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Arsenic Pollution in Ground Water of West Bengal

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ABSTRACT

It is well recognized that a huge alluvial tract along the river Hooghly covering a stretch of around 470 km., encompassing eight districts is affected by arsenic pollution of ground water. The probable source of occurrence of arsenic has been reported to be of geological formation of source material. Occurrence of iron-pyrite and the change of geo-chemical environment due to over-exploitation of ground water or excessive fluctuation of ground water table are the possible reasons of decomposition of pyrite to ferrous sulphate, ferric sulphate and sulfuric acid. However, no definite explanation regarding the source of arsenic could be given.

The arsenic concentration in water samples collected from some selected villages of Nadia district, West Bengal shows elevated concentrations of arsenic. The ground water of the region is characterized by high iron content. The trace element data of lithological log of drill cuttings of the PHED bore hole site at Ghetugachi in Chakdah block, Nadia district shows a consistent arsenic contamination in the upper aquifer also.

The hydrochemical study of the river Hooghly also shows a consistent arsenic concentration in water and sediment samples of the river. The content of arsenic in the sediments were quite higher than the associated water due to the prolonged industrial activity along the banks of the river Hooghly.

The Farrakka Super Thermal Power Plant (STPP) operating in the state of West Bengal is the another source of arsenic contamination in the nearby area. The analysis of fly ash deposited in the fly ash disposal ponds indicate arsenic content of the order of 400-500 $\mu g/g$. The ash generated from thermal plant finds its way into open environment of air, water and soil from atmospheric precipitation, spillage from pipe lines carrying fly ash slurry to ash ponds and from decanted water of ash pond. It contaminate ground water due to seepage and mixing of fly ash into surface and subsurface water.

1.0 INTRODUCTION

The presence of arsenic in ground water has been reported in recent years from several parts of the world, like USA, China, Chile, Bangladesh and India (Robertson, 1986, 1989; Moncure et al., 1992; Schlottmann and Breit, 1992; Frost et al., 1993; Das et al., 1994, 1995; Chatterjee et al., 1995; Mandal et al., 1996). Recently, Hering and Elimelech (1995) have reviewed the international perspective and treatment strategies on the problem of arsenic contamination in ground water.

Arsenic rarely occurs in free state, it is largely found in combination with sulphur, oxygen and iron. Arsenic occur in the environment as a result of several inputs that contain this element as organic and inorganic forms (Rubio et al., 1992). The presence of arsenic in natural water is related to the process of leaching from the arsenic containing source rocks and sediments (Robertson, 1989; Hering and Elimelesh, 1995), or its use in agriculture or industry. Influx of arsenic from various anthropogenically induced sources may also contaminate both soils and ground water especially under anoxic conditions (Bhattacharya et al., 1996, 1997).

Arsenic can appear in the environment in a number of valency states, viz., As(V), As(III), As(0) and As(-3). In oxic aqueous systems arsenic appear mostly as oxyanion. The valency state is an important factor for the behaviour of the element in the environment. The most well characterized toxic aqueous ionic species of arsenic include arsenite and arsenate (Irgolic et. al., 1983). In addition to other parameters, the valency state also determines the sorption behaviour and, hence, the mobility in the aquatic environment. In ponds, sea, and lake water, and where there is the possibility of biomethylation, arsenite and arsenate together with MMAA and DMAA occur.

The toxicity of arsenic species vary in the order, arsenite > arsenate > MMAA > DMAA (Lewis and Tatken, 1978; Penrose, 1974). The trivalent arsenic, i.e., arsenite is 60 times more toxic than oxidized pentavalent arsenate (Mabuchi, 1979). The inorganic arsenic compounds are about 100 times more toxic than the methylated forms (Thompson, 1993).

The presence of arsenic in ground water is generally associated with the geochemical environments such as basin-fill deposits of alluvial-lacustrine origin, volcanic deposits, inputs from geothermal sources, and mining wastes (Welch et al., 1988; Korte and Fernando, 1991). Uncontrolled anthropogenic activities such as smelting of metal ores, use of arsenical pesticides and wood preservatives agents may also release arsenic directly to the environment (Bhattacharya et al., 1995b). Occurrence of arsenic in natural water depends on the local geology, hydrology and geochemical characteristics of the aquifer materials. Furthermore organic content in sediments as well as the land use pattern may also play an important role in controlling the mobility of arsenic in alluvial aquifers.

The oxidation of different mineral species cause arsenic to become soluble and enter the surrounding environment through drainage water. The knowledge of the geographic distribution of the As(III) and As(V) species in natural water system is important for environmental consideration of the geochemical and biological cycling of the element. Further, this will also provide insight into the geochemical process responsible for elevated arsenic concentrations in different geological environment.

The geochemistry of arsenic is a complex phenomena and is affected by various processes, viz., oxidation-reduction, dissolution-precipitation, adsorption-desorption, mineralogy of the aquifer, organic content, biological activity and aquifer characteristics. An understanding of all these processes is very essential to understand the occurrence and mobilization of arsenic in the aquifer system. Biologically, As(III) is considered more toxic than As(V) (NAS, 1977).

The adverse health effects of arsenic are well documented by Chappel et al. (1994). Symptoms of chronic arsenic toxicity (characteristics of areas with water containing >100 $\mu g\ l^{-1}$ As) include peripheral nerve damage, tissue wastage (blackfoot disease), dermal hyperpigmentation, keratosis, skin carcinomas, and gastrointestinal cancers (Abernathy, 1993). Enhanced incidences of these disorders, directly attributable to arsenic exposure, have been reported in many gold and base-metal producing countries including Chile (Borgono et al., 1980), Argentina (Astolfi et al., 1981), and Mexico (Cebrian et al., 1983). Additional instances of chronic arsenism unrelated to mining have been reported from Taiwan (Tseng et al., 1968; Chen et al., 1988) and India (Chakraborty et al., 1987; Das et al., 1994, 1995; Chatterjee et al., 1993, 1995; Bhattacharya et al., 1996, 1997; Mandal et al., 1996).

2.0 STATUS OF ARSENIC CONTAMINATION IN WEST BENGAL

In India, the contamination of ground water by arsenic was first detected in the state of West Bengal in 1978. In 1987, Chakraborty et al. (1987) reported arsenical dermatosis in 5 districts of West Bengal and found 197 patients suffering from arsenical dermatosis in 48 families. Subsequently, as per the survey conducted by the School of Environmental Studies of Jadavpur University, it is found that 560 villages under the 50 blocks in seven districts, namely, south 24 parganas, north 24 parganas, Nadia, Murshidabad, Malda, Barddhaman, and Hooghly have been hit by arsenic contamination in ground water. The maximum concentration of arsenic is found to be 3.7 mg l^{-1}. The total arsenic infected zone covers an area of 37,493 km^2 representing nearly 42% of the total area of the state (Mandal et al., 1996). More than 35% of the total population in the state are affected adversely due to the consumption of high-arsenic containing ground water for drinking purposes (Bhattacharya et al., 1996, 1997). Recent reports indicated that 830 villages under the 57 blocks in eight districts have been affected by arsenic contamination in drinking water supplies derived from ground water sources. Approximately 65,000 km^2 area covering 51 million population has been reported to be affected by arsenic (Chakraborti, 1997; The Statesman, April 20, 1997). Fig. 1 shows the arsenic affected districts of West Bengal. The overall survey reports upto January 1996 and February 1997 are given in Table 1 and 2.

The arsenic contamination of ground water in the residential area of Behala, situated in the southern part of the city of Calcutta, has also been reported due to the discharge of industrial effluent after production of the insecticide Paris-Green (Chatterjee et al., 1993). For about twenty years the chemical factory had been producing about 20 tonnes of Paris-Green per year and had been dumping its effluent in the area. The treatment of the effluent for arsenic removal was not adequate and resulted percolation of arsenic to the under ground aquifers.

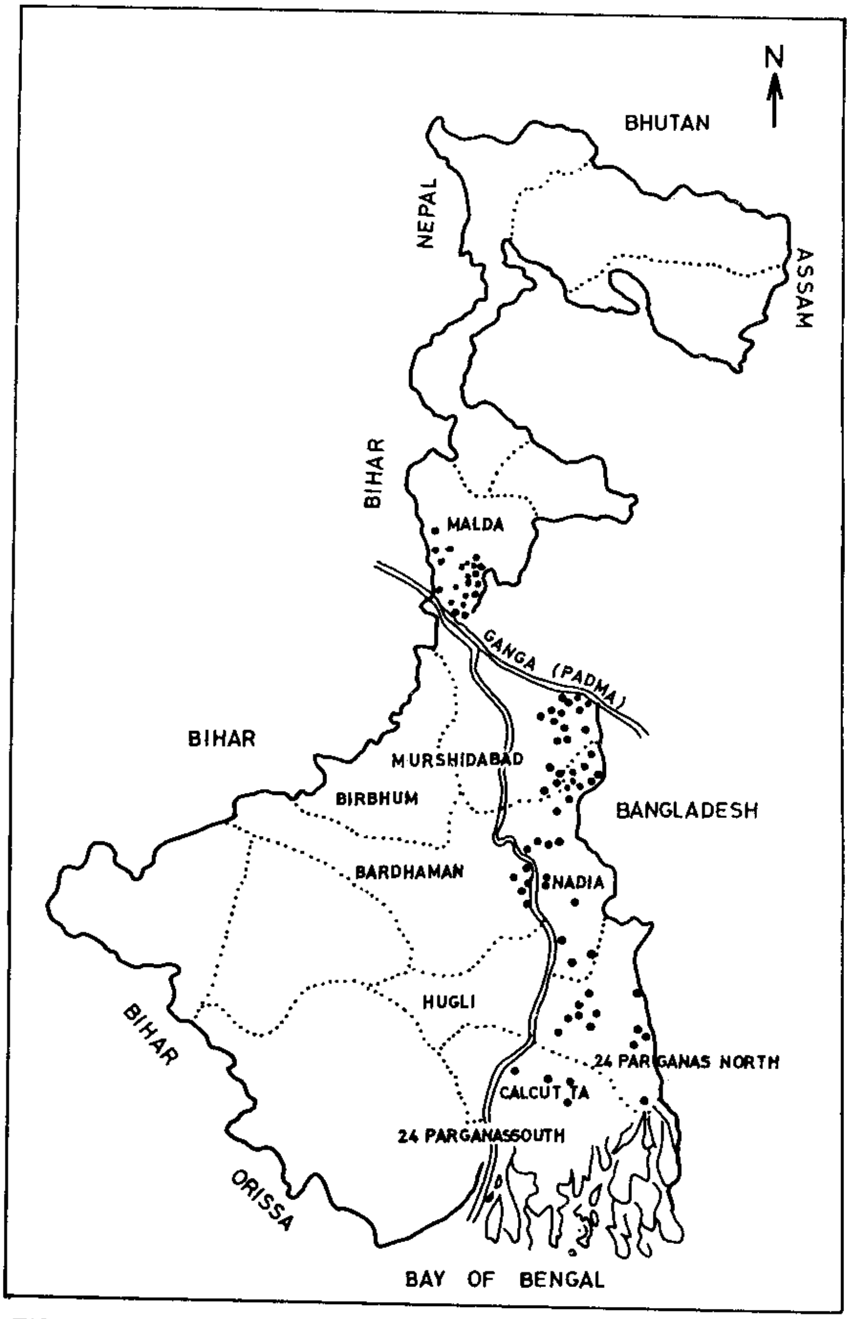

FIG. 1: MAP OF WEST BENGAL SHOWING ARSENIC AFFECTED DISTRICTS

Table 1. Survey report of arsenic affected seven districts, West Bengal (upto January 1996)

Total area	37,493 km^2
Total population	34,632,024
Total no. of blocks	162
Total no. of arsenic affected blocks	50
Total population of arsenic affected blocks	9,562,898
No. of arsenic affected villages	560
Approx. population drinking arsenic contaminated water above 0.05 mg/L	>1,100,000
Approx. population drinking arsenic contaminated water above recommended value (0.01 mg/L)	>1,500,000
Approx. population showing arsenic-related skin manifestation on their body	>220,000

Source: Mandal et al., 1996

Table 2. Survey report of arsenic affected districts and villages in West Bengal (From Jan. 1989 to Feb. 1997)

Year	Districts	Blocks	No. of villages
1990	South 24-Parganas	Baruipur	7
		Raninagar-II	
		Domkal	
1993	South 24-Parganas	Bhangor-I	
	North 24-Parganas	Barasat-I	
		Barasat-II	
		Habra-I	
		Habra-II	
		Deganga	
		Swarupnagar	
		Basirhat	
		Baduria	
		Gaighata	
	Nadia	Harighata	330
		Chahdaha	
		Shantipur	
		Nabwadip	
		Kaliganj	
		Tehatta-I	
		Tehatta-II	
		Karimpur-I/II	
	Burdawan	Purbasthali-I	
		Purbasthali-II	
	Murshidabad	Beldanga	
		Baharampur	
		Nowda	
		Hariharpara	
		Raninagar-I	
		Jalangi	
		Suti-II	
	Malda	Kaliachalk-I	
		Kaliachalk-II	
		Kaliachalk-III	
		Englishbazar	
		Manikchalk	
May 1994	South 24-Parganas	Sonarpur	13
Aug. 1995	South 24-Parganas	Joynagar	
		Magrahat-II	
	Murshidabad	Suti-I	116
		Farakka	
		Bhagalbangola-II	
		Murshidabad	
		Raghunathganj-II	

Jan. 1996	South 24-Parganas	Bhangor-II Budge Budge-I Budge Budge-II Bishnupur-I Bishnupur-II	94
	Hooghli	Balagarh	
July 1996	North 24-Parganas	Hasnabad Bangaon	70
	Nadia	Ranaghat II	
Sep. 1996	South 24-Parganas	Baruipur Sonarpur	
	North 24-Parganas	Habra I/II Bashirhat I/II	
	Nadia	Tehatta I/II Shantipur Ranaghat	169
	Bardhaman	Purbasthali I/II	
	Murshidabad	Berhampur Suti I/II Raninagar I/II Beldanga I	
	Malda	Kaliachalk I/II/III Manikchalk Englishbazar	
Feb. 1997	Parts of calcutta	-	
TOTAL	8 DISTRICTS	57 BLOCKS	830 VILLAGES

Source: Dipankar Chakraborti, 1997

Both arsenite and arsenate were found in the ground water.

Epidemiological studies (Chakraborty et al., 1987; Guha Mazumdar et al., 1988; Das et al., 1994, 1995) have shown evidence of arsenical dermatosis and hepatomegaly among nearly 92.5% of the population exposed to arsenic in the concentration range of 0.2-2.0 mg/L in contrast with about 6.25% of the population with <0.05 mg/L in drinking water. Clinical symptoms of chronic diseases such as hyperkeratosis and hyperpigmentation in palms and soles and non-cirrhotic portal fibrosis are common among the affected population. Significant accumulation of arsenic has been reported in the urine, nail, hair, skin-scales as well as biopsy samples among the affected people (Chatterjee et al., 1995; Das et al., 1995; Mandal et al., 1996). The evidence of bio-accumulation of arsenic has also been observed among cattle (Das et al., 1995) due to the consumption of 40-50 litre per day of arsenic-contaminated ground water.

The mineralogical and geochemical investigations have revealed that arsenic contaminated ground water is mainly confined to intermediate aquifer (20-80 m), while the occurrence of arsenic in the shallow and deep aquifers (90-150 m) is quite limited (Bhattacharya et al., 1997). The absence of impervious clay partings between the intermediate and deeper aquifers seems to play an important role for the occurrence of arsenic. Arsenic occurs in the silty clay as well as in the sandy layers as coatings on mineral grains. The impersistant clay horizons separating the shallow and intermediate aquifers have revealed relatively high arsenic content with occasional distinct grains of arsenopyrite (PHED, 1991). Clayey sediments intercalated within the sandy aquifers at depths between 20 and 80 m might act as a major source of arsenic in ground water. It has been reported that the sediments are transported from the source terrains located in the Chhotanagpur-Rajmahal highlands in eastern Bihar and deposited by sluggish meandering streams in the Bengal flood plain under reducing conditions.

The hydrochemical data revealed distinct trends of increasing arsenic during pumping suggesting a release of arsenic flowing from distant sources (PHED, 1991; Das et al., 1995; Chatterjee et al., 1995) The hydrochemical data further suggests that mobilization of arsenic in the ground water is related to reduction of arsenic species commonly adsorbed on the secondary Fe- and Al- phases such as goethide and gibbsite (Bhattacharya et al., 1997). These Fe- and/or Al-phases are characterized by variable surface charge, negative at higher pH and positive at lower pH. At lower pH, these surface reactive phases attain net positive charge leading to significant adsorption of As(V) species. The mobilization of As in ground water appears to be governed by changing redox conditions where the arsenic phases are selectively desorbed as a response to the reduction of Fe^{3+} phases to soluble Fe^{2+} species. The chemistry of aquifer materials and their interaction with the aqueous phase play a key role in controlling the retention and/or mobility of arsenic under different redox conditions within the subsurface environment (Bhattacharya et al., 1995a). The chemistry of arsenic in the ground water samples revealed the dominance of As(V) species in the ground water.

Recently, Bhattacharya et al. (1997) discussed the sedimentological, hydrogeological, mineralogical and geochemical characteristics of the aquifer system and stressed the need for an integrated study on geological, hydrological and geochemical characteristics of the multi-level aquifer system to predict the origin, occurrence and mobility of arsenic in ground water of West Bengal.

Inspite of wealth of information available on the occurrence of arsenic in ground water, no definite source of arsenic in the ground water could be established so far. While explaining the ground water quality of London basin aquifers, Kinniburghs et al., (1994) mentioned that due to high ground water withdrawal the pyrite oxidized and the acid released during oxidation of pyrite reacted with minerals, leading to high concentrations of cations in the pore water. Similarly, while explaining arsenic in ground water of the western United States, Welch et al. (1988) reported that mobilization of arsenic in sedimentary aquifers may be in part, a result of changes in the geochemical environment due to agricultural irrigation. In the deeper subsurface, elevated arsenic concentrations are associated with compaction caused by ground water withdrawal.

Based on the above findings, the probable sources of arsenic contamination in the ground water of the West Bangal may be attributed to: (i) Geological - the sedimentary deposits may contain minerals rich in arsenic, such as, arseno pyrite (FeAsS), orpiment (As_2S_3), and realgar (As_2S_2), etc. The excessive withdrawal of ground water from shallow aquifers in the affected areas of West Bengal started since 1974-75. The ground water is withdrawn from these aquifers for irrigation purposes during the non-monsoon period. The depleted ground water gets recharged during the following monsoon months. During this process a considerable portion of the unconfined aquifer remain exposed to the atmospheric effects which may cause oxidation of the arsenic and iron rich minerals (like arseno pyrite), thereby leading to leaching during the recharge of ground water. In addition to this, phosphate rich fertilizers used in the agricultural fields may act as catalyst for dissolution of arsenic compounds present in the soil; (ii) Some pesticides and herbicides contain trace amount of arsenic. The excessive use of these pesticides and herbicides in agricultural practices may lead to contamination in the ground water.

The concentration of arsenic in suspended and bottom sediments is always higher than the corresponding values in the associated waters. The capacity of a sediment to retain and concentrate arsenic is normally controlled by grain size (Horowitz, 1984), because smaller grain sizes have a greater surface area and a greater adsorption capacity. Clay minerals, organic matter and iron and manganese oxides, which commonly occur as coatings on sediments, commonly adsorb trace elements such as arsenic. In soils, organic matter can concentrate arsenic in the upper horizons while adsorption onto ferric oxyhydroxide can enrich arsenic at greater depths. Arsenic in certain solid phases within sediments, particularly iron oxides, organic matter, and sulfides, may be the primary source of arsenic in ground water.

The arsenic calamity of West Bengal, which has been claimed as the biggest in the World, should not be neglected any more. There is need to combat with the situation by providing an alternative source of water for drinking purposes. West Bengal has about 2000 mm of average rainfall, about 4000 km^2 of wetland and vast river basin is flooded almost every year, but due to the negligence most of these water bodies go dry. There is an urgent need for a proper watershed management so that the vast surface and rain water resource could be used to combat with the situation.

Keeping in view the above status of ground water contamination in West Bengal, a collaborative project was formulated between National Institute of Hydrology (NIH), Roorkee, and Central Ground Water Board (CGWB), Calcutta. The following work elements were envisaged under the project.

i) Precise delineation of aquifer boundaries, relationship between individual aquifers, identification of aquifers and their lateral and vertical extensions, determination of leaky conditions within the one or more aquifers systems and other related hydrogeological conditions under which ground water flow and its hydrodynamic characteristics are being maintained.

ii) Modelling of ground water characteristics its relation with surface water regime consequent to annual recharge from rainfall and other sources, establishment of recharge-discharge relationship etc.

iii) Assessment of total ground water draft that is taking place in the arsenic-effected areas and its physical manifestation in the ground water regime by analyzing hydrographs of monitoring wells in time and space.

iv) Mobilization of chemical constituents, identification of changes in hydrochemical conditions with time and assessment of effects of fertilizer and pesticides in enhancing the arsenic level in ground water.

v) Arriving at suitable economically viable alternatives to maintain sustainable drinking water supply to the affected people.

Out of these five items of task, NIH has been entrusted with the responsibility of preparation of mathematical models of the aquifer systems and hydrochemical behavior of ground water in time and space, and assessment of recharge of ground water regime.

In this connection a team of NIH scientists visited Calcutta and had detailed discussions with the CGWB officials and made a field visit of the arsenic affected areas. Few selected water, soil, sediment and fly ash samples were collected and results of the same have been presented in this report.

3.0 THE STUDY AREA

The state of West Bengal lies between latitude 2[illegible]' to 27°10'N and longitude 86° to 90°E (Fig. 1). The total area of the state is 88,752 km² with a population of 66,9[illegible] as per 1991 census. The high arsenic contamination in ground water has been encountered in Nadia, Murshidabad, Malda, Bardhaman, Hooghly, North and South 24-Paraganas districts of West Bengal. Among the all districts, Malda, Murshidabad, Nadia, North 24-Parganas and South 24-Parganas are located to the east of the river Bhagirathi, whereas, Bardhaman and Hooghly districts are located to the west of the river Bhagirathi. The geographical extent of the arsenic-infested area is about 470 km from the district of Malda in the north to the 24-Parganas district in the south. Approximately 65,000 km² area covering 51 million population has been reported to be affected by arsenic (Chakraborti, 1997; The Statesman, April 20, 1997).

3.1 Geology

The geological map shows that almost three fourth area of the state is covered by alluvial deposits and the rest is covered by various types of hard rocks ranging in age from oldest Archean to Recent Alluvium (Fig. 2).

The Bengal basin is delimited by the Peninsular Shield with intercratonic Gondwana basin and the Rajmahal Traps on the west, by the Shillong Plateau on the north east, and Naga-Lushai orogenic belt on the east. The Garo-Rajmahal gap separates the Peninsular Shield from the Shillong plateau. The sedimentary fill occurring north of the Garo-Rajmahal gap perhaps represents a part of foredeep or crustal downwarp believed to have been formed in response to the Himalayan orogeny.

The Peninsular Shield disappears below a thick pile of sediments ranging in age from Cretaceous to Recent. The thickness of the sediments increases south-easternly and the top of the probable Tertiary sediments occur at shallow depths of about 80

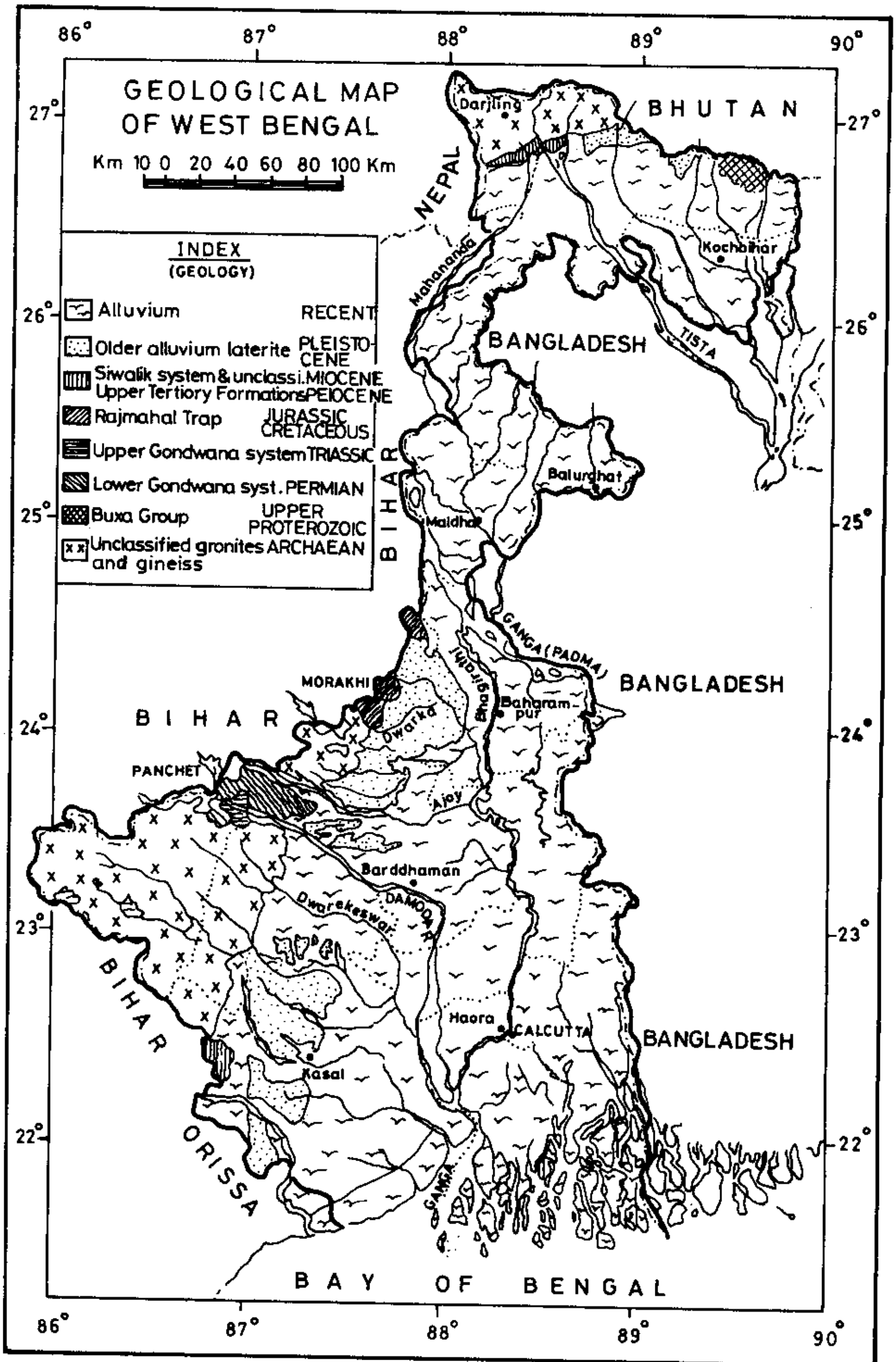

FIG. 2: THE GEOLOGICAL MAP OF WEST BENGAL

m. The structural profile of Bengal basin show the occurrence of a number of buried basement ridges, a row of basin margin faults and the stable shelf of the Bengal basin in succession from the west to east.

The Quaternary sediments are fluviatile in nature and are deposited by the Ganga-Brahmaputra river system with a network of distributaries and tributaries. The Ganga-Brahmaputra delta complex which is thickening towards south, has three broad stratigraphic sequence; i) the proto-Ganges delta formed immediately after break up of the Gondwana land, ii) the transitional delta, and iii) the modern delta with a successive sequence of muds, sands, sandymuds and silt which were deposited under a major eustatic sea-level.

The modern delta has been primarily formed of alluvial sediments transported by the rivers, namely, Mayurakshi, Ajoy, Damodar etc. originating from the Chotanagpur uplands in the west and subsequently by the rivers flowing from the Himalayan foredeep basin, namely, the Ganges, Padma, Bhagirathi, Brahmaputra in the north when a gap, viz., Gara-Rajmahal was created due to tectonic movements.

The arsenic contaminated ground water occurs in the modern deltaic sediments. These sediments extend eastwards in the districts of Rajsahi, Kushtia, Jessore, Khulna and beyond in Bangladesh.

3.2 Physiography and Geomorphology

The major physiographic and geomorphic features in the state of west Bengal and their geographic locations are given in Table 3. The area enriched by the rivers Padma and Bhagirathi and the Bay of Bengal in the south represents the Gangetic delta. The delta plain comprises a thick succession of sediments deposited by the Ganga-Brahmaputra river systems with a typical southward gradient. The delta plain is typically of moribund character and formed due to silting of the old river levees. The Ganga has

Table 3. Major physiographic and geomorphic domains of West Bengal

Geographic location	Physiographic domain	Geomorphic domain
Darjeeling and northern parts parts of Jalpaiguri district	Mountainous terrain	Himalayan and sub-Himalayan ranges
Cooch Bihar, Jalpaiguri and northern part of West Dinajpur	Sub-montane terai	Sub-montane terai
Malda and West Dinajpur	Para delta	Terrace of older lateritic alluvium
Birbhum, Bankura, Purulia and part of Midnapur	Laterite upland	Laterite piedmont plain
Murshidabad, Nadia and parts of Barddhaman and North 24-Parganas	Gangetic delta	Upper fun plain of meander belt
Barddhaman, Hooghly and parts of Midnapur	Gangetic delta	Marginal fan and valley margin fan
Calcutta, Howrah, South 24-Parganas and parts of North 24-Parganas	Lower Gangetic delta	Lower delta plain

Source: Bhattacharya et al., 1997

shifted eastwards from its original course and is branched into two distributaries, Bhagirathi-Hooghly and Padma-Meghna. The causes of shifting of the Ganga and the meandering behaviour of the river have not been properly understood. Among the possible explanations for the changes in the river courses are alluviation at the heads of successive main spillways, response to neotectnism and eustatic sea-level changes. Secular swing in the course of the Teesta towards the east is a recent manifestation (PHED, 1991).

The modern delta could be divided into two distinct divisions on the basis of the landforms present; i) the upper delta plain of meander belts of the Padma-Bhagirathi rivers in the north, and ii) the lower delta plain with several tidal creeks in the south.

The upper delta plain (UDP) is characterized by a series of meander belts formed by the fluvial processes as a response to varying hydrodynamic conditions. The wavelengths and amplitudes of the various segments of the meander belts vary widely and are often characterized by detached loops of ox-bow lakes and alluvial ridges. Abandoned meander scrolls are the most common forms and could be related to flood plain formations in upper delta plain with a very gentle southernly slope. Other prominent landforms are levees and swamps in between inter-distributary levees. The basin-filled deposits are fluvial deposits and comprise stacks of different cycles of upwards fining sequences (sand-silt-clay) (Fig. 3). Such cyclic sedimentation in the form of festoon-bedding are found with coarse to medium sand, fine sand, clay and silt respectively. The arseniferous belts are located in the upper delta plain and in the abandoned meander channels as well as acrolls.

The plain between the moribund delta in the north and the Sunderbans (the coastal part) is considered as the lower delta plain (LDP). The lower deltaic plain constitute a tidal mudflat, distributary levees and an inter distributary marsh complex, formed under a fluvial estuarine and marine environment under the influence of fluctuating sea-level condition is

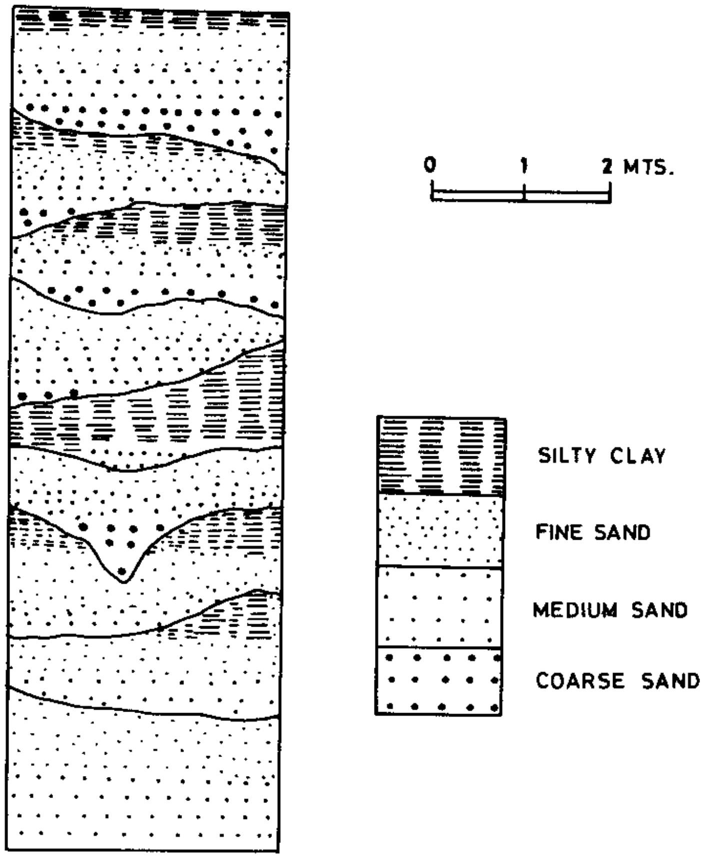

FIG. 3: DIAGRAMMATIC SKETCH SHOWING THE DEPOSITION OF MUTUALLY TRUNCATING FINING UPWARD SEQUENCES IN A TYPICAL CROSS SECTION OF THE ARSENIFEROUS ALLUVIAL SEDIMENTS OF THE UPPER DELTA PLAIN

geologically recent time. The lower deltaic plain is characterized by the presence of an extensive clay capping of varying thickness (15-75m) which is underlain by silt, sand and gravel in many places. Areas affected by arsenic contamination in ground water are all located in the upper deltaic plain and mostly in the abandoned meander belts (Fig. 4).

3.3 Ground Water Characteristics

The subsurface geological setup of the upper Tertiary and Quaternary sediments of the Bengal basin indicate the following characteristics:

The northern part of the state is primarily in the Brahmputra basin and is characterized by extensive near surface aquifers which have ground water in unconfined conditions and are predominantly of the Quaternary age. The sub-surface ridges of the basement along the Garo-Rajmahal gap demarcate the hydrological boundary to the lower and deeper parts of the basin in the south. The basin is, however, open towards the south-eastern parts into the tertiary formations of Bangladesh. The deeper aquifers (below 300 m) are under confined condition with possibilities of zonal inter-connection with the upper group of unconfined aquifers particularly along the tectonic troughs through which the major rivers flow.

In the upper flood plain zones of Bhagirathi and in narrow sector of the Damodar basin, unconfined occurrence of ground water is the chief hydrological feature. Ground water occurs under unconfined condition particularly in the Nadia, Murshidabad and Malda districts and in semi-confined condition in Barddhaman , and the North and South 24-Parganas districts. These aquifers gradually changes from open to semi-confined state as they extend down south in the Moribund delta. The closed aquifers are generally inter-connected with the upper groups of open aquifers.

The aquifers in the lower delta and coastal tracts of

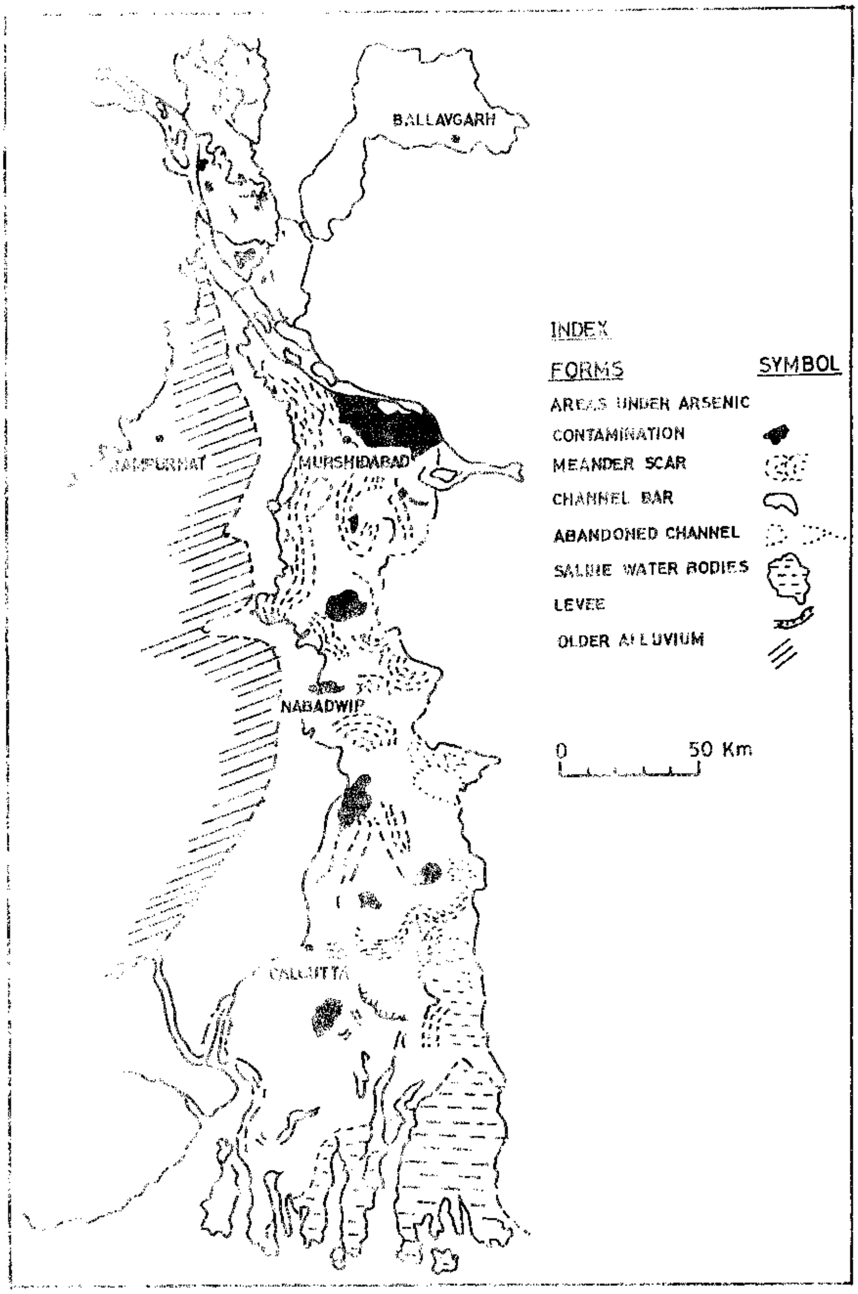

FIG. 4.1 THE GEOMORPHOLOGY OF SOUTH EASTERN PART OF WEST BENGAL

Midnapur districts lie deeper (below 200 m) under a blanket of widespread aquiclude in the near surface zone. Ground water occurrence in the western fringe of the Bengal basin is restricted to localized zones which are both under confined and unconfined conditions. In the eastern margin of the Chotanagpur plateau ground water occurs in the fractured and weathered parts of the older rocks and in minor channel-filled sediments of some streams.

Fluvial sand and gravel are the main deposits forming the major aquifers. The recharge areas are located in upland and sub-mountain fronts. The deposits in the aquifers are fine, medium and coarse sand with gravel. Clayey intercalations are darker in colour, possibly reflecting elevated contents of organic matter. Sandy clay mixed with cancer and coarse, medium to fine sand characterize the open hydrological systems. The semi-confined systems are deposits with fine white sand with clayey intercalations and medium to coarse sand with gravels towards the bottom. Fine-grained deposits are also accumulated in the bottom of the aquifer overlain by a pure fine white sand. The typical lithological succession of a well site in Nadia district is shown in Fig. 5.

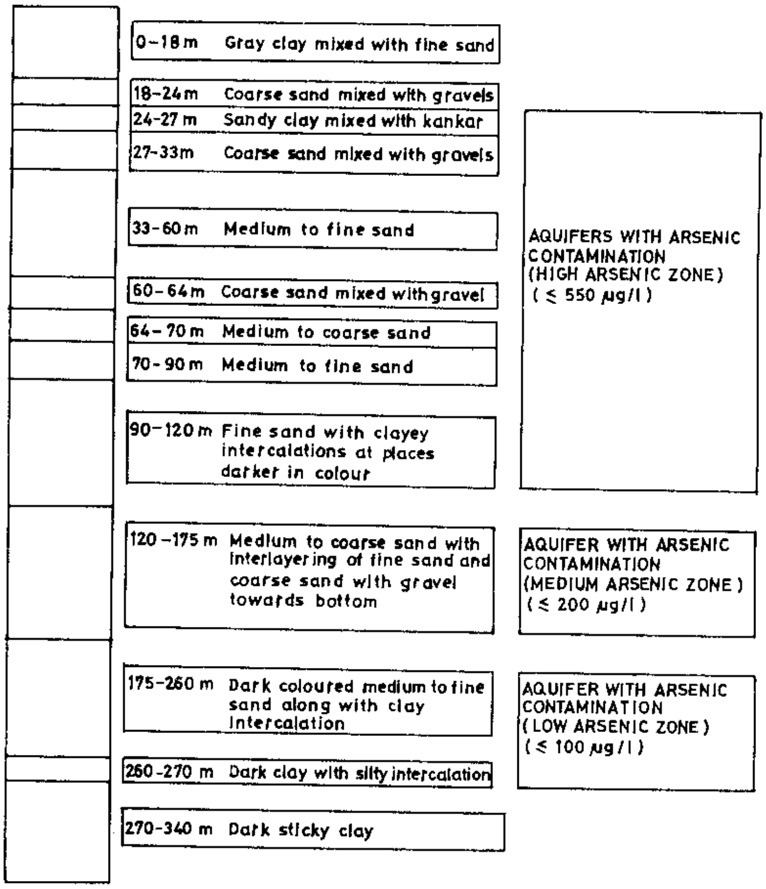

Fig. 5: A simplified lithological column togther with the disposition of arsenic contaminated aquifers at a borehole site in Nadia District, West Bengal

4.0 EXPERIMENTAL METHODOLOGY

4.1 Sampling and Preservation

Ground water samples were collected from different sites in Nadia district during the month of April 1997. One 100 mL portion of the sample was acidified with 1.0 mL concentrated hydrochloric acid of ultra pure grade for arsenic analysis. For other trace element analysis samples were preserved by acidifying with concentrated nitric acid to pH < 2 and stored 4°C in polyethylene bottles. The samples thus preserved were brought to the laboratory in sampling kits maintained at 4°C for analysis. All the sampling bottles were soaked in 10% nitric acid for 48 h and then washed several times with deionized water prior to sample collection. The details of sample locations are given in Table 4.

Soil samples were collected from PHED bore hole site at Ghetugachi, Chakdah block in Nadia district, West Bengal, upto a depth of 12 m at an interval of 3 m to see the occurrence of arsenic in the upper zone. About 100 g of soil sample was collected from each depth and properly sealed in plastic bags to avoid any contamination. The lithological details of the log of drill cuttings of the PHED bore hole site are given in Table 5.

Evenly distributed water and bed sediment samples were also collected from the river Hooghly between Hooghly ghat and Kalipur as shown in Fig. 6. The samples were appropriately preserved as described above.

Fly ash leachet and fly ash contaminated water samples were also collected from the Farrakka Super Thermal Power Plant (STPP) to investigate the heavy metal and trace element contents in fly ash leachets.

The trace elements were extracted from the soil, sediment and fly ash samples using an acid digestion mixture ($HF+HCLO_3+HNO_3$).

Table 4. Details of ground water sample locations of Nadia district, West Bengal

S.No.	Location	Depth
1.	Birohi	60′
2.	Ghetugachi	380′
3.	Mondalhat	375′
4.	Sarkarpara	200′
5.	Tribeni Ghat	30′
6.	Saguna	275′
7.	Gayeshpur	90′
8.	Napit Satbara	100′
9.	Belia	80′
10.	Belia	80′
11.	Dingal	-
12.	Dingal	-
13.	Biruhi	-

Table 5. Details of lithological log of drill cuttings of the PHED bore hole site at Ghetugachi, Chakdah block, Nadia district, West Bengal

Lithology	Depth span (m)	Thickness (m)
Surface clay	0-3	3
Clay, grey, sticky	3-6	3
Clay, grey with fine sand	6-9	3
Clay, grey, sticky	9-12	3

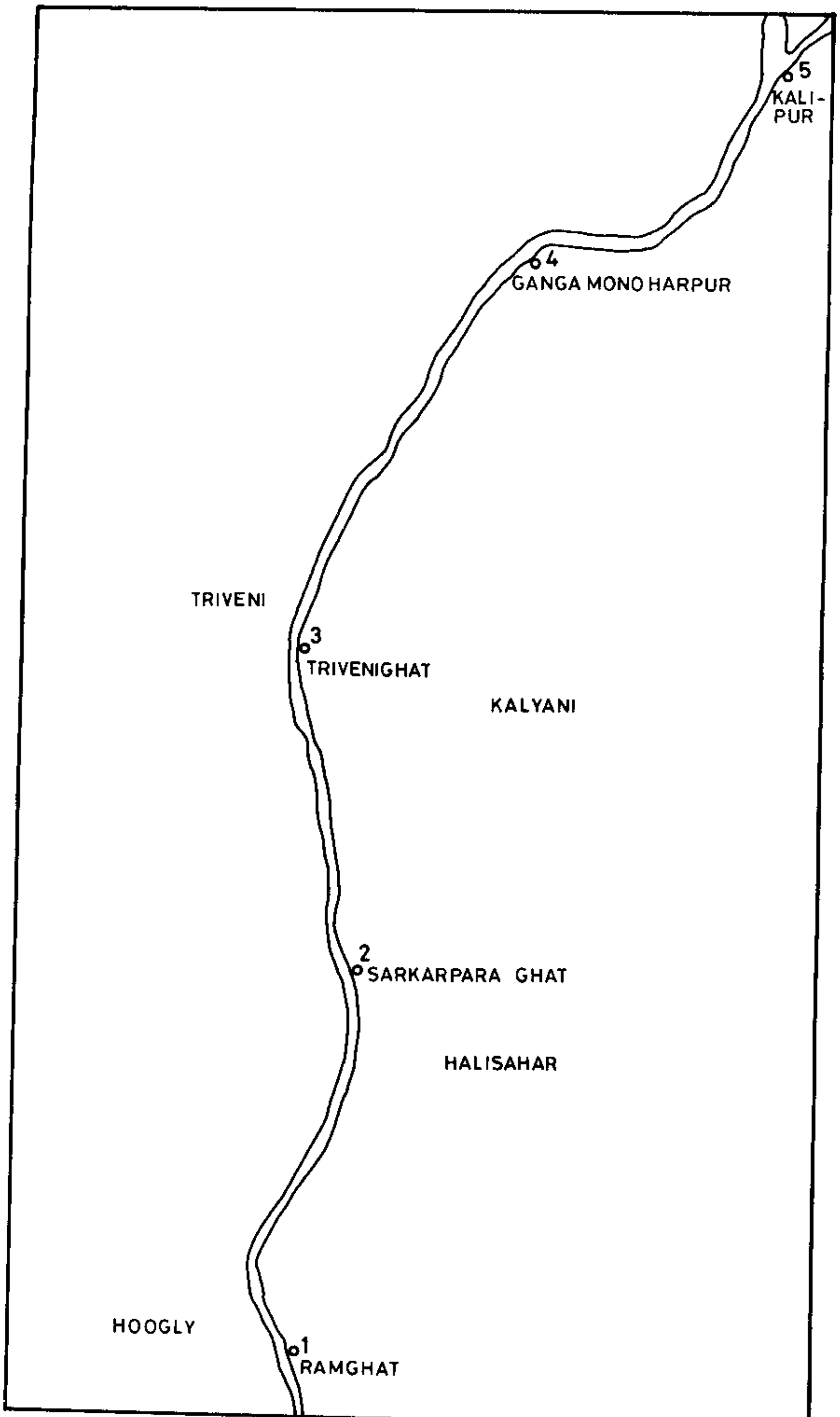

FIG. 6: THE HOOGLY RIVER SHOWING WATER AND SEDIMENT SAMPLING SITES.

4.2 Materials and Reagents

All glassware and other containers were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 h and finally rinsed with deionized water several times. All the reagents and chemicals used were of ultra pure grade. Deionized water was used throughout the study. Stock solutions of 1000 mg l^{-1} were prepared from the respective salts.

4.3 Trace Element Analysis

Trace elements (Cu, Co, Cd, Cr, Fe, Ni, Mn, Pb and Zn) were determined by atomic absorption spectrometry using a Perkin-Elmer Atomic Absorption Spectrometer (Model 3110). The detection limits for the trace elements studied are 0.001, 0.006, 0.0005, 0.002, 0.003, 0.004, 0.001, 0.01 and 0.0008 mg l^{-1} for copper, cobalt, cadmium, chromium, iron, nickel, manganese, lead and zinc respectively. Operational conditions were adjusted in accordance with the manufacturer's guidelines to yield optimal determinations. Quantification of trace elements was based upon calibration curves of standard solutions of respective elements. These calibration curves were determined several times during the period of analysis. The analysis of arsenic was carried out at Pollution Control Research Institute, Bharat Heavy Electricals Limited, Ranipur, Hardwar.

5.0 RESULTS AND DISCUSSION

The high arsenic contamination in ground water has been encountered in Nadia, Murshidabad, Malda, Barddhaman, Hooghly and North and South 24-Paraganas districts of West Bengal. Approximately 65,000 km^2 area covering 51 million population has been reported to be affected by arsenic (Chakraborti, 1997; The Statesman, April 20, 1997). The geographical extent of the arsenic-infested area is about 470 km from the district of Malda in the north to the 24-Parganas district in the south.

The arsenic concentration in water samples collected during April 1997 from some selected villages of Nadia district, West Bengal are given in Table 6. The data indicate that out of the 13 samples analysed, seven samples has arsenic content > 0.05 mg/L. The ground water in arsenic affected zone is characterized by high iron content. The correlation matrix of different elements is given in Table 7. Statistical analysis shows a positive correlation between arsenic and iron, although the correlation is not very significant. Clinical symptoms of chronic diseases such as hyperkeratosis and hyperpigmentation in palms and soles and non-cirrhotic portal fibrosis are common among the affected population. Significant accumulation of arsenic has been reported in the urine, nail, hair, skin-scales as well as biopsy samples among the affected people (Chatterjee et al., 1995; Das et al., 1995; Mandal et al., 1996).

The trace element data of lithological log of drill cuttings of the PHED bore hole site at Ghetugachi in Chakdah block, Nadia district is given in Table 8. This shows a consistent arsenic contamination in the upper aquifer also. The geochemical and micromorphological studies carried out by Nandy (1997) also revealed the presence of sulphide minerals, particularly pyrite and arsenopyrite, in the upper aquifers of the arsenic affected areas of west Bengal. The mineralogical and geochemical investigations carried out earlier revealed that arsenic contaminated ground water is mainly confined to intermediate aquifer (20-80 m), while the occurrence of arsenic

Table 6. Trace element data of ground water samples of Nadia district, West Bengal

S. NO.	Location	Depth (Feet)	Concentration (mg/L)									
			As	Cu	Co	Cd	Cr	Fe	Ni	Mn	Pb	Zn
1	BIROHI	60	0.230	ND	0.034	0.008	ND	6.143	0.032	0.257	0.019	0.096
2	GHETUGACHI	380	0.290	ND	0.031	0.007	ND	4.533	0.034	0.224	0.014	0.027
3	MONDALHAT	375	ND	ND	0.031	0.005	ND	0.176	0.025	0.088	0.009	0.001
4	SARKARPARA	200	ND	ND	0.041	0.007	ND	1.218	0.031	0.209	0.009	0.069
5	TRIBENI GHAT	30	0.140	ND	0.043	0.006	ND	0.835	0.025	0.664	0.018	ND
6	SAGUNA	275	ND	ND	0.048	0.005	ND	0.683	0.039	0.428	0.019	1.258
7	GAYESHPUR	90	0.005	ND	0.066	0.007	ND	2.442	0.044	0.492	0.032	0.001
8	NAPIT SATBARA	100	0.300	ND	0.056	0.006	ND	1.015	0.034	0.274	0.032	ND
9	BELIA	80	ND	ND	0.057	0.009	ND	0.887	0.046	1.232	0.024	0.007
10	BELIA	80	0.011	ND	0.067	0.009	ND	4.726	0.040	0.903	0.037	0.156
11	DINGAL	-	0.119	0.002	0.010	0.005	ND	4.439	0.017	0.146	ND	0.066
12	DINGAL	-	0.140	0.003	0.003	0.003	ND	0.298	0.028	0.543	ND	0.002
13	BIRUHI	-	0.360	ND	0.014	0.004	ND	3.980	0.036	0.093	ND	0.028

ND - Not Detected

Table 7. Correlation matrix among trace elements of ground water samples of Nadia district, West Bengal

	As	Cu	Co	Cd	Fe	Ni	Mn	Pb
Cu	0.029							
Co	-0.425	-0.686						
Cd	-0.285	-0.575	0.739					
Fe	0.413	-0.097	-0.097	0.351				
Ni	-0.183	-0.508	0.687	0.527	-0.005			
Mn	-0.444	-0.055	0.532	0.545	-0.198	0.554		
Pb	-0.248	-0.564	0.944	0.717	0.043	0.646	0.529	
Zn	-0.292	-0.132	0.158	-0.134	-0.156	0.218	0.012	0.090

Table 8. Trace element data of lithological log of drill cuttings of the bore hole at Ghetugachi, Chakdah block, Nadia district, West Bengal

S. No.	Depth (m)	Concentration (μg/g)									
		As	Cu	Co	Cd	Cr	Fe	Ni	Mn	Pb	Zn
1	0-3	675	89	49	ND	207	9006	86	361	ND	177
2	3-6	700	59	31	ND	146	8304	52	532	ND	128
3	6-9	620	34	28	ND	140	7866	50	572	ND	105
4	9-12	440	48	37	ND	165	8504	83	823	ND	134

ND - Not Detected

in the shallow and deep aquifers (90-150 m) is quite limited (Bhattacharya et al., 1997).

The problem of arsenic pollution in ground water in West Bengal has been reported to be due to the geological formations of the source materials. Occurrence of iron-pyrite and the change of geo-chemical environment due to over-exploitation of ground water or excessive fluctuation of ground water table have been thought to be reason of decomposition of pyrite to ferrous sulphate, ferric sulphate and sulfuric acid.

An estimate of arsenic withdrawal from a single Rural Water Supply Scheme (RWSS) supplying water to few village in Jothgopal, Malda, indicated that 147.825 kg of arsenic came out in one year. Since the arsenic of such huge proposition could not be anthropogenic, the source of arsenic is considered to be geological. The sand and clay deposited at shallow level by the Ganga-Bhagirathi river system in the late Quaternary period are originally enriched in arsenic and iron-bearing minerals, derived from trap and granitic source rock.

Use of heavy duty pumps for irrigation in the arsenious zone had also been reported and thought to be helped in mixing of waters in the isolated arsenious pockets in the aquifer, leading to progressively wide incidence of arsenic contamination. Another factor suspected to be a contributing factor to the occurrence of high concentration of dissolved arsenic in parts of 20-70 m aquifer is percolation of water downward through the oxidation zone resulting towards enrichment of dissolved oxygen that may help oxidation of the arsenic in the arsenious layers to $HAsO_4^{2-}$ anion which is soluble in the prevailing mildly alkaline ground water in that zone.

In order to see the influence of arsenic contamination on river water of Hooghly, water and sediment samples were also collected from river Hooghly (Fig. 6) and the results of trace element data alongwith arsenic content for water and bed-sediment samples are given in Table 9 and 10 respectively. The hydrochemical study of the water and sediment sample of the river

Table 9. Trace element data of water samples of Hooghly river

S. No.	Location	Concentration (mg/L)									
		As	Cu	Co	Cd	Cr	Fe	Ni	Mn	Pb	Zn
1	RAMGHAT	ND	0.179	0.012	0.004	0.008	2.020	0.015	0.100	0.033	0.134
2	SARKARPARA GHAT	0.130	0.139	0.022	0.004	0.003	2.842	0.037	0.136	0.044	0.102
3	TRIBENI GHAT	ND	0.136	0.025	0.004	0.010	4.928	0.045	0.190	0.033	0.106
4	GANGAMONOHARPUR	0.050	0.149	0.028	0.003	0.005	3.310	0.020	0.140	0.036	0.110
5	KALIPUR	0.290	0.148	0.033	0.005	0.010	4.695	0.035	0.191	0.027	0.103

ND - Not Detected

Table 10. Trace element data for sediment samples of Hooghly River

S. No.	Location	Concentration (µg/g)									
		As	Cu	Co	Cd	Cr	Fe	Ni	Mn	Pb	Zn
1	RAMGHAT	530	20	56	5.5	78	19270	45	418	60	38
2	SARKARPARA GHAT	490	21	62	6.5	72	18290	52	424	49	33
3	TRIBENI GHAT	330	30	56	5.0	79	20120	60	470	56	41
4	GANGAMONOHARPUR	335	22	63	5.0	74	18255	52	428	61	34
5	KALIPUR	600	32	66	5.0	90	26210	59	528	64	44

ND - Not Detected

Hooghly clearly indicate the presence of consistent arsenic concentration. The content of arsenic in the sediments were quite higher than the associated water. A number of favourable conditions regarding the presence of arsenic in water and sediment samples of Hooghly river exist there. The most important factors include, i) the transportation of arsenic by the river water from the coal bearing beds present in the 'Rajmahal traps' over which river flow, ii) the leaching and mixing of arsenic compounds in the river water from the ash disposal pond, and iii) due to the prolonged industrial activity along the banks of the river Hooghly.

The Farrakka Super Thermal Power Plant (STPP) operating in the state of Waste Bengal is the another source of metal contamination including arsenic in the nearby area. The main problem with the thermal plants related to environment is the production of fly ash which contain toxic elements, damaging the crops and vegetation, and human health of the region. Fly ash contain several heavy metals and trace elements, as reported by several authors (Plank, 1975; Kleir, 1975; Bel, 1979). Fly ash is disposed in the ash ponds. The fly ash contaminated water is leached from these ash ponds in the nearby land area. The vegetation also gets affected from the leachats. In the present study, metal estimations were carried out in the fly ash contaminated water as well as fly ash deposited in the pond, to establish the presence of toxic elements including arsenic in the ground water, and the results are given in Table 11 and 12. The fly ash deposited in the ash pond indicate arsenic content of the order of 400-500 $\mu g/g$. Fly ash generated from thermal plant finds its way into open environment of air, water and soil from atmospheric precipitation, spillage from pipe lines carrying fly ash slurry to ash dykes and from decanted water of ash pond. It contaminate ground water due to seepage and mixing of fly ash into surface and subsurface water. During the thermal power production, coal is combustioned at temperature 1300-1450°C. At such a high temperature most of the mineral compounds are converted into volatile and non volatile oxides. These elemental oxides when react with aquatic environment, most of the elements get hydrolysed and find their pathways into biotic components.

Table 11. Trace element data of fly ash contaminated water samples of Super Thermal Power Plant, Farrakka, West Bengal

S. No.	Sample	Concentration (mg/L)									
		As	Cu	Co	Cd	Cr	Fe	Ni	Mn	Pb	Zn
1	CONTAMINATED WATER	0.001	ND	0.012	0.003	ND	2.306	0.018	0.073	0.005	0.006
2	CONTAMINATED WATER	0.003	ND	0.010	0.002	ND	0.834	0.016	0.061	ND	0.003

ND - Not Detected

Table 12. Trace element data of fly ash samples of Super Thermal Power Plant, Farrakka, west Bengal

S. No.	Sample	Concentration (μg/g)									
		As	Cu	Co	Cd	Cr	Fe	Ni	Mn	Pb	Zn
1	FLY ASH	500	64	117	6.0	185	45030	101	512	70	36
2	FLY ASH	340	82	113	6.5	161	30735	102	336	94	58

ND - Not Detected

6.0 CONCLUSION

The study reveals high concentration of arsenic in ground water of Nadia district along with high iron content. The trace element data of lithological log of drill cuttings of the PHED bore hole site at Ghetuhachi in Chakdah block, Nadia district also shows a consistent arsenic contamination in the upper aquifer. The water and sediment samples of river Hooghly also indicated presence of arsenic in Hooghly river. The Farrakka Super Thermal Power Plant operating in the state of West Bengal is the another source of arsenic contamination in the nearby area. The possibilities of arsenic contamination in surface and ground water of the West Bengal, due to wide use of Paris Green (an arsenic based pesticide), cannot be ruled out.

The arsenic calamity of West Bengal, which has been claimed as the biggest in the World, should not be neglected any more. There is need to combat with the situation by providing an alternative source of water for drinking purposes. West Bengal has about 2000 mm of average rainfall, about 4000 km^2 of wetland and vast river basin is flooded almost every year, but due to the negligence most of these water bodies go dry. There is an urgent need for a proper watershed management so that the vast surface and rain water resource could be used to combat with the situation.

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