A Study on Spatial Distribution and Prediction of Arsenic Concentration in Groundwater and its Associated Health and Societal Risk with Possible Mitigation Measures

Synopsis submitted by

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1. Introduction

The groundwater of the Bengal Basin is found to be severely contaminated by geogenic sourced arsenic, which has been considered as the largest public health concern in the human history. The present study was done on the basis of the concerned situation of arsenic contamination in groundwater and its associated health risks. The natural contamination of arsenic in groundwater has been documented worldwide, but India is considered as one of the most arsenic contaminated region among them. In case of India, from the literature it was found that in West Bengal, the water from shallow aquifers has been treated as drinking water source for millions of people and the range of arsenic pollution in groundwater at that depth is 0 to 3200 µg/L. The provisional guideline value set by WHO (2012) for arsenic in drinking water is 10 µg/L. Chronic arsenic induced diseases are found to develop among the population due to the consumption of arsenic contaminated water more than the permissible limit for a prolonged time. While the adverse effects of arsenic induced illness on adult health are well documented, a little is known about the consequences of consumption of arsenic contaminated water among children. The arsenic contaminated tubewells present in the primary schools are one of the major source of arsenic contamination among the child population. So, there is a need for some mitigative measures to develop arsenic free water sources in arsenic contaminated region. With the view of this, the present study was done on spatial distribution pattern of groundwater arsenic and prediction at unsampled locations to assess the health risks and develop mitigative measures to lower the risk among the population.

2. Review of literature

On the basis of this concerning situation, the reviews were made on different aspects of As pollution under the sections of global distribution, prediction in groundwater at unsampled locations by using Geostatistics, impact on population and the cost related to the contamination.

The following points were noted under the sections named-

2.1. Global distribution of As concentration in groundwater

- The natural contamination of As in groundwater has been reported worldwide, the majority of the regions belong to South Asian and South American regions.
- Distribution of arsenic concentration in groundwater is geogenic in nature. The hypotheses for geological arsenic mobilization were- Pyrite oxidation over-abstraction and Oxyhydroxide reduction.
- Arsenic concentration in groundwater beyond the maximum stipulated limit of 0.01 mg/L was documented in different zones of the lower delta region of the Ganga-Padma river system.

- Arsenic concentration was high along the eastern bank and low along the western bank of Hooghly River.
- The arsenic contaminated regions were found to be confined in the shallow aquifer (<150 m below ground level). Arsenic concentration in groundwater was observed to decrease with depth.
- Rice was considered as a potential source of arsenic exposure next to drinking water of the people living in arsenic affected regions
- Positive correlation with arsenic were found between pH, iron, molybdenum, fluoride, manganese, sulphate and phosphate.
- The spatial distribution pattern of arsenic was found patchy with regions holding high arsenic concentration (>200 μg/L) with close vicinity (within 100 m) to low arsenic contaminated groundwater (<50 μg/L).

(Ref: Bhattacharya et al. 1997, Smedley and Kinniburgh 2002, Chakraborti et al. 2002, Ravenscroft et al. 2005, Nath et al. 2008, Kar et al. 2010, Hamidian et al. 2019, Shaji et al. 2021)

2.2. Prediction at unsampled locations by using Geostatistics

- The geostatistical approach is a distribution free method and is dependent on a theory of regionalized variables with the varying values from place to place. Geostatistics represents a proper method of prediction and extensively applied for spatial estimation taking spatial variability into account.
- The objective of Geostatistics is to predict the possible spatial distribution of a property. The property values from locations that are in close proximity, have a tendency to be more similar than the values from locations that are further apart.
- The knowledge on spatial distribution of arsenic is important to recognize the complex processes of arsenic concentration variations and spatial predictions in the unsampled regions of the study area.
- Geostatistical approaches could be suitable for planners and policy makers to mature the plan of actions for sustainable management of groundwater resources and reduce the pollution.

(Ref: Isaaks and Srivastava 1989, Goovaerts et al. 2005, Hasan and Atkins 2007, Webster and Oliver 2007, Mini et al. 2014, Belkhiri et al. 2017, Busico et al. 2018, Boufekane and Saighi 2019

2.3. Impact of arsenic on population

- The pathways of arsenic exposure in human body were found to include drinking water, food and non-dietary sources.
- Pigmentation and keratosis were supposed to be specific skin diseases developed by chronic arsenic toxicity. The other effects of chronic arsenic toxicity was observed to give rise of different systematic manifestation including chronic lung disease (chronic bronchitis, chronic obstructive or restrictive pulmonary disease, bronchiectasis), liver diseases (non cirrhotic portal fibrosis), polyneuropathy, peripheral vascular diseases, hypertension, nonpitting edema on feet and hands, conjunctival congestion, weakness and anemia. The symptoms developed after the consumption of arsenic contaminated water over a long time. Cancer development in squamous cell, basal skin, lung, uterus, bladder and genitourinary tract is common in later phase of chronic arsenic toxicity
- The Arsenical Skin Lesions (ASL) was found in the people who consumed water with arsenic concentration more than 300 µg/L for a sustained period.
- Four factors were documented to control the appearance of the skin diseases- a) the concentration of arsenic in drinking water b) period of exposure c) volume of daily intake and d) nutritional status.
- High concentration of arsenic at early life is considered as a critical period, giving rise to health effects later in life including cancer and overall morbidity and mortality.
- It was observed that arsenical skin lesions were not developed in children below 11 years of age, but exceptions occurred where the concentration of arsenic in drinking water was more than 1000 µg/L and poor nutrition was associated with more than 500 µg/L arsenic concentration in drinking water.
- The children who are exposed to arsenic may show impaired learning and memory, sleep disturbances, abnormality and hearing problem, impairments of higher neurological functions including learning, memory and attentiveness.
- The effects of Arsenicosis was documented to impact on human wellbeing i.e. labour productivity, lowering income earning capacity, loss of lifetime income due to prolonged disease or death, inter- generational poverty, health status and reduction of school enrolment.

(Ref: Guha Mazumder et al. 1988, Chakraborti et al. 2002, Watanabe et al. 2004, Chakraborti et al. 2009, Guha Mazumder and Dasgupta 2011, Samal et al. 2013, Huy et al. 2014, Rahaman et al. 2016, Kumar and Singh 2020)

2.4. Cost related to arsenic contamination in groundwater

- Medical expenses, loss of wages, expenditures to prevent the occurrence of the diseases, changes in life expectancy due to pollution induced diseases are all economically quantifiable aspects of arsenic contamination in groundwater.
- The actual cost would rise each year as the occurrence of arsenic induced illness is also increasing.
- The reduction of arsenic concentration from higher level to the permissible limit is quite beneficial to the households suffering from arsenic induced diseases. Investment for safe drinking water was found economically achievable for them.
- Two primary categories were considered in which safe water approaches fall- switching to alternative arsenic free water source and remediation of arsenic contaminated sources.
- Not so many technologies were found to reduce arsenic concentration from higher concentration to WHO standard of 10 ppb from groundwater.

(Ref: Roy 2008, Khan and Haque 2010, Khan et al. 2014, Mahanta, Chowdhury and Nath 2016, Thakur and Gupta 2019)

2.5. Research gap

From the literature review, the following gaps were found to lead the present research work-

- Geostatistics can interpolate the distribution of arsenic concentration in groundwater as kriging is considered as one of the most accurate techniques than the traditional interpolation methods.
- There are some water quality parameters, that are correlated with arsenic concentration and help to predict the arsenic concentration in groundwater.
- Due to the exposure of arsenic affected ground water, it is important to study on the vulnerability of the primary school going children who are the future of our society.
- There is a social cost for arsenic affected illness for arsenic affected regions.
- The cost for different arsenic removal technogies are not similar. It is important to find a low cost technology that will help to remediate arsenic from groundwater to meet the permissible limit consistently.

The objective and scope of the study was developed on the basis of the research gaps.

3. Objective and scope of the study

The objectives of the study are

- ➢ Prediction of arsenic concentration in groundwater in an effective and economic way with the help of GIS and Geostatistics

- Assessment of arsenic induced health risk with the possible mitigation measures with special reference to primary school going children considering South 24 Parganas as the study area.

The following scopes were identified from the objective for the study-

- Selection of the focus area from South 24 Parganas district on the basis of arsenic concentration in groundwater (more than permissible limit).
- Modeling of the spatial variation of arsenic concentration in the focus area.
- Analysis of the model with hydrogeological characterization of the region towards determination of the cause of arsenic contamination.
- Developing a geostatistical model to estimate arsenic concentration in groundwater in arsenic affected region by using semivariogram and kriging.
- Generation of primary data in the form of site selection, sample collection and sample analysis.
- Estimation of arsenic concentration from tubewells in the focus area through primary and secondary data.
- Determination of the cross correlation among chemical parameters i.e. arsenic, iron and chloride.
- Estimation of arsenic concentration at Government aided Primary Schools in the focus area through secondary data.
- Determination of the arsenic risk among the total population in different arsenic contaminated region.
- Determination the economic loss due to arsenic contamination on the total population of the focus area.
- Finding out of possible mitigative measures for the minimization of arsenic induced health risk.

4. Study area

- South 24 Parganas was selected as the study area because the district was considered as the one of the most arsenic contaminated districts of West Bengal.
- South 24 Parganas district is located between 21°29´N and 22°33´45´´N latitude and 88°3´45´´E and 89°4´50´´E longitude.
- It is the largest and second most densely populated district of West Bengal located at the south east corner of the state covering an area of 9960 sq km.
- There are total 2042 villages and 111 Census towns (urban units) are distributed in the 29 CD blocks of the district.

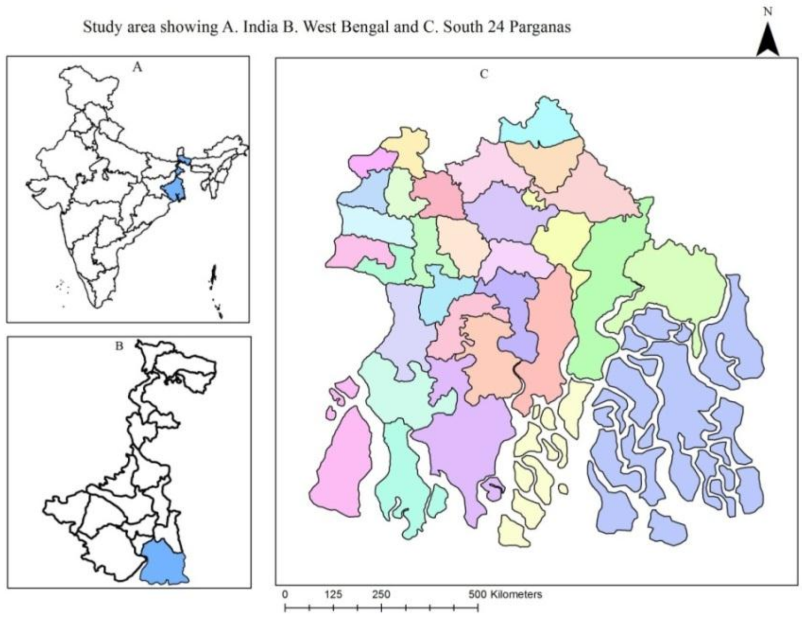

Fig 1. Location of study area

- The population of the district was found increasing from 3.7 million to 9.6 million implying a nearly 2.6 fold growth during the last 50 years. Among them 74.4% and 25.6% has been considered as rural and urban population respectively.
- High arsenic concentration (more than 10- 2500 ppb) was generally found in shallow aquifer with depth less than 100 m below ground level.
- Distribution of arsenic in shallow groundwater was found varying widely in the blocks. The deep aquifer is arsenic contaminated too.

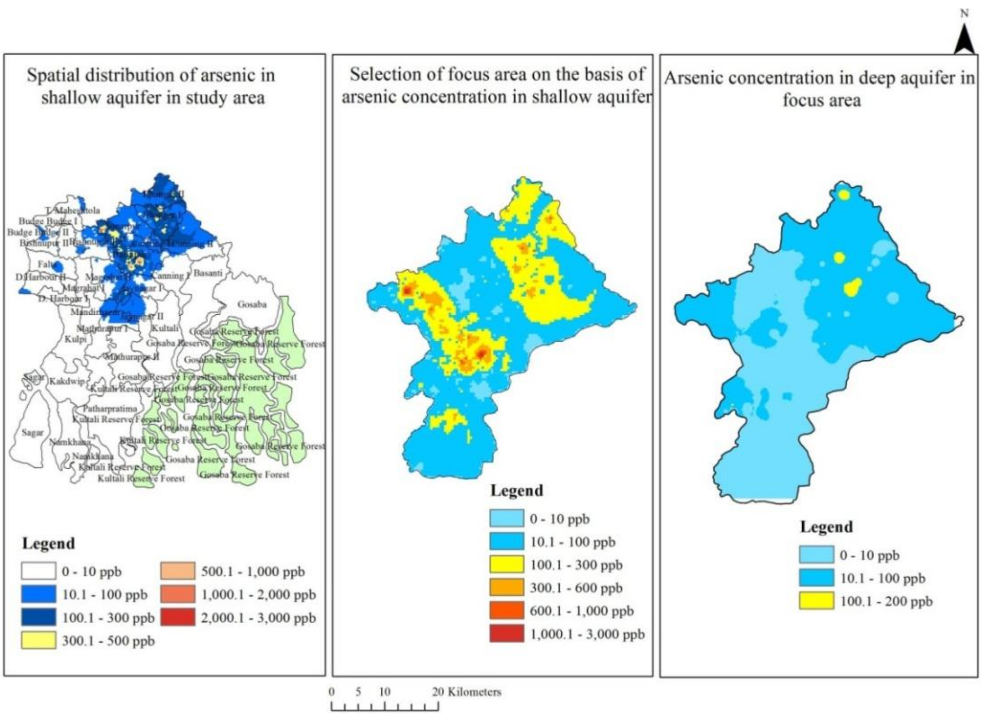

Fig: 2. Spatial distribution of arsenic in study area

Arsenic concentration was not spatially distributed in the South 24 Parganas. A focus area was determined on the basis of arsenic concentration in groundwater. The focus area consists of Baruipur, Sonarpur, Bhangar I, Bhangar II blocks in total and Bishnupur I, Canning II, Jaynagar I, Jaynagar II, Magrahat II, Mandirbazar and Mathurapur I in partial.

4.1. Characterization of the focus area

- The range of arsenic concentration in shallow (depth less than 100 m bgl) and deep aquifer (depth 101-300 m bgl) were 0-3000 ppb and 0-200 ppb respectively.
- Arsenic concentration in shallow aquifer below 10 ppb and above 10 ppb was recorded in distinct clusters and no systematic pattern was apparently noticed.
- The focus area is located at the Gangetic Delta Plain and was formed by the late Holocene to Recent sediment deposition from the River Ganges.
- A wide range of spatial variability was noticed to the arsenic concentration at a local scale (well to well variability), which made the prediction of arsenic concentration from the unsampled wells very difficult, even the arsenic concentration from the neighbouring tested wells were known.
- Presence of iron and chloride in groundwater was also noticed in the focus area.
- The focus area was divided into four zones according to the distribution of arsenic concentration in shallow depth- zone I (0-10 ppb), zone II (10.1-100 ppb), zone III (100.1- 300 ppb) and zone IV (more than 300 ppb).

After the selection and characterization of the focus area, the following studies were done on the focus area. The study was carried out in three stages-

5. Prediction and validation of arsenic concentration in groundwater by Geostatistics
6. Assessment of arsenic induced health risks
7. Management of arsenic induced health risk and cost benefit analysis

5. Prediction of arsenic concentration in groundwater by Geostatistics

Regular monitoring of spatial distribution of arsenic in groundwater is both expensive and time consuming. Using of Geostatistical kriging interpolation method including semivariogram, have been considered for determination of arsenic concentration in groundwater.

5.1. Methodology

Work done	Methodology	Data collected	Data source
Validation of the model	Spatial analysis by using the semivariance function	Location and arsenic concentration at Baruipur block at shallow depth tubewell	Secondary data collected from NRDWP-IMIS (2017-18)
Estimation of As concentration in shallow and deep tubewell	Geostatistical methods	Location and arsenic concentration at focus area at shallow and deeper depth tubewell	
Estimation of As concentration in field samples	Geostatistical methods	Location and arsenic concentration at focus area at deeper depth tubewell and the data was validated with the water samples collected from the deep tubewells of the focus area	
Cross correlation study	Spatial analysis by using the Semivariance function Rose diagram	Location and concentration of co-located variables i.e. arsenic, iron and chloride at shallow depth tubewell	

5.2. Results and discussions

The formulation of Geostatistical Modeling in this study was done with the help of Microsoft Visual Basic for Applications (VBA) (Microsoft's programming language for Excel) that run on Excel environment.

5.2.1. Validation of the model in groundwater from shallow tubewell in Baruipur block

The validation of the model was done with the dataset containing arsenic concentration in groundwater in Baruipur block.

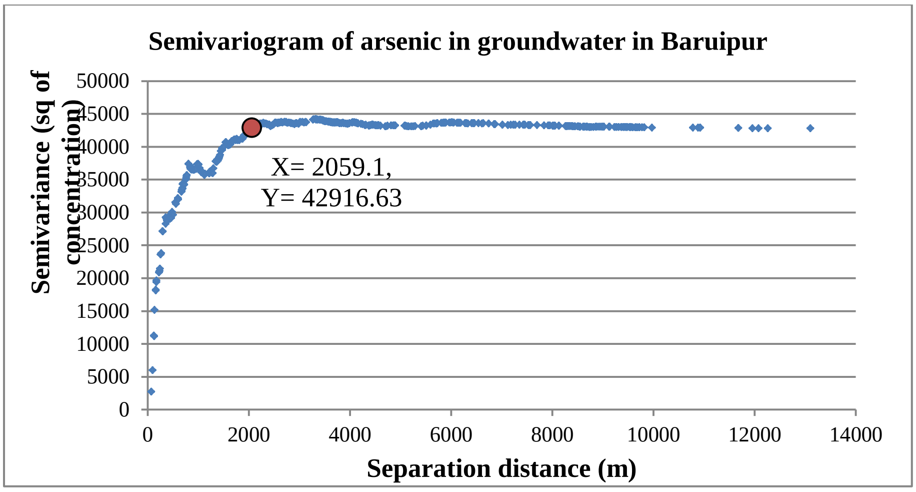

Fig: 3. Semivariogram of arsenic concentration at 0-15^{o} interval in groundwater of Baruipur block indicating the range value with red colour

- The computed semivariogram model was working properly that was made with the data sets. The semivariogram graph started from the origin and an increasing trend was observed up to a certain maximum range. Beyond this point, the curve became almost parallel to the horizontal axis.

- From the semivariogram, the range (X)= 2059.1 and sill (Y)= 42916.63 sq^2 values were obtained.
- The sample values are spatially correlated within 2059 m in this model, after 2059 m the values are independent.

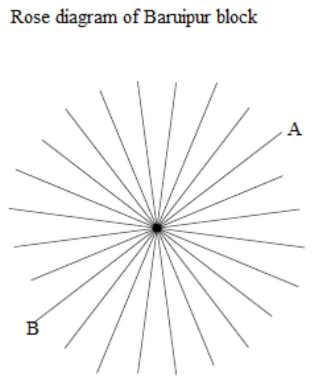

Fig: 4. A rose diagram of the 24 ranges in focus area

- The rose diagram was made with 24 angles (0-360^o at 15^o interval) with different ranges obtained from the 24 semivariogram drawn.
- The orientation of the critical direction for analysis of groundwater arsenic is along the line AB (major axis) at angle of about 37.5^o and 217.5^o measured from east towards north with a critical range of 2249.89 m. The longest range was displayed in the NE-SW direction.

5.2.2. Estimation of As concentration in shallow tubewell

Semivariogram modeling was done with 15^o angle interval from 0^o to 360^o and 24 semivariogram models were obtained. A straight line was drawn at every 7.5^o (average of 15^o) interval considering that all the points were fall on the straight line.

- The range and sill value of the semivariogram are 5611.37 and 52554.92 respectively. The sample points present within 5611.37 m are considered as spatially correlated.
- The rose diagram was made with 24 angles (0-360^o at 15^o interval) with different ranges obtained from the 24 semivariogram drawn.
- The distribution of arsenic was found homogeneous with the longest range displayed in the NE-SW direction**.**
- The orientation of the critical direction for analysis is along the major axis at an angle of 52.5^o (average of 45^o -60^o) - 232.5^o (average of 225^o-240^o) from east. The zone was considered as the influential zone.
- The variation was found to follow a power model to generate the equation for prediction.
- The equation for power model is $\gamma(h)=bh^c$

- The sample points lie within 6592.92 m and the angles 45^o-60^o and 225^o-240^o are considered as influencing sample points.
- Arsenic concentrations from these points influence to predict the concentration of estimation point.
- Estimation was done in 30 shallow tubewells.
- The deviation between estimated and actual values was observed as 20% samples at 0.01 to 0.1, 60% in 0.1 to 0.5, 13.3% in 0.5 to 1 and 6.6% was present in more than 1.
- In two sample points, the deviation was observed more than 1.
- If the estimating point is located in low arsenic contaminated region and the influencing points are present in the higher arsenic contaminated zone and vice versa, the erroneous results were found.

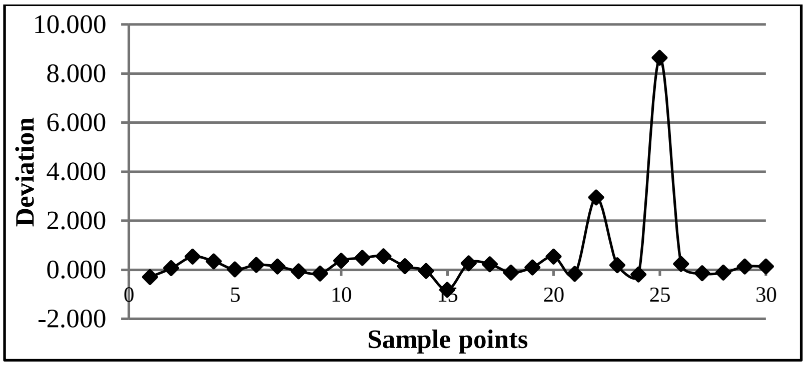

Fig: 5. Deviation of arsenic concentration between estimated and actual values in shallow tubewell

5.2.3. Estimation in As concentration deep tubewell

- The same methodology used for shallow tubewell for semivariogram modeling, rose diagram and estimation was applied for deep tubewell too.
- The sample points lie within 7859 m and the angles 45^o-60^o and 225^o-240^o are considered as influencing sample points. At 52.5^o- 232.5^o from the east, the range of the model is maximum. Arsenic concentrations from these points influence to predict the concentration of estimation point.
- The deviation observed between the actual and estimated values were 33.3% in 0.01 to 0.1, 46.7% in 0.1 to 0.5 and 10% in both 0.5 to 1 and more than 1.

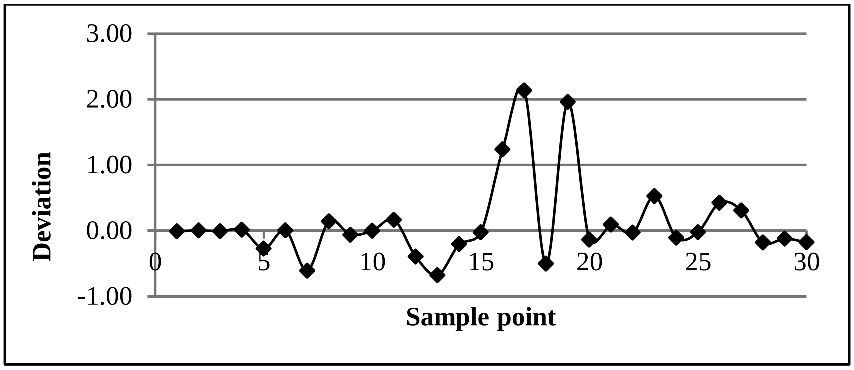

Fig: 6. Deviation of arsenic concentration between estimated and actual values in deep tubewell

5.2.4. Estimation of As concentration in field samples

- 45 field samples were collected from the deep tubewells of the focus area and arsenic concentration was determined from the samples.
- The prediction was done with ordinary kriging at those sampling points. The analysed and estimated values were then compared.
- The deviation between actual and estimated concentration values were as follows- 6.6% in 0.01 to 0.1, 66.6% in 0.1 to 0.5, 24.4% in 0.5 to 1 and 2.2% in more than 1.

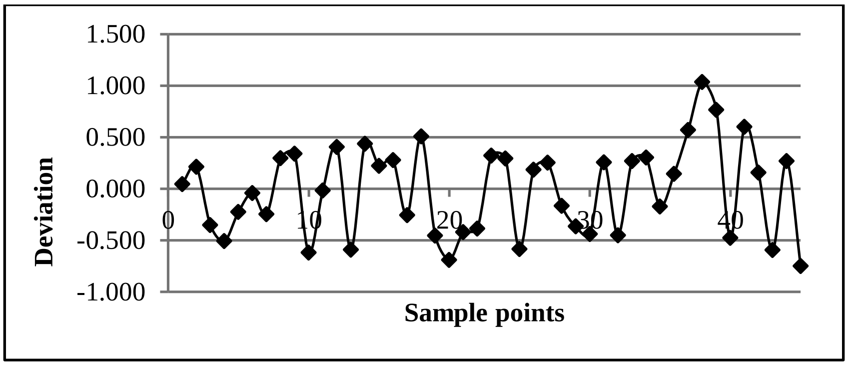

Fig: 7. Deviation of arsenic concentration between estimated and actual values in field samples

5.2.5. Cross correlation study

- **Cross correlation study between arsenic and iron**

The correlation found between the primary and secoandary variable is expressed by cross correlation model.

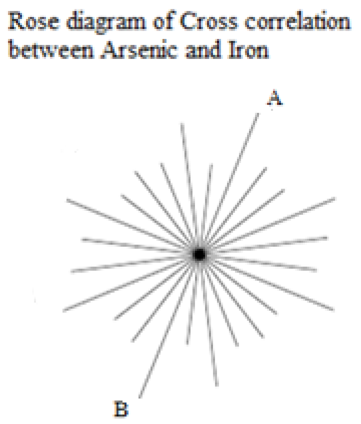

Fig: 8. Cross correlation between arsenic and iron

- The rose diagram is elliptical in nature.
- The AB line was supposed to be the critical axis for cross correlation of As and iron. The maximum correlation between As and iron was observed along this line.
- If we can estimate iron concentration along this straight line and it was high, we can assume that the As concentration will also be high at that direction.
- The maximum range at 52.5^{o} and 232.5^{o} angle observed was 1983 m that means the correlation of As and Fe can be observed within 1983 m of the focus area.

❖ **Cross correlation study between arsenic and chloride**

- The rose diagram is elliptical in nature.
- The AB line was supposed to be the critical axis for cross correlation of As and Cl. The maximum correlation between As and chloride was observed along this line.
- No cross correlation was observed between As and chloride in the study area.

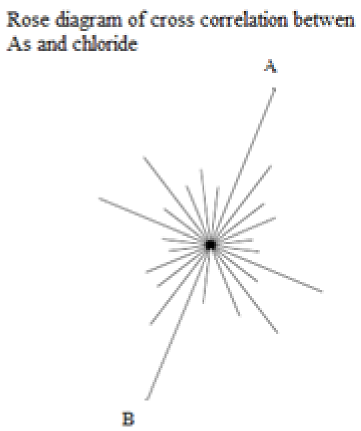

Fig: 9. Rose diagram of cross correlation between As and chloride

6. Assessment of arsenic induced health risk

6.1. Methodology

Work done	Methodology	Data collected
Population projection for the year of 2022	• Arithmetic increase method • Geometric increase method • Incremental increase method	Census data from 1971 to 2011
Location and determination of total number of primary schools and student population	Location was determined from the map	The locations of the schools were collected from Schools Geo Portal (2018) and the student population was collected from School report card portal (2018)
Estimation of As concentration in both shallow and deep tubewells in primary schools	• Semivariance analysis • Rose diagram • Ordinary kriging	The data collected for As estimation in previous part of the study
Assessment of As induced health risks	• Exposure risk assessment (tolerable daily intake) • Risk assessment (non carcinogenic and carcinogenic risk) • Decrease in Intelligence Quotient (IQ).	The estimated data generated by kriging interpolation method

6.2. Result and discussion

- The total projected rural population in 2022 was found around 2,50,00,000 in the focus area. The population share was observed maximum in Baruipur, Bhangar I, Bhangar II and Sonarpur block.
- The total projected municipal population in 2022 was found around 6,50,000.
- In the focus area around 85% of rural population and 100% of municipal population were found in arsenic contaminated region.
- The rest of the study was done with the population from the rural areas because in municipal areas, the people may have an alternative source for safe drinking water i.e. treated surface water, Public Water Supply Scheme (PWSS) by PHED,. But in rural areas, the population don't have any alternative, they do have to rely on groundwater.
- Among the total population, the child population (6-10 years) was around 2,00,000.
- Around 55% of child population among the total child population were observed to attend around 1000 Govt. aided Primary schools (from class I to V) and groundwater was used for the drinking and cooking purpose.
- Based on the kriging estimation in shallow tubewell, it has been found that in about 6% of schools the estimated arsenic concentration was within permissible limit, in about 56% schools, the estimated concentration was in zone II (10-100 ppb), in about 32%, the

estimated value was zone III (100.1-300 ppb) and in about 6% in zone IV (more than 300.1 ppb) with highest concentration was estimated as more than 1000 ppb in Sonarpur and more than 950 ppb in Baruipur.

- In case of kriging estimation in deep tubewell, it has been observed that in about 54% of schools the estimation was within permissible limit, in about 45% it was in zone II (10-100 ppb) and in about 1%, it was in zone III (100.1-300 ppb) with around 150 ppb arsenic concentration in Bhangar I and Jaynagar I.
- Exposure risk and health risk was assessed among the child and adult population as the population was affected by arsenic concentration. The school students from the 1000 schools were considered as the child (6-10 years) population and the adult (35 years) residing nearby to the schools were considered as the adult population.
- The ingestion rate of water for child and adult population was taken as 6 and 10 L/day considering only direct and indirect consumption of water.
- If a child consume 6 litre of water with 100 ppb arsenic concentration, the daily intake will be 1.5 fold more than the provisional daily intake value (2.1 µg/kg body weight). The value will be 4 fold more for the adult population when the consumption rate was 10 L/day.
- HQ>1 means that there is chances to develop adverse non carcinogenic risks. The HQ was found 10 for child and 28 for adult population when they consume 100 ppb arsenic contaminated water. Hazard Quotient (HQ) more than 1 was found in 99% primary schools indicating that there is a risk to develop adverse non carcinogenic effects among the child population.
- There is a chance to develop skin cancer in 125 adults among 10000 populations and 138 children among 10000 population if they consume 100 ppb arsenic contaminated water daily for 70 years. A carcinogenic risk of 1×10^{-4} gives rise to potential health hazard.
- Neurotoxic effects of arsenic was also found among human beings. Early exposure to arsenic can reduce the Intelligence Quotient (IQ), cognitive development and neurobehavioral function over the life time of a child. If a child consumes water with 10 ppb arsenic concentration, the estimated IQ will be 98.7 whereas the concentration is 100 ppb, the estimated IQ will be 91.5. Thus, IQ decreases with the increase of arsenic concentration in groundwater.
- In shallow aquifer when the range of arsenic concentration was found 1 to 900 ppb, around 60% of school students were found to be present in average (90-109 IQ score), 23% in low average (80-89 IQ score), 10% in borderline (70-79 IQ score) and 7% in extremely low (≤69 IQ score) scale. The average IQ score was considered 99.5 for the present study.

- In deep tubewell, 98% of school students were found to be present in 90-109 IQ score and 2% in 80-89 IQ score when the range of arsenic concentration was 1 to 150 ppb.

7. Management of arsenic induced health risk and cost benefit analysis

7.1. Methodology

Work done	Data used
Cancer risk assessment matrix	Estimated value of As concentration and cancer risk from Primary schools from the previous study
Cost analysis	
Economic loss due to As concentration in shallow tubewell	Calculated value on the basis of Roy (2008) and projected population data
Installation of As removal plant (ECAR) in shallow tubewells	Calculated value on the basis of Amrose et al. (2014) and projected population data
Installation of deep tubewell in As contaminated zone	PHED (2019) and projected population data
Installation of As removal plant (ECAR) in deep tubewell	Calculated value on the basis of Amrose et al. (2014) and projected population data

Electro-chemical arsenic remediation (ECAR) is an arsenic removal technology which works on the principle of electro coagulation (EC) method. The technology can lower down higher arsenic concentration within permissible limit.

Cost analysis	Annual per capita cost in INR
Economic loss due to As concentration in groundwater when the consumption is ✓ Adult (10 lpcd) ✓ Child (6 lpcd)	Low zone- 387.28 Medium zone- 947.07 High zone- 1746.94
Annual installation cost of As removal plant (ECAR)[Remediation cost]	
✓ Adult (10 lpcd)	Low zone- 255.5 Medium zone- 273.75 High zone- 292
✓ Child (6 lpcd)	Low zone- 153.3 Medium zone- 164.25 High zone- 175.2
Total gain after installation of ECAR in shallow groundwater	Economic loss- remediation cost
Installation of deep and submersible tubewell	Ranges from 371.05 to 717.38
Economic loss due to As concentration in groundwater among adult and child population in deep tubewell	Same as shallow tubewell
Annual installation cost for ECAR in deep tubewell	Same as deep tubewell
Total gain after installation of ECAR in deep tubewell	Economic loss- remediation cost

7.2. Result and discussion

- Social cost was determined from economic loss due to arsenic concentration in shallow tubewell, cost benefit due to the installation of ECAR in shallow tubewell, installation cost of deep tubewell, economic loss due to arsenic concentration in deep tubewell and cost benefit due to the installation of ECAR in deep tubewell.
- Per capita annual economic loss due to arsenic exposure as estimated as on 2022 considering daily consumption of water as 10 lpcd for adult and 6 lpcd for child were found as INR 387.28 in zone II (10-100 ppb), INR 947.07 in zone III (100-300 ppb) and INR 1746.94 in zone IV (more than 300 ppb). No economic loss was calculated for zone I because arsenic concentration was within permissible limit, so the population was considered to consume safe drinking water.
- Different ECAR operation cost was observed for different arsenic contaminated regions (zone II, III and IV). As the water requirement is different among adult and child population, the annual arsenic treatment cost was also different. On an average the arsenic treatment cost for zone II, III and IV are INR 0.07/L, INR 0.075/L and INR 0.08 respectively.
- Around 6% inflation rate was considered for the cost analysis.
- The estimated total economic loss due to arsenic concentration in shallow tubewell was around 1300 million INR. The share of economic loss in zone II, III and IV was observed 41%, 38% and 21%.
- The estimated operational cost of ECAR installed in shallow tubewell was found around 520 million INR. The remediation cost in zone II was observed 65% of the total remediation cost followed by 26.6% in zone III and 8.4% in zone IV.
- The estimated total gain was around 780 million INR after installation of ECAR in shallow tubewell. The maximum gain (46%) gain was observed in zone II.
- The estimated total installation cost for deep tubewell was around 900 million INR for total focus area.
- It was found from the study that after installation of deep tubewells with such huge expenses, arsenic contamination more than permissible limit was observed in several part of the focus area in deep depth aquifers too.
- 54% of villages were found containing arsenic more than permissible limit in deep tubewell.
- From the cost analysis it was found that the installation of deep tubewell was found not beneficial for zone II. The estimated installation cost was found greater than the economic loss due to arsenic concentration in shallow tubewell. Installation of ECAR in shallow tubewell may be the one of the best option for that zone. Installation of deep tubewell in zone III and IV was found beneficial to get arsenic safe water.

- The estimated economic loss due to arsenic concentration in deep tubewell was around 560 million INR. Around 90% of economic loss due to arsenic concentration in deep tubewell in zone II was found from the present study.
- The estimated remediation cost by ECAR in deep tubewell was found around 340 million INR.
- The estimated total gain due to installation of ECAR in deep tubewell was around 220 million INR.
- After the total cost analysis, it was observed that around 60 million INR would be assumed as total benefit from the economic loss due to arsenic concentration in shallow tubewell (1300 million INR), installation cost for deep tubewell (900 million INR) and installation cost for ECAR (340 million INR).

8. Conclusion

- The values of total daily intake, hazard quotient and cancer risk were found higher because higher arsenic concentration (more than 1000 ppb) was observed in the schools. So, all the values would be 10 times more than the results found with 100 ppb calculation.
- From the present study it was found that the permissible limit of arsenic in groundwater which is 10 ppb is not suitable for the child population. The HQ was found more than 1 and cancer risk was found 13 times more than arsenic free water when arsenic concentration in drinking water is 10 ppb.
- From the study it can be summarized as- the safe location should be predicted by Geostatistical method near the schools in both shallow and deep tubewell. If the shallow and deep tubewell both were found safe, then the tubewell should be installed in the shallow depth. If arsenic concentration was found less than 100 ppb in shallow tubewell, then ECAR treatment plant can be installed at that shallow tubewell. Deep tubewell can be installed where arsenic safe water is available. If both the depths are arsenic affected and the concentration is lower in deep aquifer, ECAR can be installed at that depth.
- In case of high risk zone, a cluster of schools can be selected, a tubewell location can be identified with ordinary kriging where As safe aquifer zone is available and supply of As free water can be done by pipeline to those schools.
- Some of the socio-demographic parameters including nutrition, health education, total health care, supply of treated surface water were found important to make a holistic management solution.
- In South 24 Parganas district, the health care facility for the arsenic affected population was found very low. So, there is a need to increase the number of health care centres that will treat the arsenic affected illnesses.

Solutions came out from the study

The following mitigative measures were obtained on the basis of risk matrix for the shallow tubewell from the focus area.

- ✓ 22% of total student population in around 52% schools belongs to low risk-low student population, low risk- medium student population and medium risk-low student population zone. As the schools are present in low and medium risk zone, students can be transferred from the high risk zone to these lower risk zone and arsenic removal plants can be installed in these region where arsenic concentration is more than 10 ppb.
- ✓ Only 2% schools having 0.7% of total student population is found in low risk-high student population zone, in this zone, arsenic removal plants will be the best option in these region where arsenic concentration is more than 10 ppb as transfer of students to the schools will not be possible.
- ✓ In medium risk medium student population zone, 9% schools contain around 7% student population. Installation of arsenic removal plant in those schools where arsenic concentration is more than 10 ppb is the best management option for this zone.
- ✓ In high risk- low student population zone, there are around 21 % schools with 41% of student population. Installation of arsenic removal plants is mandatory for those schools where arsenic concentration is more than 10 ppb and students are transferred from neighbouring small percentage of schools with high risk low population and medium risk high population schools.
- ✓ High risk -medium population is also having around 24% students in 12% of total schools. Management in such schools are also similar to high risk low student population.
- ✓ In medium risk high student population and high risk high student population zone there are around 4% schools with 5.5% of student population were observed. As the percentage of schools and student population both were lower than the other zone, it was found better to take the decisions about closing of the schools, installation of arsenic removal plants will not be cost effective for these schools. The students can be transferred to the low risk low student population zone. The closed schools can be used as health centres as the health care facility was found very poor in the focus area.

The following mitigative measures were taken on the basis of risk matrix for the deep tubewell from the focus area.

- ✓ 11% student population in around 36% schools was found in low risk- low student population and low risk- medium student population. Being a low risk zone, student population from higher risk zone can be transferred to these region and arsenic removal plant can be installed in those schools where the arsenic concentration is more than 10 ppb.

- ✓ In Medium risk- Low student population, there are 20% student population was observed in 28% of school, installation of arsenic removal plants was found mandatory for the schools where the arsenic concentration is more than 10 ppb and student should be transferred from neighbouring high student population schools.
- ✓ In Low risk- High student population, 68% of student populations were observed among 35% schools, arsenic removal plants may be requirred for this zone where the arsenic concentration is more than 10 ppb.
- ✓ For Medium risk- Medium student population and Medium risk- high population, only 1% school students were found in 1% schools in those zones, The schools can be closed and the students were transferred to other schools in low risk low populated zone.

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