Characterization of aquifers in contiguous parts of Bardhaman, Murshidabad and Birbhum districts, West Bengal, India

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Aquifer mapping has been carried out in 2800 sq. km of contiguous parts of three districts in West Bengal. The study area is occupied mostly by alluvial plains, with flood plains in the eastern fringes. The entire area is covered by the Quaternary sediments. Mapping and characterization of individual aquifers have been carried out to understand their occurrence, lateral and vertical extensibility, geomorphological characteristics, and potentiality and inherent quality of groundwater including contamination. Four Aquifer groups, delineated within 325 m depth, have been depicted by a 3D model and 2D sections. An outline of strategies for sustainable management of aquifers has also been presented.

Keywords: Aquifer, Bhagirathi, boro-cultivation, disposition, quaternaries.

THE natural occurrence of arsenic (As) in groundwater constitutes a major setback for provision of safe drinking water to millions of people in Asia and worldwide[1]. In India, some of the states including West Bengal are facing this acute problem. Current explanations about wide spread As contamination of groundwater by different workers include – withdrawal of groundwater for a long time, massive use of phosphatic fertilizer and decay of natural organic material by growth of sediment biota followed by desorption of arsenic from the sediments[2]; both pyrite-oxidation and iron-oxyhydroxide (FeOOH) reduction hypotheses[3]; release of naturally occurring arsenic sorbed to FeOOH by reduction of the latter due to anoxic conditions during sediment burial[4], and retreat of continental glaciers at the end of Pleistocene leading to the rise of sea level and river base levels followed by subsequent deposition of Holocene alluvium, which later became the hosts of As-contaminated groundwater[5].

Groundwater exploration has so far been carried out mostly to construct wells by tapping aquifers together up to target depth[6]; but by this, generation of quantitative and qualitative data of individual aquifer are not possible. Under prevailing deteriorating scenario of groundwater regime, aquifer mapping has been carried out to study aquifers separately. The objective of the present study is mapping of individual aquifers and characterization based on its relative position in geological succession, associated landforms, ubiquity, groundwater potentiality and inherent quality. Finally, an outline of strategies for sustainable management of aquifers has been presented.

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Study area

The study area (Figure 1) comprised[8] community development blocks and 2 municipalities in Bardhaman (erstwhile) district, 3 blocks in Murshidabad district and, 1 block in Birbhum district. The area lay between 23°11′34.8″ and 24°3′57.6″N and 87°43′26.4″ and 88°16′48″E. It covers an area of 2880 sq. km in upper delta regime of Hugli–Bhagirathi drainage; it is mainly occupied by alluvial plain with small zones of flood plains in eastern periphery. Bhagirathi river forms the eastern boundary. Normal rainfall of the present area is 1385 mm. Surface elevation ranged from 57 m above msl in the west to 8 m above msl in the east, with average slope being 0.692 m/km. Broad geomorphic units and drainage are shown in Figure 2.

Thick Quaternary sediments overlie the finer fractions of the Tertiaries. These Quaternary sediments are represented by the Older Alluvium of Upper Pliestocene to Late Holocene and Younger alluvium of Upper Holocene to Recent. The Older Alluvium is mainly yellow to brown, oxidized and developed in upland parts. The Younger Alluvium of the Ganges river system consists of clay, silt, sand and gravel; it is grey in colour.

Materials and methods

Lithologs of these wells constructed by Central Ground Water Board (CGWB) and state government departments were studied. Geomorphology map of National Remote Sensing Centre and District Resource Map[7] of Geological Survey of India were also studied. Location of wells are shown in Figure 3. Mapping of aquifers was carried out by correlation of stratigraphic features, relative elevations, etc. Prominent clays were used as markers. Observation wells

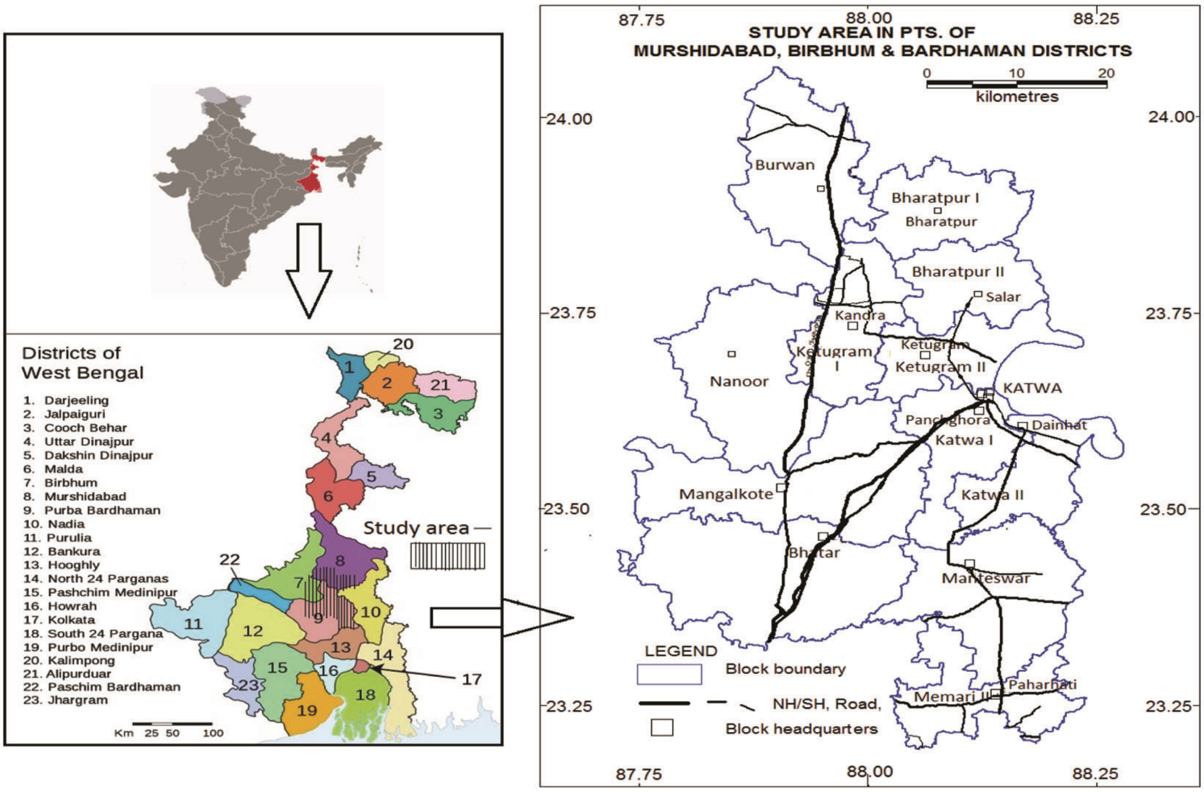

Figure 1. Study area.

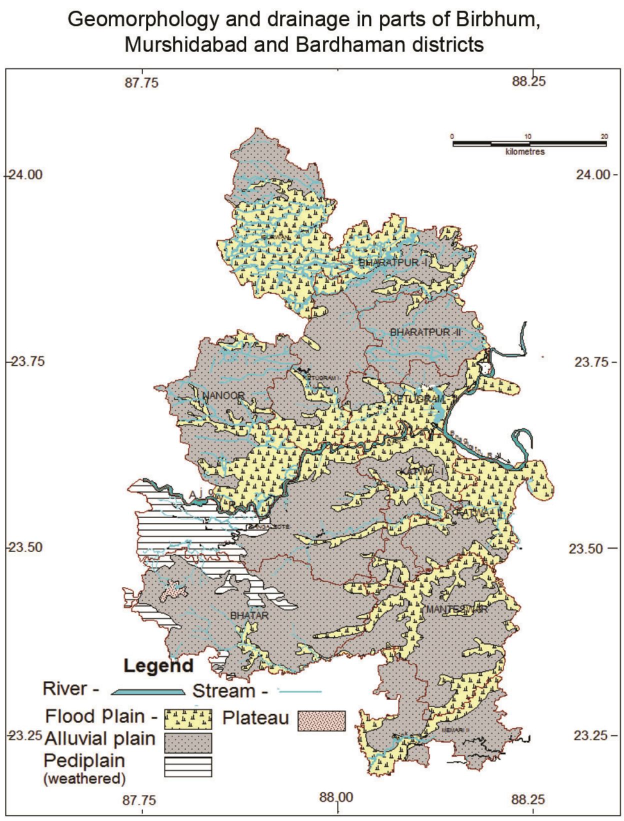

Figure 2. Geomorphology and drainage.

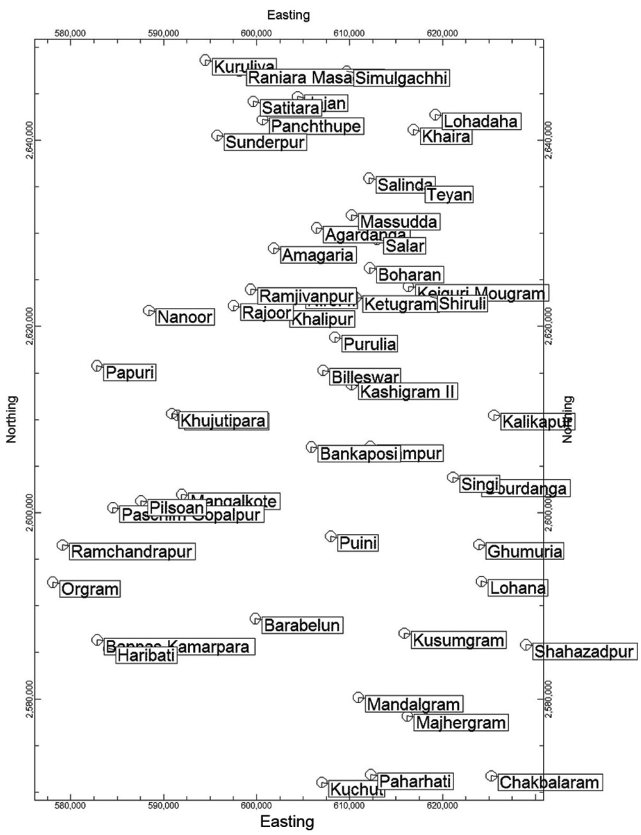

Figure 3. Location of tube wells.

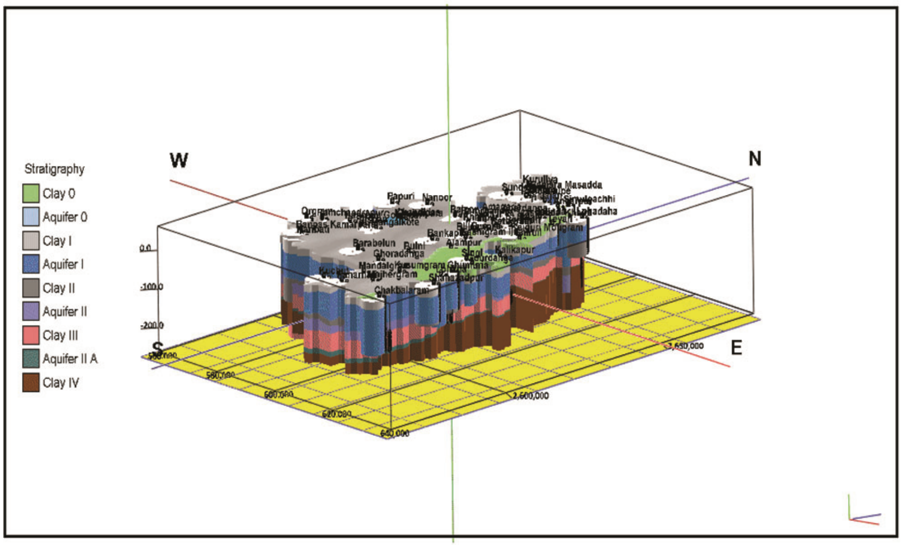

Figure 4. Three-dimensional aquifer disposition.

Table 1. Details of aquifer I and aquifer II groups

Name of block(s)	Aquifer I group			Aquifer II group		
	Depth range (m bgl)	Discharge (m^3/h)	Transmissivity (m^2/day)	Depth range (m bgl)	Discharge (m^3/h)	Transmissivity (m^2/day)
Burwan, Bharatpur I and Bharatpur II	8–114.5	5.97–59.76	59.30–601	132–145 (only Bharatpur I)	Up to 17.57 (only Bharatpur I)	Up to 97.58 (only Bharatpur I)
Nanoor	0–55	40–65	1000 (maximum)	83–134	Up to 10	–
Ketugram I and Ketugram II	8–70	31–128.30	31–1700	120–135, 150–155 (only Ketugram I)	Up to 34.2 (only Ketugram I)	–
Katwa I and Katwa II	8–121	14.4–122.40	11.4–1254	180–220 (only Katwa I)	14.4–122.40 (only Katwa I)	172–216
Manteswar and Bhatar	3–142	7.92–126	91–619	165–240 (only Bhatar)	7.92–22.75 (only Bhatar)	91
Mangalkote	5–72	42.98–117.28	425–1128	80.5–112	31.32	80
Memari II	7.5–80	36	31–1700	105–118, 165–178	14.40	40.44–41.40

were regularly monitored. Land elevation of wells was measured by Garmin make GPS instrument. Available pumping and yield test data of wells[6] and other relevant data of CGWB were utilized for characterization of individual aquifers. MapInfo Pro 16.0 software was used for the preparation of water table maps, Piezometric Surface, etc. Natural neighbour interpolation of reduced water levels was opted for this purpose. Rock Works software, version 17.0 was used to show aquifer disposition by inverse distance interpolation technique. For 3D modelling, boundary was set to show aquifers in concerned administrative units and for 2D cross-sections, it was set for best depiction of aquifers and associated features. Sampling was done following the standard procedure[8].

Three-set samples of representative aquifers for each location were collected. A set of samples, acidified by supra-pure HNO_3 at sites, was analysed by inductively coupled plasma and mass spectrometry (ICP-MS) in Geological Survey of India (GSI); besides, 48 samples were analysed by Atomic Adsorption Spectrophotometer (AAS) through outsourcing. Also, eight analytical data of Public Health Engineering Department (PHED), Govt of West Bengal have also been used.

General parameters were analysed following standard methods[9]. pH and electrical conductivity (EC) were measured respectively, by potentiometric method using pH metre and electrometric method by conductivity metre. CO_3^{2-} and HCO_3^- were analysed by acid-base titration using H_2SO_4, and chloride (Cl^-) by titrimetric method using $AgNO_3$. UV-spectrophotometer was used to determine NO_3^-; turbidimetric and molybdophosphoric acid methods by spectrophotometer were used respectively, for determination of SO_4^{2-} and PO_4^{3-}. Spectrophotometer was also used with Eriochrome Cyanin R as reagent (SPADNS method) to determine F^- and ammonium molybdate as reagent for SiO_2^-. EDTA-titrimetric method was used to determine Total Hardness (TH), Ca^{2+} and Mg^{2+}, whereas, both Na^+ and K^+ were analysed using emission method by

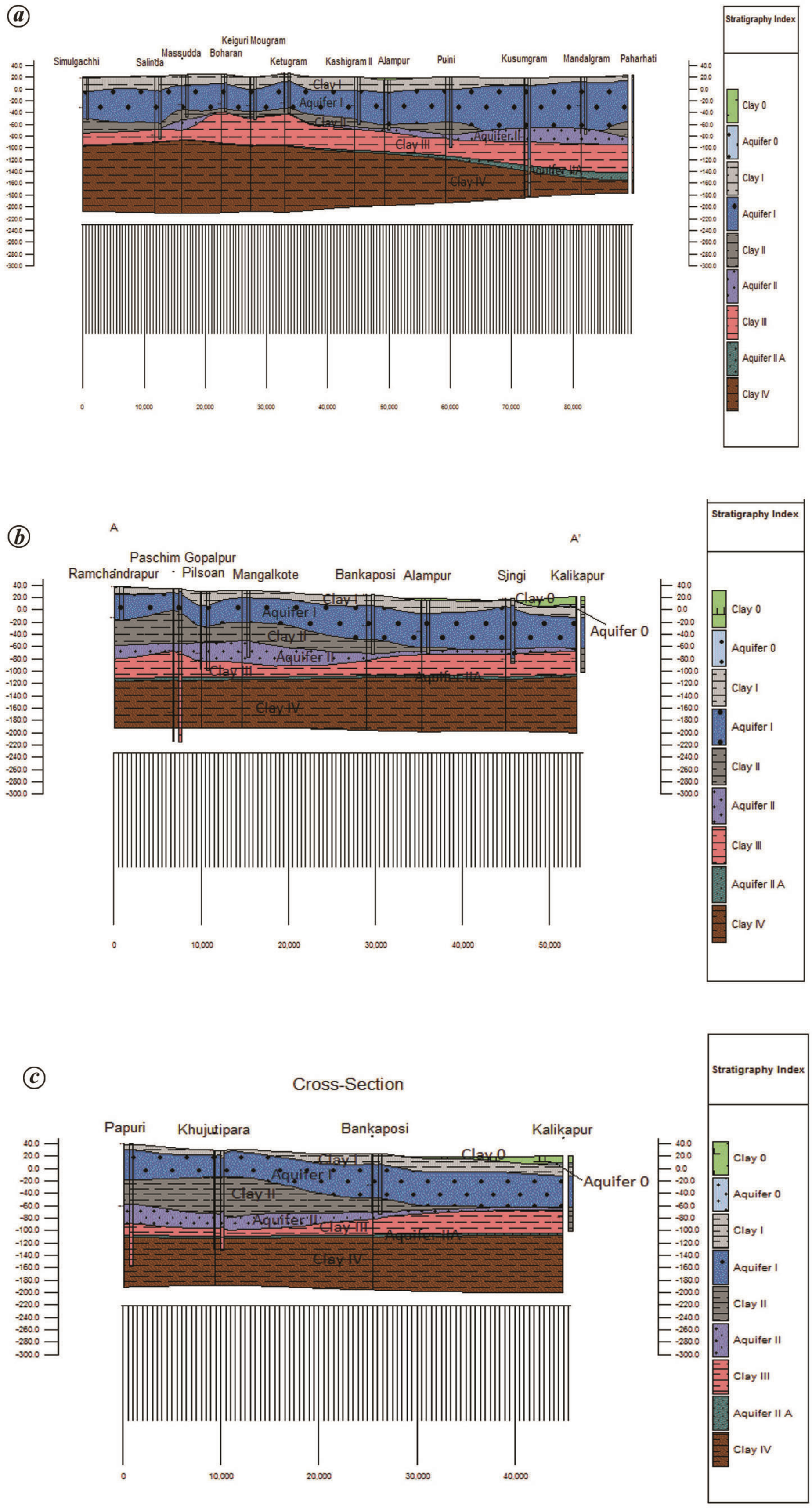

Figure 5. ***a***, North–South section of aquifers. ***b***, West–East section 1 of aquifers. ***c***, West–East section 2 of aquifers.

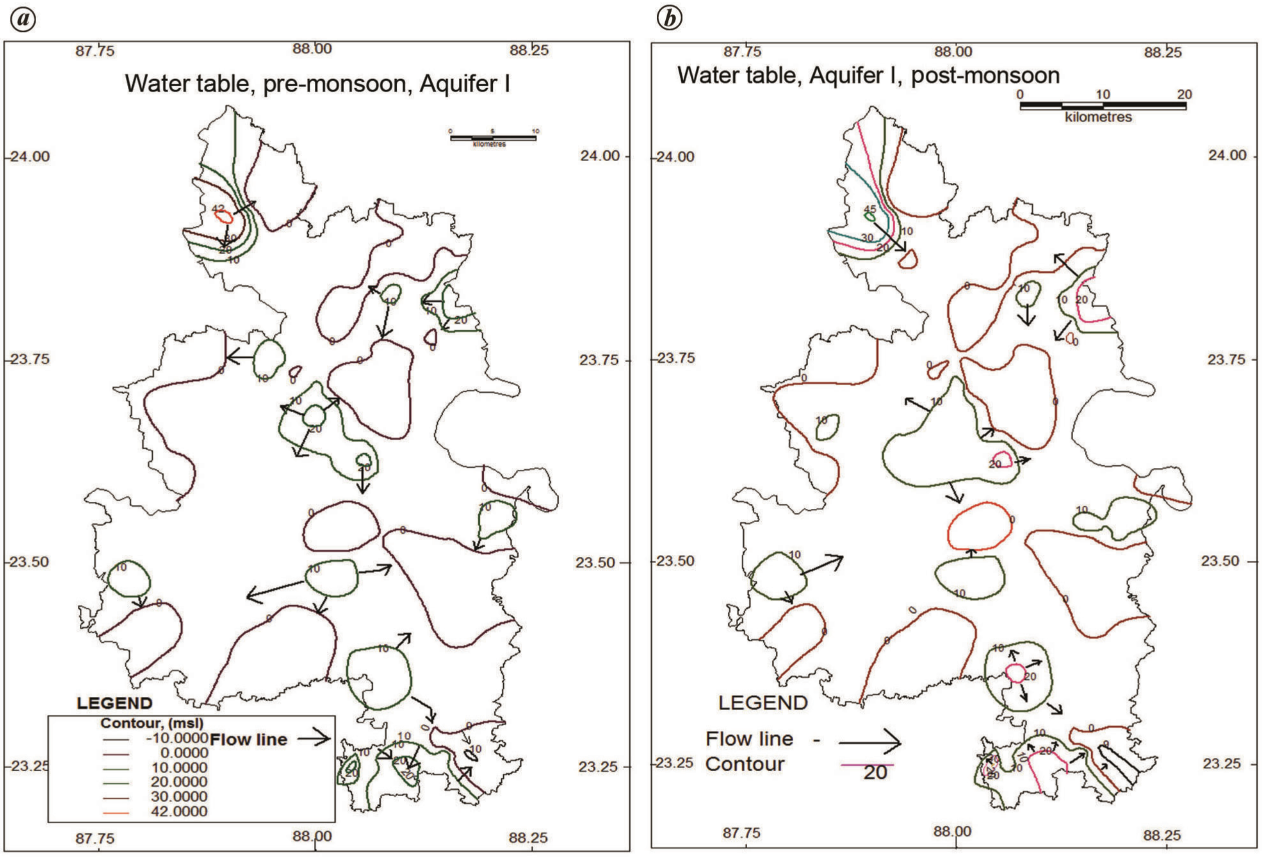

Figure 6. Water table, aquifer I: ***a***, pre-monsoon; ***b***, post-monsoon.

flame photometer. For determination of total iron, spectrophotometry was carried out by using 1,10-phenanthroline. Guideline values of World Health Organization (WHO)[10] and Bureau of Indian Standards (BIS)[11] have been consulted in this study.

Results

Hydrogeology

The study area is underlain by alluvium deposits. There are two main groups of aquifers: aquifer I and aquifer II. Apart from these there are two other aquifer groups, viz. aquifer '0' at the top, and aquifer IIA at the bottom, within 325 m depth. Occurrence and disposition of aquifers have been shown by 3D model in Figure 4 and 2D sections in Figure 5. Details of aquifers have been tabulated in Table 1.

Phreatic aquifer or aquifer '0'

Aquifer '0' Group, developed locally in flood plains within 25–40 m of Younger Alluvium, is restricted in occurrence in three eastern blocks, viz. Katwa I, Katwa II and Ketugram II. Depth to water level (DTW) ranges between 1.87 and 11.65 m below ground level (bgl) in pre-monsoon, and between 5.11 and 9.59 m bgl during post-monsoon. This group is tapped by dug wells, hand pumps (Mark I) and centrifugal pump fitted 'shallows', and its yield ranges up to 50 m^3/h.

Aquifer I group

It comprises coarse sand and gravel with or without intervening clay lenses, within a depth of 145 m bgl in older alluvium. Its total thickness ranges within 20.5–125 m in parts of blocks of Burwan, Bharatpur I, Bharatpur II, Nanoor, Katwa II and Ketugram II. In flood plains, this group occurs under semi-confined to confined condition, but in other parts it is unconfined to semi-confined. This aquifer is underlain by dark grey clay, thickness of which ranges up to 34 m. DTW ranges mainly within 10–30 m bgl in major part, and within 30–35 m in parts of Nanoor and Bharatpur II during pre-monsoon; in post-monsoon it ranges within 18–25 m bgl in major part. Details of aquifers are tabulated in Table 1. During 2006–16, long-term falling trend of water level varied from 118.7 cm/year (Manteswar) to 6.6 cm/year (Burwan) in pre-monsoon, while in post-monsoon this decadal falling

Table 2. Block-wise groundwater (GW) resources

Blocks	Dynamic groundwater resources in aquifer I				In-storage resources in aquifer I = area × average saturated thickness × average sp. yield (MCM)	Dynamic GW resources in aquifer II = area × *WLF × average S (MCM)	Annual GW flow in aquifer II (Q) = **TIL, m^3/day; F direction
	GW availability (MCM)	GW draft (MCM)	Stage of GW development (%)	Category			
Burwan	89.2039	54.1335	62.31	Semi-critical	1681.6728	–	–
Bharatpur I	49.0552	27.1777	57.39	Semi-critical	1581.8880	1.21	958.17; NNE
Bharatpur II	48.8767	30.7959	64.99	Semi-critical	911.9304	–	–
Nanoor	104.5008	47.2845	46.38	Semi-critical	1323.20	1.66	2000: NW
Ketugram I	52.3863	32.4439	62.66	Semi-critical	1093.9680	0.72	2186.99; SW 637.58: NNE
Ketugram II	60.3103	27.9406	46.82	Semi-critical	2883.5564	–	–
Katwa I	61.6064	30.2022	51.15	Semi-critical	1927.872	0.10	3127.32: SSE
Katwa II	69.3776	30.0733	44.55	Semi-critical	1502.232	–	–
Manteswar	96.9411	64.0124	66.85	Semi-critical	2762.1612	–	–
Mangalkote	123.94	47.6767	39.48	Semi-critical	4743.6576	0.95	1889.76: SE
Bhatar	130.2567	57.2361	45.01	Semi-critical	2541.4474	0.25	3299.13: SSE
Memari II	55.6745	35.0025	65.33	Semi-critical	1169.832	0.10	3432.97; E
Total	942.1295	483.9793	652.92		24123.4179	4.99	

*WLF, Water level fluctuation zone; **TIL, Transmissivity × hydraulic gradient × length of flow path; S, Storativity. F, Flow; NNE, North–North East; NW, North West; SW, South West; SSE, South–South East; SE, South East; E. East.

trend had been accentuated in most blocks. The yield of aquifer I group ranges within 8–128 m^3/h, and maximum transmissivity (T) of 1700 m^2/day was encountered in Ketugram I block[6]. The approved (as on 31 March 2013) dynamic groundwater resource of top aquifer[12], as estimated jointly by CGWB and the concerned state government department has been incorporated in Table 2.

In pre-monsoon, water table ranges from (–) 10 m below msl in Memari II block in southeast to within 30–40 m above msl in Burwan block in northwest, and the same has been shown in Figure 6 *a*; during post-monsoon, general groundwater flow is from northwest to southeast, as shown in Figure 6 *b*.

Aquifer II group

This group is encountered beneath aquifer I in blocks of Bharatpur I, Nanoor, Ketugram I, Katwa I, Bhatar and Memari II. Its groundwater potentiality is less and thickness of this aquifer ranges within 17–51 m. It occurs under semi-confined to confined condition in fine to medium sand within 80.5–240 m bgl. In Manteswar and Mangalkote blocks, aquifer I and aquifer II coalesce to form a single aquifer; its collective thickness ranges up to 135 m. DTW ranges within 10–30 m bgl in major part and 30–35 m bgl in minor part during pre-monsoon; in post-monsoon DTW ranges within 18–25 m bgl in major part and within 10–33 m bgl in minor parts. A few wells show decadal falling trend of water levels from 110.7 cm/year (Bhatar) to 25 cm/year (Katwa I) in pre-monsoon, and from 154.5 cm/year (Bhatar) to 7.1 cm/year (Ketugram I) in post-monsoon. The yield of wells ranges within 10–122.40 m^3/h and T exceeds 1000 m^2/day in most blocks.

Elevation of potentiometric surface is within 15–20 m amsl in Bhatar–Mangalkote sector in southwest, 10–15 m bmsl in Memari II in southeast, and in north it is restricted within 0–5 m amsl. In south, groundwater flows from west to southeast in pre-monsoon, as shown in Figure 7 *a*, and west to northeast in post-monsoon; whereas in north it flows towards northeast, as shown in Figure 7 *b*.

Aquifer IIA group

This group has only been encountered in Nanoor block within 247–336 m bgl, separated from upper aquifer II by 125 m thick clay. It comprises very fine, steel grey grains of thickness ranging up to 25 m. Groundwater occurs under confined condition; DTW varies between 1.2 and 4.07 m bgl and T ranges within 0.83–17.91 m^2/day, and yield is 5.98 m^3/h.

Quality of groundwater

Groundwater in general, is slightly alkaline with pH within 6.13–8.13 and average being 7.40. EC varies within 147–686 μS/cm at 25°C. Concentrations of Na^+ and K^+ range within 10–45 and 0.88–6.18 mg/l respectively. Fe content is sporadically encountered from less than 0.1 to more than 2.5 mg/l with its average being 0.39 mg/l. Mg^{2+} varies from less than 4.86 to 36.45 mg/l. HCO_3^- ranges within 30.5–298.9 and Cl^-within 7.11–67.55 mg/l. F^- ranges within 0.93–1.62 mg/l. SO_4^{2-} varies up to 16 mg/l. Total hardness as $CaCO_3$ ranges from 35 to 195 mg/l, whereas Ca^{2+} varies from 12 to 38 mg/l. NO_3^- ranges up to 9.3 mg/l. In Figure 8, plots of groundwater of aquifer I and aquifer II have been shown by plotting chemical

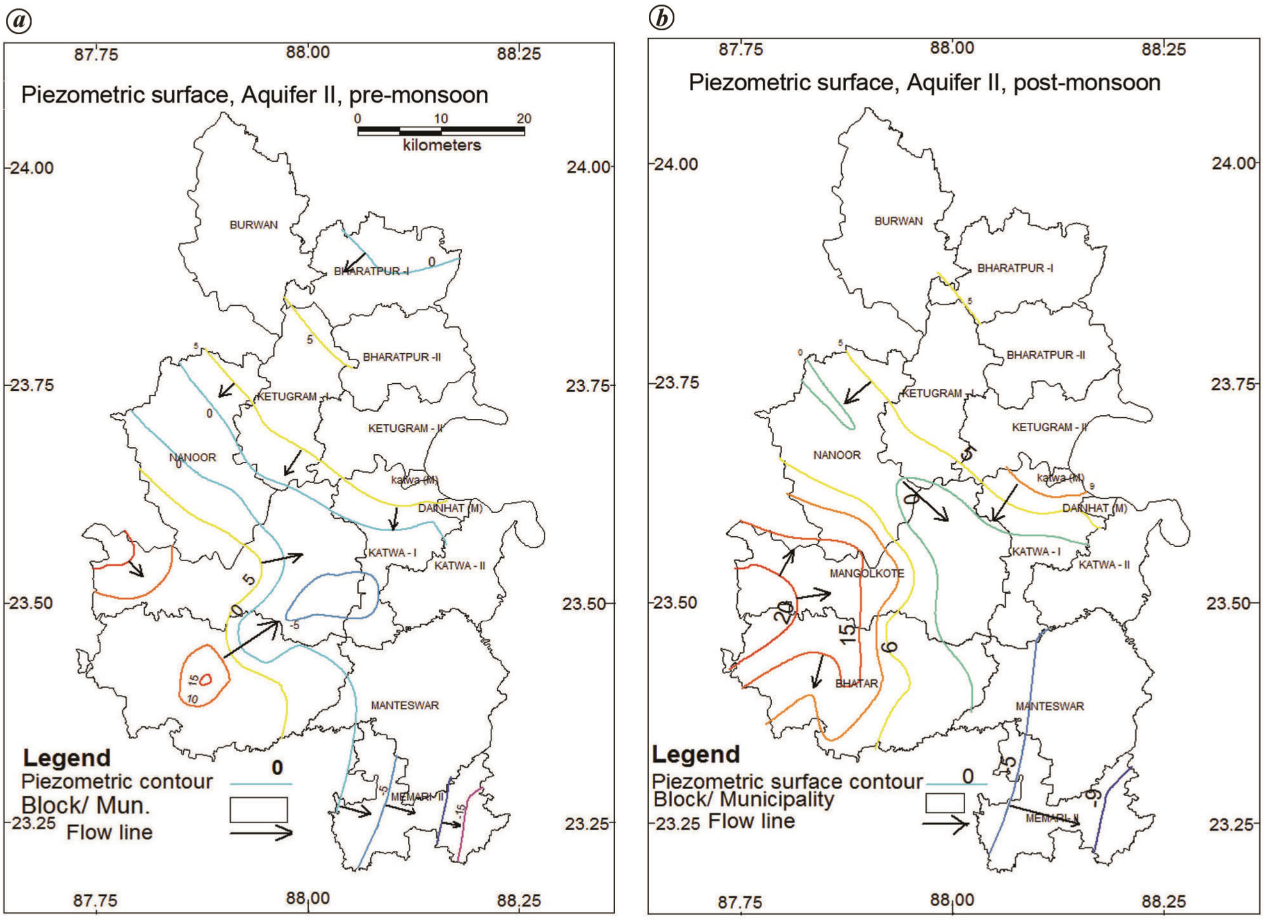

Figure 7. Piezometric surface, aquifer II: (***a***) pre-monsoon; (***b***) post-monsoon.

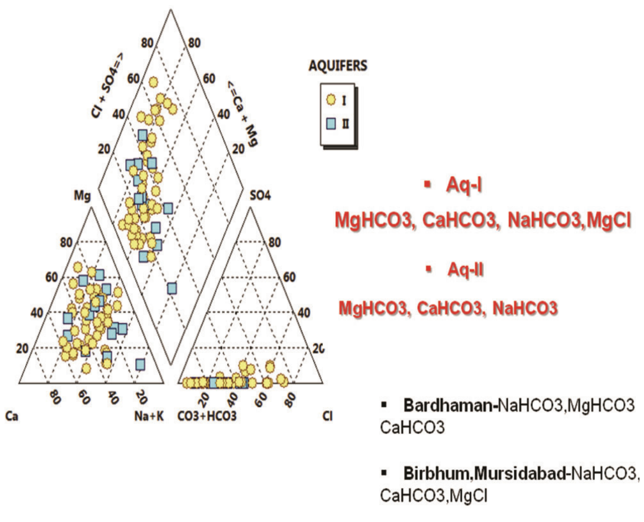

Figure 8. Piper–trilinear diagram. Piper plot of NAQUIM study area of Bardhaman, Murshidabad and Birbhum districts.

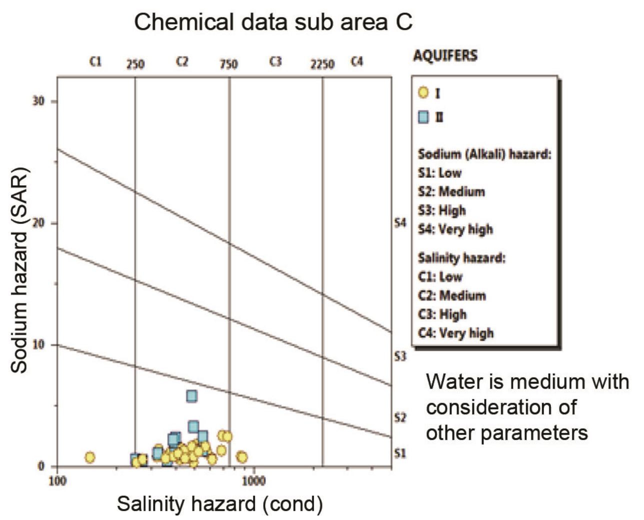

Figure 9. Salinity hazard plots. Wilcox plot of NAQUIM study area of Bardhaman and Birbhum district.

constituents in Piper–Trilinear diagram, which indicate that it is mostly HCO_3^- type. Salinity hazard data of water samples are plotted in Figure 9; less EC values implies that salinity hazard is nil. The sodium adsorption ratio (SAR) of groundwater in the study area ranged from 2.15 to 8.80; it is well within permissible category for irrigation.

Table 3. Salient data of previous studies

Block	Total samples analysed	Percentage of tube wells having As content						
		<0.01 mg/l	No. of samples	<0.01 ⩾ 0.05 mg/l	No. of samples	>0.05 mg/l	No. of samples	Maximum concentration (mg/l)
Katwa I*	1332	95.27	1269	4.35	58	0.38	5	0.10, 2.23 (ref. 17)
Katwa II*	1079	90.08	972	7.78	84	2.13	23	0.84
Bharatpur I (ref. 16)	616	92.86	572	6.82	42	0.32	2	–
Bharatpur II (ref. 16)	625	100	625	–	–	–	–	–
Burwan[16]	699	98.71	690	1	7	0.29	2	–

*PHED data.

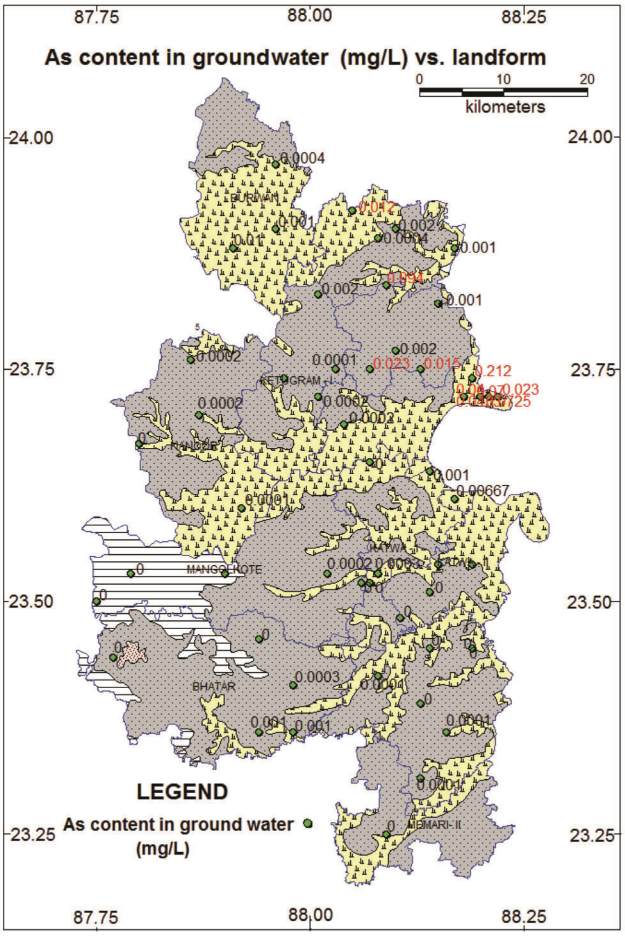

Figure 10. Point data of arsenic concentration in groundwater of aquifer '0'.

Groundwater pollution

As-contamination in groundwater of wells has been studied by some experts. In addition, PHED has also surveyed contamination in a few other blocks. The salient data of those studies are summarized in Table 3. The present study confirms that the sporadic contamination of As of more than 0.01 mg/l in groundwater is restricted in aquifer '0' of nearby flood plains in blocks of Bharatpur II and Bharatpur I within 0.012–0.094 mg/l and Ketugram II within 0.023–0.212 mg/l. Location of data of As in groundwater is shown in Figure 10.

Groundwater in other aquifers, i.e. aquifer I and aquifer II are good except in pockets where somewhat higher concentration of Fe has been encountered and the same could be reduced by simple aeration and filtration.

Discussion and recommendations

(i) The top or aquifer '0' is restricted in younger alluvium within 25–40 m depth of flood plains in a few eastern blocks. This aquifer shows shallow water level. Contamination by As in these Holocene shallow aquifers, largely less than 7 ka in age, might be due to not so well flushed[13]. Earlier studies[14] showed that the maximum As concentration in groundwater of parts of Bangladesh occurred in aquifers at 20–40 m depth. As-contaminated tube wells in Uttar Pradesh, India, are located in Holocene newer alluvium entrenched channels and flood plains which are characterized by grey to black coloured organic-rich argillaceous sediments[15].

In this As-contaminated top aquifer, wells could be constructed tapping only deeper aquifers. Surface water bodies, river and 'bils' of the area are also good source of potable water.

(ii) Aquifer I, in older alluvium, is prolific and the groundwater in it is potable. It may be that As in the deep aquifer was mobilized during early diagenesis, but has long since been flushed out by meteoric waters, which have been flushing the deep aquifer since way before the 18 ka sea level, and at a minimum of around 130 m below the present level[5], and got oxidized too. Aquifer II and aquifer IIA are in Tertiaries, and though these aquifers have limited groundwater potentiality, its quality is good and, wherever encountered, could be used for all purposes.

Both aquifer I and aquifer II are characterized by deep water levels with falling trend in both seasons, which might be due to large scale irrigation by groundwater. Sen, IIT (Kharagpur), in his presentation titled 'Surface and Ground Water Resources of the District of Burdwan and Management Strategies for Optimal Utilization' (accessed from http//:bardhaman.nic.in>Geography), also showed heavy decline in water level in Bhatar, Mangalkote, Memari II, Manteswar and Ketugram I. In these blocks, stage of groundwater development, i.e. total draft of groundwater for all uses in a block divided by its net availability in the same unit multiplied by 100, varies between 39.48% and 66.85%. This decline in water level might be due to 'Boro' irrigation in large area.

Reducing the area of 'Boro' cultivation and its substitution by low water requiring crops (cropping pattern change), say oilseeds, pulses and cash crops, etc., could be the possible remedial measures. Again, sowing of 'Aman' rice by one and a half months in advance than what is in practice now, as envisaged by Sen, for advancing time for Boro-sowing and lessening dependency on external irrigation, is another probable way in comprehensive management of water resources. Increase in wheat and maize cultivation is other viable option.

(iii) By application of modern irrigation techniques, water requirement of crops could be reduced manifold. During this study, agricultural expert of Bidhan Chandra Krishi Viswavidyalaya (BCKV), nominated by CGWB, opined that the water requirement could be reduced by micro-irrigation techniques like: rice 0.8 m, wheat 0.2–0.35 m, mustard 0.2 m, pulse 0.08–0.12 m, vegetable 0.12–0.16 m.

(iv) Suitable rain water harvesting and artificial recharge structures could be constructed by utilizing non-committed run off. By doing this, the declining water level and contamination of groundwater could be managed to a large extent. Budgeting of rainfall runoff could be estimated by taking into account 75% normal monsoon rainfall and, the corresponding runoff coefficient may be considered to work out 50% non-committed runoff, which is meant for conservation and/or artificial recharge.

(v) Regular monitoring of groundwater level in individual aquifers and its quality is essentially needed for management of aquifers.

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