |
|---|---|---|---|---|---|---|---|
| | | *Ingestion* | | | | | |
| **HI** | Adult | 5.07E+1 | 5.07E+1 | 5.02E+1 | 5.03E+1 | 5.03E+1 | 1.01E+2 |
| | Child | 8.44E+1 | 2.10E+0 | 8.35E+1 | 8.36E+1 | 8.37E+1 | 3.37E+2 |
| **Risk** | Adult | 1.96E-4 | 1.96E-4 | 1.96E-4 | 1.96E-4 | 2.05E-4 | 9.89E-4 |
| | Child | 1.50E-1 | 1.50E-1 | 1.50E-1 | 1.50E-1 | 1.50E-1 | 7.49E-1 |

The hazard index identified in the 5 monitoring wells are higher (HI > 1) compared to the accepted threshold value (HI < 1) for both receptors, child and adult in the residential scenario. In comparison with the two receptors (adult and child), the Total Hazard Index (THI), as presented in Fig. 4 (**b**), is higher for the child ($3.37 \times 10^2$) and lower for the adult ($1.01 \times 10^2$), however both reflect a THI above 1. Regarding the carcinogenic risk, based on the World Health Organization (WHO) the accepted individual carcinogenic risk level is $1 \times 10^{-6}$, and the cumulative risk is $1 \times 10^{-5}$. The cumulative risk results, as presented in Fig. 4 (**a**), considering the residential scenario, are higher for child receptor with a Cumulative Risk = $7.49 \times 10^{-1}$ compared to the adult Cumulative Risk = $9.89 \times 10^{-4}$. The cancer risk results for children are usually higher compared to the risks posed to adults attributed to a variety of aspects such as: size (ingest a larger dose of contaminants in comparison to their body weight), behavior (closer proximity to the ground which encourages exploratory behavior), water and diet (drink or consume proportionately more per unit size compared to adults, also the differences on the eating preferences) [21].

Based on the results obtained, the risks derived from the consumption of groundwater during a given timeframe pose carcinogenic and toxicological human health threats to both receptors, with a higher risk to child water consumption.




(**a**)




(**b**)

Fig. 4 Cumulative results obtained for the 5 monitoring groundwater wells (**a**) cumulative risk results for both agricultural and industrial scenario and (**b**) total hazard index results.

The risk results are exceeding the WHO imposed carcinogenic limit ($10^{-6}$) and cumulative ($10^{-5}$). Considering the groundwater drinking risks obtained in the current research, the highest cumulative risk is posed by child receptor ($7.49 \times 10^{-1}$) and most of the carcinogenicity is given by Cd ($9.97 \times 10^{-2}$). Herein, high attention must be paid to the quality of the groundwater wells of consumption, as it affects human health, especially vulnerable categories (such as children in our case).

Integration of risk assessment tools while analyzing polluted groundwater can support the process of quantifying the data and reduce data management to decision-makers. At the same time, it is crucial to develop a tool incorporating broader exposure pathways, such as dermal contact with groundwater during bathing or showering, dermal contact with surface water during swimming. Dermal contact is another element which must not be neglected while determining risk associated with groundwater exposure.

Furthermore, the results of this study can be used to inform communities living close to mining ore, on the potential risks of consuming direct groundwater and prevent health effects.

## 4.3. International research

*4.3.1. Human health risks from groundwater consumption derived from mining activities in international research*

Similar studies on the determination of human health risks posed from groundwater ingestion metal contaminated as a result of the mining activities have been conducted across different countries with past or current mining exploitations. Researchers used diverse tools (human health risk assessment, remote sensing for geospatial distribution, uncertainty analysis, etc) in assessing accurately the human health risks. Heavy metals (As, Cd and Cr) in drinking groundwater were identified as part of the study conducted by Shams et. al. in rural areas near mining regions in Iran. The carcinogenic and non-carcinogenic risks were evaluated for child and adult receptors, considering an acceptable risk of $1 \times 10^{-4}$. The associated risks obtained are considerable higher for the child receptor compared to adult, with the highest carcinogenic risk posed by As [22]. Additionally, Giri and Singh have conducted similar approach on a river basin in India, where a larger number of metals were identified (As, Ba, Cd, Cr, Co, Cu, Fe, Mn, Mo, Ni, Se, Sr, V and Zn). The results indicate a non-carcinogenic concern was given to Mn, Co and As presence [23]. Moreover, Chunlu and team using spatial data analysis and Monte Carlo method determined the health risk assessment associated with the shallow groundwater consumption in a coal mine area in China, for adults and children receptors. Contaminants identified: metals. In this research, As and Cr exceeded the maximum acceptable risk value ($1 \times 10^{-4}$) [24]. Arsenic was found to present a high carcinogenic risk for inhabitants living nearby gold mines in Ghana [25].

At Global level, countries where mining activities are or were a key industry in the region are affected by metal and metalloids contamination in the groundwater further used for inhabitants' consumption.

## 5. Conclusions

The South-eastern region of Morocco is recognized for its' intense past and present mining activities. Some of the mining ores are abandoned once achieved quantity extraction purpose, while others are in use or in plan for future ore construction.

Considering the high mining process in the region, the article aimed to evaluate the well groundwater quality which has been widely used by the local residents as potable water and investigate what are the possible carcinogenic risks related to the frequent consumption of water from the wells. The drinking water quality has been assessed in terms of Morocco legislation, while the drinking risk assessment was performed considering US EPA methodology approach.

Thus, the results showed that the high concentrations of heavy metals within the groundwater from the investigated wells in the vicinity of the abandoned mine poses a high risk to human health.

Moreover, the threshold values of water quality intended for human consumption from the spring wells need to be revised by the Authorities and impose stringent measures on analyzing the water quality and provide information to residents which are using it as fresh water. Furthermore, this article aims to highlight the need to incorporate a risk assessment tool and other methods (such as Monte Carlo, spatial analysis, Machine Learning) during the decision-making processes. By using tools and diverse methods can facilitate a rapid and correct risk evaluation and identification of the hotspots.

Even though the groundwater consumption risk assessment was performed in a non-European Union context, the main purpose of the research is to highlight the usability of a risk assessment tool which ensures a better management of contaminated sites (including soil and groundwater) developed in line with the Council of Europe Soil Monitoring Law using US EPA guideline on human health risk assessment.

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