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RESEARCH

Severe Disease Burden and the Mitigation Strategy in the Arsenic-Exposed Population of Kaliprasad Village in Bhagalpur District of Bihar, India

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Abstract

The present study was carried out in the village Kaliprasad of Bhagalpur district of Bihar to know the arsenic exposure effect in the exposed population. A total of $n = 102$ households were studied, and their water and biological samples such as urine and hair were collected and analyzed in a graphite furnace atomic absorption spectrophotometer (GF-AAS). The assessment of arsenic-exposed village population reveals that the villagers were suffering from serious health-related problems such as skin manifestations (hyperkeratosis and melanosis in their palm and soles), breathlessness, general body weakness, mental disorders, diabetes, hypertension (raised blood pressure), hormonal imbalance, neurological disorders, and few cancer cases. About 77% of household hand pump water had arsenic level more than the WHO recommended level of 10 μg/L, with highest level of 523 μg/L. Moreover, in 60% individual's urine samples, arsenic concentration was very high with maximum 374 μg/L while in hair 64% individuals had arsenic concentration above the permissible limit with maximum arsenic concentration of 11,398 μg/kg. The hazard quotient (HQ) was also calculated to know the arsenic risk percentage in children as 87.11%, in females as 83.15%, and in males as 82.27% by groundwater. This has surpassed the threshold value of 1×10^{-6} for carcinogenic risk (CR) in children, female, and male population group in the village. Hence, the exposed population of Kaliprasad village are at very high risk of the disease burden.

Keywords Groundwater arsenic contamination · Kaliprasad village · Public health assessment · Cancer risk assessment

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Introduction

In the recent times, the environmental pollutants have caused significant threats to human health [13, 46]. Among the environmental pollutants, groundwater arsenic poisoning has emerged as a major health hazard in the exposed population [7, 8, 42, 66]. It is estimated that 300 million population are exposed to groundwater arsenic poisoning in Ganga, Meghna, and Brahmaputra plains of Indian sub-continent [5, 24, 50, 51]. In India, approximately 70 million population are exposed to groundwater arsenic poisoning. In the state of Bihar, an estimated 10 million population from 22 spotted districts, out of 36, are having severe groundwater arsenic poisoning [30, 31, 38]. The arsenic catastrophe in this middle Ganga plain has brought serious health-related difficulties in the exposed population. The Himalayan bound rivers carry carcasses full of arsenic in these river plain regions and contaminate the groundwater [21, 57, 62]. Health-related problems have

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been reported from the states — West Bengal, Assam, Uttar Pradesh, and Bihar due to arsenic poisoning [16, 18, 43]).

In Bihar, the arsenic-exposed population exhibit symptoms such as skin manifestations (keratosis and melanosis in palm and soles), general body weakness, gastrointestinal disorder, neurological disorder, hormonal disorder, cardiovascular disorder, diabetis, and cancer malignancies [20, 72]. The long-term exposure to arsenic causes accumulation of it in the keratin of the human body which is reflected in hairs as 2–6 months of pre-exposure and in nails as 12–18 months of pre-exposure [59]. Moreover, the blood and urine are also the biomarkers for evaluation of metal toxicity [19, 52, 67].

Bhojpur was the first district to be reported with arsenic poisoning in groundwater in 2002 [10, 12, 64]. Our recent studies, carried out in the Buxar district in Simri village and Tilak Rai Ka Hatta, have been well documented with severe arsenic poisoning and associated health hazards. Moreover, the studies were also carried out in Gyaspur village of Patna district, Sabalpur village of Saran district, and Chapar village of Samastipur district of Bihar. These studies also enabled the installation of arsenic filter units which provided arsenic-safe water to the villagers. The maximum arsenic contamination of groundwater recorded was 1929 μg/L in Buxar and 1212 μg/L in Samastipur districts, respectively. In various other studies carried out by our team, there has been very high arsenic contamination observed in the blood, hair, and urine samples of the studied subjects [34, 36–39]. Moreover, in the arsenic-exposed population, there has been exhibition of severe health hazards including the disease of cancer [2, 22, 32, 33].

Most of the research studies carried out in the state of Bihar was in the western and the middle regions of the Gangetic plains but no such extensive study was carried out in the eastern region of the state. Hence, a significant village Kaliprasad in Bhagalpur district of Bihar was targeted for the study, when there were many cancer patients reporting such as gallbladder cancer, lung cancer, and squamous cell carcinoma of the skin to our cancer institute. There were reports of 33 cancer patients from this particular village in the last 8 years, hence enabling us to perform an extensive field survey of this village. Hence, the objective of the current study is to carry out the entire village survey and assessment of their household hand pump water, subject's urine, and hair and nails samples for arsenic contamination and to know the impact of arsenic on the health of the population in Kaliprasad village.

Materials and Methods

Location and Sample Size

The current study was carried out in Kaliprasad village of Bhagalpur district, Bihar, India. The GPS location of the study area is 25°20′45.75″ N, 87°23′40.35″ E. It is a small village, which comes under Pirpainti Block in Bhagalpur district. It is situated at 52 km from the Bhagalpur district headquarter and 273 km from the capital of the state Patna and comes under the Gangetic flood plain region. The branch stream of river Ganges is only 300 m away from the village while, the main river channel is 4 km away. The study was carried out from April 2019 to July 2022. There were $n = 102$ households and their water sources were studied as this was the maximum number of households with the members available at the time of the study. The population of the village was $n = 1960$ [11]. In the present research work, extensive study was carried out in $n = 102$ households with the collection of their household water samples, the household individual's urine, and hair samples for estimation of arsenic contamination. A comprehensive analysis of the people living in the community was also performed about their health.

Groundwater Arsenic Determination

The groundwater samples were collected in 100-mL narrow-mouthed high-density polyethylene bottles. Prior to sampling, the sample bottles were washed and pre-treated with 2% HCl. The GPS coordinates and depth of the hand pump water source were recorded. All the water samples were preserved immediately after collection with 1.5 mL/L nitric acid to reduce the $pH \leq 2.0$. The collected water samples were filtered through the 0.45-μm syringe filter. Total concentration of arsenic was determined in the studied institute by using graphite furnace atomic absorption spectrophotometer (GF-AAS) of PerkinElmer model number PinAAcle 900 T (USA).

Hair Arsenic Determination

Hair samples were collected in polypropylene zipper bags. The samples were digested as per the protocol of NIOSH [47]. Firstly, 0.120 g of hair samples were taken in 50-mL acid pre-washed beaker and 15 mL of 0.1% sodium dodecyl sulfate (SDS) was poured in it and then it was sonicated for 10 min. After that, SDS solution was decanted from the beaker, and the hair was washed three times with distilled water. Then after, 15 mL of reagent grade acetone was added and sonicated for 10 min. After sonication, acetone was poured off from the beaker and placed in the oven at 40 °C until it dried completely, and hence the first stage of digestion was completed. In the second stage of digestion on the following day, 10-mL concentrated hydrochloric acid was added in the same beaker with a watch glass on it, and then it was digested on a hot plate at 90 to 120 °C until the hair was fully dissolved and when solution became clear. After that, the solution was adjusted to 3 mL before the addition of 1 mL of 30% hydrogen perchloric acid (H_2O_2), and then solution was again heated at just below the boiling temperature until the effervescence was stopped and volume was reduced up to 2.5 mL by evaporating the solution. Now, the surface of the beaker was rinsed with 1% nitric acid (HNO_3), and final volume was made up to 10 mL and then, the sample filtered by using Whatman filter paper no. 41 with pore size 20–25 µm. Determination of arsenic concentration was done on GF-AAS. Normally, ≤ 200 µg/kg arsenic contamination is found in human hair, and above this level, it might adversely affect the human health [4].

Urine Arsenic Determination

The urine samples were collected in a 60-mL volume polypropylene collection bottles. A total of $n = 102$ urine samples were collected. The digestion of the sample was done as per the protocol of NIOSH (1994). For the study, 0.5-mL urine sample was taken in 50-mL Erlenmeyer flask and 5-mL HNO_3 was added, and then the solution was left for 12 h for digestion. After that, the solution was digested at 90–120 °C on a hot plate until the solution reduced to 2 mL. After that, 5 mL of mixture of Conc. HNO_3 and $HClO_4$ in a ratio of 6:1 was added, and once again, the sample is digested until the solution reduced to 2 mL. The wall of the flask was rinsed with 1% HNO_3, and final volume makeup was done to 10 mL and finally filtered using the Whatman filter paper no. 41. Determination of arsenic concentration was done on GF-AAS. Normally, ≤ 50 µg/L arsenic contamination is found in human urine, and above this level, it might adversely affect the human health [4].

Quality Control

For the calibration of instruments, we used 1000 mg/L arsenic standard from PerkinElmer CAS No. AS7440-38–2; Lot No. 25-127ASY1; PE No. N9300180. Stock standard and working standards were prepared by diluting 1000 mg/L of arsenic standard. A calibration correlation coefficient of 0.999 was mentioned throughout the analysis, also for the quality control standards, as samples were run after every 10 samples. The lowest detection limits of arsenic in urine, hair, and water were 0.09 µg/L, 0.08 µg/L, and 0.04 µg/L, respectively. Accuracy and precision were also determined. Accuracy is expressed in the form of recovery percentage, and precision is expressed in the form of repeatability, i.e., %RSD. The spike recovery percentage of water, hair, and urine samples was calculated by adding known amount of arsenic standard in spike samples. The sample percentage recovery was found to be 94.3%, 93.6%, and 94.9%, respectively, for water samples, 93.6% for hair samples, and 94.9% for urine samples which is within the acceptable range. Repeatability of the spike sample is also calculated by determining 5 replicates of each spike sample. The repeatability of the sample is expressed in the form of relative standard deviation which is found to be 0.8%, 0.4%, and 0.6% for groundwater, hair, and urine, respectively.

Health Survey

The total population of the village was $n = 1960$, with households $n = 102$. A total of $n = 1372$ subjects were interviewed from $n = 102$ households of the village for the health survey. For this study, a pre-typed health survey questionnaire proforma was utilized. The questionnaire used for the assessment included the number of family members, their age and gender, number of children, health problems especially arsenic-related diseases (skin manifestations — keratosis and melanosis in sole and palms, rain drop pigmentation), gastrointestinal disorders, cardiovascular disorders, neurological disorders, hormonal disorders cancer, or any other disease. Apart from this, the other information related to their drinking water source like source of water they drank, depth of hand pump, and age of hand pumps were recorded. Photograph of physical appearance disease and household GPS location were also taken during the survey using the handheld Garmin eTrex 30 × GPS instrument.

Health Risk Assessment

The health risk assessment caused by arsenic exposure was calculated using the below mentioned formula.

The level and magnitude of exposure of arsenic are expressed in terms of average daily dose (ADD).

$$ADD = (C \times IR \times EF \times ED)/(BW \times AT)$$

where.

C = groundwater arsenic concentration
IR = per day water intake rate, L/day
EF = exposure frequency, 365 days/year
ED = exposure duration in year
BW = body weight, kg
AT = average time

Hazard Quotient

The non-carcinogenic health risk is represented by hazard quotient. The potential or level showing no adverse effects is expected.

$$HQ = ADD/RfD$$

where.

HQ = health quotient.
ADD = average daily dose.
RfD = oral reference dose (0.3 µg/kg/day) [69].

If the obtained HQ value is more than 1, then non-carcinogenic effect can be possible, and if determined HQ is 1 or less than 1, then no health effect can be predicted due to exposure.

Carcinogenic Risk (CR)

Carcinogenic risk can be calculated by using this equation:

$$CR = ADD \times CSF$$

where.

CR = carcinogenic risk.

ADD = average daily dose.

CSF = cancer slope factor, (1.5 mg/kg/day).

If CR value is $\leq 1 \times 10^{-4}$ then, it has tolerable menace levels.

Spatial Analysis

A shape file was created by superimposing the GPS coordinates of samples with the help of ArcGIS Software (10.1) Google Maps (Google Earth) which was used as base map. The arsenic concentration in groundwater, urine, and hair was represented in three classes. In groundwater, it is represented in ≤ 10 µg/L, 10–50 µg/L, and > 50 µg/L. In urine, it is represented in ≤ 50 µg/L, 50–100 µg/L, and > 100 µg/L and in hair, ≤ 200 µg/kg, 200–1000 µg/kg, and > 1000 µg/kg.

Statistical Analysis

For the statistical analysis, statistical software GraphPad Prism 8.0 and SPSS 25.0 were utilized. Arsenic concentration in groundwater, urine, and hair were analyzed and graphically represented. A total of 8-correlation analysis was made with 5 variables. One-way analysis of variance was used to analyze the variation between the groups.

Results

Groundwater Arsenic Concentration of Village Kaliprasad's Hand Pump Samples

- A total of $n = 102$ groundwater samples were analyzed in which 52% of the samples had exceeded 50 µg/L arsenic concentration.
- Twenty-five percent of the sample had exceeded 10 µg/L arsenic concentration and only 23% of the groundwater samples had levels within the permissible limit, i.e., ≤ 10 µg/L.
- The maximum arsenic concentration was found up to 523.3 µg/L (Fig. 1).

Urine Sample Arsenic Concentration of Village Kaliprasad

- A total of $n = 102$ urine samples were analyzed, out of which 37% of them had arsenic concentration more than 100 µg/L.
- Twenty-three percent of samples were between 51 and 100 µg/L and 40% below 50 µg/L arsenic concentration. The permissible limit of arsenic in urine is 50 µg/L.
- Maximum concentration of arsenic found in urine samples was up to 374 µg/L (Fig. 2).

Hair Arsenic Concentration of Village Kaliprasad

- A total of $n = 102$ hair samples were analyzed, out of which 35% of them had arsenic concentration more than 1000 µg/kg.
- Twenty-nine percent of samples had arsenic concentration between 200 and 1000 µg/kg and 36% had arsenic concentration ≤ 200 µg/kg.
- The highest arsenic concentration was found up to 11,398.2 µg/kg in hair (Fig. 3).
- The permissible limit of arsenic in hair is 200 µg/kg.

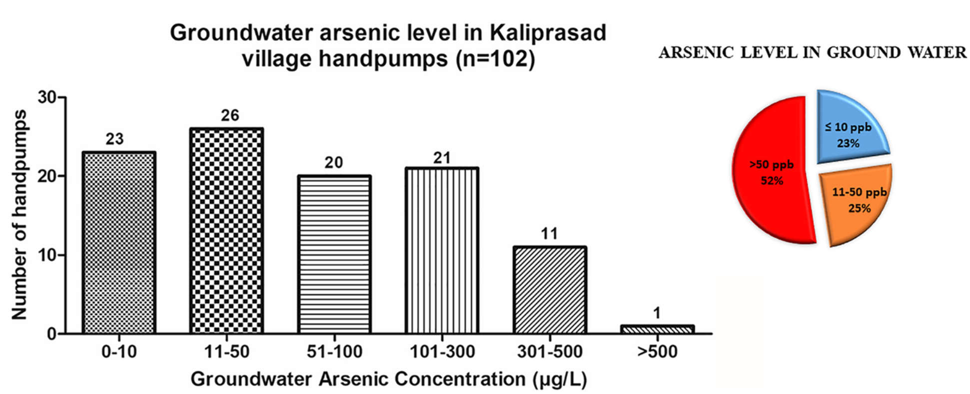


Fig. 1 Graph of groundwater arsenic concentration of hand pump water samples

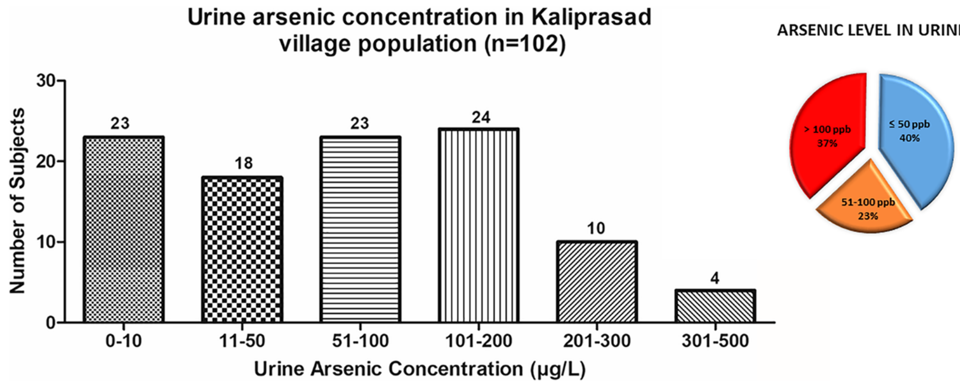


Fig. 2 Graph of urine arsenic concentration of subjects of Kaliprasad village

Correlation Coefficient Study

Groundwater Arsenic Concentration and Age of Hand Pump

A positive correlation coefficient was found between groundwater arsenic concentration and age of hand pump with $r^2 = 0.219$, $p < 0.05$ (Fig. 4A). It has been observed that the average age of the hand pump was between 10 and 20 years having maximum arsenic contamination.

Hair Arsenic Concentration and Groundwater Arsenic Concentration

A strong positive correlation coefficient has been observed between hair arsenic concentration and groundwater arsenic concentration. An increasing trend was discovered with $r^2 = 0.74$, $p < 0.05$ (Fig. 4B). The concentration of arsenic in groundwater is directly correlated with the concentration of arsenic in hair.

Hair Arsenic Concentration and Subject's Age

The correlation coefficient was found between hair arsenic concentration and subject age with $r^2 = 0.153$, $p < 0.05$. The subject average age was between 30 and 60 year which had maximum arsenic exposure (Fig. 4C).

Groundwater Arsenic Concentration and Subject's Age

A slightly positive correlation coefficient was found between groundwater arsenic concentration and subject's age with $r^2 = 0.133$, $p < 0.05$ (Fig. 4D). The average subject's age was between 40 and 60 year which had maximum arsenic contamination.

Arsenic Concentration in Urine and Subject's Age

A slightly positive correlation was observed between arsenic level in urine and subject's age. The correlation with $r^2 = 0.171$, $p < 0.05$ was found in which maximum arsenic concentration was observed in the age group between 30 and 60 years (Fig. 4E).

Urine Arsenic Concentration and Hair Arsenic Concentration

A very strong optimistic and linear correlation coefficient has been seen in between the arsenic concentration in urine and arsenic concentration in hair samples. An expanding trend was seen with the correlation coefficient of $r^2 = 0.816$, $p < 0.05$ (Fig. 4F). Arsenic concentration in urine is directly correlated with the arsenic concentration in hair.

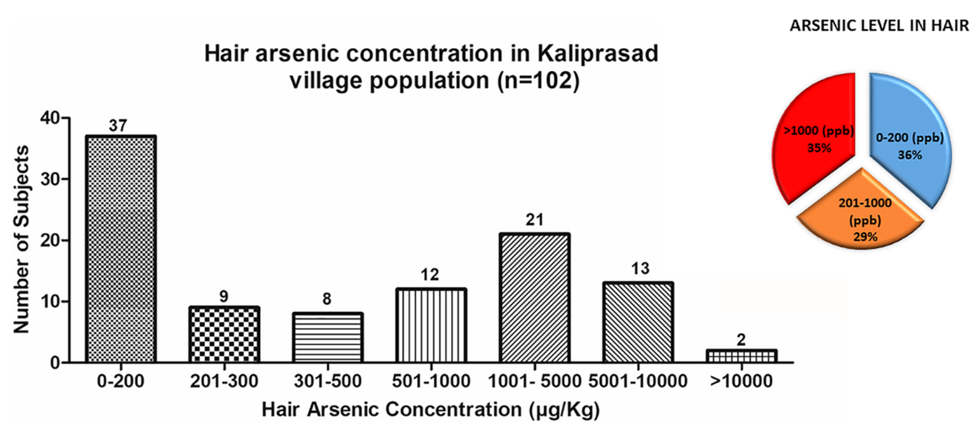


Fig. 3 Graph of hair arsenic concentration in the subjects of Kaliprasad village

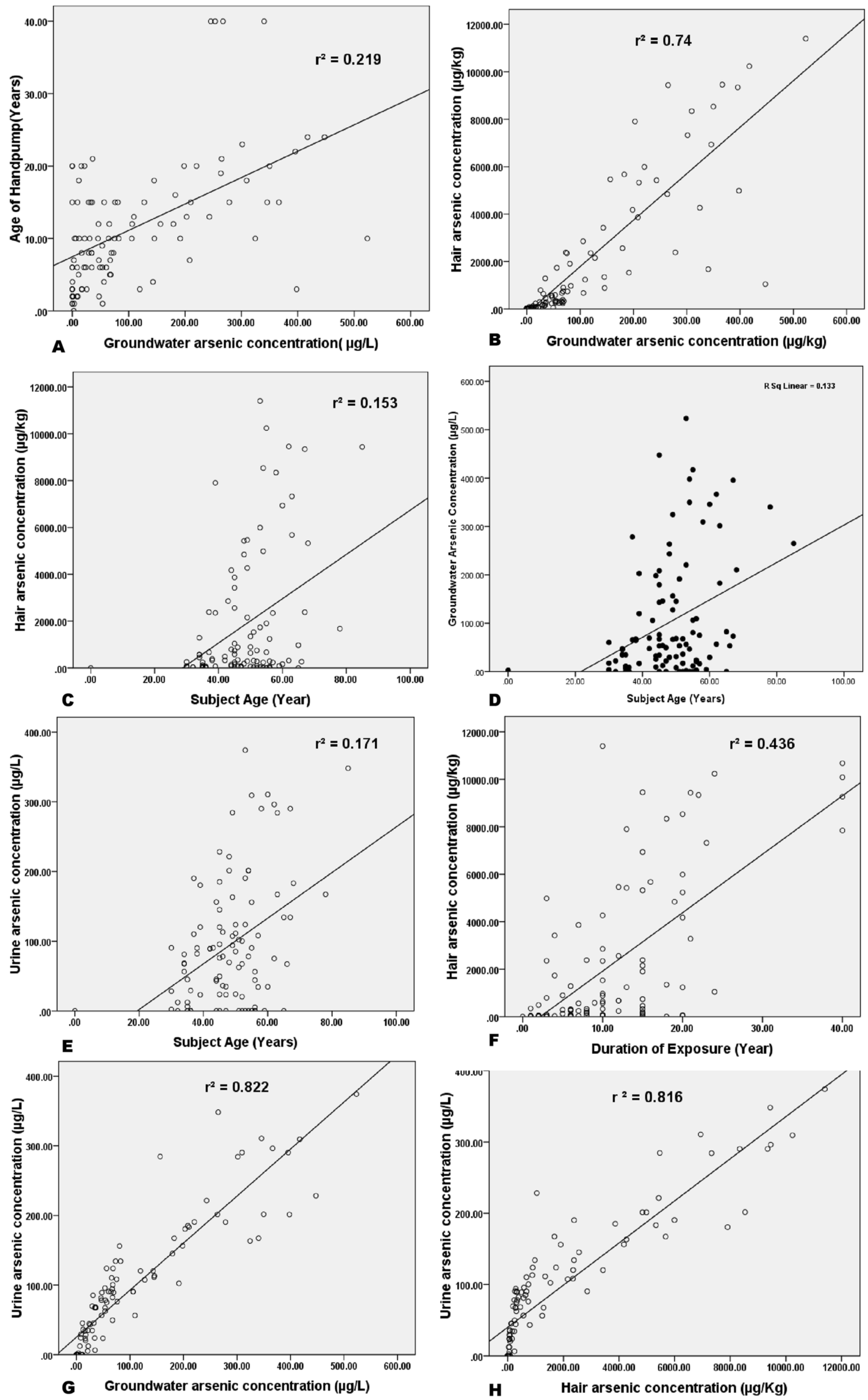
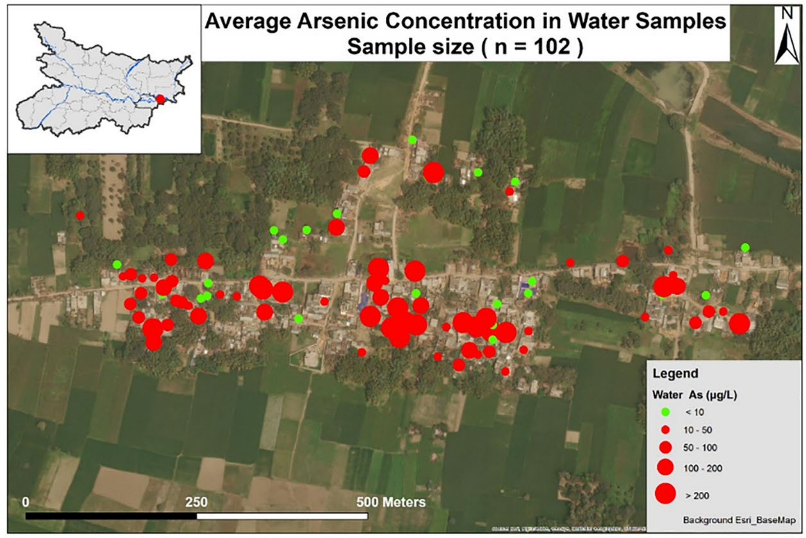
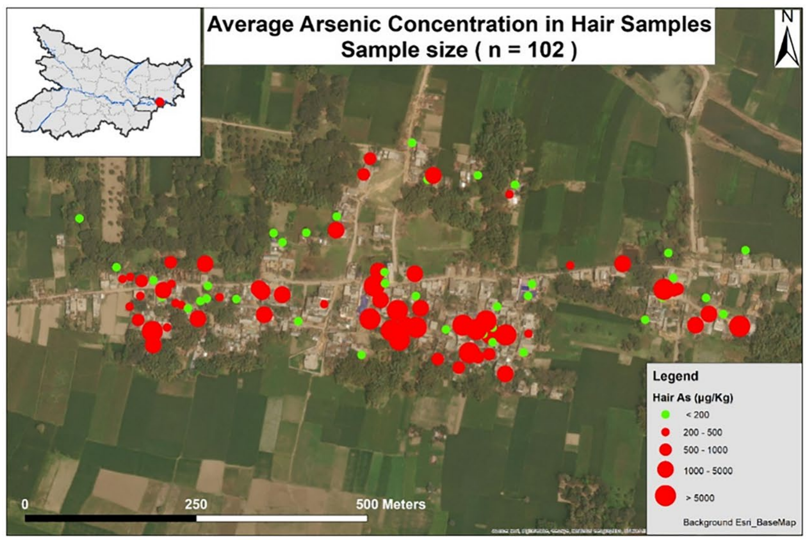


Fig. 4 Scatterplot graphs of variables: **A** hand pump age and groundwater arsenic concentration ($r^2=0.219$). **B** Concentration of arsenic in hair and groundwater arsenic concentration ($r^2=0.74$). **C** Concentration of arsenic in hair and subject's age ($r^2=0.153$). **D** Groundwater arsenic concentration and subject's age ($r^2=0.133$). **E** Urine arsenic concentration and subject's age ($r^2=0.171$). **F** Urine arsenic concentration and hair arsenic concentration of subject's ($r^2=0.816$). **G** Groundwater arsenic concentration and subject's urine arsenic concentration ($r^2=0.822$). **H** Subject's hair arsenic concentration and duration of exposure ($r.^2=0.436$)

Fig. 5 **A** Map of village Kaliprasad with spatial distribution of groundwater arsenic contamination. **B** Map of village Kaliprasad with spatial distribution of arsenic contamination in the hair samples of the village population. **C** Map of village Kaliprasad with spatial distribution of arsenic contamination in the urine samples of the village population



A



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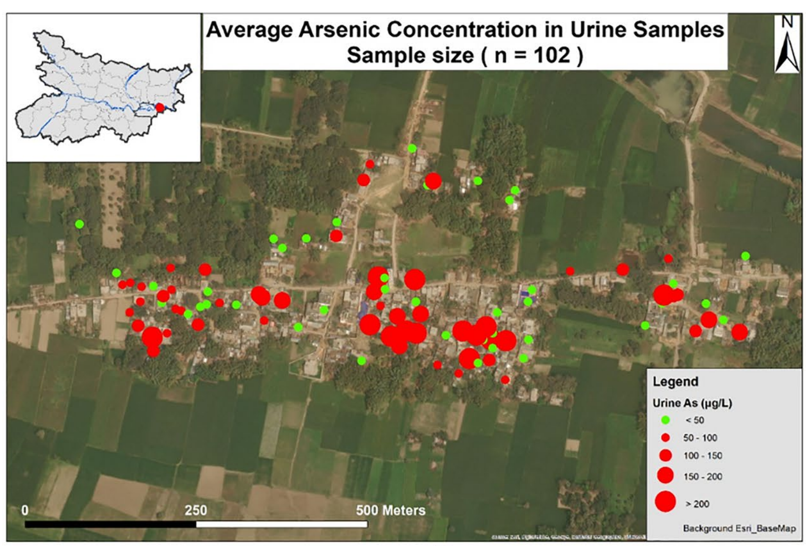

C

Fig. 6 An increase in disease symptoms of a subject (Bilas Mandal, 53 years old) of the village in 3 years of time drinking arsenic-contaminated water 533 µg/L

Urine Arsenic Concentration and Groundwater Arsenic Concentration

A noticeable correlation was found between them. The correlation was strongly positive and linear with $r^2 = 0.822$, $p < 0.05$ (Fig. 4G). It has been clearly observed that groundwater arsenic concentration is directly correlated with urine arsenic concentration.

Hair Arsenic Concentration and Duration of Exposure

A moderate relationship was found between the arsenic concentration in hair and exposure duration. Slightly increasing trend was detected with $r^2 = 0.436$, $p < 0.05$ (Fig. 4H). The age group between 10 and 30 were observed to be highly exposed with arsenic.

Fig. 7 An increase in disease symptoms of a subject (Bhola Mandal, 57 years old) of the village in 3 years of time drinking arsenic-contaminated water 347 µg/L

Spatial Analysis

A summarized form of arsenic levels in groundwater, hair, and urine is shown in Fig. 5A, B, and C. The concentration of arsenic was found to be high in hair followed by urine and lastly in groundwater.

Clinical Observations

In this study, the severely exposed subjects were tracked for 3 years, and it was found that their skin manifestations and symptoms such as ketosis in sole and palm and melanosis increased many folds. Hyperkeratosis on sole and palm is severely increased (Fig. 6A, B, D, and E), while melanosis in the back was merely found in the onset of study, but by the end of the study, it increased many folds (Fig. 6C and F). The subject had been continuously drinking this arsenic-contaminated water from his hand pump as he had no such option.

Another subject was drinking arsenic-contaminated water 523 µg/L since the last 3 years, which aggravated the disease symptoms in his body (Fig. 7A, B, C, and D). His son died with lung disease at the age of 16 years.

Health Assessment

In the present research work, a total of $n = 1372$ persons were examined from $n = 102$ households. The situation of village Kaliprasad was very serious as they were suffering from severe health hazards due to the exposure of arsenic like hyperkeratosis, melanosis, and other skin diseases. Some of them were enduring with anemia, diarrhea, general body weakness, constipation, breathlessness, mental disorders, diabetes, lumps, cardiovascular disease, and cancer. The health assessment of village Kaliprasad reveals that 20.8% of people had the symptoms of keratosis, 12% had melanosis, 59.4% had loss of appetite, 29.6% had anemia, 61.3% of people were suffering from constipation, 21.1% had diarrhea-related problem, 98.5% had general body weakness, 10.5% had raised blood pressure, 28.8% had breathlessness problem, 9.1% had diabetes, 0.4% had mental disorder cases, 0.6% had some types of lumps in their body, and 2.4% ($n = 33$) of village population were reported with cancer disease (Table 1).

Cancer Cases

- In this present population study of village Kaliprasad, a total of $n = 33$ cancer cases were reported in 8 years.
- Out of which, the hepatobiliary cancer cases were $n = 24$. The rest $n = 9$ were skin cancer, breast cancer, and thyroid cancer cases.
- From the $n = 33$ cancer patients, $n = 31$ had already died, two are still surviving with stage 4 disease (Fig. 8).
- However, 52% of the total households have more than 50 µg/L of arsenic concentration in groundwater, 37% subjects had arsenic contamination more than 100 µg/L in their urine, and 35% studied subjects had arsenic contamination more than 1000 µg/kg in their hair.
- The high concentration of arsenic in groundwater, urine, and hair could lead toward cancer incidences in the future, which is a serious matter of concern.

Health Risk Assessment

- Health risk assessment was described based on the comparison between the groundwater arsenic concentration and WHO drinking water guideline (Table 2). It also compares estimated daily exposure from all the sources of relevant exposure pathways with a toxicological reference dose value (RfD) of, i.e., 0.003 mg/kg-day of the USEPA.
- Child subject has more non-carcinogenic risk then male and female subject (Fig. 9).
- Higher non-carcinogenic risk in children is due to their lower body weight [32, 63]. For calculation of carcinogenic risk (CR), cancer slope factor of 1.5 was used.
- Cancer slope factor (CSF) was obtained from the Integrated Risk Information System (IRIS) database.
- It is obvious from Table 3 that 87.11%, 83.15%, and 82.27% groundwater samples surpassed the threshold value of 1×10^{-6} for carcinogenic risk (CR) in children, female, and male population group, respectively, proposed by the USEPA.
- CR values of children, female, and male ranged from 2.5×10^{-5} to 4.08×10^{-1}, 2.18×10^{-5} to 3.56×10^{-2}, and 1.85×10^{-5} to 3.01×10^{-2}, with averages of 7.89×10^{-2}, 6.97×10^{-3}, and 5.9×10^{-3}, respectively.

Mitigation Intervention

- The detailed report of the current study was shared to the working NGO WaterAid, Bihar, in Bhagalpur district.
- The NGO shared the entire data to the Public Health and Engineering Department (PHED), Government of Bihar, for urgent intervention.
- Then after, the state government through its piped water scheme (*Har Ghar Nal Ka Jal*) installed an arsenic filter unit in 2022 (Fig. 10).
- The filter is presently catering $n = 102$ households and $n = 1860$ members providing them arsenic-free water.

Table 1 Health assessment report of arsenic-exposed population of the village Kaliprasad ($n = 1372$) from households ($n = 102$)

Symptoms	Problems present in the population	Number of problems observed	Total cases	*p* value
Keratosis in palm and sole	286 (20.8%)	1086 (79.2%)	1372	< 0.0001
Melanosis in sole, palm and trunk	165 (12%)	1207 (88%)	1372	< 0.001
Other skin manifestations	1309 (95.4%)	63 (4.6%)	1372	< 0.01
Loss of appetite	815 (59.4%)	557 (40.6%)	1372	
Anemia	407 (29.6%)	965 (70.4%)	1372	< 0.001
Constipation	842 (61.3%)	530 (38.7%)	1372	< 0.001
Diarrhea	290 (21.1%)	1082 (79.9%)	1372	< 0.001
General body weakness	1352 (98.5%)	20 (1.5%-)	1372	< 0.001
Cardiovascular disorders (raised blood pressure)	658 (48%)	714(52%)	1372	< 0.001
Breathlessness	396 (28.8%)	976 (71.2%)	1372	< 0.001
Diabetes	260 (19%)	1112 (81%)	1372	< 0.01
Mental disability	06 (0.4%)	1366 (99.6%)	1372	< 0.001
Lumps in the body	09 (0.6%)	1363 (99.4%)	1372	< 0.001
Cancer cases	33 (2.4%)	1339 (97.6%)	1372	< 0.001
Other health problems	589 (42.9%)	783 (57.1%)	1372	< 0.01

*All data were analyzed using one-way ANOVA ($p < 0.0001$ and $p < 0.001$)

Fig. 8 Cancer patients with typical symptoms of keratosis on sole and palm. Patient died due to liver cancer because of drinking arsenic-contaminated water 265 µg/L (**A**, **B**, **D**, and **E**). Another patient died due to skin melanoma and lung cancer because of drinking arsenic-contaminated water 340 µg/L (**C** and **F**)

- To observe the health impact, after the operation of 18 months of arsenic filter, a health review will be again conducted to know the status of village subject's health.

Geological Aspect

Bhagalpur is a rare but classic example of extent of territorial boundaries on either side of the banks of river Ganga (Fig. 11). Though Pirpainti cites itself exactly on the southern bank, the river clearly sees a right lateral offset near Kahalgaon where it assumes a south to north trend (Uttarvahini) clearly guided by a regional lineament along which significant displacement has taken place. The predominantly west–east trending river conspicuously trends south-north indicating a topographical disturbance. This offset sets the southern bank much northward (i.e., west of Pirpainti) where it restores its west–east

Table 2 Human health risk assessment

Parameters	Male	Female	Children	References
IR	2.5	2.5	0.78	[70]
ED	64	67	6	[45]
EF	356	365	365	[70]
BW	65	55	15	[27]
ET	23,360	24,455	2190	[70]
C (mg/L)				Present study

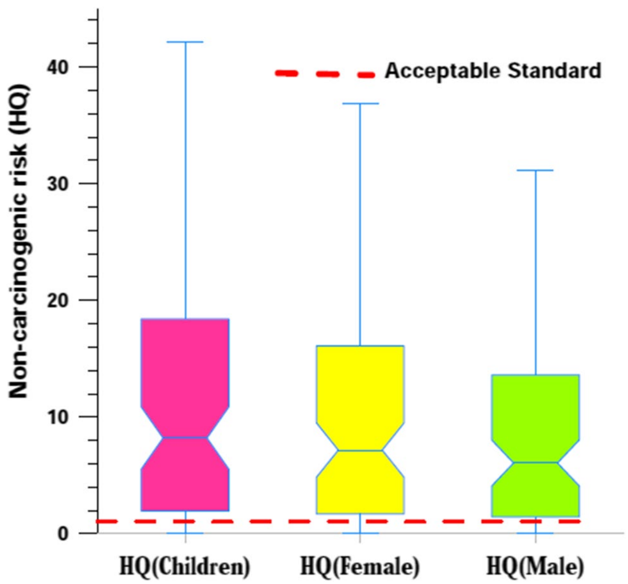

Fig. 9 Boxplot showing the result of non-carcinogenic risk of arsenic in various population

Table 3 Human health risk assessment of non-carcinogenic risk vs. carcinogenic risk

Population	Exceed non-carcinogenic risk (% sample)	Exceed carcinogenic risk (% sample)
Children	82.17	87.11
Female	78.23	83.15
Male	78.23	82.27

trend. But the sympathetic parallel flow of Kosi River before it makes a confluence with river Ganga near Kursela Ghat, west of Pirpainti defines the interfluve zone of Ganga and Son river, which is significantly anomalous with arsenic concentration. Pirpainti is the ideal destination for primary transportation of arsenic-rich sediments and secondary enrichment of concentration of arsenic favored by the role of organic material, microbial substances, clay mineralogy to adsorb greater arsenic molecules, and probably enhanced reducing conditions to accentuate the concentration. Geological observations supported by drilling down to a depth of 60 m near Gopalpur and Naugachhia vouch for a very high concentration of arsenic in groundwater and within subsurface sediment. There is higher concentration of arsenic in the groundwater (> 100 ppb) in and around Naugachia, Singhia Makandpur, Sahu Parbatta, Marwa, Bhawanipur, Jagatpur, and Gopalpur villages. These are identified as vulnerable zone for the incidence of arsenic. Maximum contamination ~ 500 ppb is analyzed from Singhia Makandpur and Gopalpur localities.

High arsenic concentration is found in localized pockets, mostly confined to tubewells located close to abandoned or present-day channels. River banks, areas adjoining fluvial landforms such as natural levees, back swamps, old point bars, and meanders, are the sites where the biomass gets accumulated due to water logging, and the same is released in the aquifer during groundwater recharge. This provides a favorable environment for the release of arsenic in water from the aquifer sediment by reductive dissolution or desorption. The affected area falls in the interfluves of Ganga and Kosi River. Likewise, it also found that higher concentration of arsenic is present where two or more drainages coalesce to form higher-order drainage.

The lower-order streams may supply its sediments containing arsenic at the confluence eventually recharging the shallower aquifer. The confluence point of tributaries checks the water flow resulting in accentuated deposition along banks and even within channel. Continued deposition of fluvial sediment shows an accelerated trend in contamination values.

From the study, it is observed that the area falling toward the left bank of river Ganga is highly contaminated with arsenic compared to its right bank (Fig. 12). The former is drained only by Himalayan rivers which is perceived to carry sediments containing arsenic. Various authors have already established that the storehouse of arsenic is in the sediments of Siwalik groups of rock [58, 68] which act as secondary source while the primary source in Ganga basin lies in the Indus Valley Suture Zone of Higher Himalaya. According to [43], active and palaeo-foreland basin of the Himalayan orogenic belt is considered as extensive arsenic enriched provenances in the world. Depending on its relation with solution composition, redox condition, pH, and temperature, it becomes available in groundwater causing severe impact on population using it. Considering the rivers from Chhotanagpur Gneissic complex, Rajmahal hills and Kharagpur hills draining the southern part of the study area show occasional contamination. Higher contamination is observed only along the bank of Ganga River in the southern part in present-day formation and Belhar formation contrary to further south.

Discussion

In Bihar, there are a total of 38 districts and among them, 22 districts are arsenic affected including Bhagalpur [15, 41, 49, 60]. There are several hypotheses regarding source

Installed Filter Units	Depth (Feet)	Tank Capacity (Litres)	Household catering capacity through piped water distribution	GPS Location	Arsenic Concentration in the Inlet water of the filter as tested on 10.02.2022 (µg/L)	Arsenic Concentration in the Outlet water of the filter as tested on 10.02.2022 (µg/L)
Arsenic Filter Unit -	240	10,000	150	25°20'48.5"N 87°23'40.0"E	8.091	1.38

Fig. 10 Installed arsenic mitigation unit in January 2022

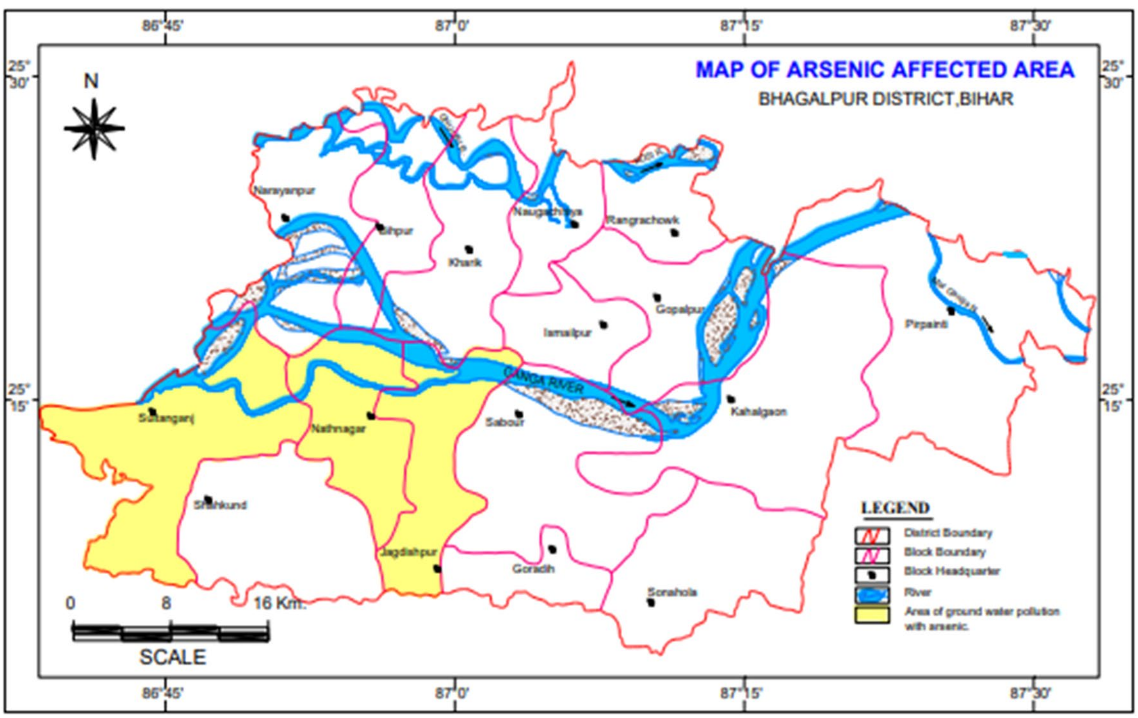

Fig. 11 Geo-map of river Ganga in Bhagalpur district

of arsenic in India. Many researchers have shown that the source of arsenic is geogenic. In India, arsenic is mainly coming from the Himalayan region and is distributed throughout the flood plains of river Ganga and Brahmaputra. In Bihar, the fluvial basin of river Ganga is highly contaminated with arsenic. It is also observed that the recent alluvial sediment deposit has maximum concentration of arsenic as compared with the older alluvial deposits [38, 40, 53–56].

However, Pirpainti falls in the south bank and situated within the oscillating zone of river Ganga. In that area river, Ganga flows through west–east direction, but it also oscillates in north–south direction, thus making the zone of homogeneous inflow of sediments from contrasting sources.

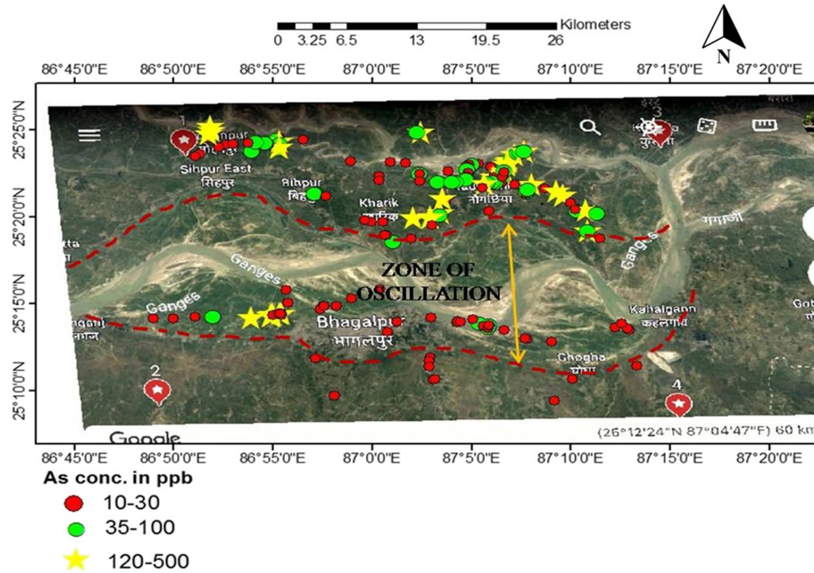

Fig. 12 Groundwater arsenic values superimposed on Google Earth map of the study area

Google Earth imagery is used to understand the zone of oscillation and arsenic contamination in groundwater. From Fig. 12, it is very clear that high value of arsenic in southern area falls within the oscillation zone. This sinuosity defines the active flood plain and older flood plain area which are supposedly contaminated with anomalous arsenic values more than 10 μg/L. Kaliprasad village within Pirpainti block finds itself arrested between favorable enriching conditions where primary deposition has accentuated to secondary enrichment manifesting itself to enhanced disease burden in the area. This is the reason for the high arsenic contamination in the village Kaliprasad [43].

In the present study, the village Kaliprasad's hand pumps contained high contamination of arsenic in the studied water samples. The exposed population of the village were consuming arsenic-contaminated hand pump water knowingly or unknowingly. Even the low concentration of arsenic in drinking water can cause many types of cancer like skin, gallbladder, prostrate, lung, and bladder [20, 26]; [34, 35, 37, 39, 40]. Arsenic usually enters the human body in the form of As(III) and As(V) through the process of ingestion, inhalation, and dermal contact and furthermore undergoes methylation process to form mono- and di-methylated arsenic species in the metabolic organ liver. Methylation is a detoxification process, but nowadays, many experimental evidence suggest that methylation of As(III) has toxic and carcinogenic effects. It alters the DNA repair mechanism, enhances the cell proliferation, induces chromosomal abnormalities, and is responsible for suppression of p53 gene (called as the guardian of the genome). It binds with sulfhydryl groups to inhibit the conversion of pyruvate to acetyl coenzyme A (COA). Arsenic toxicity is also responsible for the generation of free radicals like reactive oxygen species (ROS). These free radicals are very active molecules and can damage the cell components like DNA, cell structures, lipids, cell membrane, and proteins [23, 48].

In human body, arsenic usually accumulates in nails and hairs and is excreted through the urine; hence, in the present study, these biomarkers have played a vital role in the detection of arsenic toxicity. In this study, the highest concentration of arsenic in hair samples observed was 11,398 μg/kg, while in urine it was 374 μg/L. This indicates that the subjects were exposed to arsenic for a very long time which has led to severe health-associated problems in them. About 35% of the people had arsenic concentration higher than 1000 μg/kg in hair which correlates the long-term arsenic exposure. Moreover, the urine samples of the subjects had significant arsenic contamination which indicates that the metabolic organs are on the verge of severe toxicity, which may cause serious health impact in the exposed individuals. In the study, a very strong correlation has been observed between the arsenic concentration in urine and hair with arsenic concentration in groundwater, which indicates that how arsenic menace would cause the health-related problems in them. Similar studies have been carried out in the different geological terrains of Gangetic plains [3, 9, 14, 13, 17, 28, 29, 32, 34, 36, 37, 39, 38, 40, 50, 51, 61, 65].

The health assessment of a total of $n=1372$ subjects from $n=102$ households showed that maximum village population were suffering from the arsenicosis symptoms such as skin manifestations in the form of keratosis, melanosis, and other skin diseases. About 20.8% of them had keratosis, 12% had melanosis, 59.4% had loss of appetite, 29.6% had anemia, 61.3% had constipation, 21.1% had diarrhea, etc. This denotes that the health of the village population is abnormal, and the population are at the risk of getting serious disease like cancer. Since, there were reports of 33 cancer patients in 8 years of time span denotes the magnitude of arsenic toxicity in their body. Moreover, the carcinogenic risk in the study shows that the children are more vulnerable to the disease with 87.11% of risk followed by females with 83.15% and males with 82.27%. This indicates that the exposed subjects are highly vulnerable to cancer risk in the future. Similar health problems and symptoms from arsenic-exposed population have been documented by various researchers [1, 6, 25, 38, 40, 44, 71, 73].

The study of this village was in the eastern zone of the Gangetic plains of Bihar, where the human health assessment in the arsenic-exposed area has not been explored and reported. However, this study was focused only on this village as there were 33 cancer reports. The other villages could have been associated in this study but were very densely populated which limited the present study. However, the present study is an eye opening for the state government to carry out needful interventions for the arsenic-exposed population. Moreover, this serious study report influenced the state government to install an arsenic mitigation unit in the village in 2022, through piped water scheme. It is hoped that the symptoms and the disease burden in the exposed village population will decrease in due course of time. There is need for the routine monitoring and surveillance of the water quality of this filter units time to time. The usage of this arsenic-free drinking water by village population will decrease the symptoms as well as the disease burden in them. Moreover, the village population needs to be aware and motivated about the use of safe drinking water time to time. It is also recommended that health-related policies should be implemented for the arsenic-exposed population to reduce the disease burden. This study will further influence the state government and NGOs to work for similar arsenic-exposed population habitations in the Gangetic plains of Bihar to combat the problem.

Conclusion

In the present study, the village population of Kaliprasad in Pirpainti block of Bhagalpur district of Bihar were drinking arsenic-contaminated water since a very long time. In $n = 102$ households' study, 77% of water samples had arsenic concentration more than the WHO permissible limit of 10 μg/L, 60% individual's urine samples had the arsenic contamination more than the permissible limit, i.e., 50 μg/L, while 64% individual's hair samples had arsenic contamination more than the permissible limit, i.e., 200 μg/kg. Moreover, the studied subjects had various health-related diseases such as skin manifestations (hyperkeratosis, melanosis, raindrop pigmentations), gastrointestinal disorders, hormonal disorders, cardiovascular disorders, neurological disorders, loss of appetite, diabetes, and cancer. About 33 cancer patients were recorded in 8 years of time span, which is a huge number causing death. The carcinogenic risk also correlates the toxicity in the terms that the children are more vulnerable to this risk followed by females and lastly males in the exposed village population. The correlation coefficient study also significantly correlates the disease burden. Moreover, the geological aspect finally correlates that there are huge deposits of arsenic-bearing minerals such as arsenopyrite in the sediments of this village causing arsenic contamination in the groundwater. The study enabled the state government in installation of arsenic filter in this village in recent months. It is believed that the exposed village population will have a decrease in disease symptoms after the usage of arsenic-safe water. Furthermore, the exposed village population also require medical facilities for the proper treatment of the diseases. Hence, it is expected that the disease burden of the exposed village population will gradually decrease in the due course of time.

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Author Contribution The entire experimental work was conceptualized by AK and AKG. The field work sampling was carried out by Rishav, K, MS, PKN, MK, and AK. In the manuscript writing, AK, KK, AB, SK, Santosh K, MS, and AKG contributed the majority of writing activities, but support was also provided by MA, VR, AS, MK, PKN, Mukesh K, DK, RK, and GA. Literature search was done by KK, MK, VK, GA, and AS. Figures were developed by AK, KK, SK, Santosh K, and DK. The study design was carried out by AK and AKG. The experimentation was carried out by PKN, Mukesh K, VK, AS, and GA and data analysis by MA, RK, DK, MS, and AB. The final manuscript writing was done by AK, MA, DK, KK, AB, SK, Santosh K, MS, and AKG. All the authors read and approved the final manuscript.

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Data Availability The study-related raw data has been already submitted to Editorial desk for the validation of the present work.

Declarations

Ethical Approval Before the start of this research work, an ethical approval was obtained from the Institutional Ethics Committee (IEC) of Mahavir Cancer Sansthan and Research Centre with IEC No. MCS/IEC/2019, dated 10/01/2019 (agenda no.07). The study was carried out from April 2019 to July 2022.

Consent to Participate An informed consent was also obtained before the collection of the biological samples from the studied subjects of village Kaliprasad.

Consent for Publication The authors provide their kind consent to publish this research data.

Competing Interests The authors declare no competing interests.

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