

Evaluating the health risks connected with groundwater contamination

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Abstract

Groundwater is a key source of water for many different uses in the study region. Nineteen groundwater samples were chosen, and several physicochemical water quality indicators were examined to evaluate groundwater quality and health hazards. The correlation between the physiochemical parameters at each site was determined using Pearson's correlation coefficient. Groundwater quality was determined using the comprehensive evaluation (CEM) method for more accurate results that aid in decision-making. The multiple exposure pathways for drinking water consumption and skin contact were also evaluated for the health effects of NH_4^+ and Fe pollutants for adults and kids. The findings indicated that the majority of the chemical parameters have a positive association as indicated by the statistical analysis. The groundwater wells designated as (Q1, Q2, S2, and J6) cannot be used as a source of drinking water, according to the findings of the CEM technique about the quality of groundwater. However, fifteen groundwater samples could. The assessment of health risks showed that children are more susceptible than adults. The results of the examination show that the dangers connected to dermal contact exposure for both kids and adults are negligible, manageable, and may be ignored. The risks of consuming water, however, are excessive and unacceptable for both kids and adults. The findings also showed that youngsters are at much higher risk of exposure than adults from both skin contact and water consumption. The outcomes can offer more information on groundwater quality development and the potential effects of groundwater use.

Key words- Groundwater quality; Physicochemical parameters; CEM Method; Health risk assessment

I. INTRODUCTION

Humans depend heavily on water resources, particularly in arid and semiarid areas [1], [2]. These regions have a variety of water-related issues (see Fig 1), including water pollution and scarcity, which worsen human health and have an impact on society's ability to grow sustainably [3], [4]. The problem of contaminated groundwater is made worse by the numerous human activities, including agricultural, industrial, and other ones, which allow nitrates, organic debris, and pesticides to seep deeply into the aquifer [4], [5]. Agriculture, mining, industry, and other anthropogenic activities continuously have an impact on groundwater due to fast development and the haphazard way that some development projects are carried out [6], [7], [8]. Surface and groundwater are contaminated as a result of waste items being dumped into river systems [5], [9].

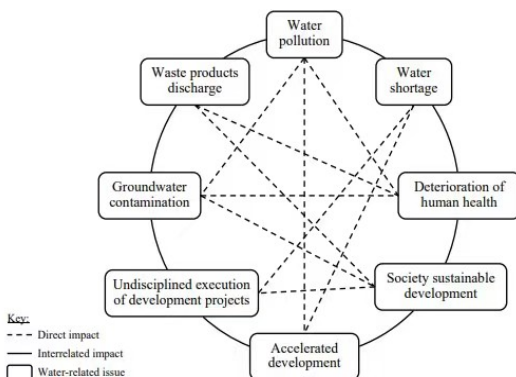


Fig. 1. Water-related problems in arid and semi-arid regions

Due to the importance of groundwater in arid and semi-arid regions, substantial research on groundwater pollution and associated health hazards has been done on a global scale [4], [10], [11]. According to data from the Water Resources Bulletin 2014, groundwater resources play a significant role in China's water supply. The nation's whole water supply in 2014 was 609.5 billion m³. 18.3 of them came from groundwater sources. The national groundwater resources are 774.50 billion m³, the shallow groundwater resources in the hilly parts are 640.78 billion m³, and the groundwater resources in the plains are 161.65 billion m³. Shallow groundwater makes up around 85.8 of the total resources [12]. Since stopping the contaminants at their origins cannot restore the quality of polluted groundwater, it can only be kept and exploited to its fullest potential if the quantity and quality are accurately measured. Since water quality affects human health, it's critical to constantly assess groundwater standards and create evaluation and protection strategies [13], [12]. There are numerous ways to evaluate the quality of groundwater and whether it is fit for drinking at this time. Depending on the goals of the study, each approach has a unique set of characteristics. Additionally, several academics evaluated the threats that groundwater contamination poses to human health in various regions, offering helpful information into safeguarding human health [14]. As a result, the study's objectives are to (1) evaluate the quality of groundwater using the comprehensive evaluation (CEM) method; (2) pinpoint the key ions and pollutants in groundwater; and (3) determine the danger of drinking polluted water. Local decision-makers in the management and conservation of regional groundwater will find this study beneficial.

II. MATERIALS AND METHODS

A. Description of the study area

The research area is in the Chinese province of Sichuan, in the town of Longqiao, on the North Chengdu Plain, between the longitudes of 103° 54'N and 104° 16'N and the latitudes of 30° 40'E and 30° 57'E. The location is about 10 kilometers from Chengdu City, the capital of China's Sichuan province (Figure 1). The study region has a total area of about 72 km², is split up into numerous villages, and has a population of over 140,000. It is bordered by numerous rivers, many of which are tributaries of the Minjiang River. As a semi-tropical environment, the study area has a humid subtropical climate with four distinct seasons, heavy rainfall, high humidity, lots of clouds, little sunshine, slow average wind speeds, long frost-free periods, and hot, muggy summers. 16.6°C is the average annual temperature. The 26°C monthly average is the highest. A full 80 of the time is relative humidity. The amount of sunshine each year is 1337.5 h. The northwest wind dominates the region, reaching a maximum wind speed of 17 m/s and an average wind speed of 1.3 m/s. The research region is a porous rock layer of the compacted gravel layer, as well as the neighboring low mountains and shallow hills, according to the hydrogeological survey. In this region, unconsolidated Quaternary sediments make up the majority of the aquifer types. The primary supply of water for domestic and other uses is this basin, which has a groundwater table that is between 1.5 and 6 meters deep. In the aquifer, groundwater typically flows from northwest to southeast.

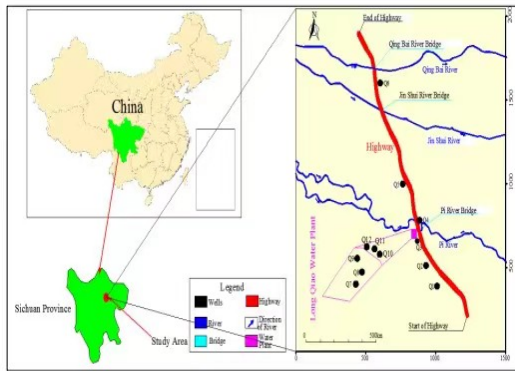


Fig. 2. Groundwater samples and study site in the North Chengdu Plain

B. Sampling procedures and analysis

19 groundwater wells donated Q1, Q2, Q3, Q4, Q5, Q6, S1, S2, S3, S5, S6, J1, J2, J3, J4, J5, J6, and J7 were frequently checked as part of this investigation from various sites around the study region. Residents of Longqiao town and its surrounding region receive drinking water from these wells collectively as part of the Longqiao water treatment facility. Fig 2 shows the locations of all groundwater samples. The samples were tested for 20 different physicochemical water quality characteristics, including total hardness (TH), electrical conductivity (EC), hydrogen ion concentration (pH), and total dissolved solids (TDS). This is in addition to the important

major cations such as sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺) as well as major anions such as bicarbonates (HCO₃⁻), chlorides (Cl⁻), sulfates (SO₄²⁻), secondary ions such as ammonia (NH₄⁺), potassium permanganate index (COD_{Mn}), nitrite (NO₂⁻), nitrate (NO₃⁻) and heavy metals iron (Fe), manganese (Mn), arsenic (As), chromium (Cr⁶⁺), and lead (Pb). Following the recommendations of BIS and the American Public Health Association [15], the samples were examined in the laboratory using conventional analytical techniques.

C. Pearson's r/Correlation Coefficient

It is possible to learn a lot about the typical values and variable forecasts of physicochemical attributes through descriptive statistics and correlation analysis [16]. Using Pearson's r [17], it is possible to assess how strongly two variables are related. The statistic that is most widely used is Pearson's r. The variance of two variables is divided by the sum of their respective standard deviations in the formula for Pearson's r, often known as a linear correlation coefficient. The linear correlation coefficient (r) between the variables x and y for the sample, if x and y are the two variables and n is a sequence of observations for x and y, is as shown in equation 1.

$$\text{Correlation}(r) = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum y^2) - (\sum y)^2]}} \quad (1)$$

Where: n = number of variables measured for each sample, $\sum xy$ = the sum of variables, x represents the first variable measured and y = the second variable measured.

D. Comprehensive evaluation method (CEM)

According to the quality standard for groundwater in China (GB/T 14848-2017) [18], the complete evaluation methodology is the most popular way to determine if groundwater is fit for drinking. The comprehensive evaluation approach, as shown in Table 1, first classifies a single component to identify the necessary quality category before using the comprehensive assessment to determine the value of F. The fuzzy evaluation approach is used to conduct the assessment using the Chinese groundwater quality standard (GB/T 14848-17) [15]. The entire evaluation process can be calculated using conventional equations 2 and 3 [19].

$$F = \sqrt{\frac{\bar{F}^2 + F_{\max}^2}{2}} \quad (i = 1, 2, 3, \dots, n) \quad (2)$$

$$\bar{F} = \frac{1}{n} \sum_{i=1}^n F_i \quad (i = 1, 2, 3, \dots, n) \quad (3)$$

Where: n = number of indices selected for the assessment, F = the value of the comprehensive evaluation method for a given sample, and F_i = the assigned value for the i^{th} index by the quality standard for groundwater (GB/T 14848-17). $\bar{F}$ = the average value of each component score of F_i , $(F_i)_{\max}$ = the maximum value of the individual component evaluation score F_i . Once F is determined, groundwater quality classification can be obtained as per the criteria in Table II: [20].

TABLE I
CLASSIFICATION OF INDIVIDUAL COMPONENTS

Type of groundwater quality	1	2	3	4	5
Value for Fi	0	1	3	6	10

TABLE II
STANDARDS OF THE GROUNDWATER QUALITY CLASSIFICATION.

Level	F
Excellent	< 0.80
Good	0.80 ~< 2.50
Moderate	2.50 ~< 4.25
Poor	4.25 ~< 7.20
Very poor	> 7.20

E. Health risk assessment

Assessment of health risks is crucial to safeguarding all water supplies. Additionally, it is antequique for gathering health data to evaluate a person's habits and state of health [21]. Employees are assisted and encouraged to respond to straightforward questions about their health history and lifestyle through health risk assessment [22]. By evaluating the hazards to human health, it is extremely simple to estimate how contaminants affect people's overall health. Skin contact and water consumption are two of the most typical ways that risks are exposed [23], [24]. The model proposed by China's Environmental Protection Ministry in 2014, which was developed using US Environmental Protection Agency (USEPA [4] models, was adopted and used in this study.

F. Health risk assessment factors and method

In this study, the main chemical pollutants that exceeded Chinese standards according to the CEM method are ammonia (NH_4^+), Fe, and Mn. Through skin contact and drinking water, these pollutants may not cause cancer. Fe concentration has a good correlation with Mn, therefore, Fe can be selected with NH_4^+ in this work. The chemical pollutants of NH_4^+ and Fe are computed, respectively, as shown in equation 4.

$$HI_E = \frac{E}{RfD}, HI_D = \frac{D}{RfD} \quad (4)$$

Where: E = the average daily intake of groundwater (mg/kg/day) and D = the model of daily exposure through skin contact (mg/kg · day). RfD = the reference dose according to USEPA. The RfD of NH_4^+ and Fe are 0.97 and 0.7 mg/(kg.days), respectively. The formula and parameters through the pathway of drinking water intake expressed as E, are computed as per equation 5.

$$E = \frac{C * IR * EF * ED}{BW * AT} \quad (5)$$

Where: C = the pollution concentration in water (mg/L), and IR = the daily water consumption (L/days), which was adopted 2.0 and 1.0 (L/days) respectively, for adults and children in this study [25]. EF = the exposure frequency and the number of days exposed in a year (day per year), and it is 350 (d/a) for both children and adults. ED = the total exposure duration, and the usually suggested value for children are 12 years and for adults is 30 years. BW = the average body weight of an adult

and children (kg), and the value of BW proposed for children and adults are 15 and 60 kg, respectively. AT = the mean exposure time (day), and the suggested value of AT is ED × EF d/year or (AT = 365×ED). The formulas of the dermal contact pathway are shown in equations 6 and 7.

$$D = \frac{DA * EV * ED * EF * SA}{BW * AT} \quad (6)$$

$$DA = K * C * t * CF \quad (7)$$

where: EV = the frequency of daily exposure to skin contact, as defined in 1 in this study according to [25], [26], SA = the dermal surface area available for contact (cm^2), DA = the dermal absorbed dose (mg/cm^2), K = the skin permeability coefficient (cm/h) and its recommended value is 0.001 cm/h, t = the duration of contact (h) and CF = unit conversion factors (L/cm^3), which equals 1000. The area of exposure for adults and children when bathing is approximately 16,600 and 12,000 cm^2 , respectively, based on the physical characteristics and regional bathing customs of the Chinese people. According to the study, bathing should take 0.35 hours three times a week on average for both adults and kids. There are 1900 cm^2 of exposed skin on the face for children and 1930 cm^2 for adults when washing their hands and faces, and each wash takes 0.03 hours [20]. Equations 8 and 9 can be used to express the overall hazards (HI_T), which is a measure of the total effects of various chemical pollutants on human public health.

$$HI_i = HE_E + HI_D \quad (8)$$

$$HI_T = \sum_{i=1}^n HI_i \quad (9)$$

If (HI_T) is greater than 1, there is a health risk (unacceptable). If less than 1, the risk is acceptable.

III. RESULTS AND DISCUSSIONS

Statistics were used to analyze the concentration values of the physicochemical groundwater quality indicators acquired from the 19 wells in the research area Table III. To determine if they were safe to drink, their concentrations were compared to the allowable levels suggested by China's national quality criteria for groundwater (GB/T 14848-17).

Table III compares the acceptable levels recommended by the WHO with Chinese national quality standards and groundwater quality measurements (2011). All groundwater analyses' majority of physicochemical parameters were found to be within the (WHO 2011) permitted limits for drinking water, except for EC, TH, TDS, Ca^{2+} , and SO_4^{2-} in some samples being above the permissible limits of (WHO 2011). Additionally, some samples' concentrations were higher than the Chinese standards in the research area. For several sampling sites, these concentrations were primarily composed of TH, NH_4^+ , Fe, and Mn. National quality criteria for groundwater (GB/T 14848-93) are used as the primary evaluation standard in this study. Therefore, 63.2% of the research area's twelve sampling sites' groundwater quality indicators (class III) exceeded the standard ratio (Fig 3).

TABLE III
WATER PARAMETER STATISTICS AGAINST WHO (2011) AND (GB/T 14848-2017) STANDARDS

Parameter/ Unit	Min	Max	Mean	Std.Deviation	(GB/T 14848-2017) standard, Class III
pH	7.0	7.9	7.37	0.26	6.5–8.5
EC, $\mu\text{S}/\text{cm}$	357.6	1222.9	664.6	165.7	-
TH, mg/L	170.0	418	326.8	76.84	450
TDS, mg/L	250.32	856.0	507.02	155.92	1000
Na^+ , mg/L	5.27	45.3	14.4	9.06	200
K^+ , mg/L	1.08	4.16	2.33	0.9	-
Ca^{2+} , mg/L	53.2	171.2	108.94	33.06	-
Mg^{2+} , mg/L	8.97	856.0	507.02	155.92	-
HCO_3^- , mg/L	168.0	437.6	314.71	79.43	-
Cl^- , mg/L	5	103.0	27.34	22.72	250
SO_4^{2-} , mg/L	34.6	142.28	75.14	29.22	250
NO_2^- , mg/L	0.004	0.04	0.02	10.01	1.0
NO_3^- , mg/L	0.01	4.15	1.63	1.35	20
NH_4^+ , mg/L	0.05	0.7	0.32	0.22	0.5
COD_{Mn} , mg/L	0.19	0.5	0.37	0.11	3.0
Fe, mg/L	0.05	1.36	0.42	0.45	0.3
Mn, mg/L	0.003	0.37	0.08	0.11	0.1

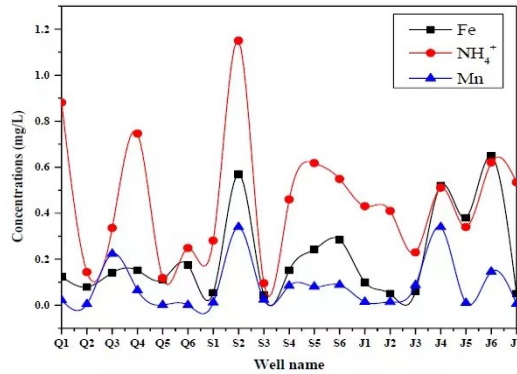


Fig. 3. The values of concentrations exceeded Class III Fe, NH_4^+ , and Mn

A. The Parameters Pearson's Correlation Coefficient

Table IV displays the correlation matrix between the 16 measured parameters. The range of Pearson's correlation coefficients is zero (no correlation) to one (when the correlation is perfect). A strong correlation is defined as samples with a correlation coefficient higher than 0.7. When r is between 0.5 and 0.7 at a significance level of $p = 0.05$, the samples exhibit a moderate correlation but r less than 0.3 indicates a weak link [27]. Several physicochemical parameters also showed strong linkages in the correlation matrix, as shown in Table IV, showing that these parameters are strongly related to one another. Results of correlation analysis showed that the high positive correlations between TDS and the electrical conductivity (EC) demonstrate the increase of conductivity when the concentration of all dissolved constituents increased. It also illustrates that TDS and EC show a high positive correlation with Ca^{2+} , Mg^{2+} and Cl^- . The relationships identify clearly the main elements contributing to groundwater salinity and its tendency to follow a similar trend. Also, strong positive correlations between Cl^- and NO_2^- were significantly derived from anthropogenic-induced pollution sources, such as decay-

ing organic matter, leakage of septic tanks, sewage wastes, and fertilizers. The majority of physicochemical parameters have a strong negative relationship with pH. It is important to note that the chemical reactions in a groundwater system involve several intricate processes [28].

B. Evaluation of groundwater quality using the CEM technique

Groundwater is the main source of drinking water for locals in the study region. The relevance of this work is further shown by the comprehensive evaluation method (CEM) evaluation of the groundwater quality in the Quaternary Unconsolidated Sedimentary Basin. 19 wells in the study region, designated Q1, Q2, Q3, Q4, Q5, Q6, S1, S2, S3, S5, J1, J2, J3, J4, J5, J6, and J7, had their groundwater quality evaluated using this method. Of the 20 groundwater parameters examined, 14 (pH, TH, TDS, SO_4^{2-} , Cl^- , NO_2^- , NO_3^- , NH_4^+ , COD_{Mn} , Fe, Mn, As, Cr^{6+} , and Pb) were chosen because the remaining 12 did not meet the requirements of China's standard for evaluating the quality of groundwater (GB/T 14848-17), which calls for a five-level division. The outcomes are displayed in Table V. The F values of all examined samples in the research region range from 2.17 to 7.30, ranging from extremely good quality to severely bad quality, as shown in Table V and Fig 4. The results of the assessment show that fifteen groundwater samples (grade II and III for seven samples and 42.11 percent for eight samples) are of good and moderate quality and are suitable for a range of uses. Four groundwater samples out of the total acquired are evaluated as having water of low and very bad quality (grades IV and V, respectively), which is judged unsafe for human consumption (10.53% of Q1 and S1 and 10.53% of Q2 and J6). The results of the full evaluation approach showed that fifteen groundwater samples, but not (Q1, Q2, S2, and J6), may be used as a source of drinking water.

TABLE IV
VARIOUS GROUNDWATER QUALITY PARAMETERS' PEARSON'S CORRELATION MATRIX.

parameters	pH	EC	TH	TDS	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	NO ₂ ⁻	NO ₃ ⁻	NH ₄ ⁺	Mn	Fe
pH	1															
EC	-0.97	1														
TH	-0.85	0.87	1													
TDS	-0.95	0.99	0.91	1												
Na ⁺	-0.29	0.28	-0.19	0.23	1											
K	-0.38	0.52	0.63	0.63	-0.01	1										
Ca ²⁺	-0.81	0.83	1.00	0.87	-0.27	0.62	1									
Mg ²⁺	-0.95	0.97	0.96	0.99	0.09	0.62	0.93	1								
HCO ₃ ⁻	0.33	0.43	0.44	0.36	-0.23	0.00	0.46	0.34	1							
Cl ⁻	-0.94	0.98	0.80	0.97	0.37	0.51	0.75	0.93	0.32	1						
SO ₄ ²⁻	-0.85	0.90	0.92	0.93	-0.01	0.64	0.89	0.95	0.29	0.91	1					
NO ₂ ⁻	-0.78	0.86	0.77	0.86	0.12	0.49	0.73	0.85	0.41	0.92	0.93	1				
NO ₃ ⁻	0.58	-0.44	-0.65	-0.48	0.21	-0.27	-0.66	-0.58	-0.01	-0.31	-0.40	-0.08	1			
NH ₄ ⁺	-0.48	0.43	0.57	0.53	-0.05	0.60	0.55	0.60	-0.48	0.47	0.65	0.41	-0.56	1		
Mn	0.01	0.03	0.36	0.09	-0.50	0.42	0.42	0.16	0.26	-0.16	0.01	-0.25	-0.60	0.07	1	
Fe	0.02	-0.03	0.34	0.08	-0.47	0.46	0.38	0.17	-0.17	-0.17	0.05	-0.29	-0.74	0.45	0.88	1

Notes: Correlation is significant at the 2-tailed level of 0.01 and the level of 0.05. (2-tailed).

TABLE V
CLASSIFICATION OF GROUNDWATER QUALITY BASED ON THE COMPREHENSIVE EVALUATION METHOD.

Well title	F value	Grade
Q1	7.30	Very poor
Q2	7.17	Poor
Q3	2.44	Moderate
Q4	4.22	Moderate
Q5	2.31	Good
Q6	2.29	Good
S1	2.22	Good
S2	7.30	Very poor
S3	2.24	Good
S4	4.12	Moderate
S5	3.49	Moderate
S6	3.36	Moderate
J1	2.19	Good
J2	2.33	Good
J3	4.02	Moderate
J4	4.22	Moderate
J5	2.17	Good
J6	7.04	Poor
J7	2.98	Moderate

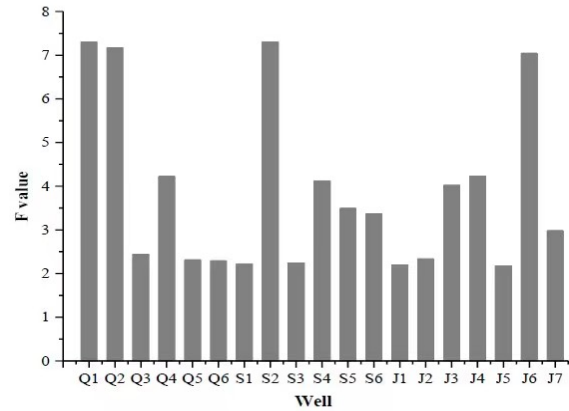


Fig. 4. Results of the well's water quality evaluation established by the comprehensive evaluation method

respectively. The maximum danger of Fe concentration was surpassed by 1, exceeding both the risks of Fe contamination on kids and adults via skin contact and drinking groundwater.

C. Discussion of health risk assessment results

This study evaluated the dangers to children's and adults' health from groundwater contamination in the study area caused by high NH₄⁺ and Fe concentrations. The health risks associated with exposure to each pollutant through skin contact and water consumption are shown in Table VI. According to Table VI and Fig 5, the risk of exposure to NH₄⁺ from drinking water and skin contact for adults ranged from 0.05 to 0.72 with a mean of 0.33 and from 0.19 to 2.65 with an average of 1.21 for children. The risks of NH₄⁺ pollutant in adults is lower than 1, demonstrating the minimum permissible health risks [29]. Whereas the risks of NH₄⁺ pollutant for children exceeds 1, which poses a risk health of children in this area. In the same vein, the Fe pollutant risks to adults and children varied from 0.07 to 1.94 and 0.26 to 7.12 with averages of 0.60 and 2.20,

TABLE VI
HEALTH RISKS OF DIFFERENT POLLUTANTS

	NH ₄ ⁺		Fe	
	Adult	Children	Adult	Children
Minimum	0.05	0.19	0.07	0.26
Maximum	0.72	2.65	1.94	7.12
Mean	0.33	1.21	0.60	2.20

Table VII depicts the health concerns in several ways (drinking water intake and dermal contact). Table VII and Fig 6a show that there are overall risks associated with drinking water that is larger than 1 for both adults and children. This implies that drinking water carries significant health hazards and is probably bad for people's health. however, the overall risks from cutaneous touch are less than 1 for both adults and children. Skin-to-skin contact causes no harm to people's health and only minor health problems (see Fig 6a and Fig

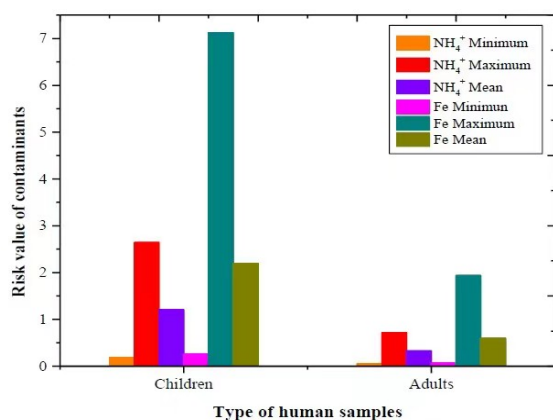


Fig. 5. Statistical graph of the risk indexes of NH_4^+ and Fe in our study area

6b). Health concerns from skin contact should be ignored because they are far lower than those from drinking water in the study region. Tables VI and VII further demonstrate that children are much more at risk of exposure in the study area than adults for both pathways (drinking water intake and skin contact). In general, both children and adults are at significant risk in this area due to NH_4^+ and Fe pollution. Therefore, it is crucial to take prompt action to address groundwater contamination at these levels. Since high NH_4^+ concentrations might produce a toxic buildup in internal tissues and blood, which could result in death. Additionally, the nose, throat, and respiratory tract immediately burn when exposed to high NH_4^+ concentrations in the air. This may result in airway damage, bronchiolar and alveolar edema, and respiratory discomfort or failure. Concerning Fe, if it comes into touch with and stays in the tissues, its excessive concentration may result in conjunctivitis, choroiditis, and retinitis. Longterm exposure to large amounts of iron oxide fumes or dust may result in siderosis, benign pneumoconiosis that shows up as an x-ray change.

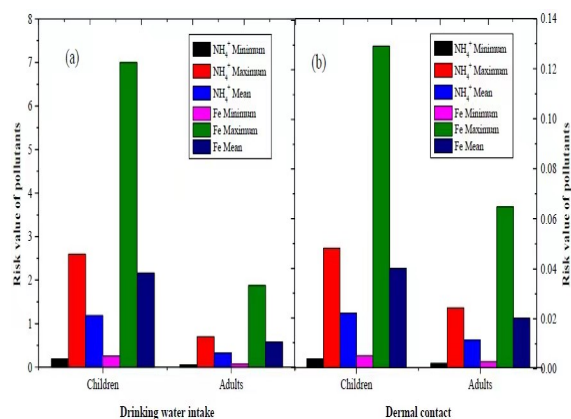


Fig. 6. The risk indexes of NH_4^+ and Fe for different exposure pathways

The health risks linked to NH_4^+ and Fe contaminants for both adults and children were assessed using the various exposure paths. The evaluation's findings demonstrate that there are unacceptable levels of danger associated with drinking water

for both adults and children. However, the risks of cutaneous contact are negligible and manageable for both kids and adults.

IV. CONCLUSIONS

To evaluate groundwater quality and health hazards, 19 samples of groundwater were taken and subjected to various physicochemical water quality analyses. Within the boundaries of this paper of the North Chengdu Plain area, the following can be inferred:

- 1) According to hydrochemical analysis, the general order of dominance of major cations and anions are $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ and $HCO_3^- < SO_4^{2-} < Cl^-$ respectively in the groundwater of this area.
- 2) When all groundwater parameters in the research region were analyzed, the majority of the physicochemical parameters were found to be within the (WHO 2011) permitted limits of drinking water of both standards.
- 3) The majority of the factors in this study have a positive association, according to Pearson's Correlation Coefficient ($r > 0.7$).
- 4) 15 groundwater samples might be used as a source of drinking water, however wells Q1, Q2, S2, and J6 cannot, according to the results of the full examination approach.
- 5) The Health risks of NH_4^+ and Fe contaminants for adults and children were assessed by the different exposure pathways. The evaluation's findings indicate that drinking water intake has little and tolerable risks to both children and adults. The hazards of dermal contact, however, are excessive and undesirable for both children and adults.
- 6) The findings of this study offer a crucial reference framework for the government's decision-making procedures on enhancing the water quality in the study area and the vicinity.

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TABLE VII
RISK TO HEALTH FROM VARIOUS EXPOSURE ROUTES

Drinking water intake				Dermal contact				Total	
NH ₄ ⁺		Fe		NH ₄ ⁺		Fe		Children	Adults
Children	Adults	Children	Adults	Children	Adults	Children	Adults		
0.186	0.05	0.257	0.069	0.003	0.002	0.005	0.002	0.451	0.123
2.598	0.696	6.994	1.875	0.048	0.024	0.13	0.065	9.77	2.66
1.188	0.318	2.16	0.579	0.022	0.011	0.04	0.02	3.41	0.928

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