Budding Challenges of Arsenic Contamination in Bengal Fan: in the Anthropocene Epoch

Abstract:
Arsenic toxicity has deteriorated human health status in West Bengal, India, in the past after detection in 1983. The area-specific pollution is increasing: sub-soil explorations, over-extraction of potable water, lift irrigation and mining activities. A hydro-geo-epidemiological assessment of the negative impact of arsenic toxicity on human health residing in the sensitive areas in the Bengal basin is viewed with meagre data and a vast anastomosed drainage system. To address data unavailability, the limitations are inconsistent sampling, comprehensive monitoring, groundwater level variation in aquifers and potential bias in the report. The search uses previous works, site surveys, geographic information systems, and conceptual maps of the geology and petrology of the area. The chemistry of arsenic compounds, their upshot on the human body, and technologies used to decontaminate arsenic in potable water in West Bengal are studied. The key findings are due to the geological lithological formation of the Himalayas. The change in drinking water sources from water bodies to shallow tube wells and mining in the Bengal basin has altered the geochemistry of groundwater with the surge in arsenic contamination from the pre-Holocene to the present. Aquifers below the Bengal Basin and flood plains are non-point geogenic sources of arsenic. Lift water is the primary contamination source in West Bengal that contributes to the rising trend of arsenic toxicity and health hazards. All concerned should cooperate to decontaminate the arsenic concentration and save West Bengal people from Arsenic exposure by adopting new technologies that comply with SDG 2, SDG 3 and SDG 11 requirements.

Keywords: Arsenic toxicity, Anthropocene, groundwater, Kolkata city, Bengal basin,

Introduction

The apocalyptic killers in the Indian deltas are Arsenic, fluorine, and Salinity intrusion. Arsenic, "As," is the most toxic metalloid that threatens human health. The level of toxicity depends upon concentration (Conc.), lithology, stratigraphy, speciation, topology, and bioavailability. Arsenic toxicity is a national subject in many countries, such as the US, India, Bangladesh, Argentina, Chile, China, and Cambodia.

Arsenic is available in air, soil, and water. The Toxic and carcinogenic arsenic exists in many districts in northeast Assam, Bihar, Jharkhand, and West Bengal in the Ganga–Brahmaputra-Meghana (GBM) basin, India **(Fig 1).** India has 1% of people vulnerable to arsenic poisoning. Since the last decade, arsenic contamination in groundwater(GW) has escalated due to the Ganga Brahmaputra Delta (GBM) lithology and anthropogenic stress on the Ganga basin (1), (2). Arsenic pollution in GW/surface water is of Himalayan origin, and many authors have researched paleohydrology (3); (4); (5); (6).

The arsenic levels in the GW are above the maximum allowable limit recommended by the World Health Organization (7) of 0.01µgm/l. In (8), the limit for arsenic in drinking water is 0.05µg/l. About 14-132m depth bore wells covering an area of 34 km in West Bengal (WB) in India have turned polluted with arsenic water. The Ganges system and Bengal Basin, India, have high concentrations (Conc.) in Malda, Murshidabad, Nadia, Purva Bardhhaman, South and North 24 Parganas, Howrah, and Hooghly. Out of 11 cities in the deltaic plains of the Ganga River, the worst polluted city is Kolkata.

According to WHO's report, prolonged exposure to arsenic-contaminated water and food causes malignancy, skin lesions, cardiac disease, and diabetes. During pregnancy, long exposure may affect cognitive development and increase infantile deaths. So, drinking water in India must be free from the risk of arsenic pollution, which requires intensive study.

The present article explores a critical public health and environmental issue, arsenic contamination in West Bengal, providing valuable insights into its causes, effects, and potential solutions. Arsenic contamination, aggravated by anthropogenic stress in the Ganga basin, affects groundwater in 221 districts across states like Assam, Bihar, Jharkhand, and West Bengal. Arsenic levels often exceed WHO limits, with West Bengal bore wells showing contamination at 14–132m depth. Long-term exposure to Arsenic leads to severe health risks, especially Malignancies, Diabetes, Heart disease, congenital abnormalities in fetuses, and pediatrics, Cardiovascular disease, Blackfoot disease, Genotoxic diseases etc.

Study area: India has 28 states and eight union territories(UTs), out of which 25 states have drinking water contaminated with more or less Arsenic as a pollutant. Out of 788 districts in India, about 221 districts are suffering from contaminated GW with Arsenic (≥0.01 mg/l).

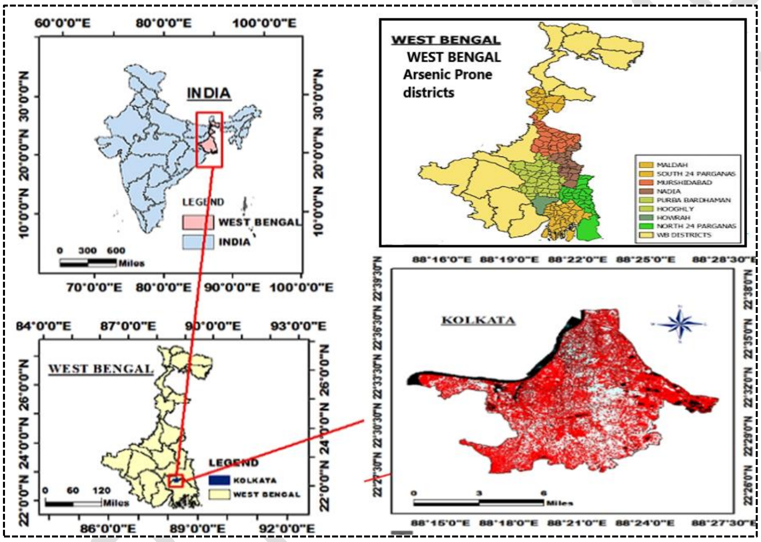


Figure 1: Study area map of Eastern and West Bengal (Arsenic Epidemic prone) states; India

Arsenic pollution was established in Indian states such as Punjab (1976), West Bengal (1983), Bihar (2002), Uttar Pradesh (UP) and Jharkhand (2003). Arsenic contamination has been diagnosed recently and has become apocalyptic during the Anthropocene epoch (from 1950). In West Bengal, Dr K C Saha, the dermatologist from the School of Tropical Medicine (STM), Kolkata, identified the first patient from the village Ramnagar in the South 24-Parganas on 6th July 1983 (three patients from three families reported) 24 Parganas of WB.

Later, many cases were reported from West Bengal (12 dist., 111 blocks, “As” level 50-3700 µg/l), Bihar (12 dist., 32 blocks, and 201villages, “As” level > 50 µg/l.), Assam (18dists/72 blocks, “As” level - 50 - 657 µg/l), Jharkhand (one district and “As” level > 50 µg/l), Odisha (Five districts and range, > 50 µg/l), and Uttar Pradesh(UP) (eight districts and “As” level > 50 µg/l as reported by 2022. The eight districts have become the worst contaminated area of villages in the Ganga, Hooghly flood plains below Farakka in West Bengal *(9)* (Figure 1).

Review of Literature:

The alluvial deltaic region of the Ganga/Brahmaputra/Meghna River of the Indian subcontinent houses groundwater (GW) arsenic contamination (10); (11). Arsenic concentration (< 0.01 mg/l) is safe for human health, while the permissible limit in India is accepted as 0.05 mg/l (50 µg/l). (12), (13).] When available in portable water, arsenic-contaminant water is a pervasive Group I carcinogenic metalloid (14) (Figure 2).

In 1995, a survey and study reported 1.75 mi patients with arsenical skin lessons out of 8 mi. people from 312 villages in 37 blocks. A 2010 study found that about 0.14 million people out of ≈0.84 million were suspected of suffering from arsenicosis. Chronic exposure to arsenic leads to several health issues, including Cardiovascular, Gastrointestinal, Neurological, Renal or Pulmonary, Hepatic, etc. So, one must decontaminate the water from arsenic to protect one's family (15); (16). The diseases are caused by prolonged exposure to arsenic-contaminated GW and contaminated food chains or industrial effluence.

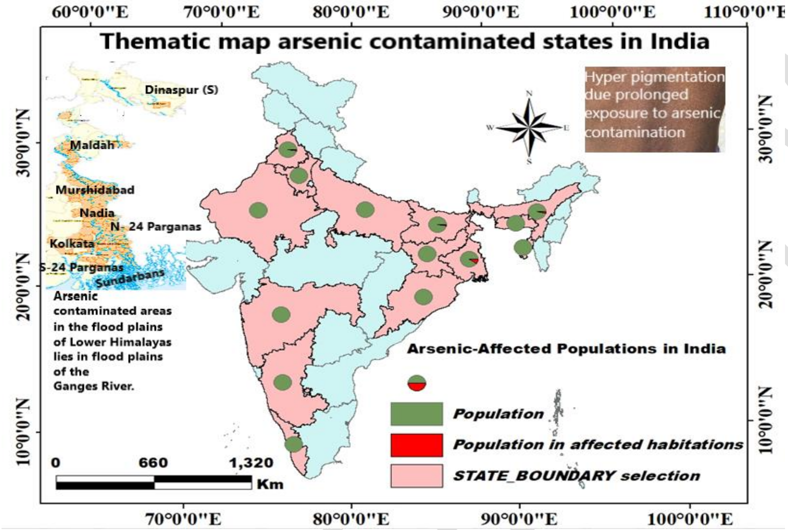


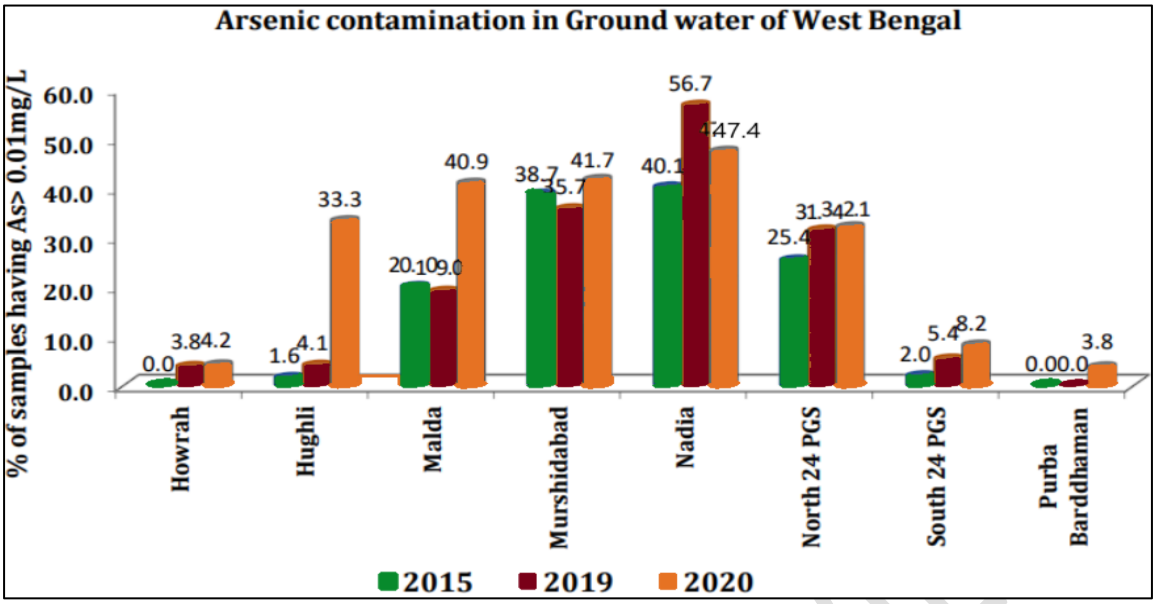
Figure 2: The arsenic contamination of groundwater in various states of India

Arsenic poisoning, similar to food poisoning, has symptoms of headache, fatigue, numbness, tremors, etc. Melanosis disappears when applied to medicine, but keratosis persists, and further problems may not be worse (17).

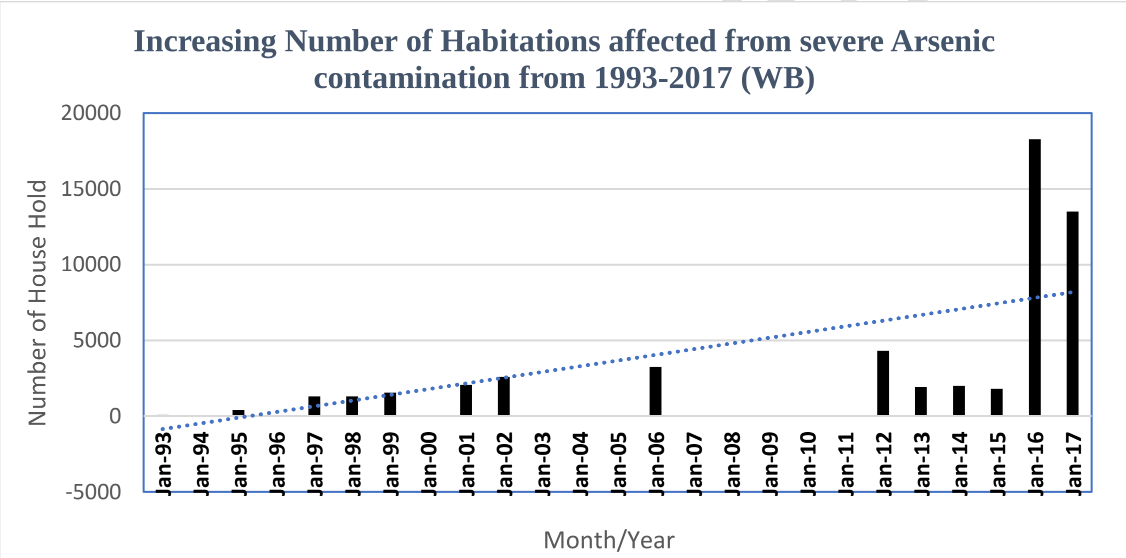
Environmental stable isotopes (^{2}H, ^{18}O, ^{34}S) and radioisotopes (^{3}H, ^{14}C) studies reveal that the districts Maldah, Murshidabad, Nadia, North and South 24 Parganas of West Bengal (WB) have aquifers when shallow are anthropogenic (< 100 years). However, the deep aquifers are old, of pre-Holocene accumulation, i.e. 5000-13000 yrs (collaborative study between CGWB & BARC). Arsenic is less necessary for plant metabolic growth (18).

Reasons for study:

According to Institute for the Management of Information Systems (IMIS) data, the Central Accountant General, India's Report of 2018, reveals that along the GBM delta, about 18258 settlements accommodating 17 million were affected by arsenic poisoning. The community water purification plants (CWPPs) constructed only benefitted 5.4%.



(a)



(b)

Figure 3(a & b):Surging "As" pollution affecting district-wise habitations >0.01mg/l) (in WB)

So, the present search is for assessment of the "As" polluted area, cause and detoxifying measures in various blocks housed within the Gangetic plains, the Damodar and the Bhagirath deltas from Farakka to the south in WB, Fig 3 (a and b)

Methods and methodology:

The present work reviews past literature on geological and statistical data of various Arsenic-infected areas and decontamination processes developed in WB. Interaction with the community people, medical personnel, and public health workers from affected areas about the arsenic mitigation Programme and its efficacy. The field data and laboratory observational results were gathered from the CGWB annual reports, WB Public Health Department, previous literature and various electronic sources and analysed.

The geological, geomorphological, geophysical, hydrological, hydrogeological, health care and physicochemical studies are referred to for analysis of aquifers, and their management plans are chalked out (Figure 3). The groundwater domain in various literature is gathered from various past literature and sources. Based on data analysis and interpretation, a management plan is chalked out.

Water management, either underground (UG) or surface flow, is a state subject. Data collection and initiatives for quality water management and drinking water are primarily the states' responsibility. However, the Indian Government has taken many steps. The present study focuses on finding the arsenic source in the Ganges aquifers (19), (20). Water samples were collected from the arsenic-contaminated area, and the X-ray fluorescent spectrometer was used to find the arsenic content in West Bengal's groundwater. The research arena was downloaded from USGS and georeferenced with ERDAS software. The stacked layer map was generated using the software Arc-GIS (version 10.8), and the water samples were distributed spatially in the Ganga basin. The statistical analysis of the observed water quality parameters is done in (21), (22) Figure 4.

Figure 4: The workflow diagram of the rising Arsenic health hazard in West Bengal

The Ganga-Bhagirath-Hooghly Basin
Limnology

The aquifers in the Bengal basin are confined or unconfined and shallow or deep. The subsurface sediment in the Bengal canopies is a few hundred meters below ground level (b.g.l). The area comprises buried late Pleistocene landscapes like Paleo Channels, or Paleo Interfluves, overlain by younger Fluvial sediments. The late Pleistocene landscape formed between 125 and 18kYBP (thousand years before the present) when the mean sea level (MSL) declined, and the sea withdrew southwards. The interfluves weathering created Latosol (lateritic clayey soils)called the LGMP soil (Last glacial maximum Paleo-soil). Later, the sea levels rose by active Indian summer monsoon (ISM) during the Greenlandian period of the Holocene (12.6- 6KYBP) in two stages within the Bengal Basin (3).

Geohydrology

The geo-hydrology of Gangetic plains exhibited two significant aquifers across the Bengal Basin. The upper one is over the LGM surface, and the younger paleo channel is infiltrated with grey sand from shallow aquifers with plenty of arsenic, called late Pleistocene Aquifers

(LPA). They are deep aquifers of sand (brown) overlain grey. These LPAs contain groundwater with <10 µg/L, which is naturally safe from "As".
Lithology: In nature, Arsenic is found in red and yellow colours. Labile Arsenic captured by Holocene grey sands of the shallow aquifers is a significant source (23), (24). They exist in the biome as organic and inorganic in their oxidation state, such as arsenide, arsenite and arsenates in -3, +3 and +5 ionic states, respectively (25). The highly toxic Arsenic enters nature through volcanic activity or weathering of rocks and subsequently dissolves in precipitation and joins the drainage system. Arsenite (As^{+3}) has a slower emission rate than arsenate (As^{+5}) (26).

Geogenic Mechanism and Sources: In India, the rivers of the Himalayan origin, Sindh, the Ganges, the Brahmaputra, and the Mghana, and their tributaries carry a considerable amount of arsenic-dissolved groundwater and deposit them in their flood plains.

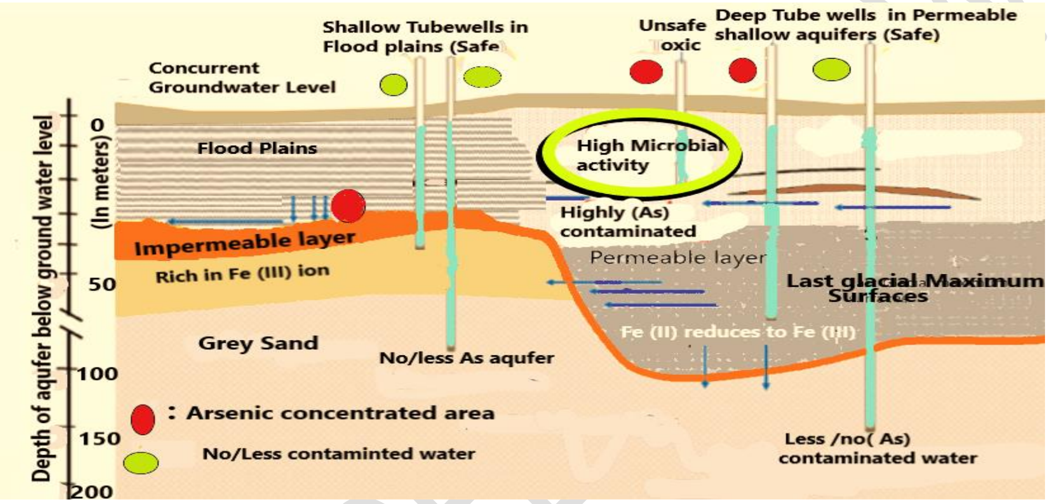


Figure 5: The vertical sections of arsenic invasive areas in the Ganga-Bhagirath River system (Source modified Majumdar et al., 2011):

The aquifers below the Ganga Delta and its tributaries (Bhagirath-Damodar) have significant deposits of native sources of arsenic. The mining effluents, hydraulic fracturing, coal-fired power plants, arsenic-treated lumber, and pesticides increase the arsenic level gradually in the upper and mid deltas of the Ganga (27). Metamorphic rock slates and Phyllite have the highest As^{+3} concentration (conc) of about 18 mg Arsenic/kg of rocks. Sedimentary, sandstone, quartz, and feldspar sandstone have less As (III) conc (28) and (29) (Figure 5)

Anthropogenic sources:

Available in free nature: Workers from the semiconductor or the microelectronics industry (Agri-units using arsenic herbicides/pesticides, workers in wood preservatives containing copper, chromium, and arsenic. Similarly, some benign foodstuffs contain arsenic, such as non-polished rice. Occupational hazards that spread Arsenic toxicity included wood preservation, semiconductors manufacture, vineyard spraying, nonferrous metal alloys, and glass.

The catchment area, flood plains and levees of the river Damodar, the Bhagirathi in Bengal basin are rich in coal and iron mines. The area is susceptible to arsenic deposits, and the iron helps dissolve insoluble "As" into soluble status; the upper aquifers are highly contaminated in districts like Maldah, Murshidabad, Nadia and north 24 Parganas.

Stratigraphy and lithology of arsenic-contaminated aquifers

Lithological Radiocarbon dating data reveals that the deep GW in the "As" affected areas exist in younger Delta plains (YDP) of the Ganga basin during 2.0 ± 0.6 kYBP (Meghalayan, post-Holocene epoch), whereas the deep, low-arsenic GW everywhere are of Greenlandian age (12.0 ± 4.0 KYBP; Pre-Holocene) (29). The stratigraphy of arsenic-poisoned aquifers stored in the younger alluvium of the Upper Gangetic Delta plain (YDP) towards the south of the Gangetic plains. They extend 1-2 m thick with Fe-Mn with soft concretions of 0.2 m, covered over the calcretes. The imprints of morpho stratigraphy of the Rivers of Bhagirathi and Damodar are observed to have subsurface continuity. The arsenic-laden aquifers exist in the pre-Holocene deposits (1000 to 8000YBP) below YDP, extending even up to the Maldah district of WB (2).

Arsenic in the Ganga/Hooghly basin aquifers:

Arsenic aquifers are received from the Damodar and west of the Bhagirathi River fan-delta. That influences fluvial geomorphology and Quaternary morpho-stratigraphy (30). The Bhagirathi (east) and Damodar flood plains (lower part), are lacustrine areas, swamps, river flood plains, sources of arsenic due to lithological shear zones, Gondwana Coal seams, etc. The shallow aquifers are triggered by arsenic pollution due to anthropogenic stresses. The deep Bengal Basin aquifers are of the Greenlandian age due to the shared impact of the MSLR (Pre-Holocene) and fast erosion in the Indian Himalayas.

Mobility mechanism "As" in Ganga basin:

Three mechanisms of the arsenic propagation hypothesis were established. **(i)** entry of arsenic to shallow aquifers in the recent period due to microbial action during the Anthropocene epoch due to sediment transport from high arsenic deposits from the Himalayan to the lower Ganges. The arsenic-carrying sediments enter aquifers with anoxic dissolved Fe, Mn, PO_4^{-2}, high alkaline organic matter, and low SO_4^{-2} concentrations. **(ii)** Few researchers argue that arsenic evolved from organic matter, sewage, and anthropogenic pollutants, initiating the oxidation and reduction reactions towards an anoxic state and raising the concentration of "As" propagated through the unconfined aquifers. **(iii)** In pre-Holocene, during the active Indian summer monsoon (ISM), the dilution of arsenic favoured blending into the deep aquifers.

Arsenic gradient along Ganga delta:

Highly contaminated aquifers of the eight districts in WB are observed by depth below ground level (b.g.l) variation in Murshidabad (50–80 m), Nadia (30–60 m), North 24 Parganas (> 100 m), South 24 Parganas (≥180–200 m) etc. trending from North to south downstream along the flood plains and levees of the Ganga River. *The conc. of arsenic in GW aquifers gradually increases below groundwater level as it moves along the district from north to south.* Many aquifers in WB up to 100m deep have severe arsenic disorders in the groundwater and the people (31), (32).

Chemistry of Arsenic compound:

Arsenic is a metalloid with atomic number 33; a relative atomic mass of 74.92 $g.mol^{-1}$ lies in the modern periodic table group V(A) and occurs in four oxidation states: –3, 0, +3, and +5. The taste of arsenic-contaminated water is metallic and gives a garlic smell. As(±III), As(V) and Arsine gas are the three forms: available as inorganic, organic salt, and gaseous state.

The metalloid Arsenic is brittle and grey or tin-white powder. It is available in nature as a free element but as the compound of oxygen, hydrogen, chloride, lead, mercury, gold and iron. Aarsenic ignited in oxygen to form "arsenic pentoxide" – tetra-arsenic Deca-oxide, As_4O_{10}, and As_4O_6. *The metalloid, elementary AS, is inert to water without air and has no chemical reaction with dry air*. Arsenic forms a surface layer of bronze colour retorting with moist air (33) (Figure 5).

(i) When Arsenic reacts with Oxygen in air $4As\ (s) + 3\ O_2(g) = As_4O_6$ (S)…(1)

(ii) When reacting with Oxygen in moist air: $4As\ (s) + 5O_2(g) =\ 2As_2O_{5\ (S)}$.....(2)

(iii) The halogens react with $As^{3+,}$ fluorine (F_2), chlorine (Cl2), bromine (Br2), and iodine (I2) to form the corresponding tri-halides in controlled conditions.

i. (a) $2As(s) + 3F_2(g) \rightarrow 2AsF_3$(liquid) [colourless]…..(3)

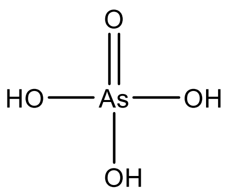
(b) $2As(s) + 5F_2(g) \rightarrow 2\ AsF_5(g)$ [colourless]……….(4)

ii. $2As(s) + 3Cl_2(g) \rightarrow 2AsCl_3(l)$ [colourless]………….(5)

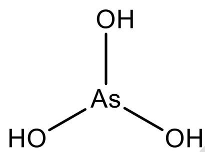
iii. $2As(s) + 3Br_2(g) \rightarrow 2AsBr_3(s)$ [pale yellow] ……... (6)

iv. $2As(s) + 3I_2(g) \rightarrow 2AsI_3(s)$ [red]…………………….(7)

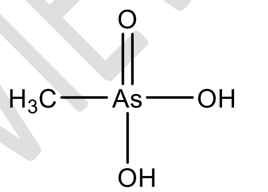
(iv) A few organic and inorganic acids of arsenic available are;



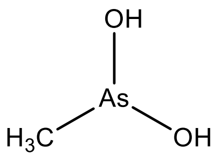
arsenic acid, Arsenate



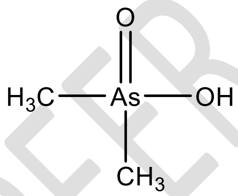
arsenous acid, Arsenite



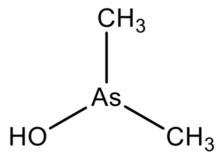
monomethylarsonic acid



monomethylarsonous acid



Dimethylarsinic acid



Dimethylarsinous acid

Figure 6: Various arsenic compounds and their structure

The arsenic-adulterated areas include arsenic trioxide, arsenic trichloride, and sodium arsenite, freely available trivalent compounds. In contrast, arsenic pentoxide, lead and calcium arsenate, and arsenic acid are common pentavalent complexes tainted with Fluorine, causing health hazards (26). https://www.webelements. com/arsenic /chemistry.html.

Degree of Concentration and Toxicity:

The toxicity grade and the element's oxidation state vary from inorganic to organic. The inorganic forms of the metalloid (arsenate/arsenite) are more toxic than the organic forms. The trivalent $AsO3^{3-}$ is more noxious inorganic forms than the pentavalent "As" (V). The As (III) is a significant public health threat. "As", as a trace element, exists on earth's surface layer with a concentration of 1–2 mg/Kg, but the conc. of arsenic in the sediments in the WB aquifers ranges from 0.4 on average to 40 mg/Kg for an average of 2–10 mg/Kg found in unconsolidated sediments (34), (35). The fatal dose of Arsenic trioxide is 180mg but varies with the duration of ingestion, fatal period ranges from 2-3 hours to 12-48hours and the tolerance of patients.

Global Arsenic History.

The mineral "As" has been reported since the 2nd century AD as "Fowler's solution" (1% potassium arsenite) and has been in use since 1786. Various human uses of arsenic have been known since 1842 as dimethyl arsenic acid. It is odourless, tastes less, and was used as a poison in wars and enmities. Later, it treated diseases like malaria, syphilis, asthma, chorea, eczema, psoriasis, etc. Salvarsan was the medicine invented by Paul Ehrlich (1910), named the "magic bullet" for treating syphilis before the use of penicillin (universal antibiotic) turned out to be more dominant during the 1940s (36).

Arsenic availability in Bengal basin:

Atmospheric: Arsenic is available globally at≈7900 MT/ year via natural and anthropogenic sources, mainly by vulcanisation and low-temperature volatilisation as Vegetation and dust. About 24000MT of arsenic dust is produced by human sources such as mining and smelting, fuel/coal combustion, etc. Traces of Arsenic have been found in the air of WB, Gangetic plains, Bihar Korba, etc. (37) and (38).

Hydrologic: Water carter arsenic through oxygenation, biological activity, leaching, and source proximity (26). The eight districts in WB are highly contaminated due to the sulfide oxidation or reduction of Fe-oxyhydroxides in the alluvium, microbial activity, and human activities in the Ganges' levees and flood plains (39).

In the earth's crust, Arsenic-rich pyrite and other arsenic minerals are available in the flood plains of the Gangas as sedimentary rocks but in lower conc. The "As" concentration data shows that the arsenic concentration is high in the levees and floodplains of the Ganges due to the coprecipitation of arsenic from sulphide deposits with or foraged by iron (Fe^{3+})) and manganese (Mn^{4+}) in the sedimentary setting.

In living flora and fauna: The human blood, urine, aquafauna species, cereals, vegetables, milk, wine, beverages, etc., contain arsenic at a limiting level as arsenous acid, arsenite, As (V): arsenic acid, arsenate, etc. (38).

Across the longitudinal section:

The weathering residues from arc-related rocks from the Suture zone along the Indus-Tsangpo and the Siwalik range foreland possess arsenic reservoir from the Cambrian (245ma BP) to the Cretaceous (66ma BP) period (3).

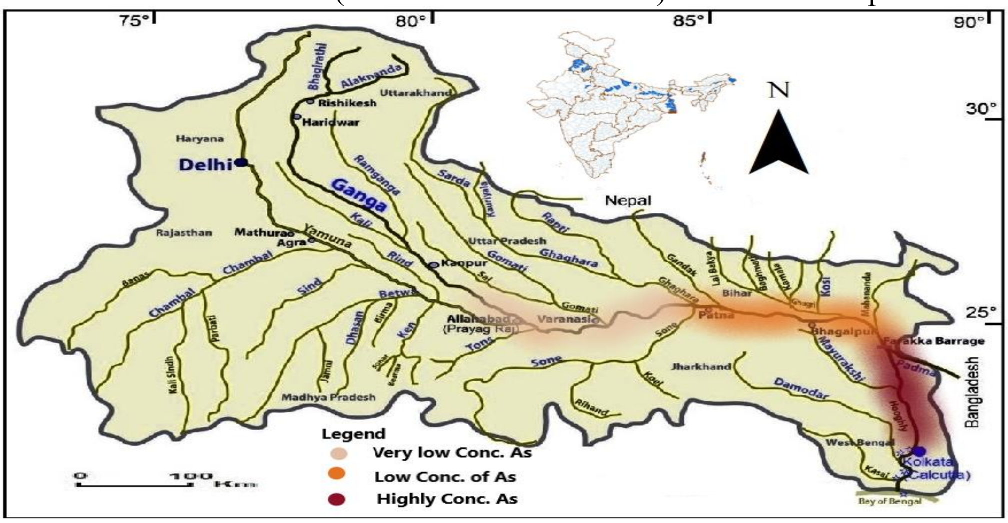


Figure 7: The Arsenic toxicity in India from Siwalik Range to BoB in South 24 Parganas

The Ganges alluvial tract suffers from small-scale arsenic contamination in Uttar Pradesh (UP) and Bihar (arsenic concentrations 0 to 0.7 mg/l) compared with higher values in WB (36 mg/l).

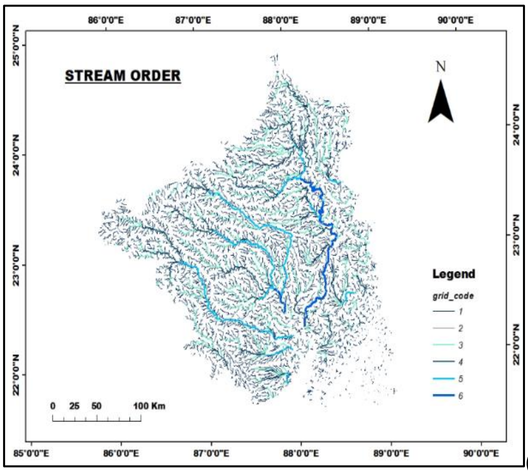
However, the concentration decreases with depth in WB. Arsenic conc is mainly below 50 mg/l in 'oxic' (shallow) wells, not shallow (oxic) wells. Lift irrigation has become popular, and phosphate fertilisers are widely used in the Gangetic flood plains. This widespread drawing of GW has surged phosphate derived from fertilisers. The rise in phosphate concentration encourages arsenic desorption in aquifer water. Moreover, the Ganges water is contaminated due to mutual microbiological and chemical processes promoting arsenic's natural mobility (Figure 7).

LU/LC and Contour map of Kolkata

The LU/LC map and the contour map of Kolkata City are generated by constructing GIS data. With the Anthropocene, it is found that the flat terrain has been filled with built-up areas. The physicochemical data shows that the contamination is widespread along the flood plains. More than 25% of these shallow wells in alluvial aquifers in the countryside possess arsenic in drinking water beyond the permissible limit of WHO, 1993, 2017 (0.01 mg/l). West Bengal in the aquifers in the Ganges delta has high contamination of arsenic (<0.05mg/ml). All tributaries also carry Arsenic debouching in the Ganga River Figure 8 (a and b).

Spread of Arsenic in the Ganga Plains:

WB has three arsenic-contaminated zones. They are (1) highly Arsenic-contaminated in the Ganga flood plains and towards the east flanks of the Bhagirathi River, (2) medium arsenic-contaminated areas in the north of the Damodar and Bhagirathi Rivers, and (3) The arsenic-unaffected zone in the west of the state. During the Anthropocene epoch, the penultimate aquifer (less than 100m) was highly polluted with arsenic as per CGWB AR-2022-23 (40).

(a)


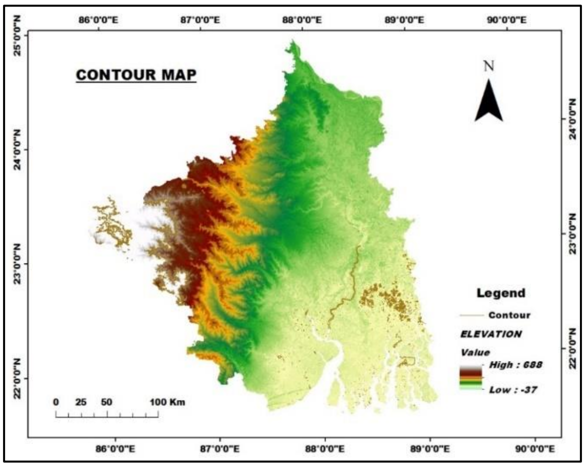
(b)


Fig 8(a and b): The stream order and contour map from the WB, India DEM map.

Data collection:

Central Ground Water Board (CGWB) has reported arsenic in 221 districts in 25 States/UTs, but the arsenic-poisoned persons are the state water supply department's responsibility. The number of fatalities recorded by the WB Health Department. It only records the number of arsenic-contamination habitations and locations per the West Bengal Drinking Water Sector Improvement Project (RRP IND 49017-006) (Table 1).

Table 1: The districts and assessment units in the WB districts affected by Arsenic poisoning

District/habitation	Arsenic-affected blocks in WB	Places High in Arsenic conc. (2022-23)	Status of arsenic in GW
Hooghly	Balahgarh, Pandua	≈25-50 µg/l	Sparse arsenic toxic
Maldah/65 hab.	Manikchak, Kaliachak I, II and -III, English Bazar, Ratua-I and II.	Kaliachak-1	Semi-critical to safe (Improved)
Murshidabad/ 27 habitations.	Beldanda I and II, Bhagwan Gola I and II, Domkal, Berhampur, Farakka, Harihar-para, Jalangi, Lalgola, Sagardihi, Jalangi, Nawda, Murshidabad, Samserganj , Raghunathganj Iand II, Rani nagar I & II, Suti I & II, Sagardihi, Udaya Nagar, Kandi, Bharatpur, Nawa Para, Samserganj, Khar gram, Nab gram, etc.	Hariharpara' Berhampur, Bel danga- I; *Rani Nagar, Rag-hunathganj*	Semi-critical to safe (Improved) Safe to Simi critical (deteriorated)
Nadia/ 35 habitations	Ranaghat-II, Kaliganj Nakashipara Karimpur-I Ranaghat-I, Santipur, Hanskhali , Krishnaganj, Tehatta-I, Haringhata, Nabadwip Karimpur-II, Chapra, Tehatta-II, Krishna Nagar-II, Krishnanagar-I, Chakdah	Karimpur; Nabadwip	Critical to semi-critical (Improved)
North24-Parganas/ from 6 to 5 in 2022-23	Barasat-II, Haroa, Basirhat-I , Bongaon, Habra-I&II Barrackpur-I, Gaighata, Amdanga, Deganga, Barasat-I, Bagda, Barrackpur-II, Baduria, Basirhat-II, Rajarhat, 17 Swarupnagar	Gaighata,Habra-I, Bagda, Swarup-Nagar	Critical to Safe(improved) SC to safe (Improved)
PurBardhaman	Kalna-II, Katwa-I & II Purbasthali- I &II	Manteswar, Kalna II	Semi-critical to safe (Improved)
Kolkata	South Kolkata (Ward Number	Ward No 26, 28, and 33	Sporadic at low conc contamination
South 24 Praganas	Jaynagar I, Baruipur (Ramnagar), Bhangore I and II, Sonarpur, Bishnupur I and II, Budge Budge II, Morahat II, basnati	Sporadic at low concentration	Baruipur Gosaba and sonarpur
AU: Assessment units; GW: Groundwater; WB: West Bengal: Semi critical: SC; S: Safe:			

Source: (30),(40),(41),Kolkata-water-table-arsenic-contamination-NGT- JudgmentDec1-2023.

The high pollution in the eight blocks was the most "As" affected from 2009 to 2016. The summer and winter seasonal variations of arsenic concentration occur. It is observed that arsenic concentration in aquifers in summer is higher than in winter. The Minister of State for Jal Shakti provided the data in 2022 that about 513 arsenic-safe aquifers will be exploited for drinking water. The habitations are in Bihar (40 numbers), W.B. (188), and 285 in UP. The district-wise habitations with arsenic poisoning have arsenic contamination in drinking water sources (4) and (30), (Table 2).

Table 2: Arsenic-affected Blocks/ habitation in WB, India (2019-2022) (source: JJM-IMIS)

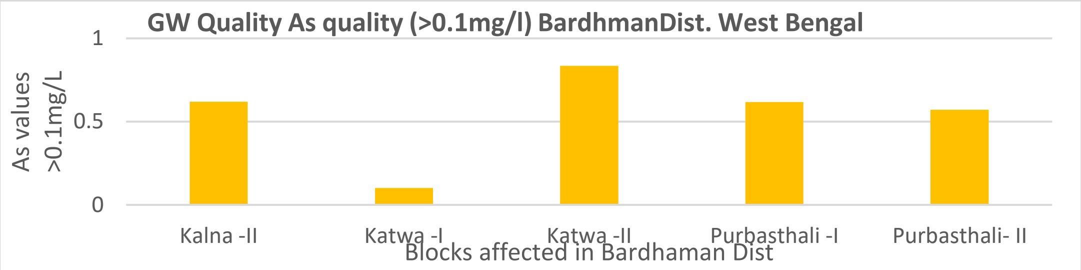
State	District	As Increase/Decrease in Blocks in the districts in WB				
		2009	2016	2019	2020	Inference from data
West Bengal	Maldah	7	7	3	5	More blocks identified
	Murshidabad	19	21	14	11	More blocks affecting
	Nadia	17	17	7	6	Blocks decreasing
	N- 24 Parganas	19	22	14	12	blocks decreasing(As)
	Howrah	2	02	01	01	Reducing As in water

	Hooghly	1	02	01	03	Pollution surging (As)
	S- 24 Parganas	9	08	3	4	As pollution increasing
	Purv Bardhhaman	5	0	0	1	As pollution increasing

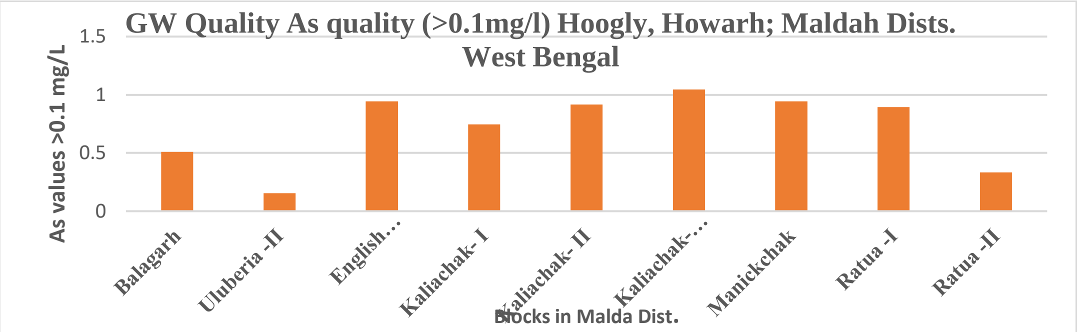
Source (40).

Worst arsenic affected West Bengal:

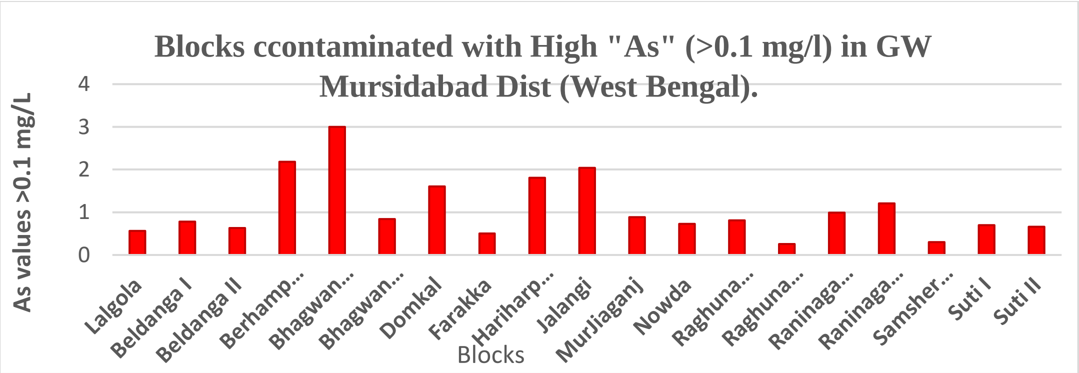
WB is the highest arsenic-affected state in India, where 1.1 crore people from 83 blocks use arsenic-contaminated groundwater. One study reveals about 212 skin cancers and 38 internal cancers out of 4865 arsenic-affected cases are identified in flood plains villages in the Ganges delta (1). Alluvial aquifers and flood plains of Himalayan-origin rivers are the prime sources (≈90%) of arsenic contamination in India. Details are in Figure 9 (a-f)



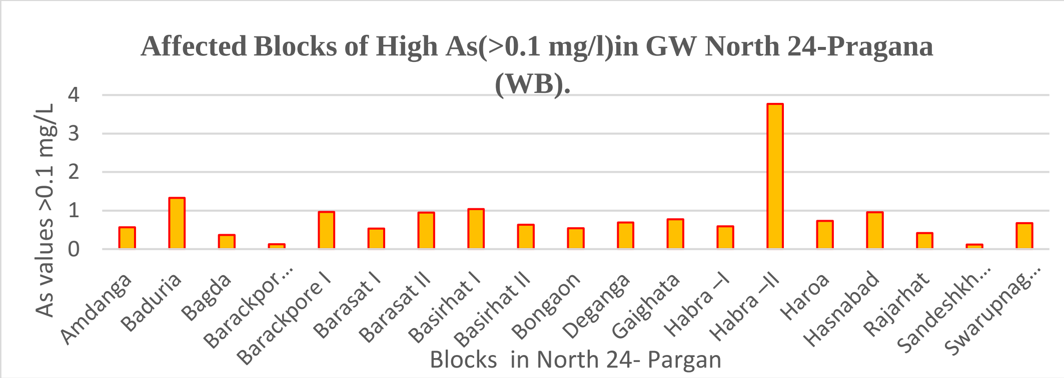
(a)



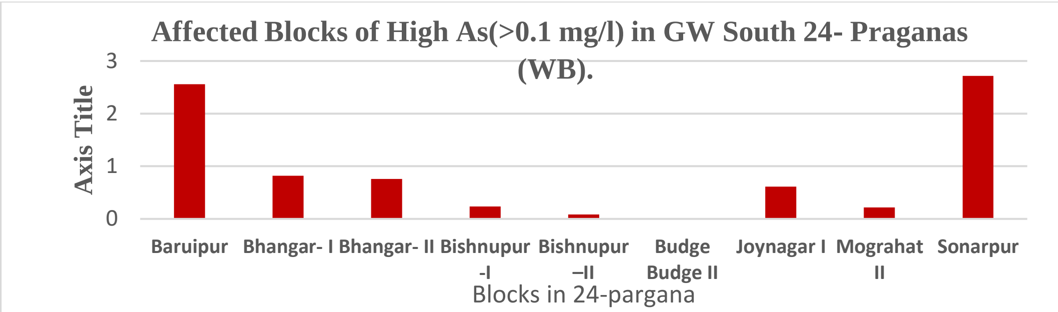
(b)



(c)



(d)



(e)

Fig 9 (a-e): The Arsenic contaminated districts of West Bengal in India (Source CGWB -2016)

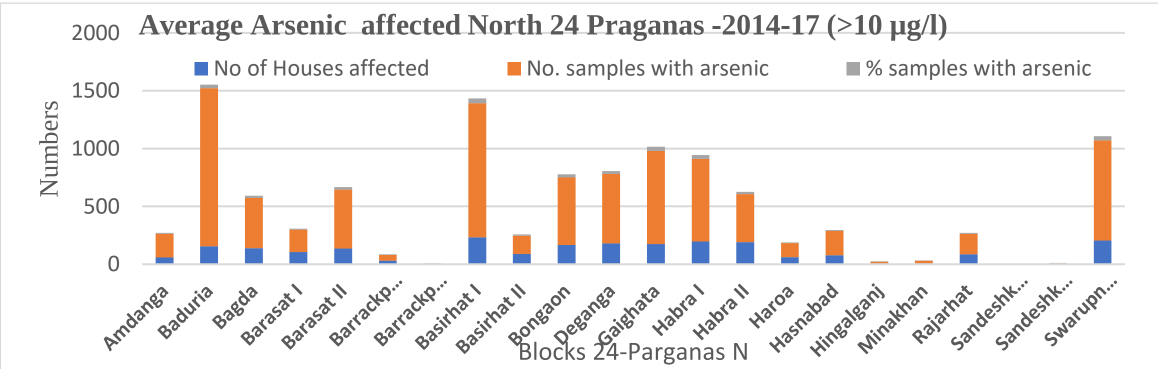


Fig 10 (f): The arsenic-contamination in 24- North Parganas District of WB From; 2014-17

Considering the gravity and the exuberance of the arsenic infection epidemic, the govt. of India (GOI) has started since August 2019 the slogan the Jal Jeevan Mission (JJM), i.e. Har Ghar Jal, in partnership with the States. The attempt includes provision for potable tap water supply in passable quantity and proper quality on a regular and long-term basis to every rural family by 2024.

Future Severe Arsenic Disease Burden (Kolkata)

Inorganic arsenic enters the blood circulation and remains in the blood for 2-6 hours after drinking "As" toxic water and is transformed into organic form. Later, it is excreted through sweat, stool and urine. "As" gets deposited over the skin, hair and nails keratin during blood circulation. The contaminant changes the epidermal keratinocytes, causing keratosis, melanosis, and other skin manifestations. Arsenic harmfully affects the epidermal system, the vascular system, and the nervous system of stakeholders. In the last 40-50 years, the drinking water in the arsenic-affected districts of WB has transformed into disaster-prone areas. People in Kolkata opted to stay elsewhere to save themselves from the monster arsenic epidemic, such as multisystem disorders, keratitis, dermal effects, and adverse obstetric and neurological complications due to long-term and chronic arsenic exposure (1), (23) (37), (42).

The *common symptoms:* The patient suffers from weakness, headache, burning of the eyes, nausea, abdominal pain, epigastric, paraumbilical, diarrhoea, cough (with/without) expectoration, hemoptysis, dyspnea, paresthesia, etc.

T***he physical signatures*** are Pigmentation, Keratosis, Anemia, Hepatomegaly, Splenomegaly, Ascites, Pedal oedema, lung diseases, polyneuropathy etc.8 (a-d)

Epidemiology

Arsenic poisoning in India occurs in three stages Figure 11 (a – d).

Preclinical stage: The initial arsenic poisoning manifestations are diarrhoea, drowsiness, headaches, malaise, abdominal pain, and confusion, mainly related to the skin.

Clinical stage: Spotted/defused keratosis in palms and soles, Melanosis, Dorsal keratosis

Acute stage: When any arsenic poisoning becomes acute, the symptoms are nausea, acute hemolysis, blood vomiting, blood in urine, and nail pigmentation.

Chronic stage: In the chronic and acute stages, the symptoms are dysfunction of the lungs, liver, and kidneys, and finally, death. The diseased person has symptoms of diseases, like palpitations, fatigue, headache, dizziness, insomnia, weakness, etc.,

Stage of malignancy: Skin cancer, Lung cancer, bladder cancer. (31).

(a) (b (c) (d)

Fig 11(a-d):(a-c) Arsenic nexus diseases (d) Inorganic arsenic stones (Source:1,000+ Arsenic Stock Photos, Pictures & Royalty -Free Images - iStock) | Arsenic poison.

Arsenic Decontamination/Mitigation Strategies

The top and the penultimate layer of the aquifer up to 100 (m b.g.l) is highly arseniferous in the Ganga Basin, and deeper aquifers are generally Arsenic-free in Maldah, Murshidabad, Nadia and 24-Parganas (North). The arsenic-safe deeper aquifers-fed wells have been constructed using sealing techniques to confine the aquifer from arsenic. Continuous pumping and artificial recharge of aquifers or groundwater reduces the arsenic infestation when the drawdown created remains within 6m, varying in various seasons in a year (43). The Arsenic removal equipment/structures are in Table 3.

Table 3: Detoxification processes to reduce Arsenic pollution possible for WB in urbans.

Detoxification Arsenic- water	Chemistry involved	Economics/ advantages	Drawbacks
Adsorption	Oxidising agents (viz. *activated Carbon),*): Al.$(OH)_3$ + H+ + H_2AsO4 =_ Al. H2AsO4 + HOH: Other Oxidising agents are Oxygen, UV radiation, chemicals, amine-functionalized -MW-CNTs aliphatic (AF–NF) and aromatic amine function-MWCNT (AAF –NF). AAF–NF membranes	Easy to operate, commercial/economic viability, reusable, adsorbent, recoverable. Problems are Residual effect and reaction kinetics. *Apyron's Arsenic treatment units* –MnO_2 activated alumina media called Aqua-Bind, TM-arsenic.	Absorption declines with regeneration and reuse of agents (Up-flow column reactor) or *Sono arsenic filter*. Oxidation of other organic elements
Coagulation/ Co-precipitation	$2H_3AsO_3$+O_2 = $2H_3AsO_4$; $Fe(OH)_3$+H_3AsO_3=FeAsO3 +3H2O; $Fe(OH)_3$+H_3AsO_4= $FeAsO_4$ + 3H2O:	Simple and easy to operate :	Chemical needed; Hazardous waste/ sludge generated
Oxidation Arsenic (III)	H_3AsO_4 + 2 H + 2e = H_3AsO_3 + H_2 O: E_0 = 0.56 V	Simple and oxidise other impurities Fe, F	Residual arsenic remains
Use of membrane	HR 3155 (cellulose triacetate) and BQ01 (sulfonated poly-sulphone	simple, no maintenance, Plant and operation requirements and no chemicals needed.	The less potential and a firm base is needed.
Sedimentation	passive and plain settling,	It is a cheap method and uses less technology.	Need alkalinity and iron in water.
Ion exchange	Water Systems International (WSI) technology	But of high efficiency	costly; natural Not for GW in WB
Biological: Bioremediation	Molecular markers involved in metabolism (i.e., aioX, ars M, ars C and arx B) are efficient at detecting arsenic bacteria). Bacterial oxidation of As (III) in water: H3AsO3 + [O] =>(Bacteria) H3AsO4:	Gallionella ferrugi remediations nea and Leptothrix ochracea are ecologically bacteria sound and chemical-free Pteris genus (viz. P.vittata) . High biomass aquatic plants (Ceratophyllum, demer sum, Hydrilla erticillate, Lemnaminor, Lemnagibba, Azolla caroliniana, Pistiastratiotes.	Sorbents: Microbes (microbial- remediation) and plants green plants phytoremediation) cost-effective/environmentally friendly bioremediation

Source: (44), (45), (46) and (47).

Surging Arsenic poisoning in WB

i. Before the 1970s, the villagers used drinking arsenic-free or within safe limits. water from surface sources, and shallow dug wells were only at meagre places.

ii. Anthropological activities, like mining, urbanisation, and over-exploitation of GW aquifers, have augmented arsenic-concentrated drinking water.

iii. Over-exploitation of groundwater within 100 m b.g.l, excess use of fertiliser and pesticides in the Ganga basin have increased arsenic contamination in aquifers.

iv. The small flashy rivers, such as Gumani, Tri Mohini, Kanloi, and Bhagirathi, flow through. In the Farakka barrage, "As" accumulates, and in conducive conditions (Fe and microbial activity), the "As" (III & V) concentration gradually increases downstream with the debouching of the Damodar River. So, the largest arsenic decontamination plant in India is installed at Farakka.

Mitigation Choices Sub-Urban Areas:

Urban agglomeration and concrete jungle in Cosmopolis have incorporated a growing challenge to water supply peri-urban, increasing industrialisation and inadequate groundwater recharge stress upon the water supply (48). Adding to scarce GW recharge, city effluent sources and hazardous wastes percolate, which generate an intermix of contaminated surface and groundwater. In the blending, there is an alteration in ambient physicochemical characteristics. pH, temp., BOD/COD, ionic strength, and Arsenic conc. Modern technology must address the ground/surface water nexus in peri-urban areas.

Mitigation choices in Rural areas:

GW Arsenic Mitigation Choices in Rural Areas: West Bengal arsenic impacts can be lowered by exploring groundwater from dug wells, rainwater harvesting, shallow tube wells, deep tube wells, or pond sand filters(49).

The dug wells exist in all houses and are popular, easy, and cheapest, but they lower yield and are prone to surface contamination.

The shallow tubewells: The hand pumps are prevalent in all settlements and are the common source of GW. They are less costly, popular and easy to install. They extract GW mostly from the uppermost aquifer so it can be contaminated with surficial flow.

The deep tube wells: People from rural and urban communities can use deep tube wells bored beyond 100m for portable and arsenic-free drinking water sources. The deep tubewell establishment is costly and needs technical skill and full management for over-extraction from the lower aquifers.

Rooftop or rainwater harvesting: The 21st-century arsenic-free water conservation methodologies prefer rainwater harvesting or rooftop water harvesting procedures. The arsenic-prone areas of West Bengal fall in the zone of the monsoon trough line and Intertropical convergence zone (ITCZ), which gives massive rainfall in the Bengal basin. However, rainwater harvesting structures are expensive and challenging to take up villagers.

Pond sand filters: IIT Madras has developed AMRIT technology for Arsenic and Metal Removal by Indian Technology for rural, urban and cities. Starting in 2006, Groups of European and Indian scientists, assisted by Queen's University Belfast (QUB), installed a low-cost, chemical-free method of treating and pumping GW of West Bengal to reduce the toxicity of potable water. The first AIRP was installed at Kasimpur (WB) in 2006 by the TIPOT Consortium, and the removal of arsenic from drinking water was successful (Fig 12 a-f) .

Offsite De-arsenisation in WB:

The methodologies can be applied in towns and peri-urban populous habitations. The plants are constructed to cater to arsenic-safe water demand, are costlier, high maintenance, regular monitoring, and sludge removal. However, it is time-consuming, demands high technology and needs to be more sustainable for the rural community and economically backward stakeholders. Technologies for the availability of safe water, it is wise to go for surface water supply with adequate filter systems, water from deep aquifers 100 mbgl or domestic/collective arsenic reduction plants.

Pipe Line Supplies:

The urban or semi-urban pipeline contaminant-free water supply is essential for urban settlements for sustainable health, hygiene, and water quality. It is safe, secure, riskless, efficient, centralised, and dependable. The installation cost must be lowered, and more monitoring, repair, and maintenance (R/M) costs must be required.

In-situ arsenic removal plant

These plants may serve individual houses or communities**.** The West Bengal Public Health Engineering Dept. (WBPHED) under the Arsenic & Iron Removal Plant (AIRP) for 165 units funded by NITI Ayog using indigenous technology introduced the arsenic-free water supply for 165 units of **No-sludge** removal Pilot schemes. The disadvantages are short term: less life may clog with time.

Action plans against arsenic contamination:

The assessed areas must have water quality testing labs, and regular/routine testing needs to be done. The field test kits (FTKs) are bacterial vials that must be supplied to test all water-polluting parameters, including Fe, F, and As. Peer groups or champions, especially women from the community, should build awareness among the community. Water, Sanitation, and health (WASH) should be monitored regularly. Women are more prolific saviours, and community participation is essential to improving the community's health through awareness campaigns and activities. They should include training the mothers and stakeholders about the drawbacks of arsenic in drinking water, arsenic-related health adversities, the urgency of arsenic removal, and maintaining water quality standards prioritising arsenic in WB.

Discussion:

The Ganges' dominant arsenic (As) floodplains are UP, Bihar, and West Bengal, as well as the Lower Gangetic alluvium of the Sundarbans of West Bengal. The National Aquifer Mapping Programme (NAQUIM), part of CGWB, portrays arsenic-safe GW sources as the deeper aquifers.

The Greater Kolkata arsenic contamination

The judgement was given by Hon'ble judges on 1st December 2023, as per CGWB data 2017-21: (against application The National Green Tribunal Eastern Zone Bench, Kolkata, Original Application No.34/2023/Ez. And (http://www.indiaenvironmentportal. org.in/files/file/Kolkata- water-table-arsenic-contamination-NGT-JudgmentDec1-2023.pdf)

i. Arsenic has contaminated the groundwater of Kolkata Municipal Corporation, which is rising gradually.
ii. Kolkata's groundwater level has dropped by 2.1m, a decline of 18.6% in the last five years. If not unchecked, it shall surge in depletion of GW by ≈44%.
iii. Wards No 55, 96, 113 and 122, there was suspicion of a rise in arsenic concentration.
iv. Arsenic contamination is observed in shallow aquifers in a few blocks i.e. Bishnupur, Baruipur, Sonarpur, Bhangar-I, Joy Nagar-I and Magrahat-II, not confirmed to be beyond permissible limits.

v. The annual rainfall (av) in the KMC is about 1820 mm, and net rainwater availability is 247 Mm3. A roof-water harvesting method is a judicious choice to collect and use.

vi. The decreasing order of contamination in WB is Murshidabad > North 24 Parganas > Nadia > KMA > South KMC > the KMC. The reason for minor contamination of KMC may be the use of many swallow hand tube wells that draw water from the surface.

However, Greater Kolkata will soon be at the doorstep of acute arsenic health hazards.

The Microbial Conversions of Arsenic Standpoints for Biological Removal of Arsenic from Water Potentially,(44). Arsenic is a byproduct from smelter plants during the smelting of ores like gold, nickel, lead, cobalt, and zinc (33). Organic arsenic is used as an antibiotic to treat spirochaetal and protozoal diseases, and inorganic arsenic has medicinal uses for treating leukaemia, chronic bronchial asthma, and psoriasis in the twentieth and is highly lethal when available in inorganic form (50) and 951). Arsenic exposure in flood plains of the Indo-Gangetic areas of Bihar and West Bengal has increased the rate of arsenic malignancy in more females than males, 92). About 140150 water tests from wells, borewells, tube wells, rivers, etc., were analysed since 1988 in WB (19 districts) of WB. The results reveal that 48.1% had arsenic above 10μg/l, above 50 μg/l (23.8%), and above 300 μg/l (3.3%), which is alarming for the people of the place (52). It can be concluded from a comprehensive range of studies and interactions that.

Future direction

The lower Himalayan belt and the Siwalik range are Arsenic reservoirs due to their past geological formation by vulcanisation. (a) Aquifers below the Ganga Delta are non-point geogenic sources of arsenic. (b). The water of shallow tube wells is a primary arsenic-contaminated resource. (c) The floodplain areas/levees in West Bengal have a trend of rising arsenic toxicity.

Arsenic in pure form is not soluble in water, but in the presence of iron, it is dissolved in water and contaminates water.

Anthropogenic activities like mining, urbanisation and over-exploitation of groundwater are sources of arsenic toxicity. Surface water is less arsenic-contaminated. Arsenic toxicity is turning out to be an epidemic that has become apocalyptic in the Anthropocene.

Suggestions and Recommendations

Arsenic-treatment units (ATUs) have become persuasive in assisting users whose piped-water surface water supply is achievable due to logistic issues.

Chronic exposure to "As" may come from a natural source, an industrial source, or an acute poisoning administered.

Chronic arsenical dermatosis stands from longtime consumption of arsenic-contaminated drinking water.

Dietary ingestion and water consumption are vital sources in the human body.

Humans suffer worse from arsenic pollution than animals as they consume arsenic from surface water or shallow tube wells extract. The crops that use more fertilisers can expel sulphates and hence more arsenic (53).

Health Risks

Drinking water, dust, fumes and skin contact are the carriers of arsenic diseases. Ordinary people are prey to diseases, weakness and malnutrition.

Melanosis caused by arsenic may be cured, albeit keratosis is not curable. Keratosis exuberates further complications. Medicines/antidotes at the acute stage are rarely effective. More

advanced pharmacological research is warranted for arsenicosis, cancer, and other complications.
More tracing, public health activities, tracking, testing, and medical assistance are necessary in arsenic-prone areas. People should be aware of the disaster and know the ways to live without arsenic in the atmosphere.
With arsenic-free groundwater, the environment must have decreased arsenic concentration levels, which is the only solution to arsenicosis.
The lithological and stratigraphic data reveal that Arsenic has become apocalyptic in the Bengal basin due to the low depth of lithological positioning.
Kolkata and South 24-Pargnas need appropriate watershed management to sustain precipitation for arsenic-free water supply.
Arsenic-contaminated rice and some baby foods (Cereals) are still suspected in export/import processes.
Arsenic-free and safe drinking water should be part of human rights. A universal umbrella should work on decontaminating drinking water, disseminating data, and sharing knowledge and experiences, which are essential as the arsenic disaster is of recent origin (40 years back acknowledged).

Attaining SDG Goals

The sustainable development goals (SDG -6), SDG 3.9, and SDG 11.5 demand that clean water and sanitation be stressed by 2030. The number of deaths/illnesses/ people affected must be reduced. Substantial water-related disasters, from chemicals and air to water and soil pollution, must be addressed.

Conclusion: The gravity of arsenic contamination underscores the human health strategies in the flood plains and microbial regions in shallow aquifers of WB. The health hazard warrants urgent mitigation action plans under prioritising the detection and amelioration measures. Arsenic treatment units (ATUs) like the AMRIT project of Madras IIT are very effective in helping "As" contaminated regions where the piped-water supply from waterbodies is unachievable.
The arsenic-contaminated groundwater challenged human health in West Bengal. Various skin, liver, cardiovascular, lung, and gastrointestinal disorders, neurological anomalies and genotoxicity are alarming and shall gear up in the recent past if not taken care of at present.
With Calcutta now emphatically in the arsenic-affected zone, it is stated that all residents should filter their water and use it. The CMC will use a three-year scheme to phase out shallow tube wells, particularly in the Tollygunge, Jadavpur, and Garden Ridge areas.

Ethics Approval: Not applicable.

Abbreviations: All abbreviations have expansions during their first use within the text.

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