Trop J Nat Prod Res, August 2025; 9(8): 3704 - 3711
ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

Tropical Journal of Natural Product Research

Available online at https://www.tjnpr.org

Original Research Article

Toxic Potential, Health and Environmental Risks of Pollutants Detected in the Waters of Oued Larbaa, Taza, Northern Morocco

Amina Abouabdallah[1], Tarik Moubchir[2,3]*, Fouad Dimane[1], Ihsane Ougrad[4], Aimad Allali[5], Mohamed Ben Abbou[6], Ilham Zahir[2]

[1]National School of Applied Sciences of Al-Hoceima, Department of Energy and Environmental Civil Engineering, Engineering Sciences and Applications Laboratory, Abdelmalek Essaâdi University, Tetouan, Morocco,
[2]Polyvalent team in Research and Development, Department of Biology, Poly-disciplinary Faculty, Sultan Moulay Slimane University, Av Med V, BP 591, Beni Mellal, Morocco,
[3]Centre de l'Oriental des Sciences et Technologies de l'Eau et de l'Environnement (COSTEE), Université Mohammed Premier, Oujda 60000, Morocco,
[4]Laboratory of Plant, Animal and Agro-Industry Productions, Department of Biology, Faculty of Sciences, Ibn Tofail University, Kenitra 14000; Morocco,
[5]High Institute of Nursing Professions and Health Techniques, Fez, Morocco,
[6]Laboratoire des Ressources Naturelles et de l'Environnement, Faculté Polydisciplinaire de Taza, BP 1223 Taza Gare, Morocco.

ARTICLE INFO

Article history:
Received 09 April 2025
Revised 01 July 2025
Accepted 03 July 2025
Published online 01 September 2025

ABSTRACT

The Moroccan Inaouen River suffers from significant pollution caused by various human activities. This study aimed to evaluate the concentrations of potentially toxic elements (PTEs) in surface and groundwater from the tributaries of the Inaouen River near Taza, Morocco. The eventual pollution from the public dump of Taza City was investigated using eight sites and fifteen parameters: Temperature, Electrical Conductivity, pH, and twelve PTEs were used to assess the Heavy Metal Pollution Index (HPI), Hazard Quotient (HQ), Hazard Index (HI), and cancer index (CI). Results showed that Al, As, Cd, and Pb concentrations exceeded WHO limits across all sites. Mn, Fe, Ba, and Ni exceeded limits at O2, O3, O4, and O6, closest to the public dump and in the direction of water flow. In contrast, Co, Cr, Cu, and Zn remained within permissible limits. In addition, HPI exceeded permissible limit across all sites. HQ and HI associated with using contaminated water indicated that the HI for Zn, Cu, Ba, Ni, As, Pb, Cr, Mn, Co, and Cd were greater than 1, signifying a potential risk for users of this water. Finally, the CI values of the studied elements allowed them to be ranked in ascending order of toxicity, from least to most toxic: Pb>As>Cr>Cd>Ni. The present results showed that water pollution by PTEs is more significant in surface waters that receive the leachate from the public dump and is not negligible in groundwater, which can have serious repercussions on human health and living organisms, necessitating urgent remediation efforts.

Keywords: Cancer Index, Hazard Index, Hazard Quotient, Heavy Metal Pollution Index

Introduction

In Morocco, the use of surface water for irrigation and human consumption has evolved in response to population growth, increasing agricultural demands, and climatic challenges. Historically, the country has developed significant hydraulic infrastructure, including 104 large dams with a total capacity of 16,091 million m^3, regulating approximately nine billion m^3 of water to meet irrigation and drinking water needs.[1] However, water availability per capita has declined, dropping from 3,500 m^3 per person in 1960 to 645 m^3 in 2015, far below the "water poverty" threshold of 1,000 m^3. This situation becomes more intense due to the growing water demand, estimated to increase by 3% annually, and the effects of climate change.[2] At the same time, the pollution of surface water resources poses a significant challenge. Industrial discharges, agricultural runoff rich in pesticides and fertilizers, and untreated urban wastewater contribute to water quality degradation.[3] This pollution negatively affects water availability for irrigation, creates health risks for human consumption, and harms aquatic ecosystems, emphasizing the need for stricter management and increased efforts for pollution control.[4] In this context, the Taza region in Morrocco, part of the Inaouen River's watershed regions, suffers from human activities putting substantial pressure on its water bodies, resulting in physicochemical degradation.[3] Potentially toxic elements (PTEs) are critical contaminants in aquatic ecosystems due to their persistence in the environment and their propensity to bioaccumulate within the tissues of fish and other aquatic organisms.[5,6] Some PTEs, including Zn, Cu, Ni, Co, and Mn, are essential for living organisms' growth and development. They contribute to various biochemical processes at low concentration and play crucial physiological roles.[7,8] However, their toxicity depends on factors such as the nature of element, concentration, bioavailability, mobility, and the characteristics of the surrounding medium.[9] Conversely, other substances, such as Hg and Pb, lack any known physiological function in aquatic species and are considered solely harmful.[10] Even at low concentrations, PTEs like Cu, Pb, As, Cd, and Hg can inhibit photosynthesis and phytoplankton development, resulting in delayed embryonic development, deformities, and stunted growth in fish, mollusks, and crustaceans, and may also impact humans.[11] Several studies have investigated the pollution of the Inaouen River basin, particularly near Taza City, Morocco. Ben-Abbou *et al.* (2014)[12] reported high levels of physicochemical and bacteriological contamination in the Oued Larbaâ watershed due to untreated urban discharges. More recently, Rezouki *et al*. (2023, 2024)[3,13] examined the effects of heavy metals on macroinvertebrate biodiversity, revealing significant pollution in the upper Inaouen River. However, these studies

*Corresponding author. E mail: tarik.moubchir@usms.ac.ma
Tel: +212603060384

Citation: Abouabdallah A, Moubchir T, Dimane F, Ougrad I, Allali A, Abbou MB, Zahir I. Toxic Potential, Health and Environmental Risks of Pollutants Detected in the Waters of Oued Larbaa, Taza, Northern Morocco. Trop J Nat Prod Res. 2025; 9(8): 3704 – 3711 https://doi.org/10.26538/tjnpr/v9i8.29

Official Journal of Natural Product Research Group, Faculty of Pharmacy, University of Benin, Benin City, Nigeria

 ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

did not identify the specific sources of contamination or assess the associated health risks. To address these gaps, this study aims to evaluate the concentrations of potentially toxic elements (PTEs) in surface and groundwater samples from the tributaries of the Inaouen River near Taza. It further examines the relationship between PTE distribution and proximity to the public dump and evaluates the non-carcinogenic and carcinogenic health risks associated with water exposure.

Materials and Methods

The study area and sampling sites

The study's sampling locations were chosen along the lower reaches of the Inaouen River (Figure 1). Six (O1-O6) sampling stations were carefully selected at specific points along the main Inaouen river tributaries positioned before and after the city of Taza's public dump. Two groundwater samples, designated as P1 to P2 were also taken. O5 and P2 served as a reference point far from the municipal solid waste dump and the urbanized area.

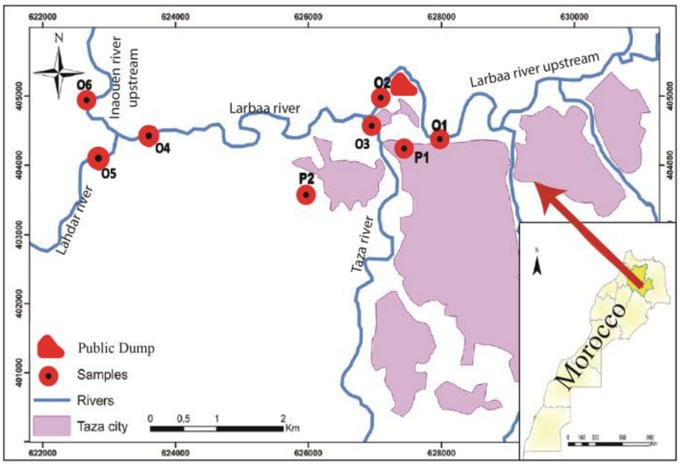


Figure 1: Location of the sampling sites in the studied area

Sampling and pre-processing of samples

Water samples were collected using the grab sampling technique. These samples were taken from key locations, including proximity to the public dump, proximity to residents, and distance from them. Temperature, electrical conductivity (EC), and pH were measured on-site following the standards described in Rodier.[14]

Physico-chemical analyses

Atomic Absorption Spectrophotometry (model AA-6200Shimadzu, Japan) was used to detect traces of the following Potentially Toxic Elements (PTEs): Al, Fe, Mn, Zn, Pb, Ba, Ni, Cd, Co, Cr, Cu, and As following the standards described by Montarges.[15]

Determination of water quality using the heavy metal pollution index (HPI)

Many authors used the HPI to evaluate the effect of the different heavy metals on the water quality [5,16–18] using the following formula in Equation 1 described by Mohan.[19]:

$$HPI = \frac{\sum_{i=1}^{n} QiWi}{\sum_{i=1}^{n} Wi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\mathbf{1})$$

Where;

Qi and Wi are the sub-index and unit weight of the ith parameter, respectively. Therefore, the sub-index (Qi) was calculated by the formula in Equation 2:

$$Qi = \sum_{i=1}^{n} \frac{(Mi - Ii)}{(Si - Ii)} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (\mathbf{2})$$

Where; "Wi" is the value inversely proportional to the recommended standard "Si" of the corresponding parameter which was calculated following the formula in Equation 3.[19]

$$Wi = \frac{1}{Si} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where; "Mi", "Ii " and "Si " are the monitored heavy metals, the ideal and the standard values of the ith parameter, respectively.

According to Mohan *et al*. (1996)[19], an HPI value of 100 is considered the critical threshold for the pollution index.

Health risk assessment

The risks associated with PTE contamination in water was assessed through two primary exposure pathways, ingestion and dermal absorption, among adults and children residing in the affected area. Both non-carcinogenic and carcinogenic health risk indices were employed, following the methodology outlined by Yahaya *et al.* (2022)[20] and Ougrad *et al*. (2024).[6]

Non-carcinogenic risk index

a. Hazard quotient (HQ)

The "HQ" was calculated using the formula shown in Equations 4 to 6.[21]

$$HQ = ADD/RfD \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where; RfD is the daily dose likely to have no harmful effects on the consumer's life, and "ADD" is the average daily dose of the PTE absorbed through the skin or ingested, calculated using Equations 7 and 8. "ADD" and "RfD" are expressed in µg/kg/day.

An HQ < 1 indicates an acceptable level of risk, while a value greater than 1 indicates an unacceptable non-carcinogenic level of risk.[21] The hazard quotient meanings and values of the above parameters are represented in Tables 1 and 2, as given by Ougad *et al*. (2024).[6]

$$HQ_{ing} = \frac{ADD_{ing}}{RfD_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$HQ_{der} = \frac{ADD_{der}}{RfD_{der}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$ADD_{ing} = \frac{CWxIRxEFxED}{BWxAT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$ADD_{der} = \frac{CWxSAxKpxETxEFxEDxCF}{BWxAT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

b. Hazard index (HI)

The "HI" calculated using Equations 9, 10, and 11 was used to assess the health risks of PTEs in water. An HI > 1 indicates an unacceptable non-carcinogenic health risk.[21]

$$\mathrm{HI}_{ing} = \Sigma\, \mathrm{HQ}_{ing} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

$$\mathrm{HI}_{der} = \Sigma\, \mathrm{HQ}_{der} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

$$\mathrm{HI} = \mathrm{HI}_{ing} + \mathrm{HI}_{der} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

Carcinogenic risk (CR) and the cancer index (CI)

The "CR" is used to assess the carcinogenic health hazards associated with exposure to PTEs using the formula in Equation 12. It represents the probability of an individual developing cancer over their lifetime due to prolonged exposure to carcinogenic substances.

$$\mathrm{CR} = \mathrm{ADD} \times \mathrm{CSF} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Where; "CR" is expressed in (mg/kg-day)$^{-1}$ and is specific for each element and each route of exposure. "CSF" is the cancer slope factor; its values are shown in Table 3, and "ADD" is the average daily dose of PTEs.

This study calculated the "CR" for five elements: Cd, Cr, Pb, As, and Ni, known to be carcinogenic, and for the two exposure routes, following the formulas represented by Equations 13 and 14. The "CI" was calculated following the formulas represented by Equation 15. A "CR" and "CI" value greater than 10^{-4} indicates a high risk of human cancer.[21]

$$\mathrm{CR}_{ing} = \mathrm{ADD}_{ing} \times \mathrm{CSF}_{O} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

$$\mathrm{CR}_{der} = \mathrm{ADD}_{der} \times \mathrm{CSF}_{ABS} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

$$\mathrm{CI} = \Sigma\, \mathrm{CR} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

Statistical analysis

In order to simplify the results, a descriptive statistic was conducted using Microsoft Office Excel.

 ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

Table 1: Hazard quotient measurement parameters [6]

Parameters	Unit	Description	Value	
			Adult	Children
ADD	µg/kg-jour	-ADDing is the Average Daily Dose of PTE taken by ingestion -ADDder is the Average Daily Dose of PTE taken by skin contact	Site specific	
RfD	µg/kg-jour	Reference dose, specific to PTE	Site specific	
Cw	µg/L	PTE average concentration in water	Site specific	
IR	L/day	Ingestion Rate	2	0.64
EF	days/year	Exposure Frequency	350	350
ED	Year	Exposure Duration	30	6
BW	Kg	Body Weight	70	15
AT	days	Averaging Time For non-carcinogens For carcinogens	 ED x 350 365 x 70	 ED x 350 365 x 70
SA	cm^2	Exposed skin area	18	6.6
ET	h/day	Exposure time during bathing and shower	0.58	1
Kp	cm/hr	Skin Permeability Coefficient in water	Chemical specific	
CF	L/cm^3	Conversion factor	10^{-3}	10^{-3}

Table 2: Kp and RfD values for the elements studied

Parameters	Kp (cm/h)	RfD_o (µg/kg/day)		RfD_{der} (µg/kg/day)	
		Value	Reference	Value	Reference
Cd	10^{-3}	0.5	29	0.025	29
Co	4×10^{-4}	0.3	29	0.06	29
Cu	10^{-3}	40	29	8	29
Zn	6×10^{-4}	300	29	60	29
Ni	2×10^{-4}	20	29	0.8	29
Mn	10^{-3}	24	29	0.96	29
As	10^{-3}	0.3	29	0.123	29
Cr	2×10^{-3}	3	29	0.075	29
Pb	10^{-3}	1.4	29	0.42	29
Ba	10^{-3}	200	29	14	29
Al	10^{-3}	1000	30	10	30
Fe	10^{-3}	700	30,31	140	30

a. RfD dermal calculated - n.d: not detected

Table 3: CSF values by ingestion and dermal exposure [6]

Parameters	CSF_o		CSF_{ABS}	
	Value (mg/kg-jour)$^{-1}$	Reference	Value (mg/kg-jour)$^{-1}$	Reference
Cd	6.30	32	76.3	a
Ni	1.70	33	4.25	33
As	1.50	32	1.50	34
Cr	0.5	32	20	33
Pb	0.0085	32	0.085	a

a: calculated using the following formula: $CSF_{ABS} = CSF_o / ABS_{gi}$

ABS_{gi}: gastrointestinal absorption factor [35]: $ABS_{gi}(Cd) = 0.08$; $ABS_{gi}(Pb) = 0.1$

Trop J Nat Prod Res, August 2025; 9(8): 3704 - 3711 ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

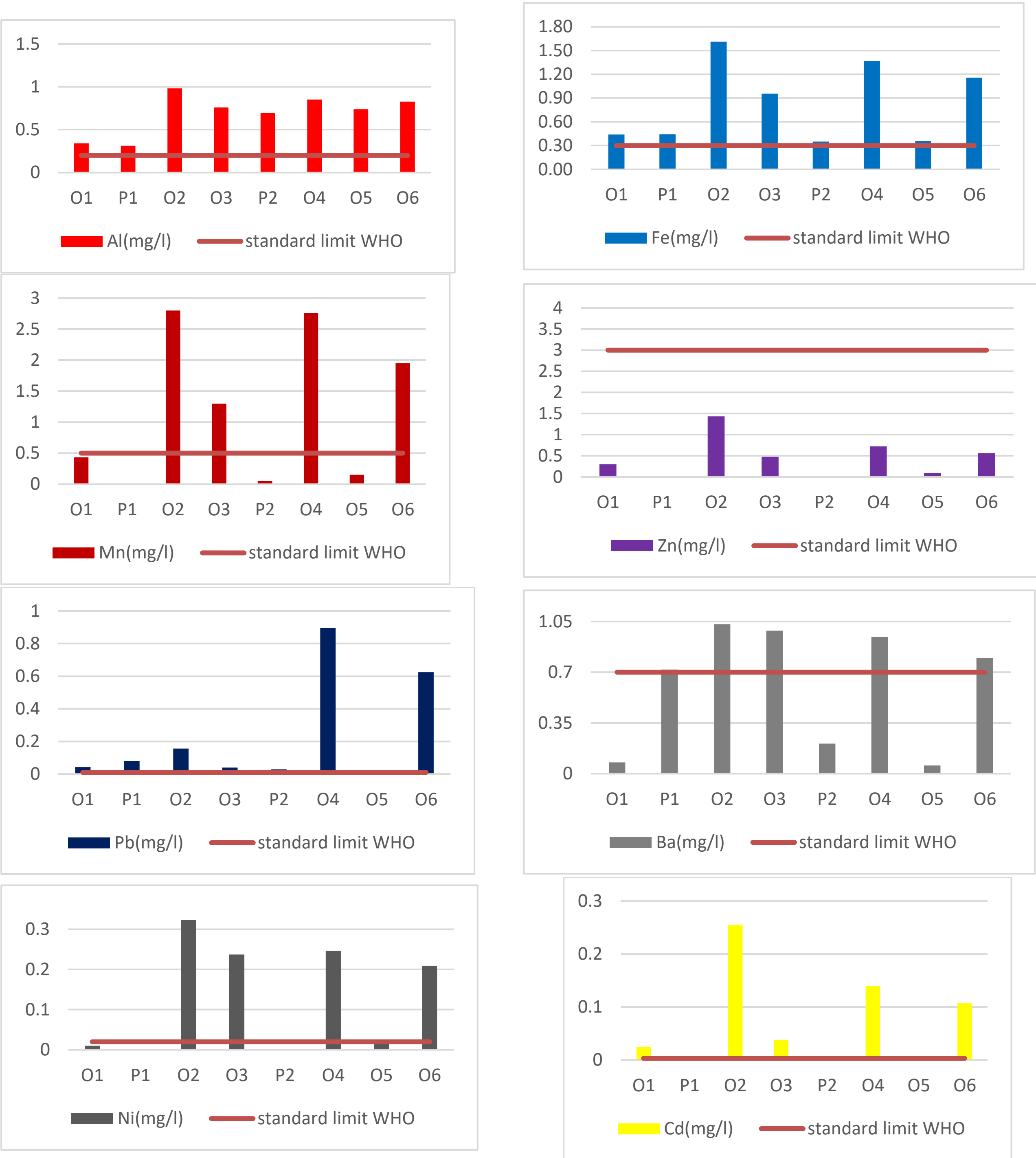
Results and Discussion

Descriptive statistics of studied variables

Table 4 compares physicochemical water quality attributes with the WHO Standard Limit (WHO_SL).[22] Based on the result shown in Table 4, the average water temperature and pH were within an acceptable range. However, the average EC exceeded the WHO limit, indicating elevated dissolved salts and ions, likely from natural or anthropogenic sources. Several PTEs exceeded the WHO limits, including aluminum (0.69 mg/L), iron (0.84 mg/L), manganese (1.35 mg/L), lead (0.23 mg/L), nickel (0.17 mg/L), cadmium (0.09 mg/L), cobalt (0.17 mg/L), chromium (0.07 mg/L), and arsenic (0.03 mg/L), indicating significant contamination and health risks. In contrast, zinc (0.60 mg/L) and copper (0.16 mg/L) remain within safe limits, while barium (0.60 mg/L) approaches the threshold, suggesting doubtful contamination.

Spatial distributions of PTEs

Figure 2 illustrates the spatial distribution of PTEs across sampling sites O1, O2, O3, O4, O5, O6, P1, and P2. Fe and Al concentrations exceeded the WHO limit at all the sites. On the other hand, these sites recorded concentrations lower than the WHO limits for Zn and Cu. Surface waters at most sites (O2, O3, and O4) located downstream of the public dump recorded concentrations exceeding the limits for most PTEs analyzed: Al, Fe, Mn, Pb, Ba, Ni, Cd, Cr, and As, suggesting contamination from the public dump. However, groundwater (P1 and P2) recorded concentrations did not exceed the limits for most PTEs analyzed.



Trop J Nat Prod Res, August 2025; 9(8): 3704 - 3711 ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

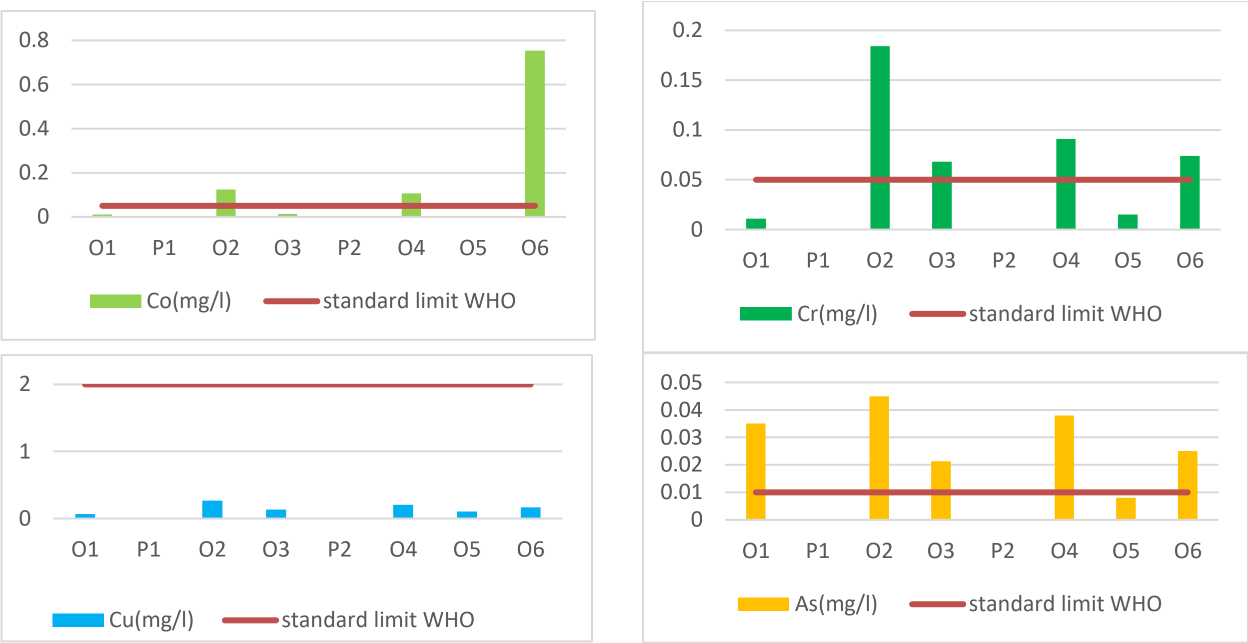


Figure 2: Spatial distributions of PTEs in samples in the study area

Table 4: Descriptive Statistics for Physicochemical and Biological Parameters

Parameter	Unit	Average	SD	min	max	WHO_SL
T	°C	23.50	2.59	20.3	28.74	Acceptable
pH	-	7.71	0.40	7	8.27	6.5 < pH < 8.5
EC	µS/cm	1736.30	1172.70	874.88	4478.88	2700
Al	mg/l	0.69	0.24	0.312	0.981	0.2
Fe	mg/l	0.84	0.50	0.352	1.612	0.3
Mn	mg/l	1.35	1.18	0.05	2.8	0.5
Zn	mg/l	0.60	0.46	0.098	1.432	3
Pb	mg/l	0.23	0.34	0.001	0.895	0.01
Ba	mg/l	0.60	0.42	0.056	1.032	0.7
Ni	mg/l	0.17	0.13	0.01	0.323	0.02
Cd	mg/l	0.09	0.09	0.0028	0.255	0.003
Co	mg/l	0.17	0.29	0.002	0.754	0.05
Cr	mg/l	0.07	0.06	0.011	0.184	0.05
Cu	mg/l	0.16	0.07	0.067	0.265	2
As	mg/l	0.03	0.01	0.008	0.045	0.01

SD: standard deviation

Water quality using the heavy metal pollution index (HPI)

Based on the average concentrations of the studied parameters, the HPI values represented in Figure 3 ranged from 104.91 (at O5) to 5068.79 at O2 (the nearest site to the public dump). Indeed, the mean value of the HPI for surface waters is 2376.85, which places them above the pollution limit thresholds defined for this index. Similarly, the mean value recorded for well water was 172.51, indicating significant contamination.

These observations highlight a generalized pollution by heavy metals across all the stations sampled. According to the HPI index represented in the Figure 3, the stations were ranked in ascending order of pollution as follows: O5 has the lowest HPI index (104.91), followed by P2 (137.19), P1 (207.83), O1 (505.90), O3 (1313.84), O6 (3165.48), O4 (4102.16) and O2 which had the highest index (5068.79). The high HPI value at station O2 can be explained by its proximity to the public dump and the reception of leachate. This value is much higher than the values in other aquatic environments receiving industrial discharges, domestic wastewater, and public dump leachate.[23] The present results showed that water pollution by heavy metals is more significant in surface water than that of groundwater, which can have serious repercussions on human health and living organisms.

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

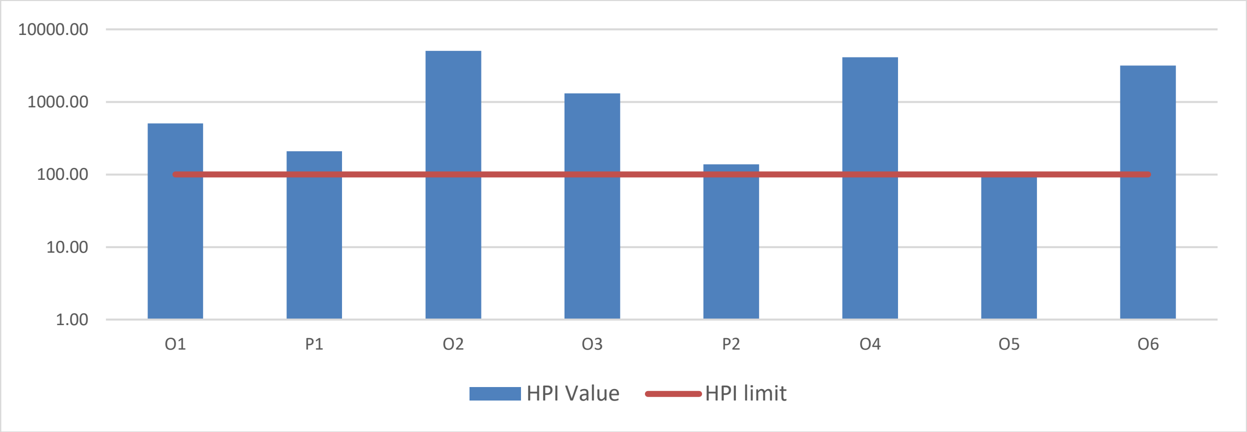


Figure 3: HPI Variation for all sites

Health risk indices

Non-carcinogenic health risk indices

As shown in Table 5, in adults, HQing values ranged from 0.02 for (Al) to 11.64 for (Co), and HQder values ranged from 0.0009 to 411,95 for Al and Co, respectively. In children, HQing values ranged from 0.03 (Al) to 17.39 (Co), and HQder values ranged from 0.002 (Al) to 1215.33 (Co). The elements Mn, As, Cd, Pb, and Co had an HQing greater than 1, and the elements Zn, Cu, Ba, Ni, As, Pb, Cr, Mn, Co, and Cd had an HQder greater than 1 in both children and adults. These results indicate that the above-mentioned elements pose a significant risk to human health. The HI intervals were 0.02 – 415.9 in adults and 0.03 – 1221.23 in children. The HI values of the trace elements studied follow an ascending order: Al, Fe, Zn, Cu, Ba, Ni, As, Pb, Cr, Mn, Co, and Cd. The HI index values of the elements Zn, Cu, Ba, Ni, As, Pb, Cr, Mn, Co, and Cd are greater than 1 and thus present a danger for users of the waters of the Inaouen basin. Children are more exposed to the risks of trace elements through both the digestive and dermal routes since the HQ and HI values are higher in children. The HQder values of the studied elements were higher than those of HQing except for Al in adults and children.

Table 5: Non-carcinogenic health risk indices

PTEs	ADDing µg/kg/jour		ADDder µg/kg/jour		HQ ingestion		HQ dermal		HI	
	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Al	18.85	28.15	0.10	0.29	0.02	0.03	0.0009	0.002	0.02	0.03
Fe	22.89	34.18	119.47	352.46	0.03	0.05	0.17	0.50	0.20	0.55
Mn	32.36	48.32	168.90	498.28	1.35	2.01	175.94	519.05	177.28	521.06
Zn	12.33	18.42	64.37	189.92	0.04	0.06	1.07	3.17	1.11	3.23
Pb	6.40	9.55	33.39	98.52	4.57	6.82	79.51	234.57	84.08	241.39
Ba	16.51	24.65	86.17	254.22	0.08	0.12	6.15	18.16	6.24	18.28
Ni	3.60	5.38	18.81	55.48	0.18	0.27	23.51	69.35	23.69	69.62
Cd	1.97	2.95	10.30	30.38	3.95	5.89	411.95	1215.33	415.90	1221.23
Co	3.49	5.22	18.23	53.79	11.64	17.39	303.90	896.58	315.55	913.96
Cr	1.55	2.32	8.09	23.88	0.52	0.77	107.93	318.41	108.44	319.18
Cu	3.26	4.86	17.00	50.16	0.08	0.12	2.13	6.27	2.21	6.39
As	0.62	0.93	3.26	9.61	2.08	3.11	26.50	78.17	28.58	81.27
Sum					24.54	36.65	1138.76	3359.55	1163.30	3396.20
									∑HI	4559.50

Carcinogenic health risk indices

As shown in the Table 6, the total carcinogenic risk index (CI) of the elements As, Ni, Cd, Cr, and Pb ranged from 0.0007 to 0.2029 and 0.0012 to 0.345 in children and adults, respectively. These values are higher than $1x10^{-4}$ indicating that the use of surface and groundwater in the region studied represents a toxic risk for its inhabitants. The CI values of the elements studied allow them to be classified in ascending order, from the least toxic to the most toxic: Pb > As > Cr > Cd > Ni. The CRing and CRder values recorded in adults were higher than those observed in children. In adults, the CRing values were between 0.00002 and 0.0053, and CRder values were between 0.0012 and 0.3425. In children, the CRing and CRder values were between 0.00001 and 0.00154, and between 0.00072 and 0.202, respectively. Cd presented the highest carcinogenic risk when absorbed through the digestive tract, while Ni presented the highest carcinogenic risk when absorbed through the skin, both for children and adults. Prolonged exposure to these two elements can endanger the living species. Studies have shown the accumulation of certain elements in the tissues of fish living in aquatic environments contaminated by heavy metals.[24,25] At low concentrations, cadmium accumulates in tissues and can cause urinary, pulmonary, renal, and bone dysfunction.[26] Cadmium toxicity also affects plants by inhibiting their growth and causing cellular damage by producing reactive oxygen species.[27] Exposure to nickel can lead to pulmonary, renal, nasal, skin, gastrointestinal, cardiovascular diseases, and cancers.[28] Thus, the health risk assessment reveals a trace element hazard for residents who use surface and groundwater for their daily activities.

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

Table 6: Carcinogenic health risk indices

PTEs	Adults		Children		Adults			Children		
	ADDing	ADDder	ADDing	ADDder	CRing	CRder	CI	CRing	CRder	CI
Cd	0.00085	0.00441	0.00025	0.00260	0.00533	0.33655	0.34188	0.00154	0.19858	0.20012
Ni	0.00154	0.00806	0.00046	0.00476	0.00262	0.34254	0.34517	0.00078	0.20211	0.20290
As	0.00027	0.00140	0.00008	0.00082	0.00040	0.00210	0.00250	0.00012	0.00124	0.00136
Cr	0.00066	0.00347	0.00020	0.00205	0.00033	0.06938	0.06971	0.00010	0.04094	0.04104
Pb	0.00274	0.01431	0.00082	0.00844	0.00002	0.00122	0.00124	0.00001	0.00072	0.00072
Total	–	–	–	–	0.00871	0.75179	0.76049	0.00255	0.44358	0.44613

Conclusion

This study reveals severe contamination of the Inaouen River near Taza, Morocco, by potentially toxic elements (PTEs), including Al, As, Cd, and Pb. Many elements exceeded WHO limits, with the concentrations of Mn, Fe, Ba, and Ni notably high downstream of a public dump. The Heavy Metal Pollution Index (HPI) confirmed critical pollution levels, peaking at 5068.79. Health risk assessments indicated significant non-carcinogenic risks, particularly for children. Carcinogenic risks from Cd, Ni, As, Cr, and Pb were also identified, with Ni being the most toxic. The results necessitate urgent remediation efforts and enhanced waste management strategies.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

References

1. FAO. Irrigation In Africa In Figures – Survey, AQUASTAT. 2005:1–18. https://openknowledge.fao.org/server/api/core/bitstreams/1399ff96-8085-4890-9156-4f452ce0cb6a/content (2005).
2. Dahan S. Water Scarcity Management in Urban Areas in Morocco. World Bank, Washington, DC. 2017:1-73.
3. Rezouki S, El Haji S, Moubchir T, Faouzi J, Ahmed B, Beniaich G, Allali A, Eloutassi N. Evaluation of the Impact of Anthropic Activities on the Physico-Chemical and Microbiological Parameters of the Water of the Wadi Inaouene and Its Tributaries. Ecol Eng Environ Technol. 2023; 24:282–294.
4. Moubchir T, Faouzi J, Loukili EH, Bendaoud A, Belkhiri A, Rezouki S, Eloutassi N, Zahir I. Investigation of the Hydrochemistry Quality of the Ouichane Groundwater (Morocco) Using Multivariate Statistical Methods and Diagram Analysis. Moroc J Chem. 2024; 12:763–775.
5. Moubchir T, Eloutassi N, Bendaoud A, Belkhiri A, Maai M, Moubchir M, Zahir I. Heavy Metals Analysis and Quality Evaluation in Drinking Groundwater Around an Abandoned Mine Area of Ouichane (Nador's Province, Morocco). J Ecol Eng. 2023; 24:118–127.
6. Ougrad I, Elassassi Z, Mrabet A, Mssillou I, Lim A, Shahat AA, Rezouki S, Moubchir T. Health Risk Assessment of Trace Elements in Surface Water from Dayat Roumi Lake, Morocco. Water. 2024; 16:3231.
7. Dhal S and Pal H. Trace Elements in Mitigating Environmental Stress: An Overview. In: Biology and Biotechnology of Environmental Stress Tolerance in Plants. Apple Academic Press. 2023. 3–66p.
8. Moubchir T, Rezouki S, Aimad A, Ougrad I, Eloutassi N, Zahir I. Environmental and Health Risks Associated with Metallic Trace Elements Pollution from Abandoned Mine Lands in Morrocco: A Review. J Biol Biomed Res. 2025; 1:92–104.
9. Kolarova N and Napiórkowski P. Trace Elements in Aquatic Environment. Origin, Distribution, Assessment and Toxicity Effect for the Aquatic Biota. Ecohydrol Hydrobiol. 2021; 21:655–668.
10. Szynkowska MI, Pawlaczyk A, Maćkiewicz E. Bioaccumulation and Biomagnification of Trace Elements in the Environment. In: Recent Advances in Trace Elements. John Wiley & Sons, Ltd. 2018; 13:251–276. doi:10.1002/9781119133780.ch13.
11. Devez A. Characterization of Risks Induced by Agricultural Activities on Aquatic Ecosystems. AgroParisTech. 2004.
12. Ben Abbou M, Fadil F, El Haji M. Assessment of the Water Quality of Streams in the City of Taza Used for Vegetable Crop Irrigation (Morocco). J Appl Biosci. 2014; 77:6462–6473.
13. Rezouki S, Moubchir T, El Hanafi L, Flouchi R, Zahir I, Alzain MN, El Guerrouj B, Noman O, Shahat AA, Allali A. Assessment of Ecological Hazards in the Inaouen Wadi and Its Tributaries Using the Presence of Potentially Toxic Elements in Its Sediments. Water. 2024; 16:2936.
14. Rodier J, Legube B, Merlet N. Water Analysis -10th Edition. Dunod. 2016.
15. Montarges-Pelletier E, Jeanneau L, Faure P, Bihannic I, Barres O, Lartiges BS. The Junction of Fensch and Moselle Rivers, France; Mineralogy and Composition of River Materials. Environ Geol. 2007; 53:85–102.
16. Appiah-Opong R, Ofori A, Ofosuhene M, Ofori-Attah E, Nunoo FKE, Tuffour I, Gordon C, Arhinful DK, Nyarko AK, Fosu-Mensah BY. Heavy Metals Concentration and Pollution Index (HPI) in Drinking Water Along the Southwest Coast of Ghana. Appl Water Sci. 2021; 11:57.
17. Chaturvedi A, Bhattacharjee S, Mondal GC, Kumar V, Singh PK, Singh AK. Exploring New Correlation Between Hazard Index and Heavy Metal Pollution Index in Groundwater. Ecol Indic. 2019; 97:239–246.
18. Tiwari AK, De Maio M, Singh PK, Mahato MK. Evaluation of Surface Water Quality by Using GIS and a Heavy Metal Pollution Index (HPI) Model in a Coal Mining Area, India. Bull Environ Contam Toxicol. 2015; 95:304–310.
19. Mohan SV, Nithila P, Reddy SJ. Estimation of Heavy Metals in Drinking Water and Development of Heavy Metal Pollution Index. J Environ Sci Health Part A. 1996; 31:283–289.
20. Yahaya T, Oladele E, Salisu TF, Izuafa A, Afolayan F, Abdulgafar IB, Abdulazeez Omotayo B. Quality Assessment of Groundwater in Mowe, Ogun State, Nigeria. Trop J Nat Prod Res. 2022; 6:811–817.
21. Environmental Protection Agency, U. Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

22. Dermal Risk Assessment). 2004. https://www.epa.gov/sites/default/files/2015-09/documents/part_e_final_revision_10-03-07.pdf.
23. WHO. Guidelines for Drinking Water Quality, 4th ed.; incorporating the first addendum; World Health Organization: Geneva, Switzerland. 2017. https://iris.who.int/handle/10665/258887.
24. Asim M and Nageswara Rao K. Assessment of Heavy Metal Pollution in Yamuna River, Delhi-NCR, Using Heavy Metal Pollution Index and GIS. Environ Monit Assess. 2021; 193:103.
25. Aarabi S, Chauiyakh O, Bouganssa T, Fahime EE, Et-Tahir A. Bioaccumulation of Heavy Metals in Five Species of Fish Obtained from the Estuary of Rabat, Morocco. Trop J Nat Prod Res. 2024; 8:6765–6770.
26. Kumar N, Chandan NK, Bhushan S, Singh DK, Kumar S. Health Risk Assessment and Metal Contamination in Fish, Water and Soil Sediments in the East Kolkata Wetlands, India, Ramsar Site. Sci Rep. 2023; 13:1546.
27. Genchi G, Sinicropi MS, Lauria G, Carocci A, Catalano A. The Effects of Cadmium Toxicity. Int J Environ Res Public Health. 2020; 17:3782.
28. Haider FU, Liqun C, Coulter JA, Cheema SA, Wu J, Zhang R, Wenjun M, Farooq M. Cadmium Toxicity in Plants: Impacts and Remediation Strategies. Ecotoxicol Environ Saf. 2021; 211:111887.
29. Das KK, Reddy RC, Bagoji IB, Das S, Bagali S, Mullur L, Khodnapur JP, Biradar MS. Primary Concept of Nickel Toxicity – An Overview. J Basic Clin Physiol Pharmacol. 2019; 30:141–152.
30. Tripathee L, Kang S, Sharma CM, Rupakheti D, Paudyal R, Huang J, Sillanpää M. Preliminary Health Risk Assessment of Potentially Toxic Metals in Surface Water of the Himalayan Rivers, Nepal. Bull Environ Contam Toxicol. 2016; 97:855–862.
31. Salcedo Sánchez ER, Martínez JME, Morales MM, Talavera Mendoza O, Alberich MVE. Ecological and Health Risk Assessment of Potential Toxic Elements from a Mining Area (Water and Sediments): The San Juan-Taxco River System, Guerrero, Mexico. Water. 2022; 14:518.
32. Das Sharma S. Risk Assessment Via Oral and Dermal Pathways from Heavy Metal Polluted Water of Kolleru Lake - A Ramsar Wetland in Andhra Pradesh, India. Environ Anal Health Toxicol. 2020; 35:2020019.
33. US Environmental Protection Agency. Guidelines for Carcinogen Risk Assessment. Washington, DC; 2005.
34. Adimalla N. Heavy Metals Contamination in Urban Surface Soils of Medak Province, India, and Its Risk Assessment and Spatial Distribution. Environ Geochem Health. 2020; 42:59–75.
35. Kamunda C, Mathuthu M, Madhuku M. Health Risk Assessment of Heavy Metals in Soils from Witwatersrand Gold Mining Basin, South Africa. Int J Environ Res Public Health. 2016; 13:663.
36. Akoto O, Gyimah E, Zhan Z, Xu H, Nimako C. Evaluation of Health Risks Associated with Trace Metal Exposure in Water from the Barekese Reservoir in Kumasi, Ghana. Hum Ecol Risk Assess Int J. 2020; 26:1134–1148.