Seasonal variations of groundwater arsenic at Silchar, Assam, and its correlation with the flood plains and landfill area

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In this study, we collected 60 samples from 30 sites in pre- and post-monsoon from Silchar municipal area (15.75 sq. km of Cachar district, Assam) during 2012–13 to evaluate seasonal variations in groundwater arsenic. It was observed that 27% were safe (0–10 μg/l), while 18% exceeded alarming zone (51–100 μg/l) and 3% were in the most alarming zone (>100 μg/l). The highest arsenic contamination of 188 and 161 μg/l was recorded in pre- and post-monsoon. The pH and EC ranged from 5.6–7.4 and 132–854 μS/cm in pre-monsoon. The iron content varied from 0.1 and 9.7 mg/l. Flood plains and landfill areas constituted the majority of arsenic-affected aquifers.

Keywords: Affected aquifer, arsenic contamination, flood plains, landfill areas.

GROUNDWATER contamination with arsenic is a worldwide problem due to its hazardous effects on health. The allowable limit of arsenic in drinking water as per WHO[1] is 10 μg/l, however abnormally high level of arsenic is common in some parts of the world, West Bengal and other parts of India[2–6].

An organic and inorganic form of arsenic in aquatic environments is found in oxidation states –3, –1, 0, +3, and +5. Arsenic +3 form is more soluble in water and 25–60 times more toxic than As +5 (ref. 7). Despite this varied degree of toxicity, there is no difference between these two arsenic species in water quality standards[8].

Poor management and careless use of water systems pose a serious risk to the quality and availability of water in this Valley[9]. Recent studies show that the problem of arsenic contamination is emerging in many northeastern (NE) states of India including Assam, Manipur, Mizoram, etc.[10–14]. It is therefore important to minimize the arsenic contamination in water as it has a long-term detrimental impact on mankind[15]. Our study was conducted to evaluate seasonal variations in groundwater arsenic at Silchar Town area in Barak valley, South Assam.

Groundwater samples were collected in plastic bottles (10 ml). They were pre-washed with dilute HNO_3 (1 : 1) followed by washing with distilled water. One drop of HNO_3 was added as preservative immediately after gathering the sample.

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The flow injection hydride generator AAS was used at the School of Environment Studies, Jadavpur University (SOES, JU), Kolkata, to estimate the total arsenic in sample, and iron was determined with spectrophotometer[16,17]. Other parameters such as conductivity and pH were determined with a digital conductivity meter and pH meter respectively, following standard methods[18].

The study area is located in the southern part of Assam (24°49′0″N, 92°48′0″E; Figure 1) with a population of 1,72,709 (2011 census) and an area of 15.75 sq. km in the district headquarters of Cachar. This area drained by river Barak through the alluvial plains. During our study period, the annual rainfall ranged from 2571 to 2711 mm. A total of 60 samples (30 in pre-monsoon, February–April, and 30 in post-monsoon, August–November) were collected from 30 different sites randomly (Figure 2). These areas include Ramnagar, Chirukandi, Tarapur, Malugram, Central Silchar (Tulla Patty), Shillong Patty, Ambicapatty, Subhash Nagar, Hospital Road, Kanakpur, Padma Beel, Shiv Colony, Rangirkhari (East & West), Sarat Pally, 1st Link Road, N. H. Road, Chengkhuri-Panchayet Road, Malini Beel, Ashram Road and Vivekananda Road. No sample was collected during the monsoon season because of fluctuations due to dilutions after rains. The majority of the populace is well connected with PHE water drawn from Barak while additional water demand is met by groundwater.

The geology of the area is conducive for good aquifers comprising clay, silt, sand and gravel. A generalized model of the soil matrix at Silchar Municipal area is shown in Figure 3. The nature of aquifers with a depth of 65 m shows multi-layer sequence of sand, alternating with aquitards like sandy-clay and clay. This finding is corroborated by the Central Ground Water Board, Govt. of India. Most of the aquifer strata are moderately homogeneous. The extent of thickness of individual phreatic layer varies from place to place. A strong relationship is observed between the internal flow of water from sandy to gravelly layer and vice versa. In Silchar Municipal areas, the majority of wells are borewells (20–65 m) while a few are shallow (20 m). The Tara Pumps (20 m depth) were dug by government agencies or by domestic users for drinking and other purposes. Chirukandi west of study area witnessed this category of Tara Pump.

We collected and analysed water samples from 30 tubewells/boreholes each in pre- and post-monsoon, spread over the whole Silchar Municipal area during 2012–13. All the tubewells/boreholes sampled were bore wells. Out of 30 tubewells, 24 samples were taken from private domestic users, 4 from schools and 2 from private nursing homes. The age of tubewells ranged from 1 to 20 years. The depth ranges from 20 to 65 m, with an average of 45 m. Majority wells had a smell while a few had no smell. The number of users of each tubewell ranged from 2 to 100. Seasonal distribution of arsenic, iron, pH and EC during 2012–13 is given in Table 1.

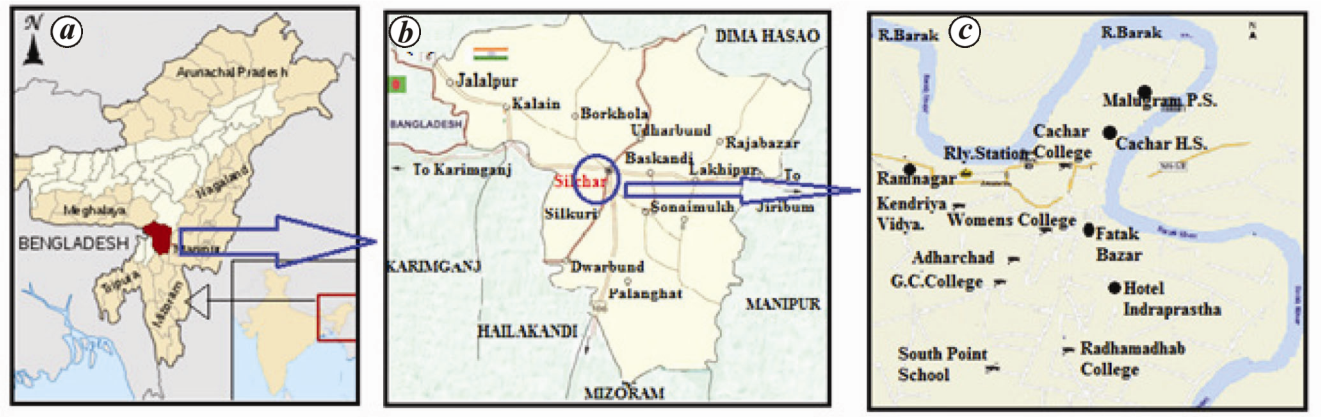

Figure 1. Study area: ***a***, Cachar district in NE India; ***b***, Location of Silchar in Cachar with adjoining neighbours; ***c***, Silchar Municipal area.

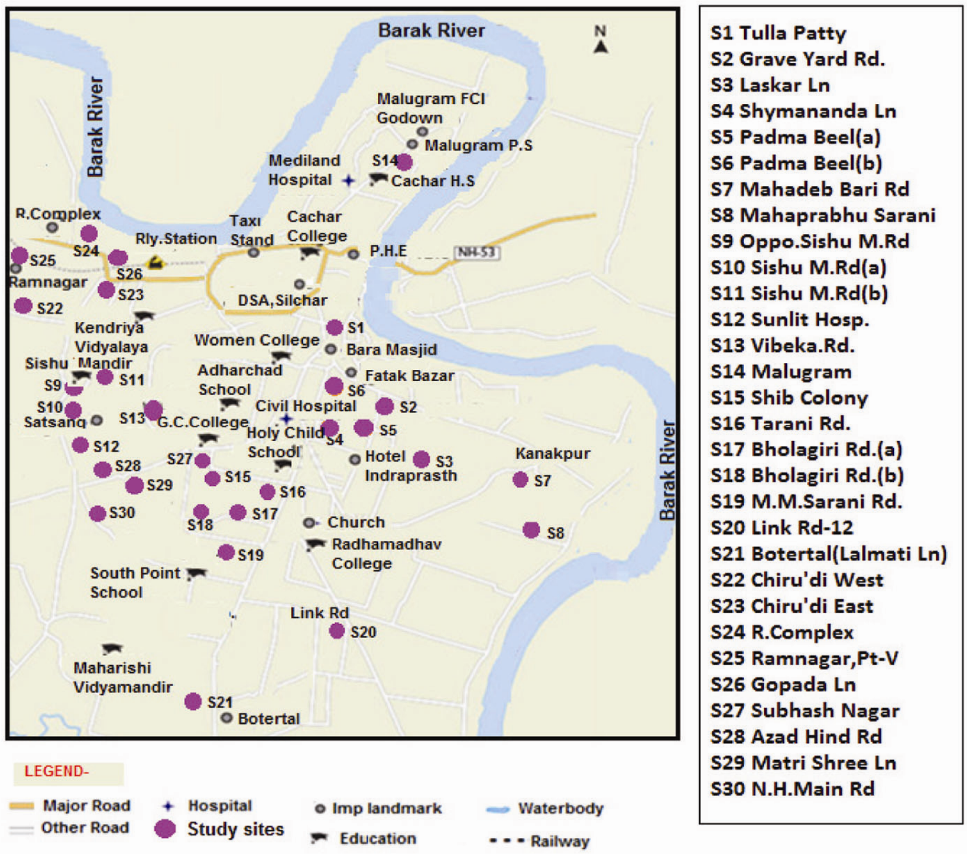

Figure 2. Study sites at Silchar Municipal area (*n* = 30).

The pH provides information regarding the extent of pollution by alkaline and acidic waste[19]. In our study, pH ranges from 5.6 to 7.4 during pre-monsoon, with an average of 6.88, and during post-monsoon it is 6.6–7.3 with an average of 6.90 (Figure 4), which is within the WHO and BIS range (6.5–8.5). pH variation is narrow and mildly acidic to near neutral indicating the absence of bicarbonates and carbonates. The mild acidic character of water of surficial aquifer is due to dissolved oxygen.

The extent of dissolved substance in water is measured by electrical conductivity (EC) value. EC varies from 233 to 854 μS/cm with an average of 534 in pre-monsoon and 215–280 μS/cm with an average of 217 at 25°C post-monsoon (Figure 5) which is within 1400 μS/cm recommended by WHO. EC depends on temperature and concentration of ions present[20]. Variation of pH may increase the dissolution process, which ultimately increases EC. Higher EC is observed in pre-monsoon while low value is seen in post-monsoon due to inundation of water table.

Table 1. Seasonal distribution of arsenic, iron, pH, EC at study sites during 2012–13

Sampling code	Mean As in pre-monsoon (February–April) (μg/l)	Mean As in post-monsoon (August–November) (μg/l)	Mean annual As (2012–2013)	Mean iron in pre-monsoon (mg/l)	Pre-monsoon pH	Post-monsoon pH	Pre-monsoon conductance (μS/cm)	Post-monsoon conductance (μS/cm)
S1	BDL L	BDL L	BDL L	0.6	6.7	6.9	354	237
S2	41	33	37	3.7	6.9	6.9	467	213
S3	30	23	27	2.6	6.8	6.8	465	270
S4	65	25	45	4.5	7.1	7.1	653	211
S5	78	78	78	3.5	7.1	6.9	243	178
S6	65	161H	113	3.9	7.1	6.8	546	254
S7	45	64	55	4.2	6.8	6.7	341	267
S8	63	39	51	3.4	7.2	7.1	324	150
S9	15	10	13	9.8H	5.6 L	6.8	233 L	132 L
S10	29	20	25	2.9	6.9	7.1	546	234
S11	12	BDL	7	6.2	6.8	6.8	345	210
S12	12	7	10	6.5	6.9	6.9	536	254
S13	11	BDL	7	4.8	6.8	6.9	854 H	240
S14	19	11	15	0.9	7.2	7.1	647	251
S15	43	24	34	4.5	7.4 H	6.9	354	178
S16	46	63	55	6.5	7.1	7.0	756	143
S17	89	78	84	3.5	6.9	6.8	334	231
S18	188 H	84	136 H	5.6	7.3	7.3 H	436	178
S19	26	11	19	3.5	6.9	6.8	564	189
S20	28	15	22	8.4	5.9	6.8	637	254
S21	BDL	BDL	BDL	4.3	6.8	6.8	645	246
S22	BDL	BDL	BDL	9.5	6.8	6.9	743	197
S23	36	12	24	3.1	6.9	7.1	645	236
S24	81	35	58	1.8	6.8	6.8	365	198
S25	24	13	19	0.3	7.1	6.8	567	231
S26	32	13	23	0.2L	7.1	6.6 L	743	160
S27	42	18	30	4.1	6.9	6.9	600	245
S28	BDL	BDL	BDL	2.4	6.8	6.8	678	274 H
S29	BDL	BDL	BDL	6.7	6.9	6.9	743	268
S30	7	BDL	BDL	3.4	6.9	6.8	645	168

$n = 30$, BDL = <3, but for Statistical Calculations it was averaged to 1; H, High, L, Low.

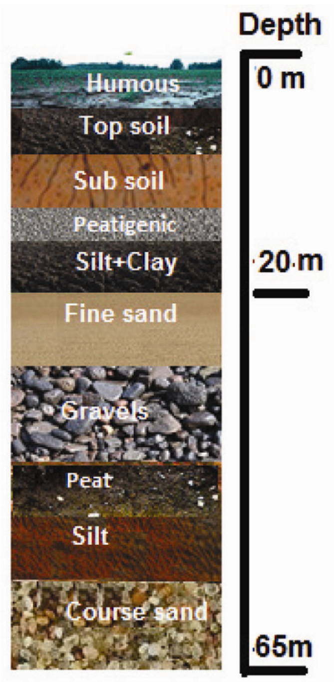

Figure 3. Generalized model of soil matrix at Silchar Municipal area.

Pre-monsoon iron content in groundwater ranges from 0.2 to 9.8 mg/l and in most cases the data exceeds the WHO permissible limit of 0.3 mg/l except a few (Figure 6), whereas variation in post-monsoon is not noteworthy. The highest seasonal mean value of 9.8 mg/l (permissible limit 1.0 mg/l) was found at Ashram Road and the lowest value 0.2 mg/l was recorded at Ramnagar Part-V, and Gopada Lane, Tarapur. The groundwater bearing iron content beyond WHO limit should be treated before use. The iron concentration was found to be lower after filtration treatment[21].

The pre-monsoon distribution pattern of Fe against pH of sampled water is shown in Figure 7, which shows that the concentration of iron in aquifer increases with increase of pH and attains the highest value of 9.8 mg/l at pH 7.4 which may be attributed to iron dissolution from iron-oxy-hydroxide into water.

Further, the variation in concentration of Fe is found to be irregular and shows a negative correlation ($r = -0.4246$) with respect to the depth (Figure 8). We notice two maximals at 20 m and 40 m depth where iron concentration hits highest while it shows bearish pattern at 65 m depth.

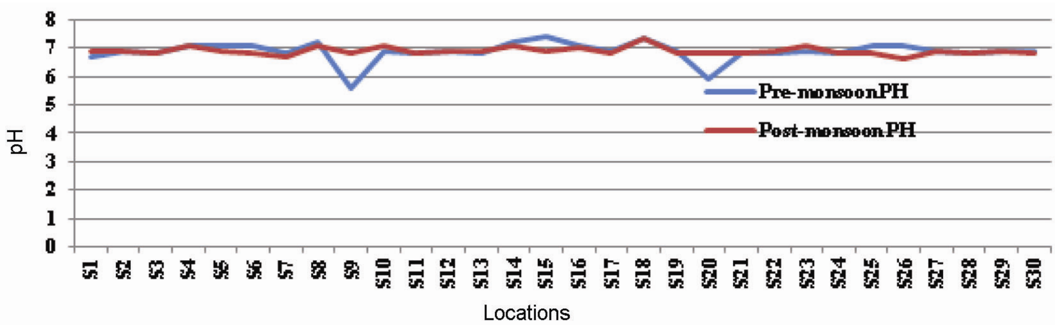

Figure 4. Seasonal variations of pH with locations.

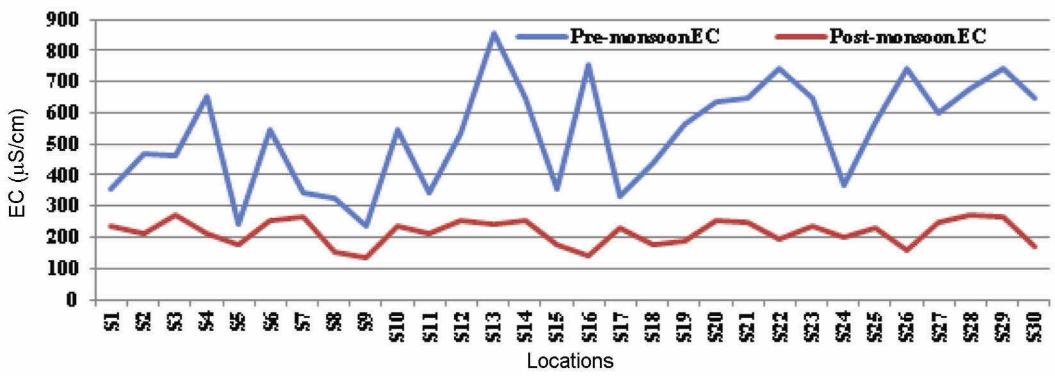

Figure 5. Seasonal variations of EC with locations.

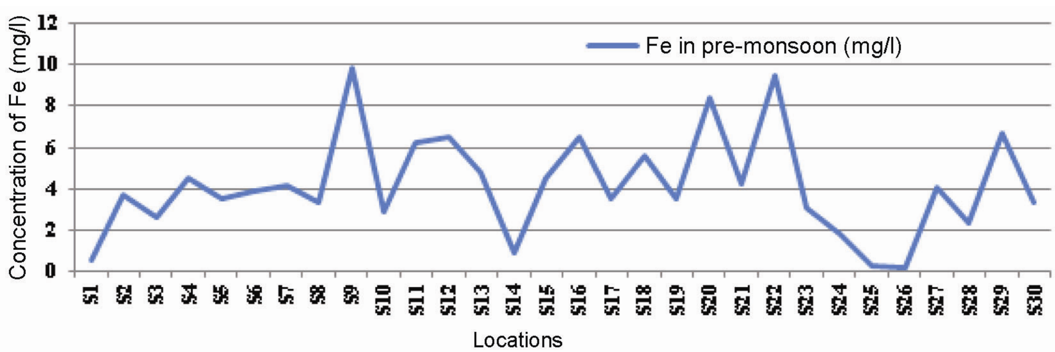

Figure 6. Variation of Fe with locations in pre-monsoon (mg/l).

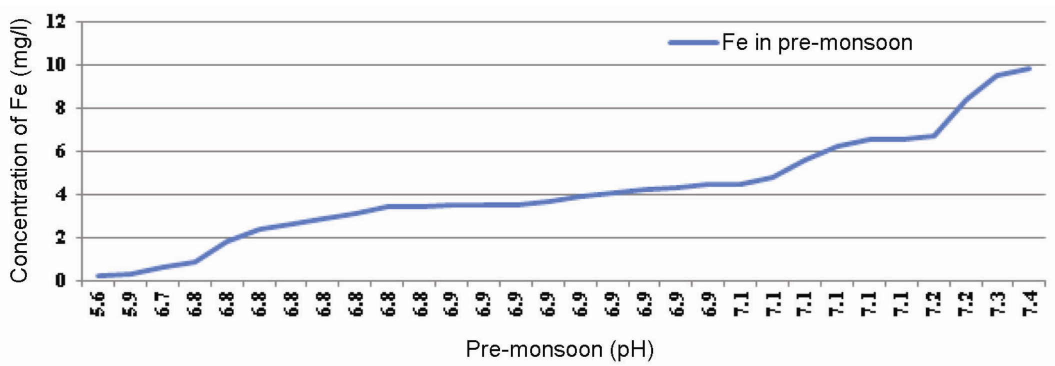

Figure 7. Variation of Fe with pH in pre-monsoon.

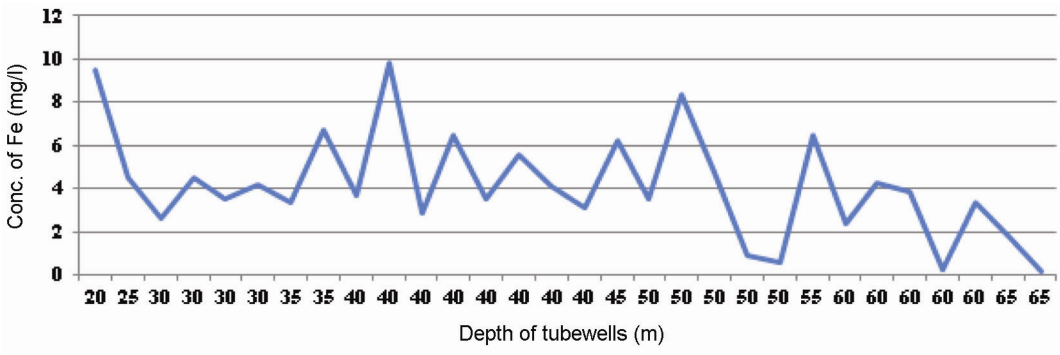

Figure 8. Variation of Fe concentration with depth of tubewells.

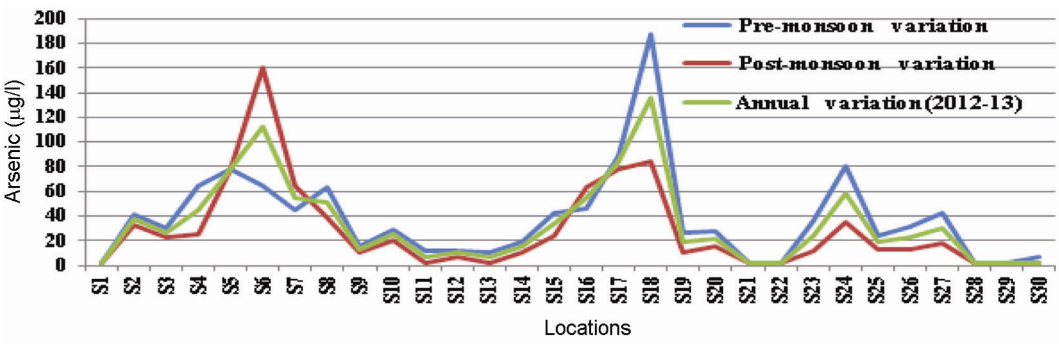

Figure 9. Seasonal and mean annual As variation with locations.

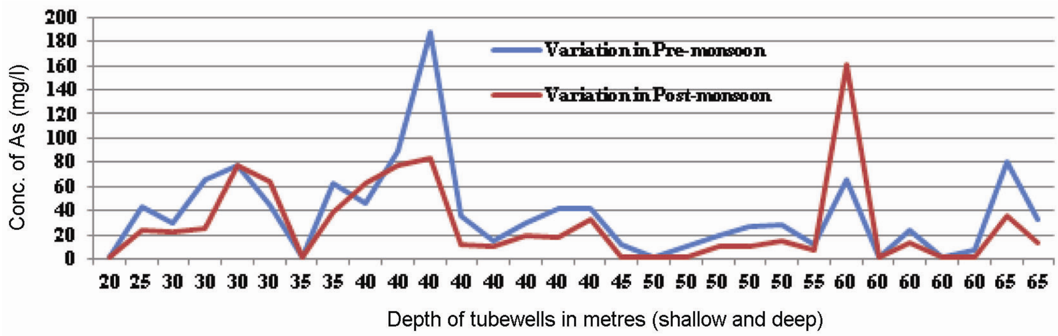

Figure 10. Seasonal variation of As with depth of tubewells.

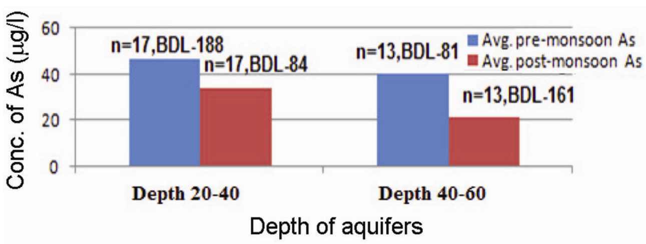

Figure 11. Seasonal variation of As at two different depths.

Arsenic in the area under study varies between below detection limit (BDL) and 188 µg/l in pre-monsoon with averaged value of 45, whereas it varies (161 µg/l) with averaged post-monsoon value of 38. Some sites show arsenic contamination within the recommended level of BDL – 10 µg/l (WHO) whereas some are within the permissible range of >10–50 µg/l (BIS)[22], and the rest is >50 µg/l. The highest seasonal average value of 188 µg/l of arsenic was found in the West of Rangirkhari Road during pre-monsoon and 161 µg/l at Padma Beel area during post-monsoon and the lowest (BDL) was recorded at Central Silchar (or Old Silchar), Chirukandi West and in the locality of Matri Shree Lane-Azad Hind Road in both seasons. However, West Rangirkhari Road recorded the highest annual quantity (136 µg/l). A comparative study of seasonal and mean annual variation of concentration of As against Fe for different sites shows inverse relations (Figure 9).

In the study area, arsenic contaminations vary with depth. The pre-monsoon contamination first increases and reaches a maximum and then decreases with increase in

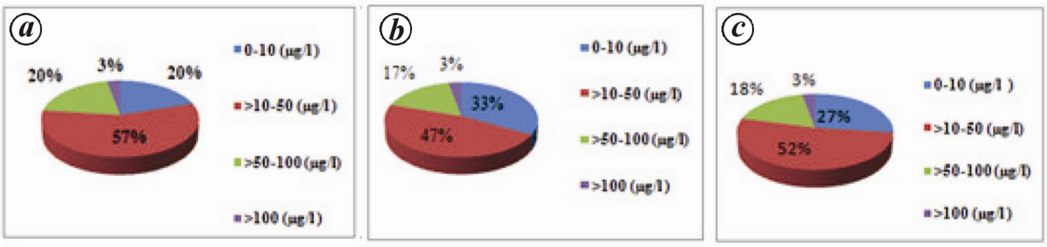

Figure 12. ***a***, ***b***, Percentage of arsenic change in pre- and post-monsoon in various ranges. ***c***, Percentage of arsenic change in annual perspective (2012–2013).

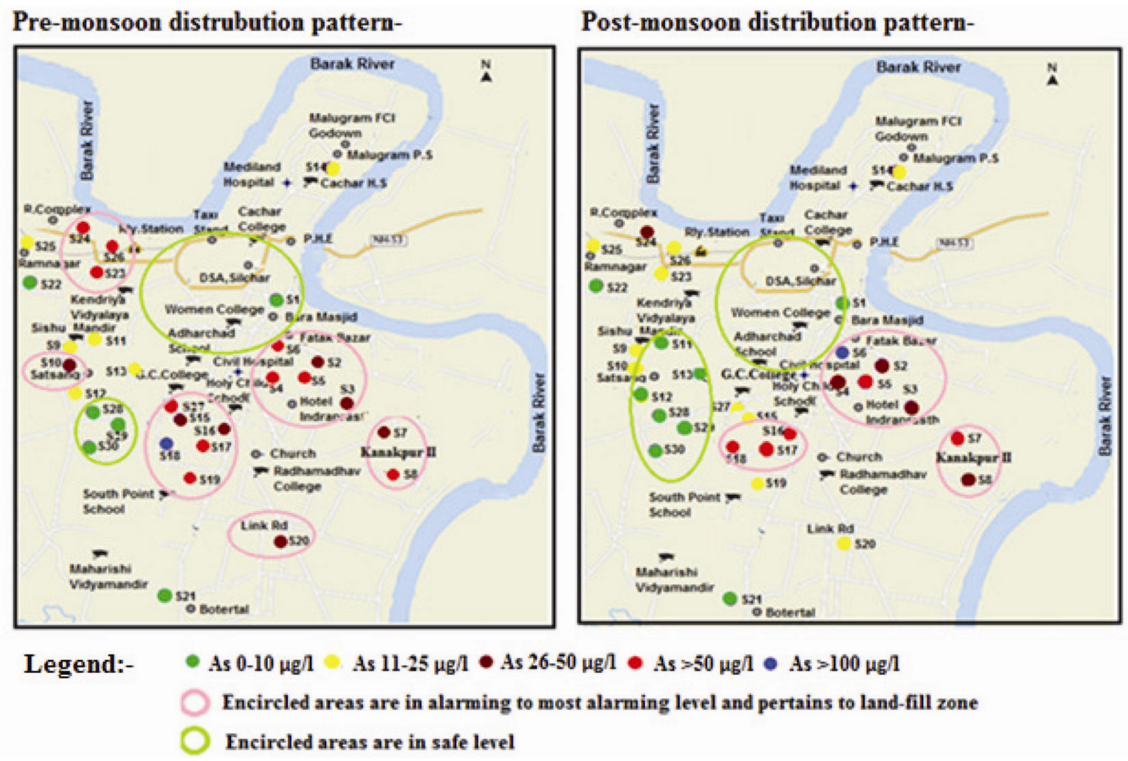

Figure 13. Comparison of the seasonal distribution of groundwater arsenic at Silchar Municipal area.

depth. However in post-monsoon, a reverse relationship exists (Figure 10). Arsenic in groundwater exhibited a wide spatial variation. Groundwater sampled at different depths within the span of 100 m distance revealed a rapid increase in arsenic load from BDL at 20 m to 81 µg/l at 65 m below ground level (bgl). If depths of tubewells/ boreholes are arranged separately into two groups comprising moderate depths of 20–40 m (for $n = 17$) and higher depths of 40–60 m (for $n = 13$) for both seasons, regular dips in arsenic contamination in both the groups are observed (Figure 11).

From the seasonal perspective of groundwater arsenic contamination, the safe limit of (0–10 µg/l) increases from 20% in pre-monsoon to 33% in post-monsoon, whereas 57% and 47% are observed within the allowable range of >10–50 µg/l in respective seasons. An alarming situation (50–100 µg/l) arises in 20% of the sites during pre-monsoon and 17% of the sites during post-monsoon mostly spread over Shyamananda Lane, Padma Beel area, Bholagiri Road of Rangirkhari West region and in Ramnagar Residential Development Scheme area. It was observed that 3% lies in the most alarming zone (>100 µg/l) and localized in the phreatic depth of 35–65 m in the west of Rangirkhari Road in pre-monsoon and in Padma Beel area in post-monsoon.

From an overall perspective, it was found that 27% is safe for domestic use, 52% exceeds the concentration of 10 µg/l but remains within the permissible limit, while 20% of that which exceeds 50 µg/l is in the alarming zone and 3% falls in most alarming zone >100 µg/l (Figure 12).

We plotted the As-loaded groundwater sites in five different colours for different ranges, viz. green 0–10 µg/l, yellow 11–25 µg/l, maroon 26–50 µg/l, red >50 µg/l and blue >100 μg/l. It is observed that the As menace decreases from pre-monsoon to post-monsoon (Figure 13). As-concentration (>100 μg/l) shifted from S18 at Bholagiri Road in pre-monsoon to S6 at Padma Beel area in post-monsoon. It may be due to heavy withdrawal of groundwater and subsequent leaching effect during monsoon.

We conclude that there is a strong relationship in the extensive variety of distribution pattern of groundwater arsenic with the landfilled areas. The pink circled areas with blue, red and marooned dark spots represent a flood-prone tract characterized by wet, spongy soil, subsequently converted into landfilled areas, are in alarming to a most alarming level where arsenic concentration is >50 μg/l. In certain pockets, it even crosses >100 μg/l. The green circled areas are a safe zone and are in the range of 0–10 μg/l.

The distribution pattern of arsenic loaded groundwater indicates that the affected areas may not be restricted to narrow entrenched flood plains of Barak. Identification of groundwater arsenic which starts from Ramnagar to NH Road via Ashram Road areas, located about 4–5 km west of Barak, indicates that even areas far from the watercourse are contaminated. The fluctuation of water table by 2–3 m at shallow depth (<6 m bgl) takes place during pre- and post-monsoon.

Elevated arsenic levels in tubewells/borewells with a depth of 65 m, make it necessary to consider whether groundwater of deep aquifers >65 m could be used for drinking purposes. A comprehensive study of water and peripheral soil coatings pertaining to different morpho-stratigraphic units, is necessary to understand templates of arsenic partition in aquifers.

We have attempted to identify the zone of incidence of arsenic in groundwater, at Silchar Municipal area of Cachar district, Assam. These findings suggest indigenous development of an economically approachable effective tool, to offer arsenic-free water to the affected populace.

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