Geosfera Indonesia
p-ISSN 2598-9723, e-ISSN 2614-8528
available online at : https://jurnal.unej.ac.id/GEOSI
Vol. 10 No. 3, December 2025, 228-239

https://doi.org/10.19184/geosi.v10i3.30171 Research Article

# Carcinogenic and Non-Carcinogenic Health Risk Assessment of Heavy Metals in Noyyal River Basin, Tamil Nadu, India

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**ARTICLE INFO**

Received :
7 July 2024

Revised :
25 October 2025

Accepted :
8 November 2025

Published :
18 November 2025

**ABSTRACT**

The extensive agriculture, industrial, and resultant urbanization have led to contamination of groundwater resources of the Noyyal river basin. This study aims to evaluate the spatial variability of human exposure risk to heavy metals, particularly in the context of geographic applications for health. The groundwater samples were collected from the 48 locations of the basin. Its heavy metal concentrations of chromium (Cr), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) were analyzed with Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Human exposure to heavy metals was evaluated using the United States Environmental Protection Agency (US EPA) standard health risk assessment guidelines. Here, the health risk assessment is carried out for adults and children via drinking and dermal exposures of the contaminated groundwater. The non-carcinogenic risk assessment results show that the $HQ_{ing}$ for the individual heavy metals of Fe, Pb, and Ni exceeds the safe level (>1) while $HQ_{derm}$ is under the safe level for all the heavy metals. The total hazard quotient ($HQ_{ing}$ + $HQ_{derm}$) is higher for children than adults. The carcinogenic risk assessment reveals that cadmium and nickel pose a high cancer risk over adults and children through the oral pathway, whereas chromium and cadmium have a carcinogenic effect on adults through the dermal pathway. The result obtained indicates that children are identified as more prone to health risks through oral ingestion of contaminated groundwater, and special attention is needed to overcome the health issues.

Keywords: ICP-MS; US EPA; Health Risk; Non-Carcinogenic Risk; Carcinogenic Risk

## INTRODUCTION

Human exposure is the contact between a chemical substance from a medium through water, soil, air, etc., and the human body over a specified duration. It is pertinent to take periodic monitoring of the groundwater quality for future sustainability. The three major pathway for human exposure to heavy metals from groundwater is direct ingestion (oral intake), inhalation (inspiration), and dermal absorption (external body contact). Due to heavy metal intake, human health risk depends on the nature of metal, the level of concentration(dose), duration of exposure, and gastrointestinal absorption/surface area availability for skin contact of metals. Age, sex, and family traits also determine a person's health risk. According to [1] first developed a framework for assessing human exposure to environmental contaminants. The human exposure risk assessment process comprises four steps; hazard identification, exposure assessment, toxicity (dose-response) assessment, and risk characterization [2].

The International Agency for Research on Cancer (IARC) has classified the different agents (chemicals, complex mixtures, occupational exposures, physical agents, biological agents, and personal habits) into three groups depending on their capability for causing cancer. Exposure to toxic elements could have several health effects (Table 1).

Table 1. Toxicities of the Heavy Metals

| Heavy metal | Toxicities |
|---|---|
| Cadmium | Kidney damage, Renal disorder, Human carcinogen |
| Chromium | Headache, Diarrhea, Nausea, Vomiting, Carcinogenic |
| Copper | Liver damage, Wilson disease, Insomnia |
| Nickel | Dermatitis, Nausea, Chronic asthma, Coughing, Human carcinogen |
| Zinc | Depression, Lethargy, Neurological signs, and Increased thirst |
| Lead | Damage the fetal brain; Diseases of the kidneys, Circulatory system, and Nervous system |

Human health risk assessment (HHRA) for heavy metals, especially fluoride, has been extensively done in many parts of India [3]; [4]; [5]; [6]; [7]. According to [8] have studied the fluoride contamination in the Nirmal District in Telangana and reported severe health concerns due to drinking water usage. Based on [9] have also studied the impacts of fluoride and nitrate in drinking water in Panipat, Haryana, and concluded that the hazard index (HI) was higher than the permissible value. The effect of heavy metal exposure on human health is more aggressive than fluoride and nitrates.

The assessment of carcinogenic risk to the living population is essential in epidemiological studies, although it is quite expensive. Therefore, selected geographic location data were used, and the data was modeled for the exposure assessment. The applications of geospatial technologies in identifying the dynamics of communicable and non-communicable diseases are increasingly adopted in epidemiological studies [10]. GIS adds a further dimension to the risk assessment studies [11]. Health and spatial information systems could be useful in the risk assessment process (includes exposure assessment, disease mapping, assessing health risks associated with point sources of pollution, and estimating the population at risk [12]. The geospatial technology provides geographic location-based information that will help planners identify the people prone to health risk, making it easier to implement the management strategies to the affected region.

Noyyal River Basin is one of the vibrant industrial regions where the people were facing groundwater contamination due to the disposal of textile effluents over the waterbodies. A study attributed that the villages along the Noyyal river belt face major health issues, including diarrhea, malaria, skin diseases, tuberculosis jaundice, eye irritation, and cholera. The root cause of several of the diseases is attributed to effluents from the wastewater with poisonous chemicals, unconsumed feed, and pest control medicines were released into land and water resources [13]. The textile dyes and subsequent finishes will cause various manifestations of allergic contact dermatitis. Metal contact dermatitis is the common type of dermatosis, in which nickel is the chief cause of contact allergy [14]. Besides, health issues like skin allergy, respiratory infections, general allergy, gastritis, and ulcers were also diagnosed [15]. The study shows that most of the respondents in the selected households were affected by water-borne diseases like typhoid fever, malaria, jaundice, and having minor health issues records like dysentery, cholera, gastroenteritis, etc. worm diseases [16]. It is understood from the review that the study area has faced several health-related issues due to groundwater contamination. In addition, previous studies have also been limited in their examination of spatial health risk assessment.

The heavy metals of Cr, Ni, Cd are under the Group 1 classification and Pb in the group 2b classification. These heavy metals concentration of the study area is above the prescribed standard of the WHO in the basin. Long-term exposure to heavy metals may cause carcinogenic and non-carcinogenic risks to people. Therefore, it is necessary to carry out the human exposure risk assessment for epidemiological studies. Here, the heavy metal exposure potential for children and adults through ingestion and dermal pathway has been calculated.

## METHODS

River Noyyal is one of the tributaries of River Cauvery that flows in Tamil Nadu. It originates from the Western Ghats at Velliangiri Hills. It drains through the two corporations of Tamil Nadu, namely Coimbatore and Tiruppur, and finally confluence to the River Cauvery at Noyyal Village. The natural basin boundary is demarcated with the help of CARTOSAT Digital Elevation Model (DEM) data using the hydrological tool from ArcGIS 10 and cross-verified using Survey of India (SOI) 1:50,000 scale toposheets. The basin lies between 10º54'N to 11º19' N latitudes and 76º39' E to 77º55' E longitudes (Figure 1). The climate of this region and the black soil favor the cotton production and growth of several textile industries. These agriculture and textile industries majorly contribute to the economy of the region. Groundwater is the major resource utilized by the people for drinking, domestic, agricultural, and industrial purposes. Population growth, industrialization, and urbanization made deteriorates the quality of the available freshwater resources with heavy metal contaminants. The people's chronic exposure to heavy metals leads to several health-related problems in the basin. Here, a study has attempted to assess the heavy metal exposure risk on children and adults due to the utilization of contaminated groundwater.

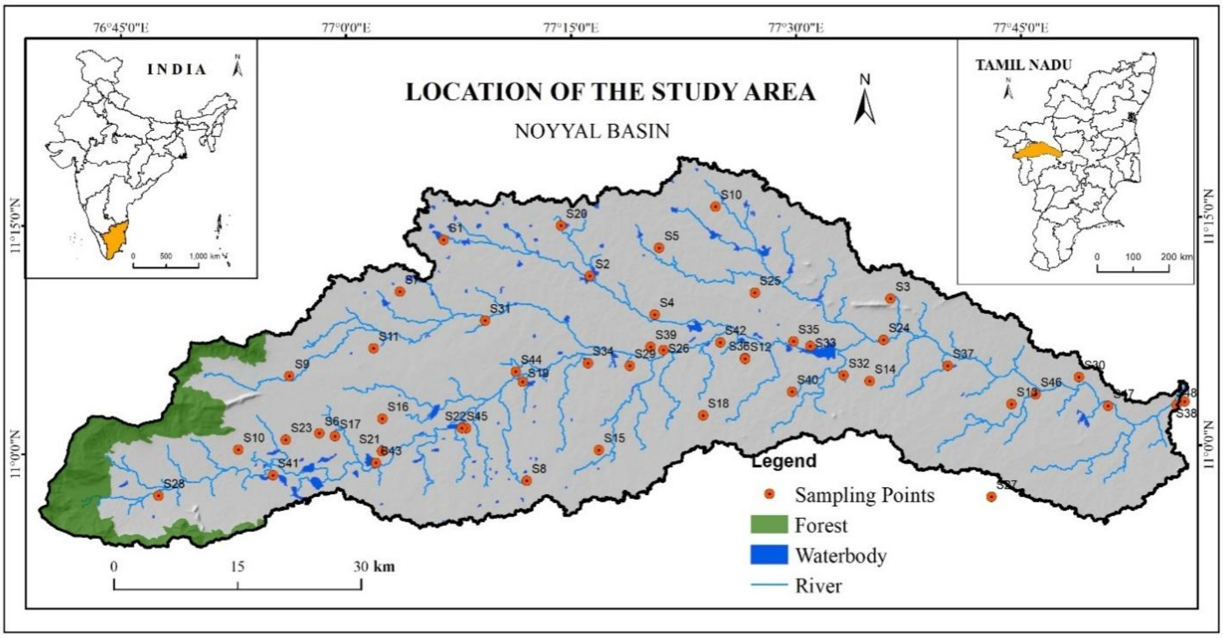


Figure 1. Location of the Groundwater Sampling Sites

Here, groundwater ingestion through drinking is the main pathway for heavy metal intake. The accountability of the dermal pathway is also essential in this basin because the people depend highly on the groundwater resources for all kinds of domestic purposes (bathing, washing, etc.) The heavy metal exposure potential for the children and adults was calculated. The human exposure and risk assessment of heavy metals through oral consumption and dermal absorption out using US EPA guideline [17]. The hazard quotients for non-carcinogenic effects of all elements' chromium, manganese, iron, nickel, copper, zinc, lead, and cadmium were calculated. The total hazard index was also calculated to assess its total non-carcinogenic risk. Lifetime cancer risk through oral ingestion was calculated for the carcinogenic elements of Cr, Ni, Pb, Cd, and the dermal carcinogenic risk was calculated for Cr and Cd.

The general framework to assess the non-carcinogenic and carcinogenic risk of the basin is shown in figure 2. Hazard identification includes the primary investigation and the estimation of chemical concentrations present at a specified location and its spatial distribution. Here, the heavy metals of Cr, Mn, Fe, Ni, Cu, Zn, Pb, and Cd were identified as hazardous chemicals present in the groundwater. Exposure assessment involves estimating the magnitude, frequency, and duration of contact to an agent, along with the number and characteristics of the population exposed. In the study, the people's Chronic Daily Intake (CDI) of heavy metals from the groundwater was estimated to assess its exposure potential. The dose-response assessment step involves the estimation of toxicity levels due to exposure levels of heavy metals. The toxicity level for non-carcinogenic elements could be identified with a reference dose (RfD), and the cancer-causing carcinogen is with the value of slope factor (SF). The risk characterization process involves the quantitative estimation of people under the potential health risk due to this toxicity [17]. The risk potential for the children (<18 years) and adults (>18 years) was estimated for this basin.

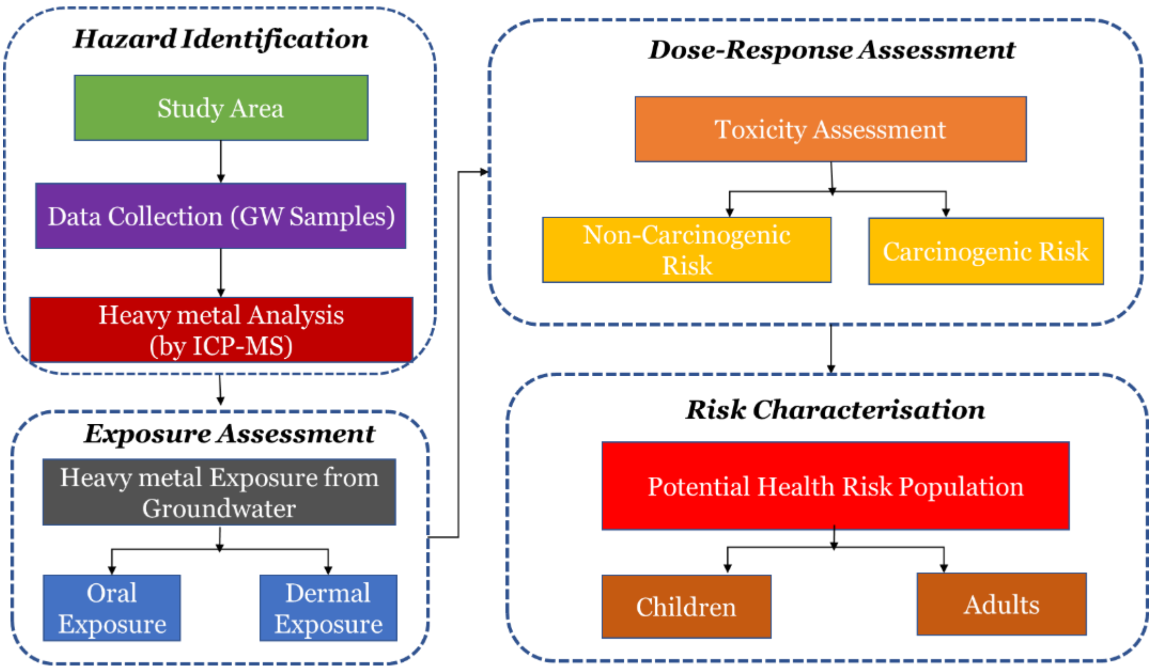

Figure 2. Methodology of the Study

**Heavy Metal Analysis**

Forty-eight groundwater samples were collected from the basin during June 2018. Twenty-one samples were collected along the riverbank, and the rest of the samples are from the peripheral parts. Acid digestion has been done for the acidified samples with $HNO_3$ and HCL acid based on the guidelines of the ICP-MS [18] 3005a method for heavy metals analysis. The heavy metals of chromium (Cr), manganese (Mn), lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu), iron (Fe), and zinc (Zn) have analyzed with the help of Thermo ICP-MS X Series II model. The instrument's detection limit is parts per trillion (ppt) level. The measurements of all the selected heavy metals were done in triplicates, and their standard deviations were less than 10 %.

**Non-Carcinogenic Analysis**

The exposure of heavy metals from the groundwater for the people is chiefly from oral consumption and dermal adsorption. Groundwater is the primary water source in the basin that is utilized for drinking, cooking, bathing, washing clothes and utensils, etc. These make the people oral and dermal contact directly with the contaminated water leads to several diseases and skin related problems. The consumption of heavy metal contaminated water leads to several gastrointestinal problems such as diarrhea, digestion problems, etc., whereas dermal exposure will pose skin diseases. Hence, the exposure dose through oral intake and dermal contact of groundwaters calculated respectively.

$$CDI_{Ingestion} = \frac{C\ X\ IR\ X\ EF\ X\ ED}{BW\ X\ AT} \quad (1)$$

$$CDI_{Dermal} = \frac{C\ X\ SAXKpX\ ET\ X\ EFXEDXCF}{BW\ X\ AT} \quad (2)$$

where $CDI_{Ingestion}$ is chronic daily intake through ingestion of water (mg/l/day);$CDI_{Dermal}$ is chronic daily exposure through dermal absorption (mg/kg/day);C is the concentration of heavy metals in water (mg/L); IR is ingestion rate (L/day); SA is skin surface area for contact with water ($cm^2$); $K_p$ is dermal permeability coefficient (metal specific); ET is exposure time (hour/day); EF is exposure frequency (day/year); ED is exposure duration (years); CF is the unit conversion factor (in $L/cm^3$); BW is mean body weight (kg); AT is averaging time for non-carcinogens (days).

The chronic daily intake and dermal contact of heavy metal are calculated for children and adults with their average daily consumption rate of groundwater, the available skin area for dermal contact, skin adherence factor (how far it retains on the skin), dermal absorption factor, exposure frequency, duration, body weight and average lifetime period. The parameters used for non-carcinogenic risk assessment are attributed in Table 2.

Table 2. Parameters used for Non-Carcinogenic Risk Assessment

| Parameter | Unit | Children | Adults |
|---|---|---|---|
| Body weight (BW) | kg | 16 | 70 |
| Exposure Frequency (EF) | days/year | 365 | 365 |
| Exposure Duration (ED) | years | 6 | 30 |
| Exposure Time (ET) | hours/day | 1 | 0.58 |
| Ingestion Rate (IR) | l/day | 1.5 | 2 |
| Skin Surface Area (SA) | $cm^2$ | 6600 | 18000 |
| Conversion Factor (CF) | $L/cm^3$ | 0.001 | 0.001 |
| $K_p$ | cm/h | 0.001 for Fe, Pb, Cu, and Cd<br>0.002 for Cr<br>0.006 for Zn<br>0.0002 for Ni<br>(Akoto et al., 2019; Mohammadi et al., 2019) | |
| Average Time (Days)<br>For carcinogens | days | 365x70 | 365x70 |
| For non-carcinogens | days | 365xED | 365xED |

The non-carcinogenic risk is assessed with the hazard quotient of the heavy metals. The hazard quotient (HQ) is the ratio between the chronic daily exposure (both from ingestion and dermal) of the heavy metals to its threshold toxicity limit of reference dose (RfD). The reference dose values for individual elements for both ingestion and dermal pathways are given in Table 3.

$$HQ = \frac{CDI_{ingestion/dermal}}{RfD_{ingestion/dermal}} \quad (3)$$

where RfD is the reference dose for heavy metals (mg/kg/day).

The total hazard quotient (THQ) is calculated to find the cumulative toxicity of the selected heavy metals (Equation 4). The total hazard index (HI) is calculated by aggregating all the non-carcinogenic exposure pathways hazard quotients (Equation 5). The exposed population would be considered safe when the hazard quotient and hazard index value is less than one [18].

$$THQ = HQ_{Cr} + HQ_{Mn} + HQ_{Fe} + HQ_{Ni} + HQ_{Cu} + HQ_{Zn} + HQ_{Pb} + HQ_{Cd} \quad (4)$$

$$HI = HQ_{ingestion} + HQ_{dermal} \quad (5)$$

**Carcinogenic Risk**

As per the US EPA definition, the carcinogenic risk is the incremental chance of lifetime cancer risk of a person due to carcinogens. Carcinogens possess the inherent toxicity to cause an adverse effect in a living organism. Carcinogenic risk estimates cancer's possibility, considering age, bioaccumulation factor, level, frequency, and duration of exposure to the agent. Here, the carcinogenic risk is calculated as follows

$$CR = CDI \times SF \quad (6)$$

where CR is the carcinogenic risk, and SF is the carcinogen potential factor (Table 3).

Table 3. Threshold values for Carcinogenic (RfD) and Non-Carcinogenic (SF)

| Heavy Metal | RfD ingestion | Reference | RfD dermal | Reference | SF ingestion | Reference | SF dermal | Reference |
|---|---|---|---|---|---|---|---|---|
| **Cr** | 0.003 | IRIS(USEPA) | 0.00006 | IRIS(USEPA) | 0.5 | IRIS(USEPA) | 20 | Pan etal., 2017 |
| **Mn** | 0.14 | IRIS(USEPA) | 0.0018 | IRIS(USEPA) | - | - | - | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Fe** | 0.07 | IRIS(USEPA) | - | - | - | - | - | - |
| **Ni** | 0.02 | IRIS(USEPA) | 0.0056 | Kamunda et al., 2016 | 1.7 | Fallahzadeh et al., 2017 | - | - |
| **Cu** | 0.045 | IRIS(USEPA) | 0.024 | Kamunda et al., 2016 | - | - | - | - |
| **Zn** | 0.3 | IRIS(USEPA) | 0.075 | Kamunda et al., 2016 | - | - | - | - |
| **Pb** | 0.004 | IRIS(USEPA) | - | - | 0.0085 | IRIS(USEPA) | - | - |
| **Cd** | 0.001 | IRIS(USEPA) | 0.00005 | Kamunda et al., 2016 | 0.38 | Nduka, et al., 2019 | 20 | Pan etal., 2017 |

## RESULTS AND DISCUSSION

### 4.1 Heavy Metal Analysis

The result obtained from the ICP-MS were imported to the ArcGIS 10.1 software, and its individual spatial layers were generated using Inverse Distance Weighted (IDW) interpolation tool. The concentration of heavy metals was compared with WHO standards for drinking. Zn, Mn, and Cu concentrations in the groundwater samples are desirable to permissible, whereas Fe, Pb, Ni, Cd and Cr concentrations are in undesirable ranges. The spatial maps are explicit that the heavy metal concentration of the Ni, Pb, and Cd follows a similar pattern. The samples present along the river banks exceed the permissible drinking limit. However, the rest of the region's heavy metal concentrations were desirable ranges (Figure 3). These findings are consistent with a previous study [19] which showed that heavy metals are affected by hydrological processes and accumulate in sediments. In addition, the concentration of these metals exceeds drinking water reference values, posing a serious threat to public health [20].

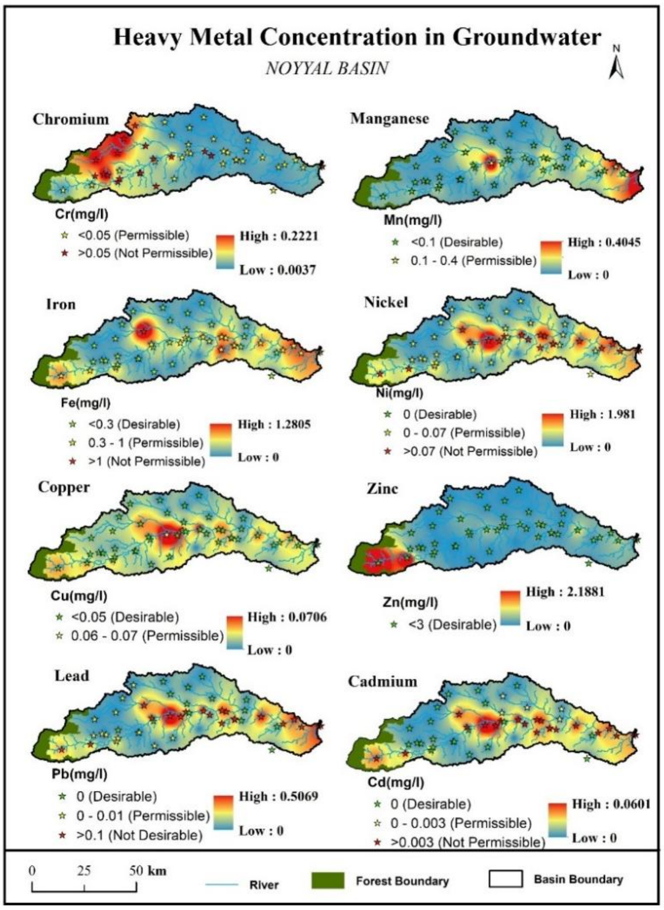


Figure3.Heavy Metal Concentration in Groundwater

### 4.2 Non-Carcinogenic Risk

#### *4.2.1 Hazard Quotient for Children*

The average hazard quotient (HQ) of the heavy metals through ingestion is followed in the order of Pb>Fe>Ni>Cr>Cd>Zn>Cu>Mn. The HQ value of individual heavy metals of lead exceeds the safe level (>1) through ingestion. About 44 per cent of samples (that are highly distributed along with the river bank samples) total hazard quotient (THQ) exceeds the safe limit for drinking (Figure 4). The HQ for dermal exposure is assessed for Cr, Ni, Cd, Cu and Zn, and its mean concentration in the order of Cr>Cd>Zn>Ni>Cu. The HQ for dermal absorption of individual heavy metals and THQ values are under the safe level (<1).

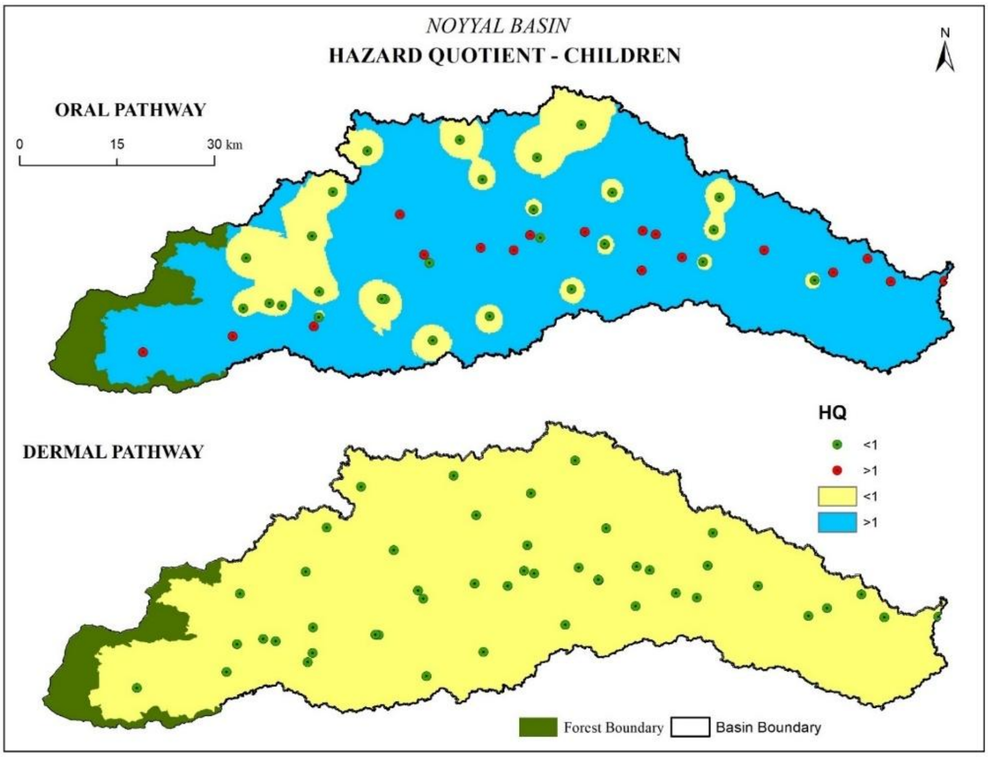


Figure 4. Hazard Quotient – Children

#### *4.2.2 Hazard Quotient for Adults*

The HQ of adults through ingestion for individual heavy metals found in the order of Pb>Ni>Cd>Fe>Zn>Cr>Cu>Mn, and all are found under the safe limits (<1) except nickel and lead. About 42 per cent of samples (that are highly distributed along with the river bank samples) THQ exceeds the safe limit for drinking (Figure 5). The HQ for dermal exposure is in the order of Cr> Cd >Ni>Zn>Cu, and the values are under the safe limit (<1).

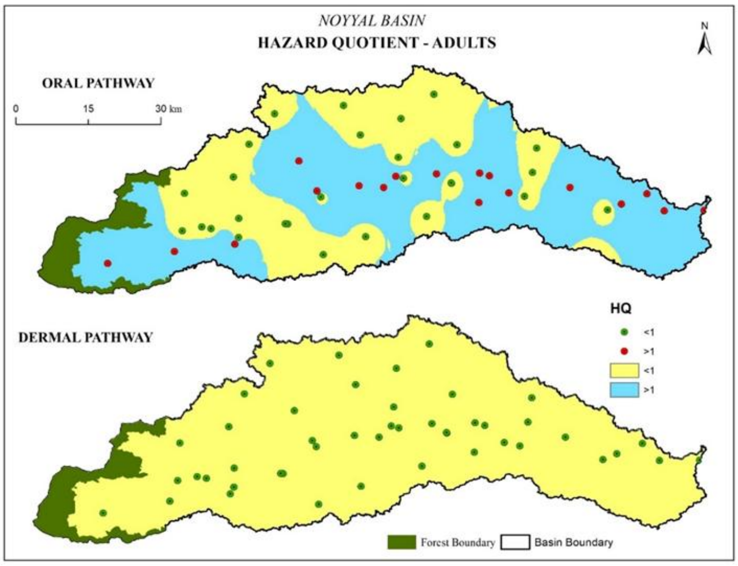


Figure 5. Hazard Quotient – Adults

#### *4.2.3 Comparison of hazard between Children and Adults*

The total hazard index in both the pathway oral and dermal is calculated for children and adults (Figure 6). The spatial distribution shows that the sampling points which are present along the river course exceed the safe limit for drinking for both adults and children. By comparing the non-carcinogenic risk (Figure 7), the result indicates that the HQ for children through drinking is higher than the adults, whereas, through the dermal exposure, it is higher for adults. And, the HI is found to be high for children than adults. The children are found to be under high non-carcinogenic risk than the adults. This finding is supported by a study by Zhang [21] which showed that children have a non-carcinogenic risk for as when HI values exceed the threshold.

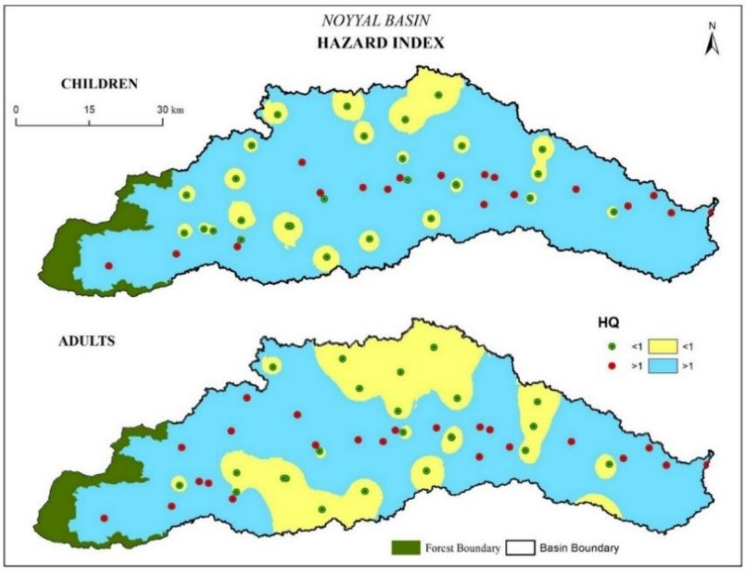


Figure 6. Hazard Index for Children and Adults

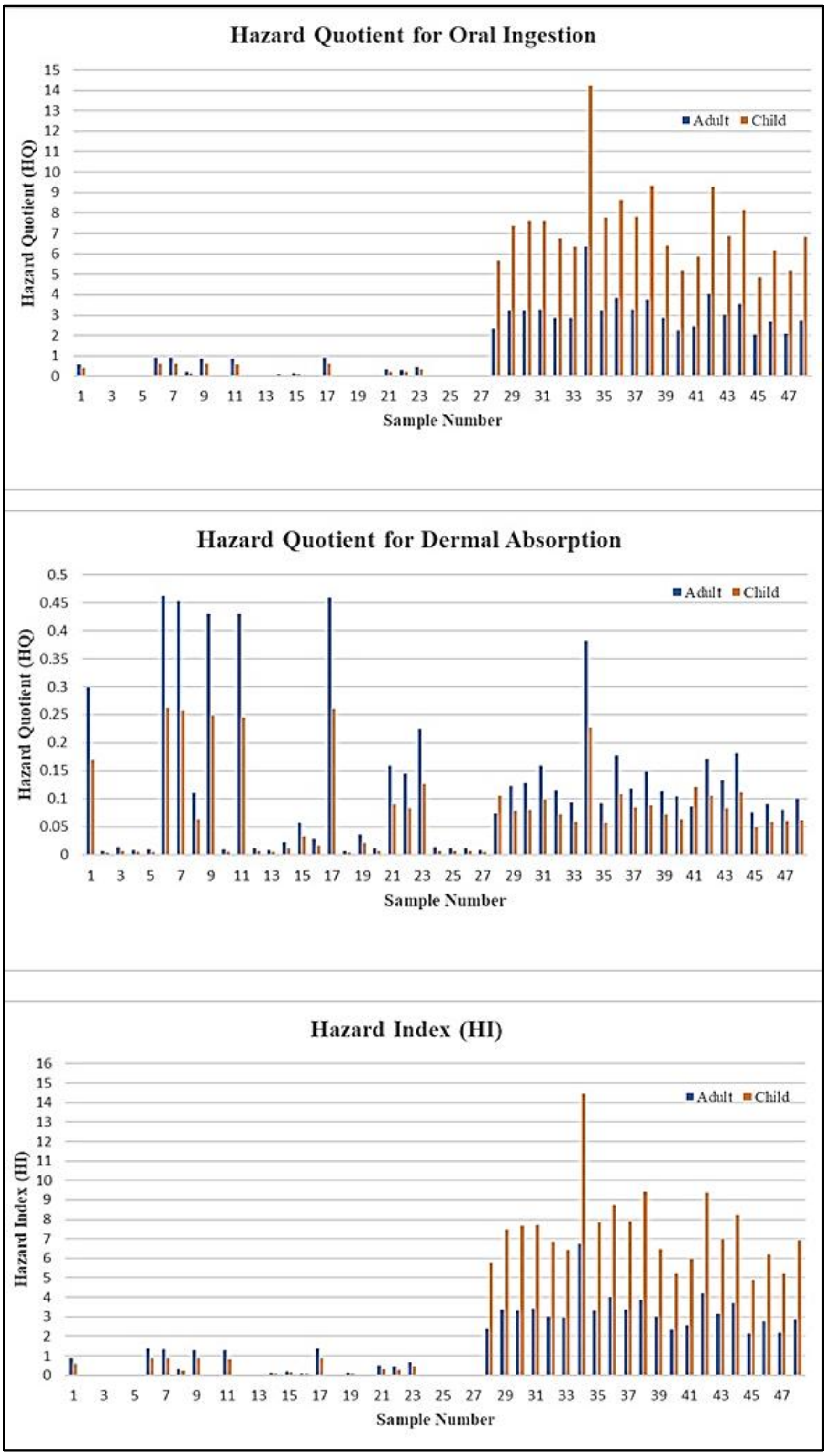

Figure 7. Comparison of Non-Carcinogenic Risk between Adults and Children

### 4.3 Carcinogenic Risk

The cancer risk of individual heavy metals with less than $1x10^{-6}$ would be considered a safe level indicating that 1 in 10,00,000 people are at the potential risk of cancer. The value between $1x10^{-4}$ and $1x10^{-6}$ is an acceptable range, whereas the risk value exceeds the limit 1x10-4, which is unacceptable and poses a severe carcinogenic effect on people. Here, the carcinogenic risk is assessed for both adults and children through the oral and dermal exposures of the contaminated groundwater. The carcinogenic heavy metals of Cr, Ni, Pb and

Cd were selected to assess cancer risk through oral consumption. The cancer risk for chromium and nickel is assessed due to dermal exposure (Figure 8). The mean carcinogenic risk on children and adults through oral consumption for the individual heavy metals of Cr, Ni, Pb, Cd are given in table 4.

Table 4. Mean Carcinogenic Risk of Heavy Metals

| Receptor | Pathway | Cr | Ni | Pb | Cd |
|---|---|---|---|---|---|
| Children | Ingestion | 2.09E-04 | 5.61E-03 | 8.29E-05 | 4.48E-05 |
| | Dermal | 7.37E-05 | - | - | 1.04E-05 |
| Adults | Ingestion | 3.23E-04 | 8.43E-03 | 2.49E-05 | 6.72E-05 |
| | Dermal | 2.55E-02 | - | - | 7.17E-03 |

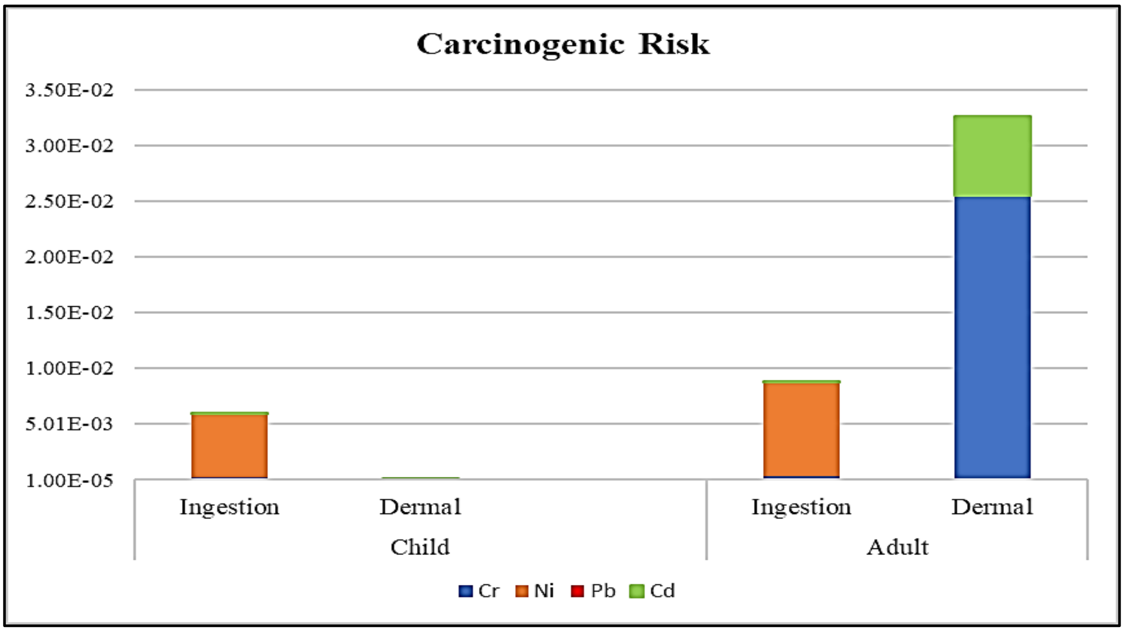


Figure8. Carcinogenic Risk of Children and Adults

The carcinogenic risk for the individual heavy metals through oral pathway for children is found in the order of Pb<Cd<Cr<Ni and for adults is in Cd<Pb<Cr<Ni. Lead and cadmium are under the acceptable range would not pose any carcinogenic effect on adults and children. At the same time, chromium and nickel would have a potential carcinogenic effect on both adults and children. The mean cancer risk of children through dermal contact for Cr is $7x10^{-5}$and Cd and $1x10^{-5}$ and for adults is $2x10^{-2}$ and $7x10^{-3}$ respectively. The result implies that there is no carcinogenic risk over the children; however, adults have high carcinogenic due to the dermal contact of groundwater. Adults show a higher carcinogenic risk on both the pathway from drinking and dermal contact of groundwater than children [22]; [23].

## CONCLUSION

The exposure risk assessment predicts the potential cancerous and non-cancerous health risk to children and adults of the basin by integrating all the information gathered to arrive at quantitative estimates of cancer risk and hazard indices. The heavy metals of Zn, Mn and Cu concentration in the groundwater samples are under the desirable range, whereas the Pb, Fe, Ni, Cd, and Cr concentration are undesirable for drinking. The non-carcinogenic risk assessment reveals that the hazard quotient for oral ingestion exceeds the safe level for both children and adults. The groundwater is significantly contaminated by lead, and it is not safe for consumption. However, the hazard quotient through the dermal pathway is under the safe level. The carcinogenic risk assessment results that the heavy metals of cadmium and nickel pose a high cancer risk on adults and children through the oral pathway. Similarly, chromium and cadmium pose a severe cancerous effect on adults through the dermal pathway. The spatial result discloses that the people residing in the villages adjacent to the main river course of the basin are highly at health risk if they prolong consuming the contaminated groundwater. Based on the results obtained, children are more prone to health risks through oral ingestion of contaminated groundwater, and special care and attention are needed to overcome the health issues. The intake of contaminated groundwater leads to several health problems, and it could be easily affected by the low immunity people. The intake of healthier food habits will improve human immunity power and overcome malnutrition. The groundwater is to be treated before the oral intake, and the children are advised to have minimal contact for dermal contact**.**

## DECLARATIONS

### Conflict of Interest

We declare no conflict of interest, financial, or otherwise.

### Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

### Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them

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