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Kumar, Arun; Kumar, Rishav; Rahman, Md Samiur; Ali, Mohammad; Kumar, Ranjit; Nupur, Neha; Gaurav, Aman; Raj, Vikram; Kumar, Santosh; More Authors

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RESEARCH ARTICLE

Assessment of arsenic exposure in the population of Sabalpur village of Saran District of Bihar with mitigation approach

Arun Kumar [1] · Rishav Kumar [1] · Md. Samiur Rahman [2] · Mohammad Ali [1] · Ranjit Kumar [3] · Neha Nupur [1] ·
Aman Gaurav [1] · Vikram Raj [1] · Gautam Anand [1] · Pintoo Kumar Niraj [1] · Nirmal Kumar [1] · Abhinav Srivastava [1] ·
Akhouri Biswapriya [4] · Gyanendra Bahadur Chand [5] · Dhruv Kumar [6] · Tuhin Rashmi [6] · Santosh Kumar [7] ·
Maiko Sakamoto [8] · Ashok Kumar Ghosh [1]

Abstract

Arsenic poisoning through groundwater is the world's greatest normal groundwater catastrophe which got an immense effect on worldwide general wellbeing. India is confronting the outcomes of arsenic poisoning in the zone of Ganga Brahmaputra alluvial plains. In Bihar, out of 38 districts, 18 districts are exceptionally influenced with groundwater arsenic defilement. In the present study, we have assessed the current situation of arsenic exposure in Sabalpur village of Saran district of Bihar after reporting of breast, renal, skin and thyroid cancer cases from this village along with typical symptoms of arsenicosis. Such cancer patients were identified at our institute and were taken for the study. The present investigation deals with the quantification of arsenic in groundwater, hair and nail samples of subjects as well as the survey of entire village to know the overall health status of the village people. A total of n=128 household handpump water samples as well as n=128 human hair and nail samples were collected from over n=520 households. Using the graphite furnace atomic absorption spectrophotometer (GF-AAS), all the samples were analysed. The investigation resulted that the 61% of the analysed samples particularly the groundwater had the arsenic levels more than the permissible limit of WHO (> 10 μg/L) with 244.20 μg/L as the highest arsenic contamination in one of the handpump water sample. The exposure effect of hair sample was worst as 88% of all the collected samples were having high arsenic levels more than the permissible limit (> 0.2 mg/Kg). In case of nail samples, 92% of the samples were having high arsenic concentration more than the permissible limit (> 0.5 mg/Kg). The health survey study revealed high magnitude of disease burden in the exposed population with symptoms such as asthma, anaemia, hepatomegaly, diabetes, cardiac problem, skin fungal infections, breathlessness and mental disability. Few cancer cases of renal, skin, breast and cervix were also found among the exposed population of this village. The percentage of cancer cases in this village was 0.94% that was low, but it would be an aggravated situation in the near future if people will continue drinking arsenic-contaminated water. Therefore, a mitigation intervention was carried out in March 2020 by installing an arsenic filter plant. The health situation in the village in the present scenario is hope to improve in the coming years. However, motivation and awareness among the village population are still required.

Keywords Arsenicosis · Health assessment · Cancer · Groundwater contamination · Sabalpur (Bihar)

✉ Arun Kumar
drarunk31@gmail.com

1   Mahavir Cancer Sansthan and Research Centre, Phulwarisharif, Patna, Bihar 801505, India

2   Department of Biotechnology, Anugrah Narayan College, Patna, Bihar, India

3   Department of Animal Sciences, Central University of Himachal Pradesh, Pradesh, India

4   Geological Survey of India, Patna, Bihar, India

5   Department of Zoology, Patna University, Patna, Bihar, India

6   Department of Biotechnology, Amity University, Noida, Uttar Pradesh, India

7   Department of Applied Geoscience and Engineering, Delft University of Technology|, Delft, The Netherlands

8   Department of International Studies, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 2778563, Japan

Introduction

Groundwater arsenic pollution is arising as a significant ecological and human wellbeing catastrophe in the recent times (Bhattacharya et al. 2007; Chakraborti et al. 2004; Kapaj et al. 2006). It is assumed that more than 200 million population are exposed to high arsenic level (>10 µg/L) through drinking water (Argos et al. 2012) and around 13 regions of world are enormously affected by high arsenic level in groundwater aquifers (Kinniburgh and Kosmus 2002). Drinking water is viewed as one of the root cause of inorganic arsenic contamination (Mudhoo et al. 2011; National Research Council 2001). In Asia, India and Bangladesh are the major affected nations from groundwater arsenic poisoning. Arsenic poisoning is representing an incredible health hazards among individuals living in the Ganga-Brahmaputra-Meghna (GBM) fluvial plains (Singh et al. 2014). In India, Assam, West Bengal, Uttar Pradesh and Bihar are the states which are highly affected by the groundwater arsenic contamination. The Himalayan originated river plains are generally severely affected from groundwater arsenic poisoning in the Asian subcontinent. Populace living close to these plain regions are presented to arsenic causing health-related issues like keratosis, melanosis, skin disorders, gastro-intestinal disorders and even cancer malignancy (Acharya et al. 1999; Chakraborti et al. 2002; Ahamed et al. 2006; Yunus et al. 2016).

A long-term arsenic exposure results in the accumulation of arsenic in keratinized tissues and also results in other skin manifestations (Shankar et al. 2014). Human hair and nail are the best biomarkers as they reflect the long-term exposure of metals. The arsenic contamination in hairs and nails reflects the mean arsenic exposure impact in the human body that is during a time duration of 2–5 months for hair and 12–18 months for nail (Nowak and Kozlowski 1998; Yoshinaga et al. 1990). They are considered as the arsenic exposure biomarkers and henceforth are generally used to assess the impact of natural arsenic on humans (Agahian et al. 1990; Schegel-Zawadzka 1992; Nowak 1993; Das et al. 1995; Chaudary et al. 1995; Samanta et al. 2007; Gault et al. 2008; Slotnick et al. 2008).

Bihar is the second most arsenic-contaminated state in India. It is divided into 38 districts, out of which 18 districts are exposed to groundwater arsenic pollution. The 15 districts are located in the vicinity of the of the river Ganga basin. It is expected that a populace of around 10 million are drinking arsenic-contaminated water with concentration more than 50 µg/L (Saha 2009; Singh et al. 2014). In 2002, groundwater arsenic poisoning was first reported in Barisban and Semaria Ojhapatti in the Bhojpur district of Bihar in the middle Ganga plain region (Chakraborti et al. 2003). Arsenic poisoning in these villages prompted numerous wellbeing perils in the populace, and numerous individuals exhibited severe symptoms of arsenicosis. Recent investigation on arsenic poisoning in

Buxar district showed serious health hazards in the exposed population, where most extreme groundwater arsenic contamination recorded was 1929 µg/L (Kumar et al. 2016a). In this village, the highest blood arsenic contamination recorded was 664.7 µg/L which is accounted for to be the most elevated till date in the state (Kumar et al. 2016b), lamentably that is the direst outcome imaginable. A critical Indian populace is as yet influenced with arsenicosis symptoms such as diabetes, hypertension, loss of appetite, diarrhoea, stomachache, breathlessness, hormonal disorders, mental disability and cancer malignancy (Kumar et al. 2015, 2016a, 2019, 2020; Rahman et al. 2019a, b; Abhinav et al. 2016; Haque et al. 2003).

Sabalpur village of Sonepur block of Saran district was undertaken for the present study, when patients from this village were accounted for with instances of renal disease and squamous cell carcinoma of skin in our organization. The current study deals with the entire survey of the village along with groundwater, hair and nail arsenic assessment, and special emphasis was taken to know about the wellbeing status of the arsenic exposed population.

Materials and methods

Ethical approval

For the present study, ethical approval was obtained from the Institutional Ethics Committee (IEC) of Mahavir Cancer Sansthan & Research Centre with IEC No. MCS/Research/2015-16/2416, dated 24/08/2016 (agenda no.15).

Location

The present study was undertaken at Sabalpur village (east) of Sonepur block, Saran district, Bihar, India (25°40′37.4″N 85°10′48.0″E). The village is situated at the confluence of river Ganga and river Gandak (Fig. 1), and many of the cancer patients reported from this village with the symptoms of arsenicosis in our institute for the treatment. This initiated us to carry out an extensive survey in this particular village. This village is flood prone region of river Ganga and Gandak. The population of the village Sabalpur was approximately n=8006 with male population n=4802 and female population n=3204 (Census 2011). There were approximately n=520 households (Census 2011) in the village.

Sample size

The total households in the village was n=520, and we conducted the study in the 25% ($n = 128$) households. The village households were so closely associated with each other that one's house handpump distance with other's was merely less than 10 m. Hence, it was decided to collect the handpump

Fig. 1 Aerial view of the arsenic exposed Sabalpur village along with inset river Ganga and river Gandak

water from the household after every 50 m of the distance. At the 10 m of the distance, there was no significant change observed in the handpump's arsenic-contamination in water. This calculation of the household study was conducted in the entire village. The study also included the collection of hair and nail samples of any one volunteer from each household (sample size, $n = 128$).

Arsenic analysis

The water samples were collected in 500-ml polypropylene bottles that were altogether cleaned with distilled water and pre-treated with 2% hydrochloric acid. Altogether, n=128 samples of water were randomly collected in duplicates from handpumps of every household situated at each 50–70 m distance in the village. The details of the handpumps such as depths were recorded after the data accumulated from the handpump proprietors and were used for the factual relationship concentrate with arsenic. The hair and nail samples of 128 subjects (selected one member from each studied household) were collected in the zipper polythene packs and prepared for arsenic assessment according to the protocol of (NIOSH 1994) and processed through graphite furnace atomic absorption spectrophotometer (Pinnacle 900 T, Perkin Elmer, Singapore) at Mahavir Cancer Sansthan and Research Centre, Patna, Bihar.

Health survey

The health survey was conducted in all the n=520 households of the village with at least one member from each household. However, the household members having symptoms of

arsenicosis were interviewed extensively. Hence, altogether n=637 subjects of the village were interviewed. The health survey of the populace was conducted through the inputs provided by the household members via the questionnaire proforma. The interview consisted of recording of the data related to the age, sex, number of members in the family, number of children, health-related problems, age of the family members suffering from any disease and photo of the diseased person. Moreover, other questions were also interrogated related to their water sources like handpumps age, depth of the handpump and duration of usage of contaminated water . Utilizing the handheld Global Positioning System (GPS) receivers (Garmin etrex10, USA), the exact location of the handpump was determined with an estimated accuracy of ≈ 10 m.

Statistical analysis

Utilizing the statistical software GraphPad Prism 5, all the data were analysed with and values expressed as mean ± SEM. Through one-way analysis of variance (ANOVA), differences between the groups were statistically analysed by using the Dunnett's test, while scattered graphs were plotted through another statistical software IBM SPSS-25.0 using linear regression analysis.

GIS analysis

GPS coordinates were overlaid using QGIS software (version 3.10.1-A Coruna), shape file was created, and Google map was used as base map. Groundwater arsenic contamination was grouped into 3 classes: ≤ 10, 10–50 and > 50 μg/L,

whereas the hair arsenic concentration data was grouped into 2 classes, ≤ 0.2 and > 0.2 mg/Kg. Similarly, the nail arsenic concentration data was also grouped into 2 classes: ≤ 0.5 and > 0.5 mg/Kg. Simple A3 landscape layout was chosen for the thematic map output.

Results

Groundwater arsenic assessment in Sabalpur village

The collected n=128 water sample analysis report showed very high arsenic contamination in the groundwater of the village. The groundwater sample with maximum arsenic concentration reported was 244.20 µg/L, while more than 50 µg/L arsenic concentrations in about 17% of the analysed samples were observed, whereas between 10 and 50 µg/L arsenic concentration was found in about 44% of the total analysed samples. Only 39% samples were found with in the permissible arsenic levels (below 10 µg/L) (Fig. 2).

Arsenic analysis in hair samples of village people

The normal ranges of arsenic concentration in the hair samples of the unexposed population usually found between 20 and 200 µg/Kg (Chakraborti et al. 2016). In the present study, the analysis of $n = 128$ hair samples showed arsenic concentration with 12% (below 0.2 mg/Kg), whereas 88% hair samples were found with the levels more than the permissible range (0.2 mg/Kg). The hair arsenic concentration with maximum level of 35.52 mg/Kg is reported among the studied village population which was extremely high (Fig. 3).

### Arsenic analysis in nail samples of village people

The normal ranges of arsenic concentration in the nail samples of the unexposed population lies usually between 20 and 500 µg/Kg (Chakraborti et al. 2016). The analysis of n=128 nail samples showed arsenic concentration with 8% (below 0.5 mg/Kg), whereas 92% nail samples were found with the levels more than the permissible limit (0.5 mg/Kg). The nail arsenic concentration with maximum level of 9.419 mg/Kg was reported among the studied village population (Fig. 4).
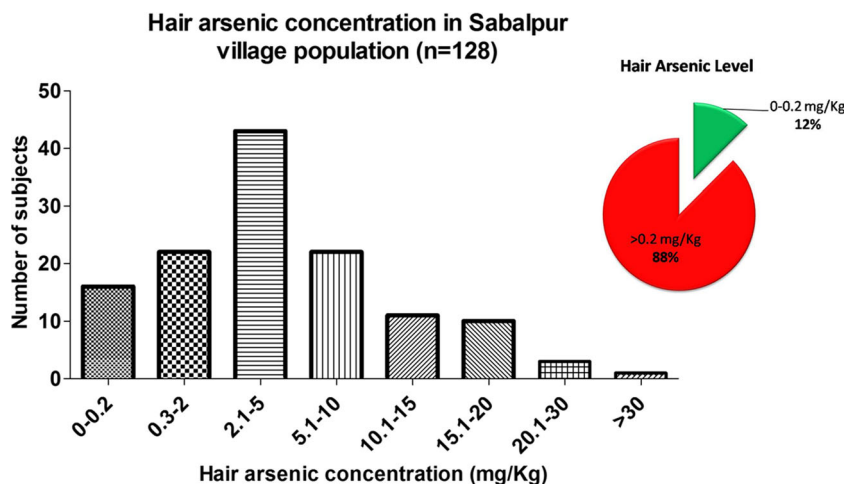
Correlation coefficient study

1. **Correlation coefficient between the age of the handpump and groundwater arsenic concentration**: According to the regression analysis, the arsenic levels were prevalently high in the range of 5–22 years old handpumps ($r = 0.040$, $P < 0.05$; Fig. 5a).
2. **Correlation coefficient between the depth of the handpump and groundwater arsenic concentration**: The high arsenic contamination level was prevalent in the handpumps between the 60 and 80 feet of depth range. An overall declining trend was observed which represents the higher arsenic contamination in the shallow aquifers ($r = $ negative, $P < 0.05$; Fig. 5b).
3. **Correlation coefficient between the age of the subjects and hair arsenic levels**: An increasing trend was observed between the subject's age and their hair arsenic levels. The subjects over 20 years of age retained relatively very high hair arsenic values representing the age-related hair arsenic deposition ($r = 0.022$, $P < 0.05$; Fig. 5c).
4. **Correlation coefficient between age of the subjects and the nail arsenic levels**: A slight increasing trend was observed between the subject's age and their nail arsenic levels. Mostly all the subjects exhibited high nail arsenic contamination ($r = 0.006$, $P < 0.05$; Fig. 5d).
5. **Correlation coefficient between the hair arsenic levels and groundwater arsenic concentration**: An increasing trend was observed between the subject's hair arsenic levels and their drinking water arsenic contamination ($r = 0.011$, $P < 0.05$; Fig. 5e).

Fig. 2 Groundwater arsenic concentration in handpumps of Sabalpur village analysed through GF-AAS (ANOVA-Dunnett's test, $P < 0.05$)
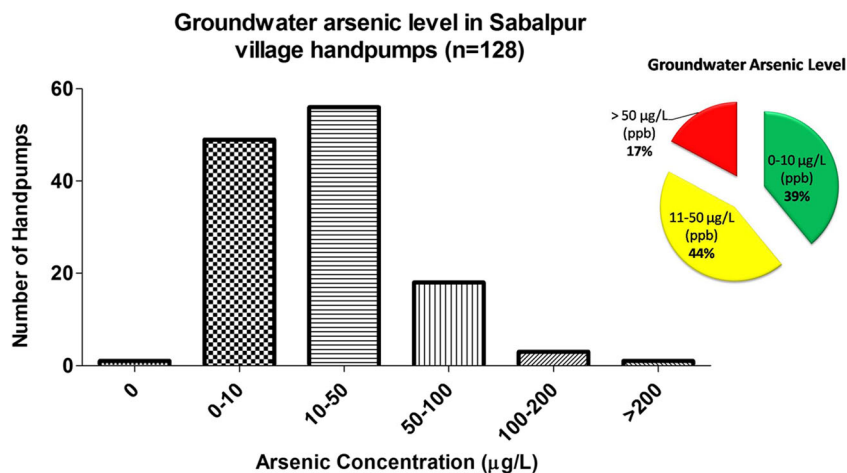
Fig. 3 Hair arsenic concentration of Sabalpur village population analysed through GF-AAS (ANOVA-Dunnett's test, $P < 0.05$)

6. ***Correlation coefficient between the nail arsenic levels and groundwater arsenic concentration***: An increasing trend was observed between the subject's nail arsenic levels and their drinking water arsenic contamination ($r = 0.011$, $P < 0.05$, Fig. 5f).

GIS study

The thematic map shows significant synoptic view of groundwater arsenic contamination in Sabalpur village with hair and nail arsenic levels distribution in the village exposed population (Fig. 6).

Clinical observations

The village population exhibited typical arsenicosis symptoms such as hyperkeratosis in sole and palm. The average population had more or less the rain drop pigmentation in their body parts. In children, the arsenicosis symptoms were seen in only one subject, who also had the lump (cervical node) on her neck (Fig. 7).
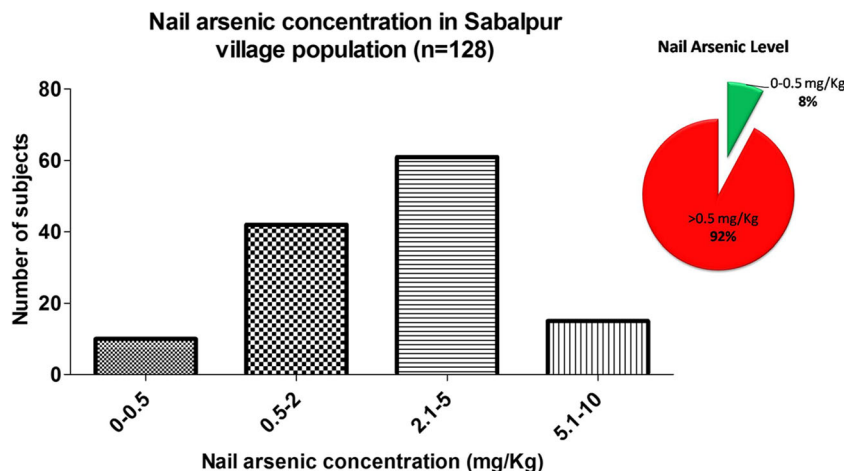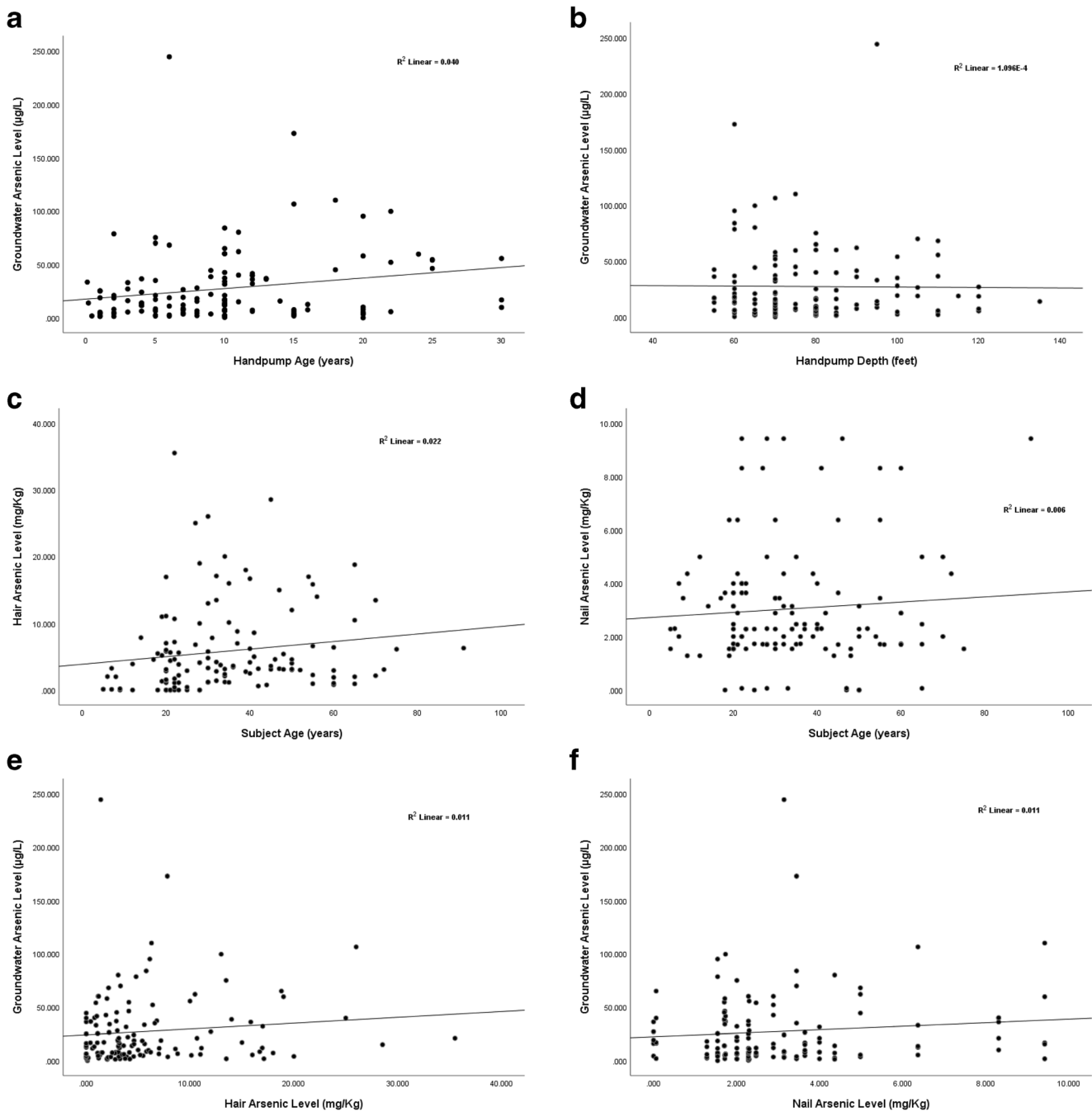
Health assessment

In the present study, all the n=520 household's representatives of the entire village were interviewed, and where the arsenicosis symptoms were higher in the household members, they were interviewed extensively. Few subjects of this village exhibited severe symptoms of arsenicosis in the form of hyperkeratosis in palm and sole (0.01%) and melanosis (0.01%), while with other skin manifestations were (14.29%), anaemic (24.01%), general body weakness (17.89%), blood pressure problem (15.07%), diabetes (8.477%), breathlessness (13.81%), mental disability (2.99%), lumps in the body (17.74%) and other health problems (28.88%) were observed (Table 1).

Cancer cases

n the present study, out of six cancer patients, one cancer patient reported to our institute with typical symptoms of arsenicosis all over the body. The patient was diagnosed with renal cell carcinoma in the stage IV of the disease. The

Fig. 4 Nail arsenic concentration of Sabalpur village population analysed through GF-AAS (ANOVA-Dunnett's test, $P < 0.05$)

Fig. 5 **a** The scatterplot graph of groundwater arsenic concentration and age of the handpumps ($r = 0.040$ and $P < 0.05$). **b** The scatterplot graph of groundwater arsenic concentration and depth of the handpumps ($r =$ negative and $P < 0.05$). **c** The scatterplot graph of hair arsenic concentrations and age of the subjects ($r = 0.022$ and $P < 0.05$). **d** The scatterplot graph of nail arsenic concentrations and age of the subjects ($r = 0.006$ and $P < 0.05$). **e** The scatterplot graph of groundwater arsenic concentration and hair arsenic level ($r = 0.011$ and $P < 0.05$). **f** The scatterplot graph of groundwater arsenic concentration and nail arsenic level ($r = 0.011$ and $P < 0.05$)

patient's drinking water source is assayed for arsenic which was found to be 172.6 µg/L, while the arsenic concentration in his blood is 245.6 µg/L, nail is 353.1 µg/Kg, and in hair is 182.4 µg/Kg, respectively (Fig. 8). However, the other 05 cancer cases reported patient were skin, breast and cervix having the treatment at our cancer centre, but till date all have died.

Mitigation intervention

In the present study area, the mitigation approach was undertaken to combat the problem in March 2020 by the installation of an arsenic filter (ceramic membrane based arsenic filter) by the joint association of CSIR-CGCRI, Kolkata, Bihar State Pollution Control Board,

Fig. 6 Thematic map showing synoptic view of arsenic level in groundwater, hair and nail samples overlaid using QGIS software (version 3.10.1-A Coruna)
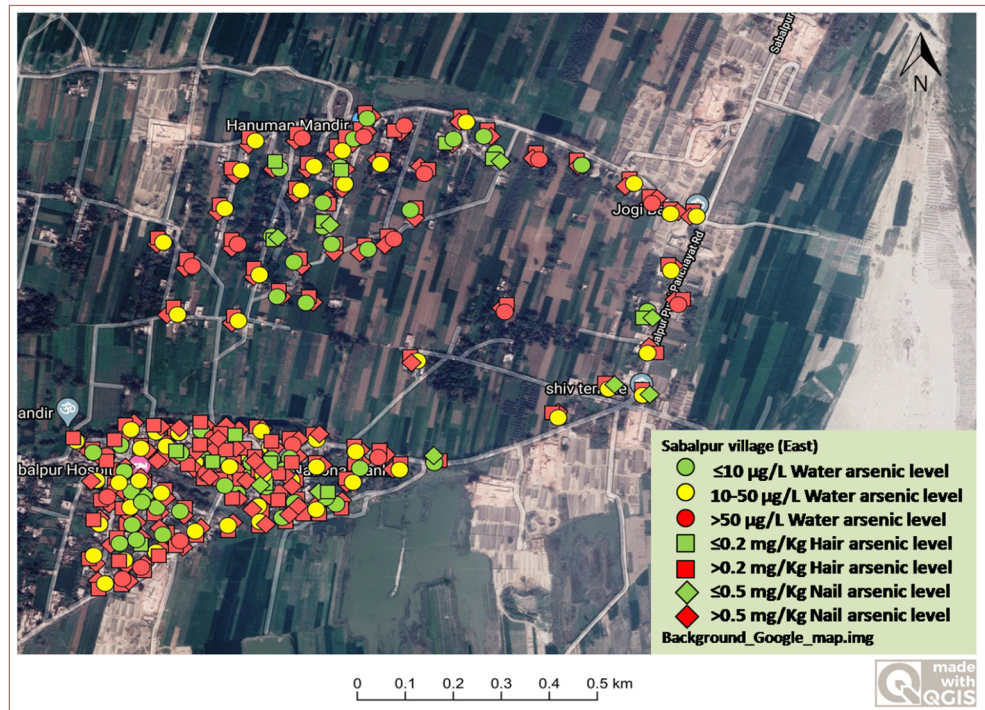
Patna and WaterAid-Bihar. This will be solving the exposed population at much extent. The health review shall be conducted after the operation of 18 months of this installed arsenic filter to know the impact at the initial phase (Fig. 9).

Discussion

The US Environmental Protection Agency (EPA) and World Health Organization (WHO) suggested that a maximum level of 10 μg/L inorganic arsenic level in groundwater is safe for

Fig. 7 Clinical observation of village people with skin disorders

Table 1 Showing arsenic caused common symptoms and their percentage in the Sabalpur village population (n= 637)

Symptoms	Problems present in the population	No problems observed	Total cases	P-value
Arsenicosis symptoms in palm and sole	7 (0.01%)	630 (99.99%)	637	< 0.001
Melanosis in palm and trunk	7 (0.01%)	630 (99.99%)	637	< 0.001
Other skin problems	91 (14.29%)	546 (85.71%)	637	< 0.001
Anaemia	153 (24.01%)	484 (75.99%)	637	< 0.001
General body weakness	114 (17.89%)	523 (82.11%)	637	< 0.001
BP problem	96 (15.07%)	541 (84.93%)	637	< 0.001
Diabetes	54 (8.477%)	583 (91.53%)	637	< 0.001
Breathlessness	88 (13.81%)	553 (86.19%)	637	< 0.001
Mental disability	19 (2.99%)	618 (97.01%)	637	< 0.001
Lump in the body	113 (17.74%)	524 (82.26%)	637	< 0.001
Cancer	6 (0.94%)	631 (99.05%)	637	< 0.001
Other health problem	184 (28.88%)	453 (71.12%)	637	< 0.001

drinking purpose (ATSDR 2005; Rakib et al. 2013; WHO 1993). Arsenic was positioned as number one general human health impact on its substance priority list by United States Agency for Toxic Substances and Disease Registry considering it as a carcinogen-causing cancer of the lung, kidney, bladder and skin (ATSDR 2005). International Agency for Research on Cancer grouped inorganic arsenic as class I human cancer-causing agent, which means adequate evidence supported their classification (IARC 2012; Martinez et al. 2011; WHO 2011). The Joint Food and Agriculture Organization of the United Nations/World Health Organization (WHO) Expert Committee on Food Additives (JECFA) re-examined the risks of arsenic exposure and found evidence of adverse impacts in regions with drinking water arsenic concentration ranging between 50 and 100 μg/L (WHO 2011).

An estimated 200 million individuals are exposed to arsenic level unquestionably more than the permissible limit, caused different arsenic related diseases (Naujokas et al. 2013; IARC 2004; Gregori et al. 2003; Nordstrom 2002; Smith et al. 2000). A new report in 2012 assessed that

Fig. 8 Arsenicosis symptoms in a renal cancer patient

about 20–45 million individuals are at high risk of arsenic exposure more than 50 μg/L concentration (Flanagan et al. 2012). According to a recent study, cancer risk is related with the normal day by day utilization of 2 L of drinking water with more than 50 μg/L inorganic arsenic. The main source of inorganic arsenic exposure is mostly through drinking water and water-based products (Sinha et al. 2003; Anetor et al. 2007; Chung et al. 2014). Recent study correlates the arsenic catastrophe in the Gangetic plains of Bihar causing increased disease burden including the cancer risk (Kumar et al. 2021). The present study revealed the highest groundwater arsenic concentration found to be 244.20 μg/L in studied area which is around 24 times greater than the WHO's maximum permissible limit. Around 61% of the handpumps were found to be contaminated with more than 10 μg/L arsenic concentration that is a problematic situation for the residing population. The highly elevated arsenic levels were found between 60 and 80 feet of handpump depth range.

The arsenic toxicity symptoms primarily manifest on skin along with the disturbances in other cellular process of organ systems. The arsenic caused skin manifestations such as hyperpigmentation, hyperkeratosis and hypermelanosis of the palm and sole (Li et al. 2011; Melkonian et al. 2012). In the present study also, many arsenic-exposed subjects exhibited the symptoms of arsenicosis like hyperkeratosis, hyperpigmentation and melanosis in their palm and sole.

Hair and nail reflect the long-term exposure of metals. The arsenic concentration in hair and nails reflects its average level in the human body for a period of 2–5 months in hairs and 12–18 months in nails (Yoshinaga et al. 1990; Nowak and Kozlowski 1998). USEPA, WHO and Atomic Energy Agency (AEA) recommended the use of hair as an important biomarker for worldwide environmental arsenic monitoring (Druyan et al. 1998; Morton et al. 2002). Generally

arsenic persists for longer time duration in hairs (Gebel 2000). Blood arsenic moves into hairs and retains there by binding with the sulphhydryl groups of keratin and finally moves toward the hair shafts (Hindmarsh 2002). Our present study explored the highest arsenic level in human hair samples that was 35.52 mg/Kg among the studied population. Even the younger age group from village was having high arsenic concentrations in their hair. Arsenic also persists for longer time duration in nails just like hairs. The present study showed that the nail samples retain lower values of arsenic concentration with the maximum of 9.419 mg/Kg in comparison with the hair samples.

The studied population's health status was very poor as they were suffering from health related issues like asthma, anaemia, hepatomegaly, diabetes, cardiac problems, fungal infection on skin, breathlessness and mental disability. Regular consumption of drinking water contaminated with elevated arsenic levels resulted to the high risk of skin, bladder, lung, liver and kidney cancer (Chowdhury et al. 2000; GuhaMazumder et al. 1998; Berg et al. 2001; Chen et al. 1999; Ferreccio et al. 2000). Long-term arsenic exposure led towards early onset of diabetes (Benbrahim-Tallaa and Waalkes 2008). In our present study, some diabetic cases were found, and the most unfortunate part of the study was the finding of few cancer cases of renal, skin, breast and cervix. Hence, arsenic in the present scenario is enhancing the disease burden in the arsenic-exposed population of this region. However, after the installation of the arsenic filter in this village, will definitely change the scenario in this village and will also change the health status of the exposed population. Hence, from the present study, it can be concluded that arsenic contamination in drinking water is causing lot of health-

related problems in the exposed population of village Sabalpur. The disease burden in the studied village population is very high. However, after the installation of the arsenic filter in the village will definitely play the major role to control the disease burden in the coming years.

Authors' contributions A.K., M A, R. K and A.K.G. conceptualized the entire work; A.K. had the major contributions in writing the manuscript, but support was also provided by A.K.G., D.K., T.R. and A.B.; literature search was done by A.S. and P.K.N.; survey data were collected by M.S.R., R.K., N.K., N.N., A.G., V.R., G.A. and P.K.N; experimental work and data analysis were done by M.S.R., P.K.N, G.A. and A.S.; data interpretation was carried out by A.K., M.A., R.K., D.K., A.B., T. R, G.B.C and M.S.; geospatial mapping was finalized by A.B., S.K. and M.S.R.; and final figures were designed by A.K., M.S.R, R.K. and S.K. All authors read and approved the final paper.

Data availability All data generated or analysed during this study are included in this manuscript.

Declarations

Ethical approval For the present study, ethical approval was obtained from the Institutional Ethics Committee (IEC) of Mahavir Cancer Sansthan & Research Centre with IEC No. MCS/Research/2015-16/2416, dated 24/08/2016 (agenda no.15).

Consent to participate Not applicable

Consent to publish All authors have read the manuscript and approve of its submission to Environmental Science and Pollution Research.

Conflict of interest The authors declare that they have no conflicts of interest.

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