Bhu-Jal NEWS

Quarterly Journal

Volume 24, No.1,
Jan-March, 2009

West Bengal Special Issue

Central Ground Water Board
Ministry of Water Resources
Government of India

Quarterly Journal *Volume No.24 , Number 1, Jan-March 2009*

भू-जल न्यूज़

Bhu-Jal News - Quarterly Journal of Central Ground Water Board with the objective to disseminate information and highlight various activities and latest technical advances in the field of Ground Water.

Inside

Page No.

Editorial

SPECIAL ISSUE ON WEST BENGAL

West Bengal At a glance

Editorial

Bhujal News has entered into 24th year of publication in 2009, aiming at bring out latest scientific inputs on ground water development and management. The present volume on West Bengal State, is the third in the series of Bhujal News published exclusively on the Hydrogeological aspects of different States.

An agriculture dependent state, West Bengal, though occupying only 2.7 % of India's land area (i. e. 88,752 sq. km.), supports over 7.8% of India's population. Lying in the eastern part of India, the state stretches from Himalayas in the North to the Bay of Bengal in the south, falling within three river basins, viz. the Ganga , the Brahmaputra & the Subarnarekha. Though there being huge groundwater prospects in the State, the development and management of every drop of ground water should be taken care of cautiously keeping in mind the environment concerns as well. It is possible only if the hydrogeological framework of the state is understood properly. Keeping the above facts in view, a special issue on Hydrogeological framework of West Bengal has been prepared.

The issue, consists of 10 papers contributed by CGWB, State & Central Agencies, and other Institutions. Abhijit Ray & S. Shekhar in their paper titled, "Ground Water Issues and Development Strategies in West Bengal ", have elaborated the ground water condition in different geological formations in West Bengal. A. Mukherjee, in his article, summarised the recent advancements in the hydrogeological aspects of Gangetic West Bengal. Mishra & Nag have presented a panoramic view on aquifer characteristics in South 24-Parganas & KMC area with vivid diagrams. Mehta & Srivastava enumerated the ground water quality problems in West Bengal. Ghosh Dastidar & Kar have suggested an approach for ground water management in Midnapur district with application of artificial recharge techniques. S. K. Nag through his paper assessed the quality of ground water in parts of Arsa block, Purulia district, West Bengal. Majumdar etal have emphasized the need of geoelectric investigation for hydrological characterization of the Sagar island. S. Mukherjee & B. A. Kumar evaluated the ground water quality in South 24 Pargana district. The sustainable ground water management options in Sunderban area has been presented by A. Gyan through his paper. Guha & Kujur in their paper illustrated the option of roof top rainwater conservation to mitigate the water crisis at Raj Bhawan, Darjeeling.

It is hoped that the present issue, entirely devoted to West Bengal state, will enhance the knowledge base about the hydrogeology of West Bengal. It is regretted that for some reasons we could not publish the 23rd year issue of Bhujal News. However we assure our esteemed readers that it will be our endeavor to bring out more informative issues in future. Dr S. Shekhar, Scientist-B & M. Adil, Scientist-C, CGWB have assisted the Editor in bringing out this issue of Bhujal News

Dr S. K. Jain
Editor

WEST BENGAL STATE AT A GLANCE

SNo	ITEMS	STATISTICS
1.	**GENERAL FEATURES**	
i)	*Location*	: 21^{O} 31' 0": 27^{O} 33' 15" (N latitude) 85^{O} 45' 20": 89^{O} 33' 0" (E longitude)
ii)	*Geographical Area*	: 88,752 sq. km
iii)	*Administrative Divisons*	: 19 districts with 341 blocks under three divisions namely Barddhaman division, Presidency division and Jalpaiguri division.
iv)	*Population (2001 census)*	: 802.21 lakhs. Rural- 72 %, Urban-28 %
v)	*Density of population*	: 904 per sq.km.
2.	**HYDROMETEOROLOGY**	
i)	*Normal Annual Rainfall*	: From 1234 mm to 4136 mm.
ii)	*Max.Temperature*	: From 28^{0}C in the Himalayan region to 33^{0}C in the rest of the State.
iii)	*Min. Temperature*	: From freezing point in the Himalayan region to 18^{0}C in the rest of the State.
3.	**PHYSIOGRAPHY**	Three distinct physiographic divisions: i) Extra – Peninsular Region of the north ii) Peninsular mass of the south – west forming a fringe of Western Plateau iii) Alluvial and Deltaic plains of the south and east.
4.	**DRAINAGE**	Three major river basins: i) The Ganga, ii) The Brahmaputra & iii) The Subarnarekha Most of the rivers are southerly or southeasterly flowing and all major rivers are perennial in nature.
5.	**LAND USE**	: 2000-2001 (In thousand hectares) Net area sown: 5417 Current fallows: 358 Forest : 1190 Area not available for cultivation: 1595 Other uncultivated land excluding current fallows: 128
6.	**SOILS**	: The major soil types of the state are Younger Alluvial soils, Older Alluvial soils, Lateritic soils and red & yellow soils. Apart from these brown soils and Bhabar soils of sub-mountain region in Darjeeling and Jalpaiguri districts Deltaic & Saline soils cover South 24 Parganas district and parts of Purba Medinipur district.
7.	**AGRICULTURE**	Areas covered under different types of crops (in thousand hectare) for 2000-2001(P) Rice: 5435, Wheat: 426,Barley, Maize, Ragi, etc.: 57, Pulses: 275, Oilseeds: 599, Fibres: 627, Plantation Crop: 110, Spices: 71, Vegetables, etc.: 333.
8.	**IRRIGATION**	Irrigation projects account for 47.70 % of the gross cropped areas of 9778815 ha (with cropping intensity 177%). About 75% of the irrigation is being done through minor irrigation schemes.
9.	**GEOLOGICAL FORMATIONS**	Archaean to the Quaternary formations
10.	**HYDROGEOLOGY**	
	Hydrogeological Units	***i) Porous hydrogeoological unit*:** • **In the zone of primary porosities:** Nearly two-third of the state is occupied by unconsolidated Quaternary sediments & occurrence and movement of ground water is controlled by the primary porosities of the sediments.

		• **In the zone of secondary porosities:** Weathering imparts secondary porosity to the hard rock which forms the depository of ground water, occurring under unconfined condition. ***ii)* Fissured hydrogeological unit*:*** Fractures, Joints and other fissures developed in Archaean to Proterozoic gneisses and schists, Gondwana Super group of rock and Siwalik rocks, Rajmahal basaltic traps, form the secondary openings, through which ground water moves down the gradient, . This mainly occurs under confined condition.	
	Depth to Groundwater Level (Pre-monsoon & Post monsoon-2007)	Pre monsoon -2007:- Depth to water level ranges from 2 to 5 m and 5 to 10m below ground level, at places more than 10m or even more than 20m. Post monsoon-2007:- Depth to Water level ranges from 2 to 5 m and at places more than 10m.	
11.	**CHEMICAL QUALITY OF GROUNDWATER**	Groundwater is in general neutral to slightly alkaline type. Iron content:- Generally less than 1.0 mg/litre, except in some isolated patches where iron content is more than 3.0 mg/l Arsenic:- High Arsenic(more than 0.05 mg/l) reported as sporadic occurrence in 79 blocks of 8 districts. Flouride:- High concentration of F(>1.5 mg/l) has been observed in 8 districts.	
12.	**GROUNDWATER RESOURCES (2004)**	Total Ground Water Recharge	3.036 million ham
		Net Ground Water Availability	2.746 million ham
		Gross Ground Water Draft for All Uses	1.165 million ham
		Current Annual Ground Water Draft for Irrigation	1.084 million ham
		Current Annual Ground Water Draft for Domestic & Industrial uses	0.081 million ham
		Stage of Ground Water Development	42 %
		Annual Allocation of Ground Water for Domestic & Industrial Water Supply upto next 25 yrs	0.124 million ham
		Net Ground Water Availability for 'Future Irrigation Use	1.532 million ham
		Category of blocks (in respect of ground water development)	Critical – 1 ((Bharatpur-II, Murshidabad district) Semi-critical: 37 blocks Safe: 231 blocks
13.	**GROUND WATER PROBLEMS AND ISSUES**	• Chronically water scarce area in western part and in hilly tract in the northern part of the State. • The area where depletion in water level has been ascertained(KMC area, Haldia Industrial Complex area) • Hazards due to mining activity in Coal mine area • Area falling under geogenic contamination (High arsenic, High fluoride, High salinity, & High iron)	

GROUND WATER ISSUES AND DEVELOPMENT STRATEGIES IN WEST BENGAL

Abhijit Ray* & S.Shekhar **

INTRODUCTION

The economy of the West Bengal state is basically agrarian. Most of the population of the state live in rural areas and depend largely on agriculture for their livelihood. The development of agrarian economy needs expansion of irrigation facilities. The state is having huge ground water reserve and at present the stage of groundwater development is only 42 percent of the available resources. Though huge reserve of ground water resource is available, every drop of ground water needs proper management. Keeping the above facts in view, an attempt has been made to depict the hydrogeological framework by synthesizing all the available data related to hydrogeological condition to assess the ground water development prospect of the state.

ADMINISTRATIVE SET UP AND DEMOGRAPHY

The state of West Bengal lies between 21°31'0" - 27°33'15" N latitude and 85°45'20" - 89°33'0" E longitude with a total geographical area of 88,752 sq. km. The Himalayan ranges form the northern boundary of the state while Bay of Bengal forms the southern boundary. The state has common border with Nepal, Bhutan and Sikkim (India) in the north, Assam (India) and Bangladesh in the east, Bihar & Jharkhand (India) in the west and Orissa (India) in the southwest. The state of West Bengal is administered through three divisions namely Barddhaman division, Presidency division and Jalpaiguri division. The state comprises 19 districts with 341 blocks under 3 Divisions. As per 2001 census report, total population of the state of West Bengal is 802.21 lakhs, the rural population being 72% of the total population. The population density in the State is 904 persons per sq.km.

HYDROMETEOROLOGY

The state is having tropical climate. The tropic of cancer runs across the middle of the districts of Nadia and Barddhaman and the northern part of the districts of Bankura and Purulia. However, extensive networks of rivers, canals, lakes and tanks, etc control the extreme climatic condition of the state. Normal annual rainfall in the State ranges from 1234 mm to 4136 mm. Himalayan region receives the maximum rainfall. During the winter temperature ranges from freezing point to 18°C in the districts situated in the Himalayan foothill zone whereas in the rest of the State it is over 18°C. During the summer, the maximum temperature goes up to 28°C in the Himalayan region to 33°C in the rest of the State, which sometimes even reaches to 43°C.The relative humidity is more in the northern districts like Jalpaiguri and Cooch Behar and is minimum in the western district like Purulia. The diameters of the depressions that are generally found to form over Bay of Bengal are 160 to 400 km long. The cyclones cause wide spread rain in the state. On the basis of the rain fall, the State may be divided into two broad zones:

- The Himalayan and the Sub-Himalayan regions covering Darjeeling, Jalpaiguri and Cooch Behar districts having Normal Annual Rainfall ranging from 3193 mm to 4136 mm.
- The Gangetic plains - Purulia and parts of Bankura, Birbhum and Paschim Medinipur districts fall in the drought prone areas whereas parts of Haora, Hugli, Barddhaman, Murshidabad and Purba Medinipur districts fall in the flood prone areas. Normal Annual Rainfall ranges from 1234 mm to 1802 mm in the Gangetic Plain.

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SOIL TYPES

The soil types of the State may be divided into five groups namely, Ultisols, Entisols, Aridisols, Mollisols and Alfisols. The major soil types of the state are Younger Alluvial soils, Older Alluvial soils, Lateritic soils and red & yellow soils. Apart from these there are brown or Bhabar soils of sub-mountain region in Darjeeling and Jalpaiguri districts, Deltaic & Saline soils cover South 24 Parganas district and parts of Purba Medinipur district.

IRRIGATION

The State of WB is principally an agrarian state with more than 70% of its population depend directly or indirectly on agriculture for their livelihoods. Irrigation projects account for 47.70% of the gross cropped areas of 9778815 ha (with cropping intensity 177%). Irrigation in the state is being effected through major, medium and minor irrigation programmes. About 75% of the irrigation is being done through minor irrigation schemes.

As per the data available the areas receiving irrigation for different seasonal crops from different sources are given in Table- 1. The table shows that canals and shallow tube wells are the two major sources of irrigation in the state. These two sources together cover about 75% of the total irrigated area in the State.

Table - I: Source wise Irrigated Area of Different Seasonal Crops(Area in ha)

Source	Kharif	Rabi	Perennial	Boro	Others	Total	% of total area irrigated
Canal	718323	42196	-	93484	-	854003	23.78
DTW	59549.78	33511.45	8173.18	46354.89	41143.34	188732.64	5.25
STW	423337.84	284280.68	20541.14	555056.43	518839.73	1802055.82	50.18
Dug Well	7381.86	12246.57	1294.11	855.60	1172.81	22950.95	0.64
Surface Flow	159143.72	39433.84	3388.84	55018.70	44540.78	301525.88	8.40
Surface Lift	75255.62	89168.96	28154.59	115447.27	114010.40	422036.84	11.75
TOTAL	**1442991.82**	**500837.50**	**61551.86**	**866216.89**	**719707.06**	**3591305.13**	**100**

PHYSIOGRAPHY

The State is divided into three distinct physiographic units as

i. Extra – Peninsular Region of the north, comprising mainly Himalayan Foot Hills, falling in Darjeeling, Jalpaiguri and Coochbehar districts,
ii. Peninsular mass of the south – west forming a Fringe of Western Plateau, covering the entire district of Purulia, western part of the districts of Barddhaman, Paschim Medinipur and Birbhum and the northern part of Bankura districts and
iii. Alluvial and Deltaic plains of the south and east.
    a. Deltaic zone falling in Sundarban area of the district of South 24 Parganas and in a small part of North 24 Parganas district and
    b. Plain flat terrain falling in the remaining areas of the state.

DRAINAGE

There are three major river basins in the state namely- the Ganga, the Brahmaputra and the Subarnarekha. In the northern part of the state Teesta is the main river which along with

Torsa, Jaldhaka, etc. are the tributaries of the Brahmaputra river. Mahananda is the main river meeting the Ganga in the north of the state. Mayurakshi, Ajoy, Damodar, Darakeswar and Kasai, are the tributaries to the river system of Ganga- Bhagirathi. The Subarnarekha river, which originated from Chhotanagpur Plateau, drains into to Bay of Bengal. Most of the rivers are southerly or southeasterly flowing and all major rivers are perennial in nature.

GEOLOGY

The state of West Bengal is covered by diverse rock types ranging from the Archaean metamorphites to the Quaternary unconsolidated sediments. Approximately two - third area of the State is covered by alluvial and deltaic deposits of Sub – Recent to Recent time and the remaining part abounds in a wide variety of hard rocks.

HYDROGEOLOGICAL SET UP

The entire West Bengal state can be grouped under two broad hydrogeological units, e.g.

- Porous hydrogeoological unit
- Fissured hydrogeological unit

<u>POROUS HYDROGEOLOGICAL UNIT:</u>

In The Zone Of Primary Porosity

Nearly two-third of the state is occupied by a thick pile of unconsolidated sediments laid down by the Ganga-Brahmaputra river system, thickness of which increases from marginal platform area in the west towards the east and southeast in the central and southern part of the basin following the configuration of the Bengal Basin. These unconsolidated sediments are made up of succession of clay, silt, sand and gravel of Quaternary age overlying Mio-Pliocene sediments. The Quaternary sediments are made up of recent and older alluvium. Occurrence and movement of ground water in this hydrogeological unit is controlled by the primary porosity of the sediments.

In The Zone Of Secondary Porosity

A thick profile of in situ soft porous material developed as a disintegration product on the upper most part of the hard, consolidated rock due to weathering. Weathering imparted secondary porosity to the hard rock which either has been compact or fractured at different places under different set of conditions. Weathered mantle derived from upper part of parental hard rock, varying in thickness from <1 m to 5 m in extra-peninsular region and from 5 to 15 m in peninsular region forms the depository of ground water as shallow aquifers in the area occupied by the hard rocks. Ground water in these depositories occur under unconfined condition, and in general developed by medium to large diameter open wells, depth of which varies according to the thickness of the weathered rock available. In the Himalayan hilly terrain, groundwater development by open wells tapping the weathered residuum, cannot be done as ground water moves away from the higher elevation to lower elevation very fast, resulting in the open well getting dry soon.

<u>FISSURED HYDROGEOLOGICAL UNIT</u>:

Fractures, Joints and other fissures form the secondary openings, through which ground water moves down the gradient, and occurs mainly under confined condition. These are developed in the cleaved Proterozoic gneisses and schists, Gondwana Super group of rock and Siwalik rocks of Extra- Peninsular region in Darjeeling and Jalpaiguri districts to the north and Archaean to Proterozoic gneisses and schists in Peninsular region occurring in western part of

Barddhaman, Bankura, Birbhum and northen part of Medinipur and entire Purulia districts and Gondwana and Purana sediments (Susunia quartzite of Bankura) deposited in the intracratonic basins in the shield area and Rajmahal basaltic traps in the eastern fringe area of the shield,

FORMATION WISE AQUIFER CONDITION IN WEST BENGAL:

In West Bengal aquifer characteristic varies considerably from north to south and west to east. Out of 341 blocks, by and large most of the areas show aquifer under both water table as well as confined condition. The entire coastal area consists of 59 blocks is under confined condition (29 blocks in S-24 Parganas, 5 blocks in N.24 Parganas, 9 blocks in Haora and 16 blocks in Purba Medinipur). Kolkata is also under confined condition. Hydrogeological Map of West Bengal has been prepared (Fig-I). Formation wise aquifer condition in the different districts is as under;

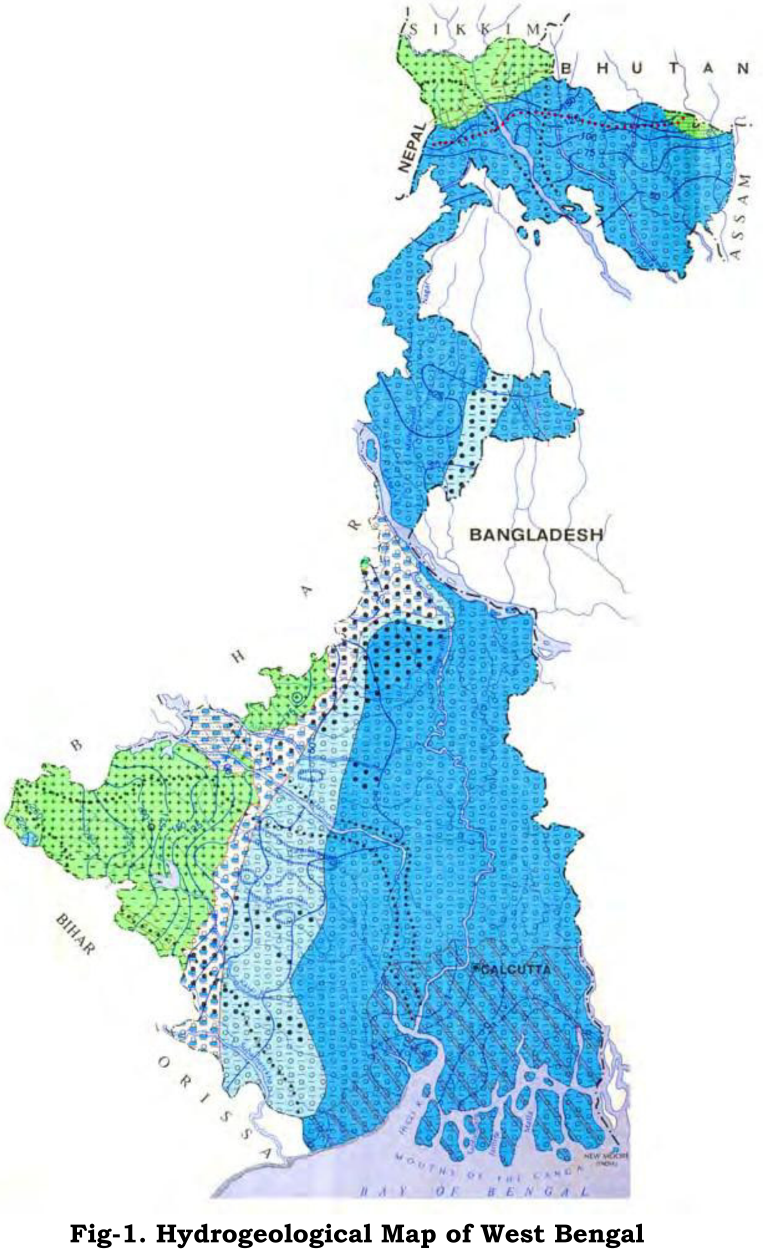

Fig-1. Hydrogeological Map of West Bengal

1. Consolidated Rocks Comprising Granite Gneisses, Phyllites, Quartzites, Limestone etc

i) Hilly terrain of Darjeeling & Jalpaiguri districts:-

Aquifer condition:-Groundwater development by open wells tapping the weathered residuum (thickness varies from <1-5 m) can not be done as groundwater moves away from the higher elevation to lower elevation very fast, keeping the open well dry. Groundwater development in deeper zone of secondary porosities has become very much limited due to the structural complexity of the rocks. Small and flat valleys are favourable sites for construction of bore wells. CGWB has taken a ground water exploration program in Mirik and established the existence of potential fractures in the depth span of 21 –33 & 50 – 68 m bgl. Yield of the bore well is 31.32 m^3/hr. The extension of subsurface water bearing joints/ fractures, when cut across surface topography, discharges ground water in the form of springs, which acts as the main source of water supply in the hilly terrain. During summer discharge in those springs diminishes. The discharge of such springs varies from 120 to 18,000 liter per hour.

Feasible Abstraction Structure:-Water supply is, in general, done through spring water. During peak summer months, discharges from springs & streams dwindle to a large extent & owing to non-availability of any alternative source, acute water scarcity affects the hilly terrain. In small valleys, the bore well sites may be selected by geophysical survey and constructed in such a manner that these may not have negative impact on the discharges of the springs.

Ground Water Development Strategy:- In order to mitigate water scarcity problem, properly designed small reservoirs at suitable sites, mainly in flat and gently slopped valley portion, may be constructed for conservation of rainwater with proper precautions (so that the stored rainwater does not get drained out) & proper treatment against bacteriological contamination may be undertaken before use. Roof top rainwater conservation is very much effective in the area as normal rainfall of the districts is 3212 mm.

ii) Western Platform area of Purulia, western part of Bankura, West Medinipur, Barddhaman & Birbhum districts.

Aquifer Condition:- Ground water occurs in weathered residuum of granitic and gneissic rocks, in general, between 5 & 15 mbgl may be tapped by dug wells. Yield of open wells is <10 m^3/hr. The weathered mantle is generally overlain by 8 to 10 m thick laterite at places, which form shallow aquifers for limited yield and acts as a zone of recharge. Potential fractures in granitic rocks within 70-100 mbgl having discharge to the tune of 10-20 m^3/hr. Transmissivity of the aquifers varies from 2 to 28 m^2/ day and Storativity from $1.6x10^{-4}$ to $6.91x\ 10^{-4}$.

Feasible Abstraction Structure:- In general, the following structures are feasible in the areas:
(i) Small or large dia open wells are feasible at topographic lows depending on the thickness of weathered zone and also depth to water level.
(ii) Bore wells tapping the fractures are feasible as identified within the depth range of 70 - 100 mbgl. Bore wells discharge in the range of 10 -20 m^3/hr. Sites may be selected where regionally extensive potential joints and fractures are identified through geophysical resistivity survey.
(iii) Dug-cum-bore well are feasible wherever thickness of weathered zone is thin/ not potential/ water level is deep.
(iv) Radial wells are expected to be successful on river beds where base flow component can be better utilized during summer months.

Ground Water Development Strategy :-Further ground water development should be planned considering the fact that in summer months shallow open wells contain little or no water due to higher water level fluctuations, poor potentiality of the formations and shallow depth of dug wells. In order to maintain sustained drinking water supply, even during the lean season, the dug/ dug-cum-bore wells may be constructed tapping the entire thickness of the saturated weathered residuum and part of the fractured rocks where a greater thickness of the saturated fractured rocks exist. Owing to steep slope, water drains out as surface runoff & base flow resulting in drying up the dug wells during peak summer months. In order to restore the water level in wells as well as to reduce the surface runoff, suitable rainwater harvesting structures may be constructed at suitable locales. In recent time, fluoride contamination in ground water in most of the areas has been reported. Hence before utilizing water from any structure, it should be ensured that water is free of fluoride contamination.

2. Gondwana Sandstone(Parts of Purulia, western part of Barddhaman & Birbhum)

Aquifer Condition:- Ground water occurs in weathered residuum of sandstones. The weathered profile varies from 12-20 m in thickness. Yield of open wells constructed in such residuum ranges between 5 & 15 m^3/hr. In sandstones belonging to Lower Gondwana group of rocks, bore wells tapping fractured zones down to the depth of 100 m may yield 10 to 25 m^3/hr of water with a maximum draw down of around 20 m. The heterogeneity of fractures has limited the scope of large-scale development of ground water in this part of the state.

Feasible Abstraction Structure:- Ground water abstraction structures like large dia open well, dug cum bore well, bore well and radial wells on the river beds, as enunciated above, are all feasible structures within sandstones as well. Gondwana sandstones are quite hard and compact and construction of deep bore well unlike other Gondwana Formations in the country, is done deploying DTH rig only.

Ground Water Development Strategy:- In the coalfield tracts of Durgapur and Asansol areas of Barddhaman district, the problems encountered are Seepages of ground water in the nearby mines causing drying up of majority of open wells, Seepages of contaminated water from mines into ground water, result in biological as well as chemical pollution, making the ground water unfit for domestic use. To minimize the problem & to augment the water supply, the following measures may be taken:

- Scope for conjunctive use of surface water and ground water in the area is to be explored.
- Utilization of additional surface water from the Damodar river in the area can minimize the chronic crisis in the supply of water.
- There is also a good scope for utilization of the water in the abandoned water logged mine shafts, pits etc. which after suitable treatment can be used for domestic and industrial purpose.
- Rainwater harvesting for conservation is very effective to mitigate the crisis of water supply in the coalfield area.

3. Rajmahal Trap -Inter-trappean Basaltic Rock (part of Birbhum district)

Aquifer Condition:-Ground water occurs in weathered residuum of basaltic rocks, in general within 12 meter below ground level (mbgl). Yield of ground water stored in the porous zone of the residuum and abstracted through open wells is of the order of 12 m^3/hr. Potential fractures in basaltic rocks in the depth range of 65-80 mbgl with discharge to the tune of 5-20 m^3/hr. Transmissivity of the aquifers varies from 10 to 40 $m^2/$ day and Storativity from $2x10^{-4}$ to $3.5x\ 10^{-4}$.

Feasible Abstraction Structure:- Ground water abstraction structures like large dia open well, dug cum bore well, bore well and radial wells on the river beds, are all feasible structures within basaltic rocks as well. DTH drilling is deployed for deep bore well drilling.

Ground Water Development Strategy:- Fluoride contamination in ground water in most of the basaltic rock areas has been reported. Hence before utilizing water from any structure, testing of water for fluoride contamination needs to be made mandatory before public consumption.

4. Tertiary Sediment of Siwalik Group of Rocks & Along Western Fringe Bordering Peninsular Shield

(In small patches in Himalayan Foothills of Darjeeling & Jalpaiguri districts and In extreme marginal part bordering Peninsular Shield in the districts of Birbhum, Bankura, West Medinipur & Barddhaman districts)

Aquifer Condition:- The Mio-Pliocene sediments of Siwalik Group of rocks in Darjeeling & Jalpaiguri districts are compact & is having very limited ground water prospect. In the marginal tract bordering Peninsular Shield, in the districts of Birbhum, Bankura, West Medinipur & Barddhaman districts, the Tertiary sediments are capped by laterites at places. The aquifers in Tertiary sediments are discontinuous with limited thickness & have lowest transmissivity. Yield of the tube well is, in general, $<50\ m^3/hr$. The thickness of the sediment increases towards east & south-east & is overlain by Quaternary Alluvium and ground water in the sediments occur under unconfined condition in the near surface aquifer & semi-confined to confined condition in the deeper aquifers.

Feasible Abstraction Structure:-Dug well & bore well/tubewell with very low yield are feasible.

Ground Water Development Strategy:- Ground water development needs to be carried out in a cautious manner using scientific tools to avoid failure as well as over stressing of the aquifers with limited prospect. Hydrological pumping tests need to be applied to ascertain the optimum yield that that can safely be extracted from the aquifers.

5. Unconsolidated/ Older Alluvium

i) Bhabhar zone in parts of Darjeeling & Jalpaiguri district

Aquifer Condition:-In the submontane zone of Himalaya, the sediments consist of assorted materials varying from boulders to sand of various grades. The water table in Bhabar zone is commonly as deep as 20 to 30 m along the foothill region, which is the recharge zone, but becomes shallow (<1.5 m bgl) in the down slope direction towards the spring line and are characterized by high seasonal fluctuation to the tune of 10-12 m. Yields of tube wells tapping this aquifer vary in general from 20 to 80 m^3/hr with a maximum drawdown of 20 m. The yield of the springs in the contact zone of Bhabar and Terai varies from 0.5 to 2 lps. Recent ground water exploration in Bhabar zone has identified the existence of potential granular zones within depth of 150 m bgl and tube well tapping these granular zones is capable of yielding up to 68 m^3/hr of ground water. Transmissivity of the aquifers varies from 130- 700 m^2/ day.

Feasible Abstraction structure:- Low to medium duty tube well of about 150 m depth having housing 40-80 m (depending on the pre-monsoon water level) yielding about 30-100 m^3/hr may be constructed. Favourable sites for construction of tube wells are in the valley and adjacent to the stream. For such areas percussion rig is suitable.

ii) Barind Tract parts of Malda, Dakshin- Dinajpur

Aquifer Condition:- Groundwater occurs under unconfined condition in the near surface aquifer and under semi-confined to confined condition below a blanket of 15 to 20 m thick discontinuous clay bed in the depth span of 90 - 110 m in most of the places, with moderate yield prospects of 50-150 m^3/hr. The water table is moderately deep with moderately high seasonal fluctuation. Depth to water level of the unconfined aquifer during pre monsoon varies from 5m to 20 m bgl. Transmissivity of the aquifers varies from 300-1500 m^2/ day.

Feasible Abstraction Structure:- In this area ground water may be developed through low to medium duty tube well of maximum 150 m depth. At places, considering poor potentiality of formations, large diameter dug wells of 10-15 m depth may be constructed

iii) Lateritic Terrain parts of Birbhum, Barddhaman, Bankura, Medinipur, Murshidabad

Aquifer Condition:- The area extends from plateau area in the west to the Recent Alluvial area in the east. The thickness of Older Alluvium increases from 30 m in the western marginal part to 150 m towards east with increasing groundwater potentialities of aquifers from 50 to 120 m^3/hr. Generally in the marginal alluvial areas, the Older Alluvium is overlain by Laterites. Individual aquifer in older alluvium is of limited thickness and discontinuous in nature. The water table is moderately deep with moderately high seasonal fluctuation. Depth to water level of the unconfined aquifer varies from 5 m to 10 mbgl. Exploration data reveals that at places, mainly in Birbhum district, unconsolidated to semi consolidated Tertiary sediments, overlain by Older Alluvium, occur in the depth span of 100-400 mbgl having yield prospect to the tune of 80-100 m^3/hr.

Feasible Abstraction Structure:- The following ground water abstraction structures are feasible:
- Big dia dug wells are feasible. If the dug wells are penetrated through the Laterites down to the lithomargic clay, chances for drying up the wells are less.
- Medium duty tube wells (about 100 m^3/hr) in the depth zone of 100-400 m depth are feasible.

- Collector wells with radial infiltration galleries in stream bed tapping considerable thickness of sand bed are feasible.

Ground Water Development Strategy for Unconsolidated/ Older Alluvium Formations

- Ground water development in some blocks in Older Alluvial areas, falling under "Semi-critical" category, may be done with caution and in a phased manner. Based on the results of monitoring of water levels and trend of water levels during different seasons consequent to ground water development, additional development can effectively be planned.
- In Bhabar zone and Barind tract, rainwater harvesting for conservation can play an important role in solving water crisis. The ponds to be utilized for rainwater conservation need to be protected from seepages. In the western part of the State, covered by Older Alluvium, rainwater harvesting, both for conservation and for artificial recharge to groundwater are feasible. On small scale even the conserved rainwater can be utilized for drinking purpose by filtering through Horizontal Roughing Filters.
- High concentration of iron has been reported in ground water at places and in order to make the water potable, proper elimination plant is required.
- Although, arsenic contamination of ground water is yet to be reported from the formations comprising older alluvium, fluoride contamination has been quite prevalent in some of the areas of Barind tract as well as in western Older Alluvial areas. Hence testing the water for fluoride contamination, needs to be made mandatory before public consumption. Available Fluoride removal technology including indigenous 'Nalgonda Technique', may be adopted.
- Large scale development of ground water in the older alluvium especially in the western margin is not feasible. However towards the east, higher discharges are available when cumulative thickness of both older and tertiary aquifers are screened. Water level in flowing wells fluctuates within wide limits during different seasons and at places at times, it rests below the ground surface. Therefore the prospect of utilization of flowing wells without energization is limited. Also, the flowing wells not necessarily provide sustained discharge at higher rate. Development of flowing wells needs to be done accordingly.

6. Unconsolidated / Recent Alluvium (Parts of Darjeeling, Jalpaiguri, Coochbehar, Uttar & Dakshin Dinajpur, Malda, Murshidabad, Nadia, North 24 Parganas, Hugli, Haora, West & East Medinipur, Barddhaman Bankura, Birbhum)

Aquifer Condition:- Ground water occurs both under unconfined & confined condition within the maximum explored depth of 600 m bgl. Aquifers are fairly thick & regionally extensive with large yield prospect of about 150 m^3/hr. The occurrence of Arsenic in ground water within 100 mbgl, restricted mainly in the eastern part of Bhagirathi river, has posed a serious problem. In view of the situation, exploration work has been undertaken in the arsenic infested areas & arsenic free deeper aquifers could be identified beneath a thick clay bed in Murshidabad, Nadia, North 24 Parganas districts.

Feasible Abstraction Structure:- The following ground water structures are feasible in the area:
- Heavy duty tube wells (>100 m^3/hr) of 150-300 m depth with housing about 35-40 m, if fitted with 18-20 HP pump may yield about 150-200 m^3/hr.
- Low duty tube well (50 m^3/hr) of 60 m depth tapping cumulative 8-10 m thick granular zones & fitted with 5 HP centrifugal/ submersible pump (depending on the depth to water level), may yield around 30 m^3/hr.
- Wherever aquifer is unconfined and depth to water level is shallow, dug wells are also feasible.

Ground Water Development Strategy:- In parts of Malda, Murshidabad, Nadia, North 24 Parganas, Hugli & Barddhaman districts where high arsenic in shallow aquifers are reported, the shallow tube wells should be avoided. In these areas, the deeper aquifers (beyond 100 m depth), which are expected to have arsenic content in ground water within permissible limit may be screened with cement/ clay sealing against a thick clay horizon above the aquifers tapped. In these areas, regulated ground water development with advanced planning is required.

7. Unconsolidated / Recent Alluvium (Coastal areas/, North 24 Parganas, South 24 Parganas, East Medinipur, Haora and Kolkata)

Aquifer Condition:- In general, occurrence of fresh ground water bearing aquifers at depths 180-360 m bgl within the drilled depth of 600 mbgl has been established. The fresh group of aquifers is sandwiched between saline/brackish aquifers. The top saline/ brackish aquifer lies within the depth span of 20-180 m with maximum depth of 320 mbgl in the extreme south. Suitably constructed tube well tapping 35 m cumulative thickness within the depth span of about 180-360 mbgl, to be identified with the help of geophysical survey, can yield 100-150 m^3/hr. Proper cement sealing is required to be placed against a clay layer above the zone to be tapped, in order to prevent vertical percolation of brackish water. Shallow fresh water aquifers occur in present day dunes in Digha-Ramnagar area of Medinipur district. down to the depth of 9 mbgl. Shallow fresh water aquifers also occur in levee deposit within 50 mbgl in Baruipur-Sonarpur-Bhangar-Caning tract in South 24 Parganas. High concentration of arsenic in ground water is reported in this levee deposit.

Feasible Abstraction Structure:- In 15 coastal blocks of Purba Medinipur district, potable water bearing aquifers occur within the depth range of 120 to 300 mbgl, sandwitched between saline aquifers. Medium to heavy-duty tube wells tapping this potable water-bearing aquifers may be constructed with suitable design providing proper cement sealing to get discharges in the ranges of 80 to 250 m^3/ hr. In 5 coastal blocks of N 24 Parganas district and in all blocks of S 24 Parganas district, potable water bearing aquifers occur within the depth range of 160 to 330 mbgl and medium to heavy duty tube wells tapping these aquifers may be constructed with suitable design providing proper cement sealing. The wells discharge in the ranges of 80 to 250 m^3/ hr. In general in 9 coastal blocks of Haora district, potable water bearing aquifers occur within the depth range of 170 to 225 m bgl. Heavy-duty tube wells tapping these aquifers may be constructed with suitable design providing proper cement sealing. These wells may discharge in the ranges of 170 to 230 m^3/ hr. In Digha-Ramnagar area, the near surface aquifer can be developed for drinking water supply through shallow tube well in a very limited scale. In coastal areas saline water may be used after blending with fresh water. Cautious approach towards development of ground water has also to be adopted to restrict landward migration of saline water /fresh water wedge. In KMC and Haldia Industrial Areas withdrawal of groundwater is to be regulated. The depleted aquifers need to be replenished artificially by rainwater harvesting.

Ground Water Development Strategy:- In coastal areas, the aquifers containing potable water occur under confined condition and while constructing the tube wells the upper zones containing brackish/saline water are to be separated out from the deeper zones to be tapped (with the help of geophysical survey) by providing clay/cement sealing. Cautious approach towards development of ground water has also to be adopted to restrict landward migration of fresh water /saline water wedge.

GROUND WATER LEVEL SCENARIO IN WEST BENGAL

During pre- monsoon, 2007, major part of the state shows depth to water level ranging from 2 to 5 m (33%) and 5 to 10 m (45%) below ground level. A considerable area along Hasimara - Jaigaon section in northern part of Jalpaiguri district falling under “Bhabar” zone, deeper water level with maximum value of 11.75 m below ground level has been recorded. Comparatively deeper water levels have also been recorded in "Barind" tract of Malda district (where maximum water level has been recorded to the tune of 14.70 m below ground level), western part of the river Bhagirathi in Murshidabad district, eastern part of Barddhaman district, western part of Hugli district, and a considerable area in West Medinipur districts. In the coastal tract of the State (South 24 Parganas, parts of E. Medinipur, Howrah, North 24 Parganas) the Piezometric surface mainly lies between 2.0-5.0 mbgl and 5.0-10.0 mbgl. However, in some parts of East Medinipur, the piezometric surface ranges from 10.0 to 20.0 mbgl. During post monsoon, 2007 the depth to water level, in general, ranges between 2 & 5 m bgl in major part of the state, except in 'Barind' tract of Malda district, 'Bhabar' zone of Jalpaiguri district and western part of the Bhagirathi river covering Murshidabad, Hugli, Birbhum districts and eastern part of Barddhaman district, underlain by Older Alluvium formation, where deeper water level has been noticed. The pieizometric surface in parts of South 24-Parganas and coastal part of Medinipur and Haora districts ranges between 2 and 10 m below ground level. Ground water level scenario in West Bengal has also been depicted in the fig-II a,b&c,.

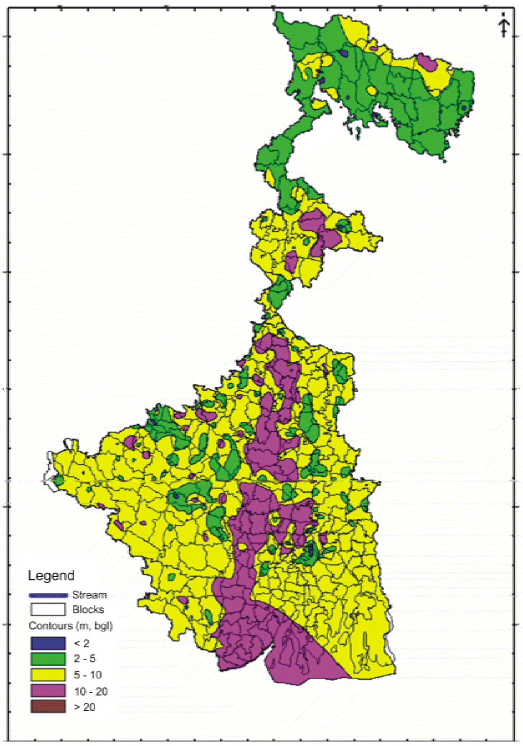

Fig-II a Depth to Water Level Map – Pre-monsoon 2007

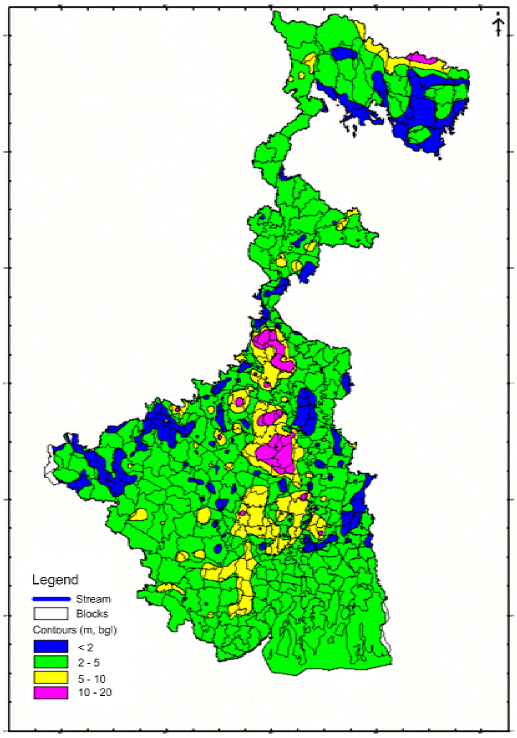

Fig-II b Depth to Water Level Map – Post-monsoon 2007

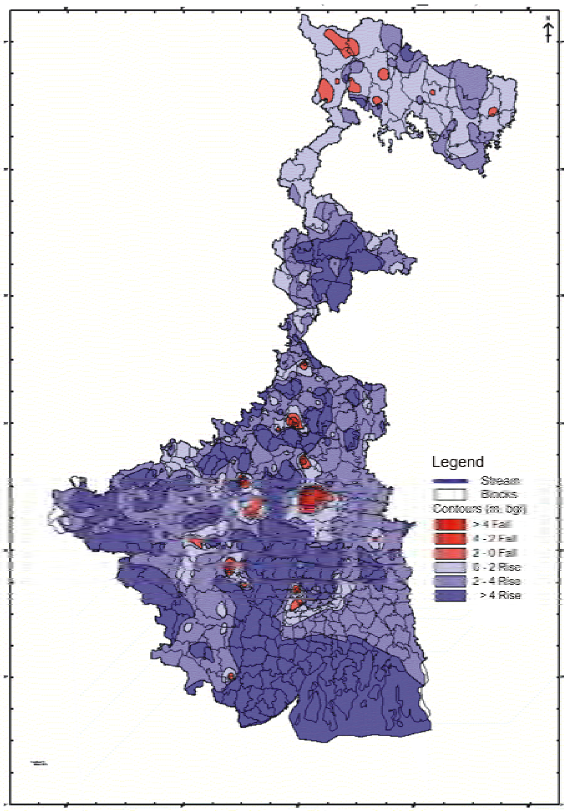

Fig-II c Water Level Fluctuation Map (Pre-Post Monsoon2007)

Long term behavior of water level:

By comparing the water level data for April Mean (1997-2006) with the depth to water level data of April 2007, the entire state of West Bengal, in general, shows the rise (43.17%) and fall (58.11%) in water level. Fluctuation is recorded mainly within 2 m, though at few places 6.83% rise and 1.42% fall were recorded in the range of 2 - 4 m. Higher magnitude of fluctuation (3.31% fall and 3.61 % rise) is also recorded sporadically in few wells. Long term behavior of water level has also been depicted in Fig-III a & b.

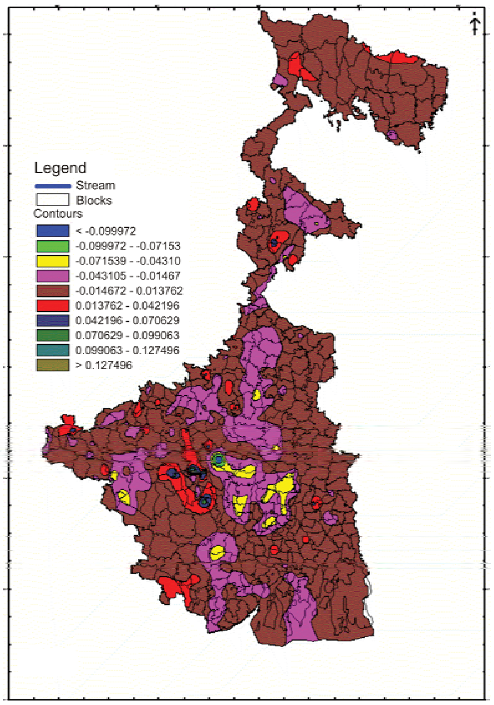

Fig-III a Depth to Water Level Trend Map Pre- monsoon (1997-2007)

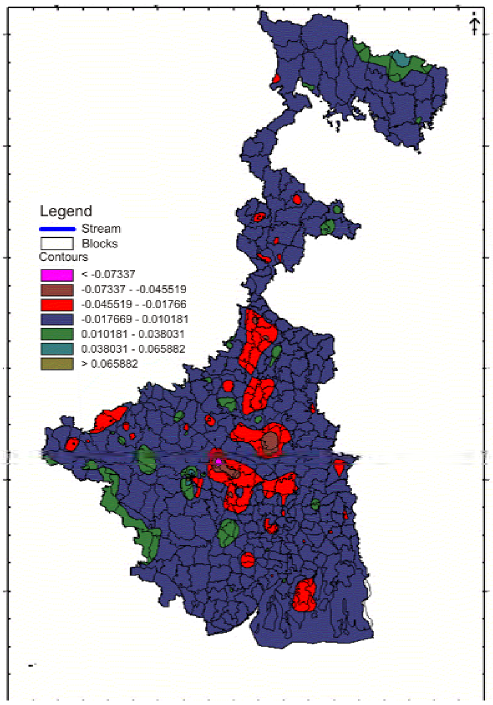

Fig-III b Depth to Water Level Trend Map Post- monsoon (1997-2007)

CHEMICAL QUALITY OF GROUNDWATER

Groundwater is, in general, neutral to slightly alkaline type and Calcium-Magnesium-Bicarbonate type, Sodium Bicarbonate type in South 24 Parganas district and Calcium—Magnesium-Chloride type in Kolkata and some isolated patches. Specific Conductance of ground water, in general, ranges between <500 and 2000 micromhos/ cm at 25°C. However, Specific Conductance of the deeper aquifers in the southern part of the state lying in the coastal tract varies from 1000 to 2000 micromhos/cm at 25°C, whereas the upper aquifers in the same tract shows that the value of Specific Conductance increases towards southeast from 5000 micromhos/cm in the northwest to 20000 micromhos/cm at 25°C in the southeast. Chloride value has been found generally below 250 mg/lt in the state except in the coastal areas where chloride content of the upper aquifers increases towards southeast direction ranging between 2000 & 6000 mg/l. Iron content in ground water in the entire state is in general less than 1.0 mg/l, except in some isolated patches of the most of districts, where ground water in near surface aquifers have iron as high as more than 3.00 mg/l, even more than 10.00 at few places. High concentration of arsenic (above the permissible limit of 0.05 mg/l) in shallow aquifers within 100 mbgl has been reported as sporadic occurrence in 79 blocks of eight (8) districts. In West Bengal, high concentration of fluoride (above 1.5 mg/l) in ground water has been observed in 8 districts.

GROUND WATER RESOURCES IN WEST BENGAL

Based on the GEC 1997 methodology (and subsequent modification in norms of categorisation as suggested by the R & D Committee on ground water assessment) and considering 3rd M.I. Census, 2000-01, projected upto March, 2004, dynamic ground water resources as on March, 2004 has been estimated for 269 blocks out of 341 blocks of West Bengal leaving aside 13 mountainous / sub-mountainous blocks of Darjeeling and Jalpaiguri districts (considering more than 20% slope) and 59 blocks in the coastal tract (29 blocks in South 24 Parganas, 5 blocks in North 24 Parganas, 9 blocks in Haora and 16 blocks in Purba Medinipur districts) where ground water predominantly occurs in confined condition.

The reconciled State figures for net ground water availability, gross ground water draft for all uses, current annual ground water draft for irrigation and domestic & industrial uses, stage of ground water development, annual allocation of ground water for domestic & industrial water supply upto next 25 years. and net ground water availability for future irrigation use are as under:

	Figures in m ham
➢ Total Ground Water Recharge	3.036
➢ Unaccounted Ground Water Discharge	0.29
➢ Net Ground Water Availability	2.746
➢ Gross Ground Water Draft for All Uses (as on March, 2004)	1.165
• Current Annual Ground Water Draft for Irrigation	1.084
• Current Annual Ground Water Draft for Domestic & Industrial Uses	0.081
➢ Stage of Ground Water Development (%)	42
➢ Annual Allocation of Ground Water for Domestic & Industrial Water Supply upto next 25 yrs	0.124
➢ Net Ground Water Availability for 'Future Irrigation Use'	1.532

Based on stage of ground water development and long term pre and post monsoon water level trend, 37 blocks have been categorized as Semi-critical and one block Critical, rest of the blocks (231 nos.) are under 'Safe' category. The list of districts indicating the number of Semi-critical and Critical blocks is given in the Table –II

Table II List of Semi-critical and Critical blocks of West Bengal

S.NO	DISTRICT	BLOCKS CATEGORISED AS	
		SEMI-CRITICAL	CRITICAL
1.	Barddhaman	6 (Bhatar,Ketugram I, Mangalkot, Memari II, Monteswar, Purbasthali II)	-
2.	Birbhum	4 (Nalhati II, Nanoor, Murarai II & Rampurhat II)	-
3.	Hugli	2 (Goghat I, Pandua)	-
4.	Malda	2 (Harischandrapur II, Kaliachak I)	-
5.	Medinipur (West)	1 (Daspur II)	-
6.	Medinipur (East)	1 (Moyna)	-
7.	Murshidapur	15 (Barwan, Berhampur, Bhagabangola I & II, Hariharpara, Jalangi, Lalgola, Mur-Jiaganj, Nowda, Raninagar I, Bharatpur I, Suti II, Sagardighi, Domkal and Nabagram)	1 (Bharatpur II)
8.	Nadia	6 (Chapra, Hanskhali, Karimpur I & II, Tehatta I & II)	-
TOTAL		**37**	**1**

VARIOUS ISSUES OF GROUND WATER DEVELOPMENT

The various issues emerged during Ground Water Development in West Bengal are:

- Chronically water scarce area in western part and in hilly tract in the northern part of the State.
- The area where depletion in water level has been ascertained.
- Hazards due to mining activity in Coal mine area
- Area falling under geogenic contamination:

Chronically Water Scarce Areas in Western Part and in Hilly Tract in the Northern Part of the State:

The districts of Purulia, western part of Bankura, Birbhum, Barddhaman, Paschim Medinipur face acute scarcity of water, mainly during the lean period due to limited yield potential of available aquifers. However, potential deep fractures have been identified in these districts and and successful borewells have been constructed by CGWB. The water crisis can also be tackled to a large extent by following;

- Developing ground water with suitable abstraction structures (including radial well) by selecting sites through hydrogeological and geophysical survey.
- Rainwater harvesting both by means of conservation and artificial recharge to groundwater. Recent study in the Purulia Ramkrishna Mission Vidyapith has established that conservation of rainwater from roof top as well as land surface can cater to a huge amount of water requirement for the Vidyapith (CGWB)

In hilly tract in parts of Darjeeling district, acute scarcity of drinking water is experienced during peak summer months due to dwindling of spring discharge. Technical guidance has been rendered by CGWB in the construction of rain water conservation structures in Raj Bhavan compound, Darjeeling town, to augment existing water supply.

The Area Where Depletion in Water Level Has Been Ascertained:

- In KMC area, the piezometric surface in the Central Kolkata has been lowered to the tune of 5-9 m in the last 40 years forming a huge ground water trough due to withdrawal of ground water in excess of replenishment. Depth to piezometric level in the area varies from 3.34m to 16.32 m bgl in pre monsoon period and from 1.57m to 15.71m bgl in post monsoon period. Long term analysis of piezometric level data also shows a distinct falling trend of piezometric level in both pre and post monsoon period. A recent project of artificial recharge to deeper confined aquifer using roof top rainwater in KMC area (Baishnab-Ghata Patuli) has been proved to be very successful.

- The Haldia Industrial Complex area falls in the coastal plains of West Bengal and fresh aquifers occur in the depth span of 120-300 mbgl. The piezometric level of the fresh ground water in the area lies within 7-15 m bgl. Study indicates that there is a distinct lowering of piezometric level of the fresh ground water to the tune of 5-7 m during last three decades due to heavy withdrawal of ground water from large number of heavy duty tube wells constructed by several organizations. As a result of this heavy withdrawal of fresh ground water, a ground water trough has been formed in the area close to the river Hugli. In order to avoid probability of sea water ingress into the aquifers, the same aquifers have been notified under CGWA to restrict withdrawal of ground water from the aquifers.

Hazards due to Mining Activity in Coal Mine Areas

In coalfield tracts of Durgapur-Asansol areas of Barddhaman district, seepage from ground water occurs in the nearby active mines, resulting in declining of water levels, drying up of majority of open wells during summer months and even in modification of the ground water flow pattern to a large extent. Hence, in future plan, ground water development. may be restricted principally for drinking purpose with proper water resources assessment and also its proper treatment to mitigate chronic shortage of water in summer months.

Area Falling Under Geogenic Contamination:

- **High arsenic in ground water:**

Arsenic contamination in ground water (more than 0.05 mg/l) occurs in isolated patches spreading over 79 blocks in eight districts namely, Malda, Murshidabad, Nadia, North 24 Paraganas, South 24- Paraganas to the east and Haora, Hoogly and Bardhaman to the west of Bhagirathi/ Hoogly river. Eastern part of Bhagirathi/ Hoogly river is much more affected than the western part. At present about 162.6 lakh populations occupying 17533 numbers of habitats are in the risk zone. In the arsenic infested areas of West Bengal the arseniferous aquifer lies mainly within the shallow depth (10 – 100 mbgl) . The topmost surface zone is free from arsenic. Deeper aquifers (> 100 mbgl) in the same area are generally free from arsenic. Ground water in arsenic affected area is characterized by high iron, calcium, magnesium, bicarbonate with low chloride, sulphate and fluoride.

The probable cause of arsenic contamination of ground water is leaching of geological materials with the arsenic and dissolution of unstable arsenic minerals. Adsorption and desorption and chemical transformations have also played a major role in the arsenic mobilization. Ground water exploration (CGWB) in Arsenic affected area reveals-

- Three aquifer systems have been identified within 100 mbgl, 120 – 160 mbgl and 200 –250 mbgl.
- The top aquifer within 100 m bgl is mostly arseniferous whereas both deeper aquifers which are separated by a thick clay (>10 m) from the overlying aquifers, are arsenic free. The thickness of clay layer (10-20 m), which acts as a barrier to arrest the transport of arsenic, is another significant factor in effectively separating shallow arseniferous aquifer from the deep arsenic free aquifer.
- Arsenic free deeper aquifers (below 100mbgl) are potential with a yield prospect of 5 to 20 lps which can cater to the need of both rural and urban water supply.
- Proper design of the well including cement sealing which has been adopted plays an important role in safe withdrawal of water from the deeper aquifer preventing arsenic rich water from the upper contaminated aquifer to percolate down to the deeper aquifer.

In arsenic infested areas of West Bengal the most common mitigation measures are Supply of treated surface water, Supply of Arsenic free ground water from the arsenic free deep aquifer and Use of Arsenic removal units attached with tube wells.

- **High Fluoride in Ground Water**

Groundwater contaminated with high concentration of fluoride has got sporadic occurrence. The Task Force on Fluoride Contamination had recommended rapid assessment of fluoride concentration in ground water in 105 blocks of 12 districts of West Bengal. After the assessment, the final scenario regarding the high fluoride concentration(more than 1.5 mg/l) in ground water of West Bengal has been observed in 8 districts, namely Bankura, Bardhman, Birbhum, Purulia, Malda, Uttar Dinajpur, Dakshin Dinajpur and South 24 Parganas. However this problem is most serious in Bankura, Birbhum, Purulia and Dakshin Dinajpur districts.

Ground Water Survey & exploration(CGWB) in fluoride contaminated area reveals that fluoride occur with different rock types as follows:

- In bore wells within 50-80 m depth in fractured granitic rocks in affected blocks of Purulia, Bankura and Birbhum districts.
- In bore wells within 30 m depth in Gondwana sediments in Khyrasol block of Birbhum district, below first coal seam.
- In bore wells within 50-80 m depth in Basaltic rocks including inter-trappean in Rampurhat-I & Nalhati-I blocks in Birbhum district.
- In tube wells within the depth of 20-80 m in Older Alluvium in affected blocks of Bankura, Uttar Dinajpur, Dakshin Dinajpur and Birbhum districts.
- In tube wells within the depth of 50-70 m in Recent Alluvium in Ratua-II, Bamangola blocks of Malda district and Baruipur block of South 24 Parganas district.

In Fluoride infested areas of West Bengal the most common mitigation measures are Supply of treated surface water, Supply of Fluoride free ground water from the Fluoride free aquifer and Use of Fluoride removal units attached with tube wells.

- **High salinity**

Based on the geophysical surveys and ground water exploration, Brackish to saline and fresh water bearing aquifers have been deciphered in the different depth zones in Kolkata Municipal Corporation area, South 24 Parganas and in parts of North 24 Parganas, Haora and Purba Medinipur districts. Considering the findings of surveys and exploration Tube well were constructed in the fresh water bearing aquifers with proper design including cement sealing which played an important role in safe withdrawal of water from the deeper aquifer preventing saline water from the upper saline aquifers to percolate down to the deeper fresh aquifers.

- **High Iron in Ground Water**

Iron content in ground water in the entire state is in general less than 1.0 mg/l. However, in some isolated patches of most of the districts te iron concentrations are found to be in the order as high as more than 3.00 mg/l, even more than 10.00 at few places. Iron removal plants are in operation at many a places.

CONCLUSIONS

- Considering hydrogeological conditions, geomorphological set up, ground water resources potential, present stage of ground water development and ground water pollution, the strategy for further ground water development has been formulated.
- In the hard rock terrain in the Western Plateau, in order to cater to the sustained drinking water supply, even during the lean season, the dug/ dug-cum-bore wells may be constructed tapping the entire thickness of the saturated weathered residuum and part of the fractured rocks where a greater thickness of the saturated fractured rocks exist.
- In coalfield tracts of Durgapur-Asansol areas of Barddhaman district, seepage from ground water occurs in the nearby active mines, resulting in declining of water levels, drying up of majority of open wells during summer months In future ground water development, may be restricted principally for drinking purpose. However in coal mining areas rainwater conservation may be recommended. On small scale even the conserved rainwater can be utilized for drinking purpose.
- In hilly terrain of Darjeeling and Jalpaiguri area, water supply is mainly based on spring water. Considering the water crisis during summer months, rainwater and spring water conservation at proper locations in different types of reservoirs are to be encouraged and is to be utilized with proper treatment. In small valleys bore wells supported by geophysical

survey can be attempted. However development of groundwater should not disturb discharges from springs.

- In Bhabar zone Ground Water may be developed through low to medium duty tube wells down to a depth of about 150 m having housing of about 40-80 m length (depending on pre-monsoon water level).
- Ground water development in some blocks in Older Alluvial areas, falling under "Semi-critical" category, may be done with caution and in a phased manner so that based on the results of monitoring of water levels and trend of water levels during different seasons consequent to ground water development, additional development can be effectively planned.
- In Bhabar zone and Barind tract, rainwater harvesting mainly for conservation can play an important role in solving water crisis. The ponds to be utilized for rainwater conservation need to be protected from seepages. In the western part of the State, covered by Older Alluvium, rainwater harvesting both for conservation and for artificial recharge to groundwater are feasible. On a small scale, even the conserved rainwater can be utilized for drinking purpose by filtering through Horizontal Roughing Filters.
- The central part of West Bengal is covered by Recent Alluvium and in general, the feasible structures are:-i)Heavy duty tube wells of around 150-300 m depth with housing about 35-40 m, if fitted with 18-20 HP pump may yield about 150-200 m^3/hr. ii)Low duty tube well of 60 m depth tapping cumulative thickness of granular zones from 8-10 m, fitted with 5 HP centrifugal/ submersible pump (depending on the depth to water level), may yield around 30 m^3/hr.
- In arsenic infested areas, the shallow tube wells are to be avoided. In these areas, the deeper aquifers (beyond 100 m depth), which are expected to have arsenic content in groundwater within permissible limit, may be tapped with cement/ clay sealing above the aquifers tapped, providing against a thick clay horizons. In these areas controlled ground water development is required.
- In coastal areas the aquifers containing potable water occur under confined condition and while constructing the tube wells the upper zones containing brackish/saline water are to be separated out from the deeper zones to be tapped (with the help of geophysical survey) by putting clay/cement sealing. Cautious approach towards development of ground water has also to be adopted to restrict landward migration of sea wedge.

ACKNOWLEDGEMENT

The authors are extremely indebted to Shri B.M.Jha, Chairman, Central Ground Water Board for his kind permission for publication of the paper. They express their heartfelt gratitude to Dr S.C.Dhiman, Member (SML) for constant encouragement in preparing the paper. The authors take the opportunity to place on record their deep sense of gratefulness to Smt Sipra Bandyopadhyay, Senior Hydrogeologist, CGWB, ER, for rendering her valuable suggestions during the analysis of the data incorporated and her esteemed opinion throughout the compilation of this paper.

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SOME RECENT ADVANCES IN UNDERSTANDING THE GROUNDWATER RESOURCES OF GANGETIC WEST BENGAL

Abhijit Mukherjee*

INTRODUCTION

West Bengal is the 13th largest state of India with an area of ~2.8% (88752 km^2) of its land, while hosting 4th highest population (7.8%) and highest population density (904 people/km^2) (Census, 2001). Major portion of this population rely on groundwater for their drinking, domestic, and irrigational water use in addition to prolific industrial consumption. Hence, in recent times, a disproportionate stress is building up on the groundwater resources of West Bengal. The Gangetic West Bengal (GWB) or western parts of the Bengal basin (WBB), comprises of the modern delta of the rivers Ganges and Bhagirathi-Hoogly, encompassing the southern districts of Murshidabad, Nadia, North and South 24 Parganas, and hosting more than 50% of this population in an area of only ~22,000 km^2 (i.e. a little more than 25% of total land of West Bengal), have a more severe scenario because of its higher population density and water quality issues. In this article, an effort is made to compile existing information and summarize recent advancements on the knowledge of groundwater condition of the GWB (Figure 1).

HYDROCLIMATOLOGY AND RECHARGE

In general, groundwater flow in GWB is strongly influenced by the heavy rainfall caused by the southeast monsoon wind from mid-June to mid-October originating from the Bay of Bengal. Annual rainfall ranges from about 125 cm in the northwest-central part of the basin to ~160 cm near the Bay of Bengal. In the GWB, the average pre-monsoon rainfall (January to May) is 16.23% of annual rainfall, monsoon rainfall (June to October) is 82.21%, and post-monsoon (November-December) is 1.57% (Mukherjee, 2007a). The average temperature is about 30 °C in the summer and about 15 °C in the winter. Monsoonal rainfall and the water from Himalayan snowmelt carried by the Ganges, Bhagirathi-Hoogly and its tributary/distributaries cause extensive, damaging floods in the lowlands, which are mostly parts of older or neo-Bengal delta.

Everywhere on the delta plain, precipitation exceeds annual potential evapotranspiration (Allison, 1998). Recharge has been estimated to range from 0.3 to 5.5 mm/d (BGS/DPHE, 2001) and an average 1.6 mm/day annually (Basu et al., 2001; Dowling et al., 2003) for the whole of the Bengal basin. According to SWID (1998), recharge would be ≤ ~223 mm/year (15% of mean annual precipitation). Rangarajan and Athavale (2000) determined a mean natural recharge rate of 198 mm/year (13.6% of annual precipitation) from their study area in North 24 Parganas in 1995 using a tritium injection method. On the basis of more than 100 years of historical climatological data, Mukherjee et al. (2007a) calculated the mean annual potential recharge (PR) for GWB as 587 mm/year or 1.61 mm/day (range: 384–767 mm/year), which is 39% of the mean annual rainfall. Because of heavy monsoonal rainfall, most of the PR is during monsoon season (mean: 3.67 mm/day, range 2.41–4.86 mm/day), with little to no recharge during the pre-monsoon (mean: 0.18 mm/day, range 0.15–0.25 mm/day) and post-monsoon (mean: 0.06 mm/day, range 0.05–0.08 mm/d). The estimated annual mean absolute recharge from precipitation is 0.41 to 0.58 mm/m^2/day (Mukherjee et al., 2007a). However, a large part of the water that is abstracted for irrigation (annual mean: 1.2 mm/m^2/day) may

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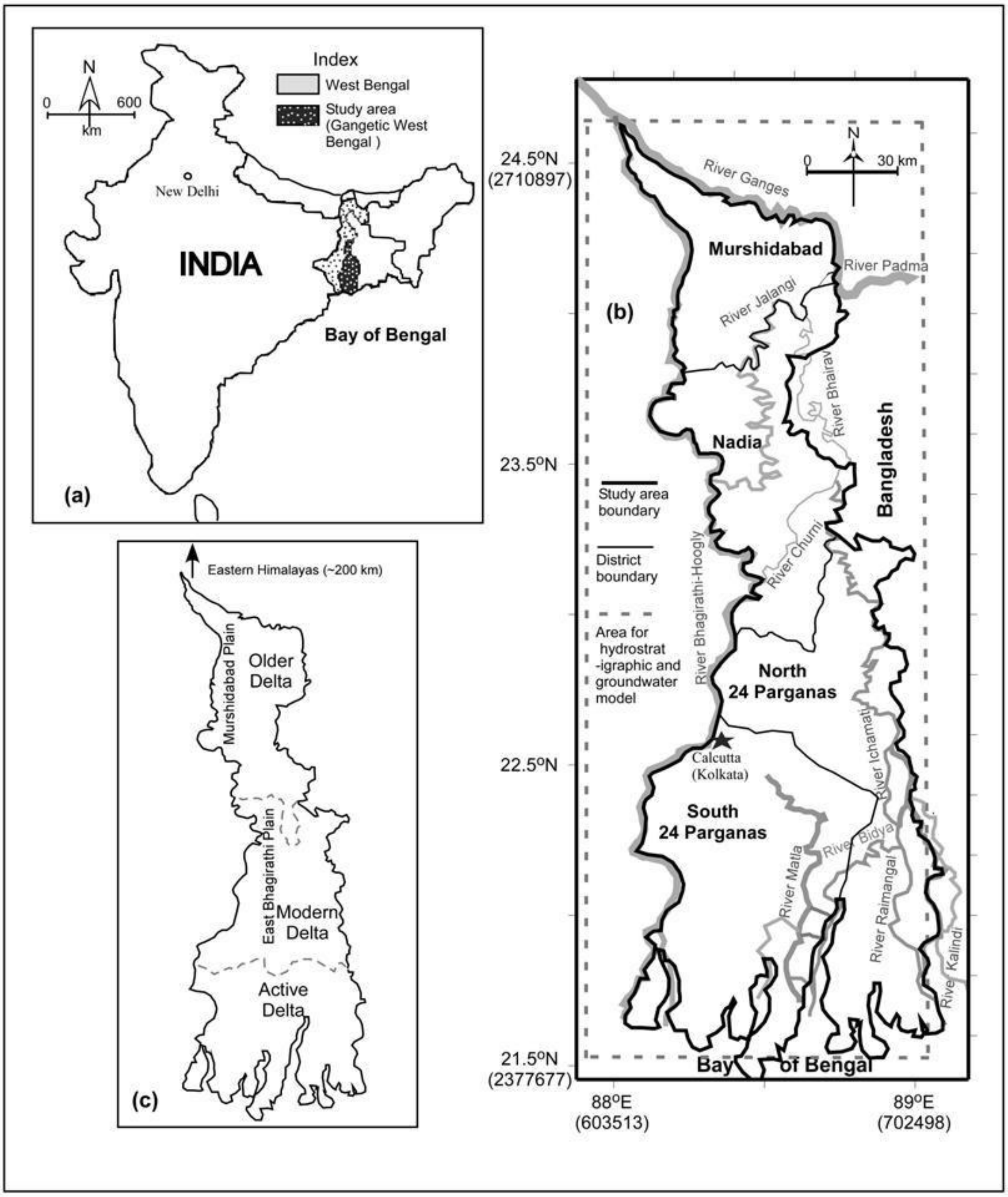
return to the groundwater as non-meteoric recharge (annual mean: 0.75 $mm/m^2/day$) (Mukherjee et al., 2007a). Using the calculated volume of the aquifer in the hydrostratigraphic model and assuming a porosity of 0.2 (Harvey 2002), Mukherjee et al. (2007a) estimated the volume of groundwater under aquifer-full conditions would be ~ 4.5×10^{11} m^3. The estimated total recharge for the study area is between 9.4×10^9 and 1.3×10^{10} m^3 each year, which is ~2% of the total groundwater resource of the area.

Figure 1: Map of the study area (Gangetic West Bengal)



Characterization of stable isotopic ($\delta^{18}O$-$\delta^{2}H$) composition of rainfall (Figure 2) shows that the local meteoric water line ($\delta^{2}H = 7.2\ \delta^{18}O + 7.7$) is very similar to the global meteoric water line ($\delta^{2}H = 8\delta^{18}O + 10$) of Craig (1961), and the slope of the line agrees well with average Indian monsoonal precipitation composition of Krishnamurthy and Bhattacharya (1991) (Mukherjee et al., 2007b); with pre-monsoonal rainfall composition being much more isotopically enriched ($\delta^{18}O$: 0.3 to 4.4‰) than monsoonal rainfall (-9.3 to -0.5‰), indicating a local moisture source rather than the Bay of Bengal (Mukherjee et al., 2007b)

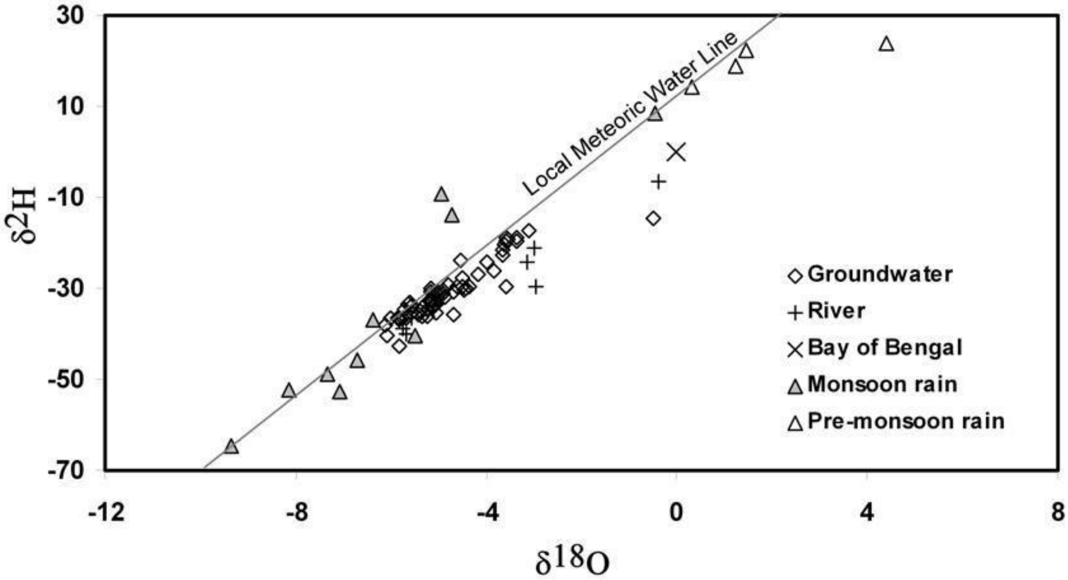


Figure 2: Bivariate plot of $\delta^{18}O$ and $\delta^{2}H$ for rainwater, river water, sea water and groundwater samples from the study area (after Mukherjee et al., 2007b)

HYDROSTRATIGRAPHY AND FLOW DYNAMICS

In various attempts to define the Aquifer-aquitard structure of the Bengal basin, the aquifer systems have been mostly classified by lithology and depth at the basin scale (e.g. UNDP, 1982; AIP/PHED, 1991, 1995; CGWB, 1994, 1997; SWID, 1998). However, stratigraphy has also sometimes been considered in smaller scale models (Ravenscroft, 2003). The difference in these processes of classification makes aquifer correlation across the basin challenging. Besides classifying the aquifers by lithology, some recent workers have suggested divisions based on the apparent age of the groundwater. Aggarwal et al. (2000) considered groundwater recharged within the past 100 years to reside in the first (shallowest) aquifer (70 to 100 m deep). Groundwater about 3000 years old is inferred to reside in the second aquifer, which extends to 200-300 m bgl, whereas water about 20,000 years old resides in the third aquifer, below 200-300 m bgl. However, Aggarwal et al. (2000) noted that depth cannot be a dependable criterion for this classification of the aquifers.

In one of the most comprehensive groundwater studies, BGS/DPHE (2001) proposed five major aquifer systems for Bangladesh part of the Bengal basin These classification is also suited for the West Bengal. These are:

a) late Pleistocene to Holocene Tista mega-fanglomerate and Brahmaputra channel basal gravel aquifers composed of coarse sand, gravels, and cobbles;

b) late Pleistocene to Holocene Ganges, lower Brahmaputra and Meghna main-channel shallow aquifers composed of braided and meandering river sediments;
c) early to middle Pleistocene coastal and moribund Ganges delta deep aquifers composed of stacked, main-channel, medium to coarse sands at depths more than 130 m;
d) early to middle Pleistocene Old Brahmaputra and Chandina deep aquifers composed of red-brown medium to fine sands underlying Holocene gray medium to fine sands;
e) early to middle Pleistocene Madhupur terrace and Barind aquifers composed of coarse to fine fluvial sands, confined by near-surface clay residuum.

According to known geologic evolutionary history of the GWB (Mukherjee et al., in press), (b) and (c) of BGS/DPHE (2001) classification seems to be appropriate. Mukherjee et al. (2007a) delineated the hydrostratigraphy of the Gangetic West Bengal in a regional scale (down to 300 m below MSL), identifying a continuous, semi-confined sand aquifer (referred to as the main or Sonar Bangla aquifer), underlain by a thick, basal clay aquitard (referred to as the Murshidabad aquitard) (Figure 3 and 4). The main aquifer thickens from the north (~80 m) toward the east (~150 m) and south (>200 m). In the southern part of the GWB, near the active delta front, there are several intermediate-depth clayey aquitards, which divide the main aquifer into laterally connected, confined aquifers. Some isolated deeper aquifers are confined within the basal aquitards.

Transmissivity (T) values from Bangladesh range from ~ 3000 to 7000 m^2/d in BGS/DPHE (2001) aquifer systems (a) and (b) and from ~300 to 3000 m^2/d in aquifer systems (c), (d), and (e) (BGS/DPHE, 2001). CGWB (1994) and SWID (1998) estimated T values in West Bengal from 3300 to 7000 m^2/d in Murshidabad, 5000 to 8800 m^2/d in North 24 Parganas, and 500 to 3000 m^2/d in South 24 Parganas. The mean T values in the four districts of GWB are around 1000 m^2/d (Mukherjee and Fryar, unpublished data). Sikdar et al. (2001) reported a maximum value of 7774 m^2/d in the north Kolkata. For Bangladesh parts of the basin, the hydraulic conductivity (K) of the young gray sediments has been estimated in the range of 0.4 to 100 m/day, while the older red-brown sediments have K on the order of 0.2 to 50 m/day (BGS/DPHE, 2001). Calculations from specific capacity tests and modeled aquifer thickness for the GWB showed mean K values for the Sonar Bangla aquifer in Murshidabad to be 65 m/d (range: 6 to 187 m/d), Nadia 54 m/d (4 to 110 m/d), North 24 Parganas 35 m/d (2 to 128 m/d) and South 24 Parganas 20 m/d (3 to 42 m/d), resulting a cumulative average of 42.1 m/d (Mukherjee and Fryar, unpublished data). However, inverse modeling with groundwater flow model provided a best fit average value of 37.5 m/d (K_x) and 25 m/d (K_y) for the aquifer and 0.1 m/d (K_{x-z}) for aquitards in the study area (Mukherjee et al., 2007a).

The hydraulic gradient decreases from about 1 m/km in the northern Bengal basin to about 0.01 m/km in the southern basin (BGS/DPHE, 2001, Mukherjee et al., 2007a). In general, the regional groundwater flow is from north to south with local variations in the vicinity of the river systems, which are mostly effluent. Modern continuation of such regional flow has been questioned by Harvey (2002) and Mukherjee (2006) in light of the large amount of pumping, mostly for irrigation, within the basin. Sikdar et al. (2001) showed that there was a north-south regional flow in the vicinity of Calcutta, prior to the 1970s, which has since been disrupted as a consequence of urban pumping. Recent regional-scale groundwater flow modeling by Mukherjee et al. (2007a) shows that prior to the onset of extensive pumping (pre-1970s, regional-scale flow occurred within the major aquifer system during the dry seasons. With the initiation of pumping, several local to intermediate-scale flow systems replaced the dominant regional flow system. The hydraulic gradients were dictated by the pumping centers and aquifer architecture. Because of the absence of continuous confining layers in much of the study area, pumping induced mixing between relatively shallow and deeper groundwater.

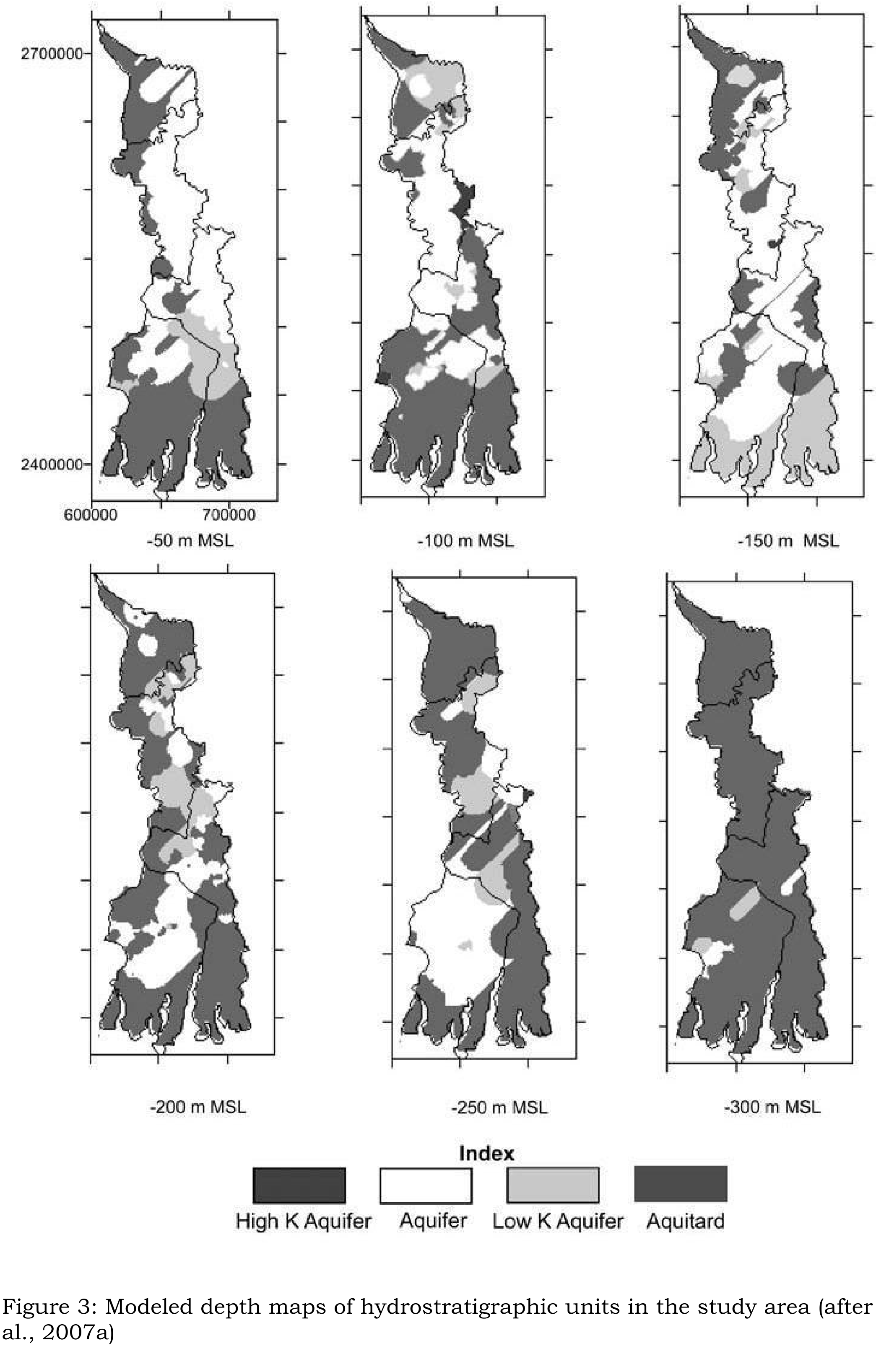


Figure 3: Modeled depth maps of hydrostratigraphic units in the study area (after Mukherjee et al., 2007a)

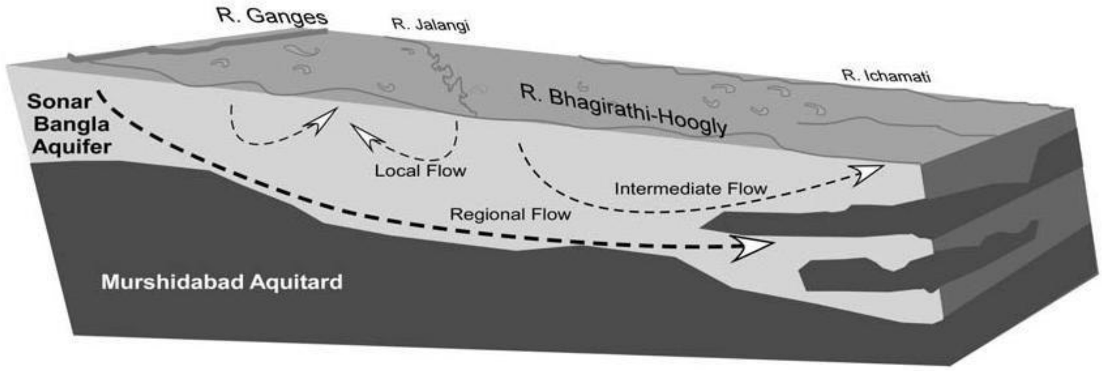


Figure 4: Conceptual hydrostratigraphy and pre-development groundwater flow in the study area (after Mukherjee et al., 2007b)

This scenario may worsen if pumping increases in the future. At present, the majority of groundwater flow occurs within 105 m depth from land surface. This indicates that the local flow systems predominate. However, the volume of medium to regional-scale flow up to a depth of ~ 200 m is also significant. Below 200 m to the deeper parts of the Sonar Bangla aquifer and the isolated aquifers, there is minimal recharge or outflow, which indicates relatively long residence times (negligible flushing). This deep groundwater has been identified as geochemically distinct by Mukherjee and Fryar (2008).

On the basis of strontium isotope analyses, the subsurface groundwater discharge (SGD) from the whole of Bengal basin to the Bay of Bengal has been estimated on the order of 2×10^{11} m^3/year, which is equal to about 19% of the total surface water flux (1.07×10^{12} m^3/year) (Basu et al., 2001). However, these estimates are controversial because a large groundwater flux is implausible in a flat terrain like the GBM plain, where in a distance of 100 km, the land surface elevation only decreases by about 10 m (Harvey, 2002). Mukherjee et al. (2007a) calculated that the present day SGD through the delta front in South and North 24 Parganas (~1/5th of the total Bengal delta front) to be ~5.9×10^7 m^3, which decreased by about 4% from an annual SGD of 6.1×10^7 m^3 since the onset of pumping. These estimates for SGD are negligible compared to the previous studies. The present day annual sea water intrusion is estimated to be ~8.8×10^2 m^3, which is still ~100% more than prior to the 1970s (Mukherjee et al., 2007a). However, as sea water intrusion causes significant modification of groundwater chemistry by mixing in southern South and North 24 Parganas [CGWB 1994d; Mukherjee et al. 2007b; Mukherjee and Fryar (2008)], it seems that the modeled seawater intrusion has been underestimated because variable density flow to compensate sea water not was taken in account in the calculations. The modeling further shows that annual total outflow to rivers is much higher than inflow, even in dry seasons (Mukherjee et al., 2007a). The stable-isotope composition of groundwater from the shallower aquifers were found to be very similar to that of the Bhagirathi-Hoogly (Mukherjee et al. 2007b), supporting this last observation.

GROUNDWATER CHEMISTRY

Stable isotopic composition shows that the groundwater of the western Bengal basin is mostly recharged by monsoonal precipitation (Mukherjee et al., 2007b), although they show a conspicuous continental depletion effect (latitudinal $\delta^{18}O$ depletion gradient of -0.8‰ per 100 km northward) as the Indian southeastern monsoon wind moves from the Bay of Bengal west-northwest toward central India and northward toward the eastern Himalayas. The major ion chemistry of ground water in the GWB can be generalized as mostly Ca-HCO_3 dominated (Figure 5), with some Na-Cl dominated waters, relatively high As, Fe, and Mn, and low or undetectable SO_4 and NO_3. However, this description may be further typified in a hydrostratigraphic context, where the main Sonar Bangla aquifer contains Ca-HCO_3 water and the isolated, deeper confined aquifers contain Na-Cl or HCO_3 waters (Mukherjee and Fryar, 2008). The main aquifer water may evolve to form the isolated waters by cation exchange with aquifer sediments and by mixing with connate water in various proportions. However, salinity caused by upward diffusion of connate water from very deep aquifers appears to be unlikely as predicted by geochemical modeling (Mukherjee and Fryar, 2008). Sikdar et al. (2001) attributed increasing salinization of ground water in the Calcutta region, which has accompanied pumping, to mixing of fresh ground water with modified connate water in low- permeability zones(Handa, 1972). Along the Bay of Bengal, relatively fresh ground water underlies shallow saline ground water(SWID, 1998). The water chemistry of the Gangetic Bengal basin is speculated to be controlled by the presence of carbonates, the composition of silicates, and the oxidation of sulfides. The weathering in the basin is dominated by H_2CO_3 liberated by degradation of organic matter in the soil, and < 10% of the weathering of the Ganges basin is caused by H_2SO_4 derived from sulfide oxidation (Galy and France-Lanord, 1999). The deposition of silt-dominated sediments in the foreland basin of the Himalayas (Burbank, 1992), however, may also favor silicate weathering (Derry and France-Lanord, 1996). Mukherjee and Fryar (2008) showed that deeper groundwater of the GWB is influenced by both carbonate dissolution and silicate weathering. Na and K may enter the GWB groundwater from incongruent dissolution of feldspars, micas, and pyroxenes in addition to recent or connate seawater. Ca and Mg can be derived both from silicate and carbonate weathering. However, analyses of groundwater samples from shallower depths of Sonar Bangla suggested that carbonate weathering predominates (Mukherjee, unpublished data). Groundwater in the Bengal basin has been found to be anoxic (Harvey et al., 2002; Swartz et al., 2004,), with abundant detections of sulfide and CH_4 e.g. Ahmed et al., 1998; Gavrieli et al., 2000; Nickson et al., 2000; McArthur et al., 2001, 2004) and very little dissolved O_2. Higher SO_4 and NO_3 concentrations are available at the shallow depths and generally decrease rapidly with depth (Mukherjee and Fryar, 2008). Most of the recent studies of groundwater chemistry in the GBB have advocated that the dominant redox process in the main aquifer is FeOOH reduction coupled to microbially mediated oxidation of natural organic matter (NOM) (Bhattacharya et al., 1997; Mukherjee and Fryar, 2008) NOM may be in forms of dissolved organic carbon or peat (McArthur et al., 2004), and oxidation of natural organic matter (NOM) may result in elevated HCO_3 concentrations. On the basis of chemical and stable isotopic data, Mukherjee and Fryar (2008) and Mukherjee et al. (2008) suggested local-scale re-oxidation of authigenic Fe sulfides, which indicates that Fe, S and C cycles within the subsurface are interrelated and complex. In recent times, the quality of the GBB groundwater has been severely questioned. Presence of elevated concentrations of carcinogenic As in dissolved state has endangered the life of millions of groundwater-drinking habitants of GBB. Arsenic concentrations vary widely in the basin, generally ranging from less than 0.005 mg/l to 4.1 mg/l (Ghosh and Mukherjee, 2002). The contaminated area is mostly restricted by the recent alluvial distribution of the River Bhagirathi-Hoogly in the west, the Rivers Ganges and Padma in the north. There has been much speculation about the primary source of As in this basin. It may have been transported by the River Ganges and its tributaries from the Gondwana coal seams in the Rajmahal trap area (Saha, 1991), by the north Bengal tributaries of the Ganges from near the Gorubathan base-metal deposits in the eastern Himalayas (Ray, 1999), or with other fluvial sediments derived from the Himalayas (e.g., McArthur et al., 2004). Arsenic may also have been biogenically deposited in the paleo-channels of the River Bhagirathi-Hoogly and the River Padma under euxinic conditions (P. Chakrabarty, West Bengal State Remote Sensing Board, 1999, personal communication).

Four main mechanisms have been identified by various workers to explain the mechanism of As mobilization in groundwater of the Bengal basin. These are:

1) As is released by oxidation of As-bearing pyrite in the alluvial sediments (e.g. Mallick and Rajgopal, 1995).
2) Arsenic anions sorbed to aquifer mineral grains are displaced into solution by competitive exchange of PO_4^{3-} available from fertilizers of surface soils (Acharyya et al., 1999).
3) As absorbed to FeOOH (HFO) is released by reduction of solid-phase Fe(III) coupled to oxidation of peat (Bhattacharya et al., 1997; Nickson et al., 1998, 2000; McArthur et al., 2001, 2004; Ravenscroft et al., 2001) or of dissolved organic carbon (DOC) (Harvey et al., 2002).
4) As is released from HFOs or other sediment phases by redox reactions related to Fe and S cycling (Zheng et al., 2004) and is retained in solution by partial redox equilibrium (Mukherjee et al., 2008b). This proposed mechanism is a combination of mechanisms 1 (involving reoxidation of authigenic pyrite) and 3.

CONCLUSIONS

There is one major unconfined/semi-confined aquifer in the subsurface (<300 m MSL) of the Gangetic West Bengal, along with presence of some isolated aquifers within the basal aquitards. The aquifer is made up of mostly gray alluvial sediments deposited by the rivers Ganges, Bhagirathi-Hoogly and its tributaries/distributaries. The structure of the aquifer gets more complicated and divides into several interconnected aquifers near the Bay of Bengal. The northern aquifer sediments tend to have higher hydraulic conductivity. Regionally, groundwater tends to flow towards the coast with a very low hydraulic gradient, particularly in the south. Prolific groundwater abstraction has resulted in serious impediment for the regional flow, and also resulted in huge volume of recharge from irrigational return flow. The groundwater is mostly of monsoonal origin with an isotopic composition consistent with the present-day climate. Groundwater chemistry is generally dominated by Ca-HCO_3 with some Na-Cl waters; the water also has high As, Fe, and Mn and is relatively low in SO_4 and NO_3 concentrations. Processes controlling groundwater chemistry include carbonate dissolution, silicate weathering, redox reactions (especially including Fe, C, and S), and mixing between fresh and saline waters.

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AQUIFER CHARACTERISTICS IN SOUTH 24-PARGANAS AND KOLKATA MUNICIPAL CORPORATION (KMC) AREA, WEST BENGAL.

A. K. Misra* & S. K. Nag**

ABSTRACT

The role of water resources in the field of agriculture, industrial and domestic is well known. Development of agriculture depends mainly on the availability of water in proper time. With the creation of irrigation facilities through small and minor irrigation schemes and with wider utilization of high yielding varieties of various agricultural production programmes including improved technology, agriculture has registered a remarkable progress. With the growing population in South 24 Parganas district and Kolkata Municipal Corporation area demand for water in drinking, agriculture and industrial sectors are increasing tremendously. Although plenty of agricultural land is available here, scope for irrigation is very limited due to non-availability of sufficient fresh water. Surface water resources in the South 24-Parganas district are inadequate and the water is brackish in nature as the area falls in the coastal plain. So major cultivation is done only during khariff season, which is, essentially rain fed. As such a search for alternative source of water is inevitable to convert this mono-cropped area into a multiple one. Ground water development in this coastal tract is beset with salinity hazards. Fresh ground water occurs in varying depth ranges and mostly occurs under confined conditions except in a linear tract in central part of South 24 Parganas district as in Garia-Sonarpur-Baruipur-Joynagar tract and Bhangar area, where fresh ground water occurs both in semi-confined and confined conditions.

INTRODUCTION

The South 24 Parganas district and Kolkata Municipal Corporation (KMC) area of West Bengal form an extensive deltaic tract where availability of adequate supply of irrigation water has been conspicuous by its absence. Influence of the tidal waves render the surface water resource unsuitable for irrigation purpose. Estuaries in the area also behave in a similar way. Ground water therefore is of great importance for the region and is used extensively for irrigation. The occurrence of fresh ground water varies both spatially and at depth due to peculiar hydrodynamic and hydrochemical situation prevailing in this coastal plain. Keeping in view the seriousness of the problem of the area the Geological Survey of India (GSI), Central Ground Water Board(CGWB) and the state departments, Govt. of West Bengal have been engaged for deep ground water exploration and hydrogeological surveys in this coastal part of West Bengal. The present authors undertook a study on this problematic coastal part of West Bengal.

STUDY AREA

The district of South 24 Parganas and KMC area are located in the southern most part of West Bengal and occupies the southeastern strip of the Ganga delta proper. It belongs to the Presidency sub-division of the state. The area is located between North latitudes $21^{0}32'$ - $22^{0}36'$ and East longitudes $88^{0}02'$ - $89^{0}06'$ [Fig.1]. The south 24 Parganas district and Kolkata area are spread over an area of 9849 sq.km. It is bounded to the east by Bangladesh, to the north by North 24 Parganas district, to the west by river Hugli and to the south by the Bay of Bengal.

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Fig.1. Map showing Administrative Divisions of Calcutta and South 24-Parganas Districts, West Bengal

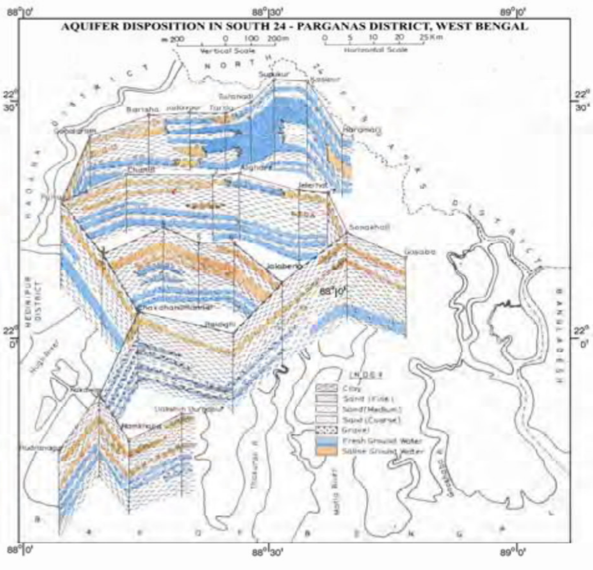
The South 24 Parganas district, which encloses the metropolitan city of Kolkata, has its headquarters at Alipore. It has 5 subdivisions viz. Sadar, Diamond Harbour, Baruipur,Canning and Kakdwip. In Sadar subdivision there are 5 blocks, in Diamond Harbour subdivision there are 9 blocks, in Baruipur sub-division there are 7 blocks, in Canning subdivision there are 4 blocks and in Kakdwip sub-division there are 4 blocks. South 24 Parganas district and CMC area are located on the lower deltaic plain on the composite Ganga delta and is covered by the quaternary sediments deposited by the Ganga and its tributaries.

HYDROGEOLOGY

Extensive study has been carried out in South 24 Parganas district and KMC area for determining the hydrogeological situation of the area. The study includes hydrogeological surveys, remote sensing studies for understanding the hydrogeomorphological set up of the area, collection of lithological samples (depth wise) for understanding the subsurface geological formation and correlation of geological horizons, interpretation of geophysical borehole logging at several localities for delineating the fresh and brackish/saline water bearing horizons, analysis of water level data collected from different established hydrograph stations. Analysis of pump tests data has been carried out in different localities for determining the aquifer parameters. Besides these, meteorological, agricultural, irrigational, land use, soil, hydrogeological data are collected, synthesized and interpreted for better understanding of the hydrogeological situation of the studied area.

The principal aquifers in south 24 Parganas district and KMC area belong to the unconsolidated sediments of quaternary and upper tertiary age deposited under fluvial and submarine to marine environments. Precise delineation of boundaries between upper Tertiary-Pliestocene and Pliestocene- Recent has not been possible till date due to lack of adequate faunal data. The area under study is underlain by a thick-pile of unconsolidated sediments of Quaternary and upper tertiary age. The sub-surface geology is revealed from a number of bore holes drilled in the area by CGWB, G.S.I., Agri-Irrigation, SWID, Govt. of West Bengal and other private agencies. The boreholes drilled down to a maximum depth of 614m.bgl for ground water exploration in the area reveal a succession of coarse to fine grained sand, clay and kankar and their various admixtures with localized patches of gravel and cemented sand grains. The sand beds are generally extensive laterally and vertically making it possible for them to be good aquifers. The top surface is marked by effective clay blanket whose thickness varies from 15-70m (Mishra, 1996). Underlying the clay blanket occurs huge thickness of sediments composed of fine to coarse sand, gravel, silt and clay. There appears to be a pattern of rhythmic sedimentation represented by alternate deposition of clay and sand (Misra,1989). Generally groundwater occurs here under confined condition in the depth range of 20- 400m with numerous alterations of clay and sandy clay beds of varying thickness.

The top clay blanket generally 15-76m thick attains a thickness of about 100m in the southern most part of South 24 Parganas district (Kakdwip, Rudranagar, Namkhana area Fig.2). The confined aquifers can be divided into two groups particularly in the N-S linear tract from Diamond Harbour to Namkhana and beyond. This sand gravel horizon acts rather as a marker bed and pinches out eastward. The lower group of aquifers occurring in the depth ranges of 180-360m and is separated from the upper and by a thick impermeable sticky clay bed that is laterally extensive (fig.3). In certain localities of Dhakuria, Jadavpur, Garia, Sonarpur block, Baruipur block, Joynager block, Bhangar I & II blocks and Canning II blocks there occur a shallow aquifer on paleo channels (fig.4). Ground water occurs in the shallow zone under unconfining to semiconfining condition. The shallow aquifers are generally 10-15m thick (Misra,1995). In certain places it extends down to 50m bgl. The hydrogeological map of Kolkata and South 24 Parganas district is shown in Fig.5.



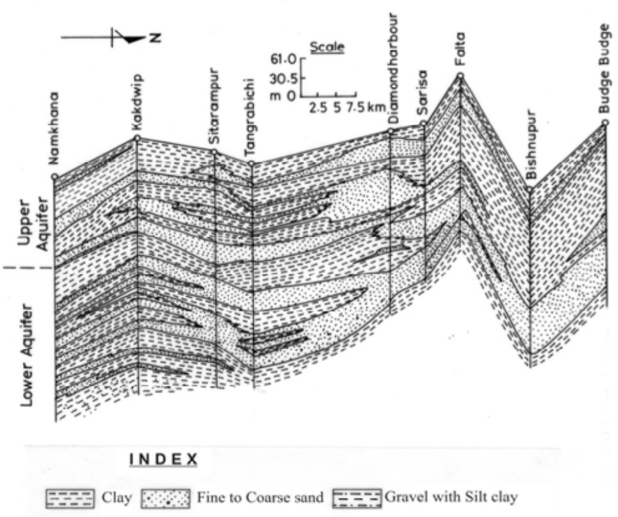


Fig 3 : Lithological correlation of bore holes in the BudgeBudge – Namkhana Section South 24 Pargana District, West Bengal.

Fig.4. Hydrogeomorphological Map of Calcutta Municipal Corporation area and South 24-Parganas Districts, West Bengal.

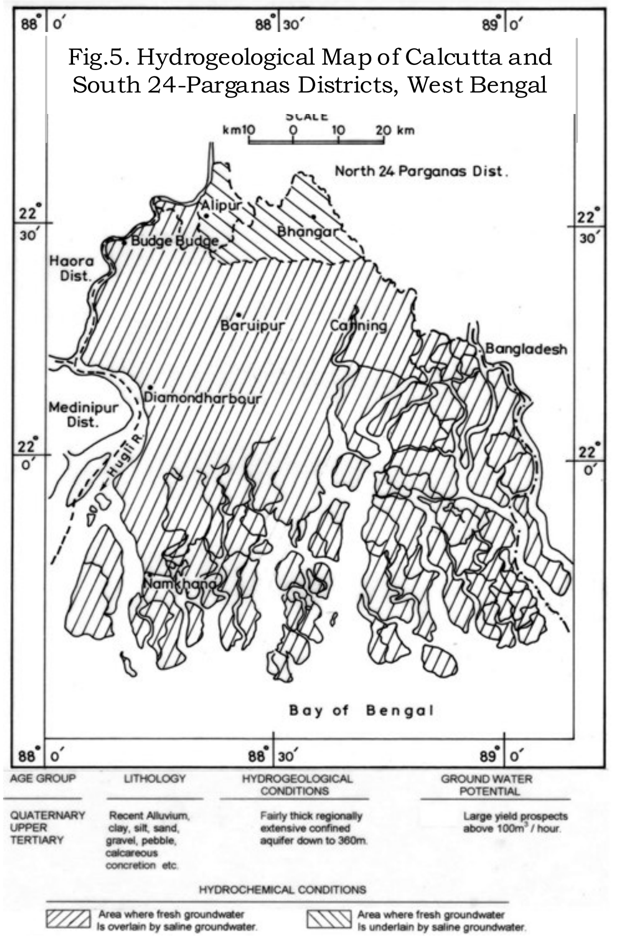


Fig.5. Hydrogeological Map of Calcutta and South 24-Parganas Districts, West Bengal

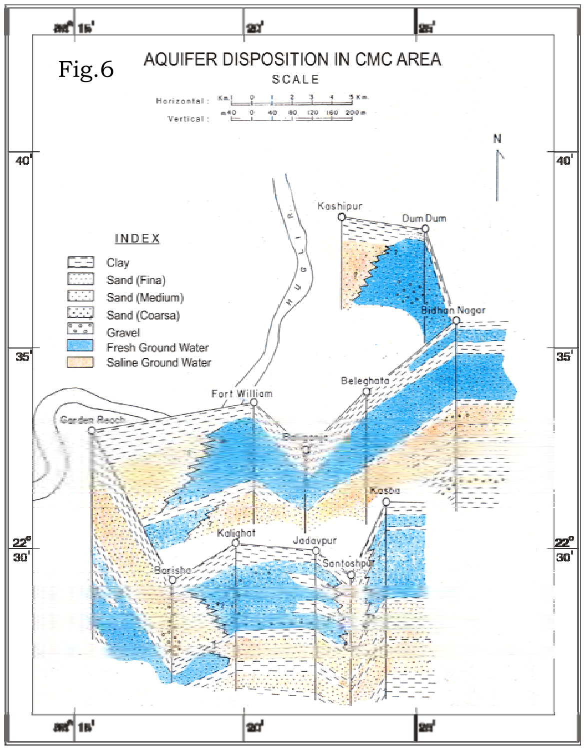


Fig.6

Interpretation results of electrical logging of boreholes, lithological log of the boreholes in several places of KMC and South 24 Parganas district indicate the presence of two broad group of aquifers in the study area. The upper group of aquifers by and large contain saline/ brackish water where as the lower group of aquifer is characterized by fresh water content. Potential fresh water bearing aquifers are occurring within 160-360m bgl in the central and southern part of South 24 Parganas district; where as in the northern part of the district and central and northern part of KMC area it lies within 20-160m bgl (Misra,1995). In the extreme north eastern part (i.e. Tarahadi,Supukur, Kasipur) the fresh groundwater bearing aquifer exists down to the depth of 180m bgl (fig.2).In KMC area generally fresh groundwater bearing aquifers occur within 30-160m bgl. e.g Fortwilliam, Kalighat, Jadavpur University, Kasba area (fig.6).After studying the geophysical log (S.P. and resistivity log) it is known that the fresh ground water bearing aquifers occurs in Ganguly Bagan, Calcutta High Court and Income Tax Building near E.M. Byepass of KMC area within 157,146 &170m bgl respectively. Below which saline/brackish water bearing aquifers occur whereas in Barisha & Garden Reach area, fresh groundwater bearing aquifers occur within 20-160m bgl.(CGWB, TR, Series D, 1999).

The fresh ground water bearing aquifers occur below 200m bgl at Satyajit Ray Film Institute, Panchasayer, and E.M. Byepass, KMC area. At Nizam Palace on J.C.Bose Road, KMC area fresh ground water bearing aquifers occur below 45m bgl. At New Secretariat Building Premises, Strand road, KMC area fresh groundwater bearing aquifer occur within the depth span of 150-360m bgl.(fig.2). The fresh ground water bearing aquifers are lenticular in nature and thickness of individual aquifers varies between 5-30m bgl. Thick clay layers separate each aquifer. The aquifers are characterized by fine to coarse-grained sand with occasional gravels.

There are 3-5 such lenticular aquifers in the central part. The brackish water bearing aquifers occur between 25-205m bgl (fig.2). In Falta, Chandi, Mamudpur area fresh ground water bearing aquifers occur below 160m bgl. In Canning area fresh groundwater bearing occur below 180m bgl.In Sonakhali and Gosaba area the fresh ground water bearing aquifers occur below 330m bgl. In Diamond Harbour 7Iswaripur area fresh groundwater bearing aquifers occur below 220m bgl. In Jalaberia fresh ground water bearing aquifers occur below 220m from ground surface (fig.2).

In southern part of the South 24 Parganas district i.e., in Raidighi, Kakdwip, Namkhana, Dakshin Durgapur (Patharpratima block), and Rudranagar (Sagar block) the fresh groundwater bearing aquifers occur below 156-250m from ground level. In Raidighi and Jalaberia area the fresh groundwater bearing aquifers occur below 250m from ground level. In Rudranager area (Sagar block), Kakdwip and Dakshin Durgapur , (Pather Pratima block) area fresh groundwater bearing aquifers occur below 200m bgl. The individual aquifers are not very thick. It varies between 5-15m. There are 3-4 such fresh water-bearing aquifers in the area (fig.2). Saline/ brackish water bearing aquifers occur between 20-180m bgl. The individual brackish water bearing aquifer varies between 5-20m thick. There is generally two district brackish water bearing aquifers. Each individual aquifer is separated by thick clay horizon. (Fig.2).

MAP OF CMC AREA SHOWING PROGRESSIVE DECLINE OF PIEZOMETRIC SURFACE (1958-1998)

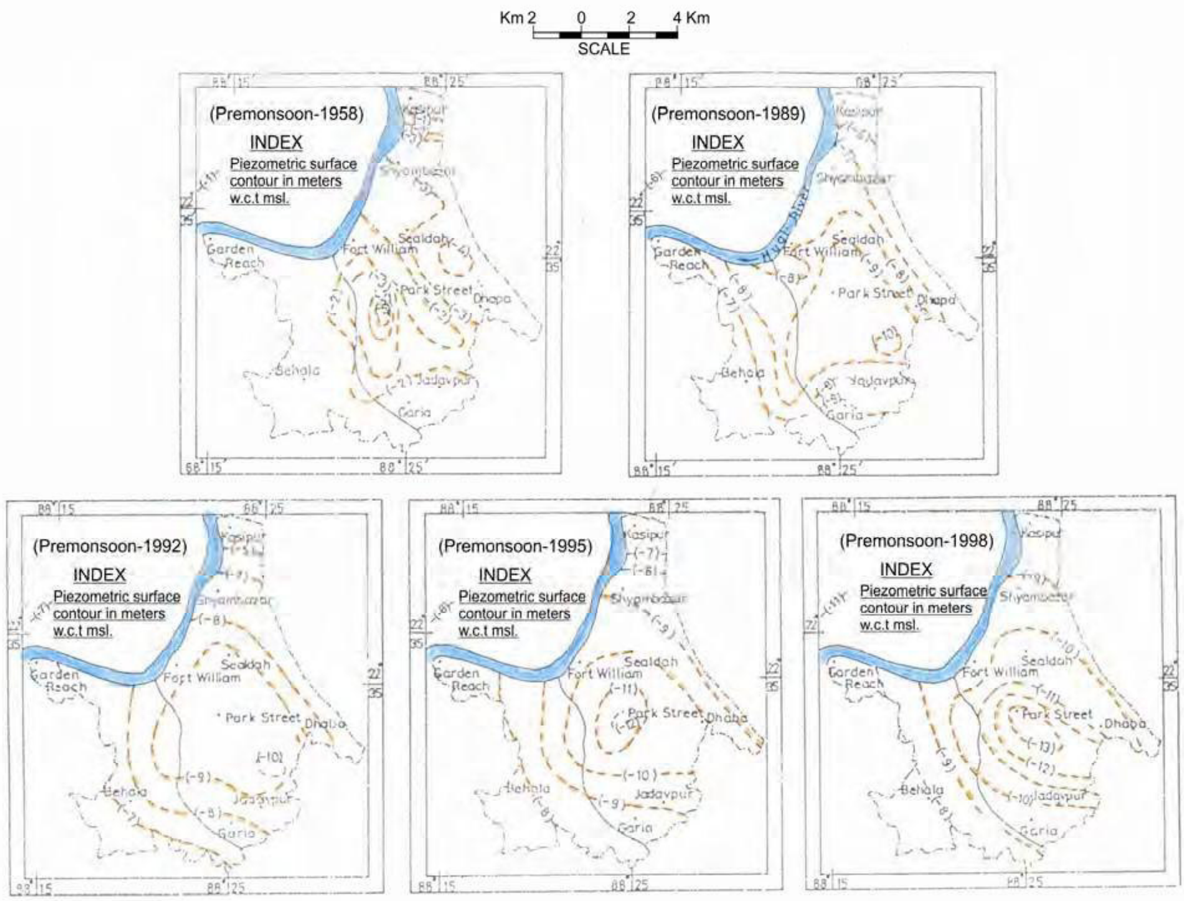


Fig.7.

Average piezometric level for January, May, August and November for each Hydrograph Network Stations are analysed by computer programming for a period from their inception to

1997. Average piezometric level during May for Fraserganj, Namkhana, Kakdwip, Kulpi, Diamond Harbour, Joynagar, Raidighi stations are 0.80, 2.03, 2.68, 3.82, 4.11, 3.03 and 2.40m from ground level. Study of piezometric level from hydrograph stations in the area during pre-monsoon and post-monsoon for the period of its inception to 1997 indicates that generally there is a falling trend of piezometric level in the entire South 24 Parganas district and CMC area. It is seen that there is a fall of 3.62m, 2.75m, 2.36m, 1.31m and 2.64m piezometric levels in Kakdwip, Diamond Harbour, Namkhana, Baruipur and Fraserganj during pre-monsoon period in last three decades. In Raidighi, Canning and Bhangar area the fall of piezometric level are 1.68,0.80 and 1.52m during pre-monsoon period in last two decades. The piezometric surface in CMC area has been lowered to the tune of 5-9m over a period of 40 years (i.e. from 1958-1998) (CGWB, TR, Series, D, 1999) due to heavy withdrawal of ground water in excess of replenishment (fig.7). Study of hydrographs from Hydrograph Network Stations in the South 24 Parganas district and Kolkata area indicate that there is falling trend of piezometric surface in the entire study area.

From the study of the trend of piezometric surface in KMC and south 24 Parganas district during last 3-4 decades it may be concluded that lowering of piezometric surface is due to gradual withdrawal of ground water from the fresh ground water bearing aquifers for domestic and irrigational purposes.

ANALYSIS OF AQUIFER SYSTEMS

Intensive geomorphological, geological, hydrogeological, geophysical, hydrochemical and isotope studies in South 24 Parganas and KMC area indicate that there occur three groups of aquifers in different hydrogeological and hydrochemical conditions. Isotope geochemical study of ground water in the studied area indicates that ground water of different aquifer groups are of different ages. Generally two extensive broad groups of aquifers occur in South 24 parganas district. Of these, the upper group of aquifers occurs in the depth range of 22-168mbgl. The aquifers are saline/brackish ground water bearing. The lowermost group of aquifers occur in the depth range of 180-360m.bgl and are fresh ground water bearing aquifers by thick impermeable clay bed (fig.2,3).

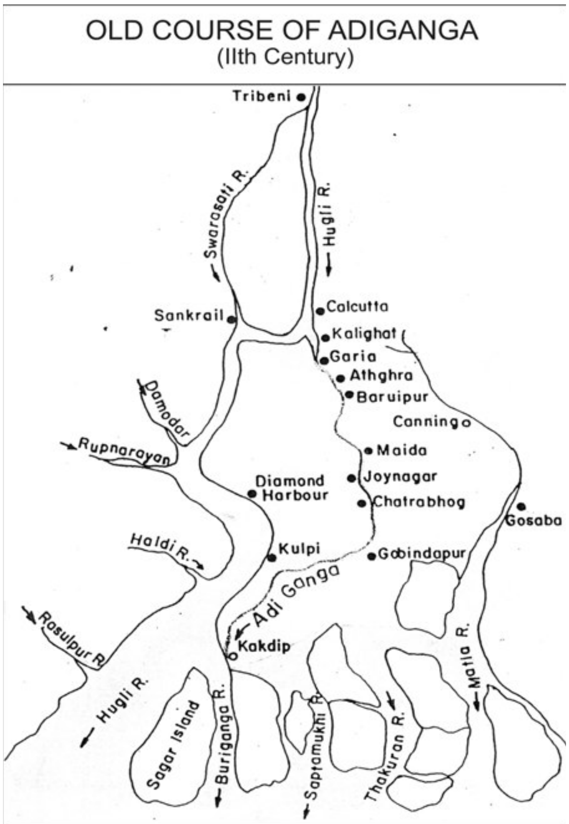


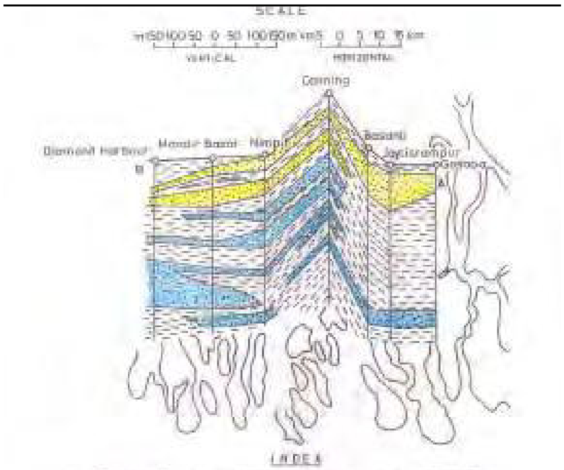
Fig.8. Map showing Old Course of AdiGanga

The topmost aquifer occurs in linear tracts, which are not very extensive laterally. The longest tract passes through Ballygunge, Dhakuria, Jadavpur, Garia of KMC area, Rajpur, Sonarpur areas of Sonarpur block, Mallickpur, Baruipur, Suryapur areas of Baruipur block and Barasat, Baharu and Joynagar areas of Joynagar block of South 24 Parganas.

This uppermost aquifer occurs on Paleo channel of Adi Ganga, which flow through Kalighat- Ballygunge-Garia-Rajpur-Baruipur-Joynagar and Gobindapur area during 11th century (fig.4,8). In northeastern part of South 24 Parganas district, this upper most aquifer also occurs in linear patches and passes through parts of Bhanger-I, Bhanger-II and Canning-II blocks. This aquifer occurs on paleo channels of Bidyadhari and its tributaries (fig.4).

The uppermost aquifer formed by the sediments is of very Recent age (200-300years). The aquifer is generally 10-15m thick and 2-3km wide. In few localities it extends down to 50mbgl. This aquifer is recharged directly from rainfall precipitation. Ground water in this aquifer is of very recent age. The aquifer material consists of very fine to medium grained, grayish micaceous sand. Ground water occurs in the uppermost aquifer under unconfined condition. Average pre-monsoon and post-monsoon water level varies between 1.80-7.50 mbgl and 1.0-6.0 m bgl. respectively. The chemical quality of groundwater is very fresh. Chloride content ranges between 25-202 mg/l and specific conductance ranges between 540-1210 micromhos/cm at 25^{0}C. The flow of ground water is towards south and southeast. Ground water resource has been estimated for this uppermost-unconfined aquifer by water table fluctuation method. About 70 MCM ground water is available annually from this aquifer. Ground water from this aquifer is being utilized for domestic and irrigational uses through dug well and small diameter tubewell. There is enough scope for utilizing this water for irrigational uses through small diameter tubewell (101mm x 64mm) during rabi and summer season. The average yield from such small diameter tubewell is 20m^3/hr for a draw down of 3-4m.

Fig.9. Disposition of Fresh / Saline Aquifer in Coastal Tract of South 24-Parganas District, West Bengal.



The second group of aquifers in South 24 Parganas district generally occurs within 22-168 mbgl. The aquifers are laterally extensive and the individual aquifers are 3-20m thick and are separated by clay layers of different thickness. The aquifers are made up of grayish to yellowish, fine to medium sand with occasional coarse-grained sand. This group of aquifers by and large contains saline/ brackish water (fig.2, 9 & 10). Chemical analyses of water samples from this group of aquifers indicate that chloride value ranges between

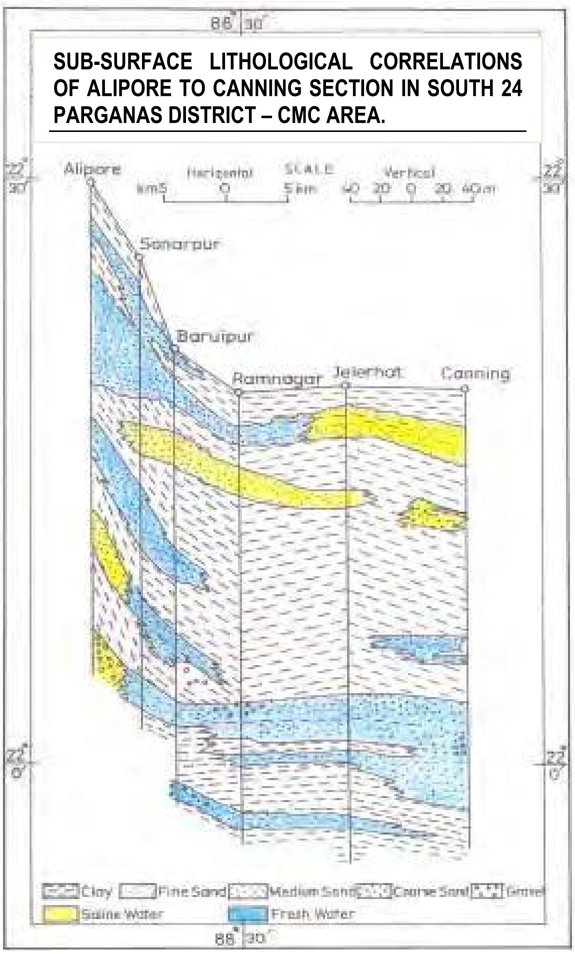


Fig.10. Map showing Sub-Surface Lithological Correlations of Alipore to Canning Section in Calcutta and South 24-Parganas Districts, West Bengal.

3000-6000 mg/l. The aquifers occur under confined condition. The piezometric surface of the second group of confined aquifers (saline/brackish) rest at 2-4 mbgl during pre-monsoon period and 1-3 mbgl during post-monsoon period. Occurrence of piezometric level at shallow depth indicate that groundwater is under great hydrostatic head and it is very advantageous during development of this untapped saline/brackish water resources from this deltaic part of West Bengal.

The third group of aquifers (deeper aquifers) in the area occurs in the depth range of 180- 360 m and is separated from second group of aquifers (saline/brackish water bearing) by a thick impermeable sticky clay bed. The aquifers are laterally extensive and the individual aquifers are 2-30m thick and are separated by clay layers of different thickness. The aquifers are deposited during Tertiary age. The aquifers are made up of grayish fine to medium sand, coarse sand with occasional gravel. The gravels are made of quartzite, siltstone etc. The ground water of this group of aquifer occurs under confining condition. This group of aquifer contains fresh ground water. Generally specific conductance and chloride value in the ground water range between 700-2300 microhmos/cm and 28-518 mg/l respectively. In northern and central part of KMC area the fresh ground water bearing aquifers occur within 20-160mbgl (fig.6).

The distribution of salt water – fresh water aquifers in this coastal tract is generally uniform with fresh ground water being overlain by saline groundwater except in north-eastern part of KMC area, northern part of Bhanger-I block and entire Bhanger-II block where fresh ground water is underlain by saline ground water (fig.5). The salinity in these aquifers is mainly due to NaCl concentration which decrease from the coast towards the inland areas.The salinity may be derived from (a) sea water ingress (b) salt water entrapped in the sediments deposited under marine conditions.

RESULTS AND DISCUSSION

During early Pliestocene time, shallow marine conditions prevailed in the deeper parts of the Bengal basin. Possibly only very late in the Pliestocene did the sea finally recede completely from the Bengal basin area. Erosion then occurred, followed by peneplanation of the whole Tertiary basin area of Bengal. Finally the older sediments were covered completely by a thick mantle of river borne Holocene alluvium. During late Pliestocene period to early Quaternary period the Bengal basin area had experienced glaciations and deglaciation (fall and rise of sea level). While transgression of the sea, the water was entrapped within the sediments. The original seawater was modified later by flushing with meteoric water. As a result the salinity of the aquifers is reduced.

During the high stand of the sea level in Pleistocene, the sea invaded far inland changing already deposited fresh water sediments with salt water or depositing salt water charged sediments in marine conditions. During the succeeding low stand of the sea, salt waters were flushed out, but some salt water might be left behind due to sluggish flushing, because of the predominance of clays and silts. Similarly during the flushing out of salt water from the overlying sediments, invasion of underlying fresh water sediments with salt water might also have salinised some fresh water aquifers.

As the aquifer opens up to the sea, sea water ingression occurs in the form of a wedge within the fresh water aquifer depending upon how the fresh water piezometric head at the out let point counter balances the salt water column at that point. Hence in a multilayered sequence of aquifer, the length of salt-water wedge is non-uniform depending upon permeability, recharge and depth of individual aquifers.

The cumulative thickness of saline/brackish water bearing aquifers in South 24 Parganas and KMC area are more than 20m. Suitably designed tubewells (304 mm x 125mm) may yield more than $100m^3$/hr. This huge untapped saline/brackish water may be used for irrigation purposes by blending with fresh surface water and ground water. In the inland part, the brackish ground water may be utilized for prawn cultivation, which will bring foreign exchange. The brackish water may also be used for irrigation by changing traditional cropping pattern to salt tolerant crops. The suitability of ground water for irrigation is contingent upon the effects of mineral constituents of water on both plants and soil.

In KMC area total quality of fresh ground water flow has been estimated to the tune of 45.3 mgd. Whereas the total ground water withdrawal from Government heavy-duty tubewells, private tubewells and private hand pump fitted tubewells comes to 249.60 mgd. As a result the piezometric surface in KMC area has been lowered to the tune of 5-9 m over a period of 40 years (1958- 1998) due to heavy withdrawal of ground water in excess of replenishment (fig.7).

Although there is enough scope for ground water development in South 24 Parganas district, but in the event of prevailing hydrochemical and hydro dynamical situation, any large scale ground water development in the district need to be planned scientifically. Uncontrolled ground water extraction in this coastal area may lead to piezometric level depression beyond replenish able limit and offset the hydrochemical balance of fresh water and saline water causing seawater intrusion. Hence in this coastal tract overexploitation or clustering of wells should be avoided and pumping hours and rates of withdrawal should be restricted.

To arrest the decline of piezometric level in KMC area, further groundwater development should be restricted. Artificial Recharge to groundwater for each complex/building should be taken up. The rainwater from rooftop may be used to recharge to the fresh groundwater bearing aquifer.

ACKNOWLEDGMENT

The authors are greatful to Shri B.M.Jha, Chairman and Dr S.C.Dhiman, Member (SML), Central Ground Water Board for their encouragement in writing this paper. The authors are also grateful to Shri Abhijit Ray, Suptdg Hydrogeologist,Central Ground Water Board, ER for his help while writing the paper. They are also thankful to Dr. S. P. Sinha Ray, Member(Retd.), Central Ground Water Board for his guidance and supervision in writing this paper. They are also thankful to various agencies, Central and State Government, autonomous bodies and non-governmental private bodies for using valuable data on hydrogeology.

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CHEMICAL QUALITY & ITS PROBLEMS IN GROUND WATER OF WEST BENGAL

B. C. Mehta* & K. K. Srivastava**

ABSTRACT

The major ground water quality problem in the West Bengal state are high concentration of Flouride, Arsenic, Iron, Nitrate etc, High salinity and contamination in Coal field areas. In the coastal tract of Medinipur, S-24 Parganas and Haora districts of the active delta of the Ganga- Bhagirathi river system, ground water in general is high in chloride content in upper aquifers. However the aquifers occurring in the depth span of 115-300 m in the Digha area, 125-300 m in Haldia area, 170-350 m in S-24 Parganas and in Kasai sub basin & Subarnrekha basin are relatively fresh . The ground water occurs in confined conditions along Mahisabad- Haldia tract and brackish ground water occurs down to about 115 m depth below which fresh water bearing aquifer persists down to 300 m depth. The principal productive aquifers in Kolkata area generally occur within the depth of span of 60-180 m , however the quality of water is brackish in North & Eastern part, good quality in South western part, highly mineralized in northern part. High Flouride concentration in Ground Water is observed within 50-80 m depth in fractured granite rock in parts of Bankura, Birbhum and Purulia , within 30 m depth in Gondwana sediment in Khyrasol block of Birbhum , within 50-80 m in depth in basaltic rock including intertrappean in Rampurhat I and Nalhati I blocks in Birbhum district. At present arsenic contamination in ground water of West Bengal is restricted sporadically in 79 blocks of Bardhman, Hoogly, Howrah, Malda, Murshidabad, Nadia, North 24 Pargana & South 24 Pargana districts. The exploratory drilling carried out in the districts of Murshidabad, Nadia and North 24 Parganas revealed that the shallow aquifer (15-100 m) is contaminated with arsenic where as the intermediate aquifer (100-160 m) and deeper aquifer(200 –270 m) are almost free from arsenic contamination. In this paper attempt has been made to overview the ground water quality scenario in West Bengal.

INTRODUCTION

The ground water resources are being utilized for drinking irrigation and industrial purposes. However due to rapid growth of population, urbanization, industrialization and agricultural activities ground water resources are getting stressed with contamination and pollution. . In some case over exploitation of ground water has resulted in the lowering of water level and deterioration in water quality. The original quality of ground water is parented by the quality of the precipitation water which is further modified by reactions with organic matter, soils and rocks over the period of time. In general, ground water quality tends to be uniform within a given aquifer system in respect of location and time. Only in case of redox environment it may be well specific because of the presence of organic matter and microorganism.

GEOLOGY AND HYDROGEOLOGY

The state of West Bengal is divisible into a rocky area covering about $1/3^{rd}$ 125and alluvial covering rest of the state . The hard rock area is underlain by geological formation from older Archeans to younger tertiary rocks. The occurrence of Gondwanas comparatively representing mesozoic era in the western part is significant. The hard rock formation are mainly located over

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western and northern part of the state viz. Purulia, western part of Barddhman, Birbhum Bankura and Medinipur district and Darjeeling and in the northern fringe of Jalpaiguri district.The ground water occurs in the hard rock terrain in the upper weathered mantle (thickness 5-10 m) and at deeper levels (60-100 m depth) in the fractures ,fissured and joints.

The Alluvial deposits in the Bengal basin covering nearly 2/3 of the state is occupied by the thick pile of unconsolidated sediment laid down by the Ganga –Brahmaputra river system the thickness of which increases from marginal platform area in the west towards the east-south east in the central and southern part of the basin. These unconsolidated sediments are made up of succession of clay, silt, sand ,gravel of quaternary era. The ground water occurs both under water table and confined condition in Nadia, Murshidabad (except Kandi sub division) district down to the depth of 150 m . There is absence of any significant clay bed making entire aquifer from surface to 150 m depth to occur under water table condition. Clay beds generally act as continuing layers in the coastal part of Medinipur, South 24 Parganas, parts of Howrah, Hugli, North 24 Parganas districts, where ground water occurs under confined condition. However in the major part in the districts of Birbhum ,Bankura, Bardhman, Medinipur, Hugli, Hoara and North-24 Parganas and also Malda and West Dinajpur ground water occurs both under water table and semi confined conditions at different depths.

GROUND WATER QUALITY PROBLEMS

The major ground water quality problem in the state are

- Salinity
- Fluoride
- Arsenic
- Iron
- Nitrate
- Water quality in Coal field Areas

Salinity

Coastal areas represent the zone where land and sea meet and comprises of variety of complex environments including deltas estuaries, bays ,marshes, dunes, and beaches. Withdrawal of fresh ground water may result in disequilibrium resulting in intrusion of saline water inland. Normally saline water bodies owe their origin to entrapped sea water(connate water),sea water ingress, leachets from navigation canals constructed along the coast, leachets from salt pans activity etc. In general following situations are encountered in coastal areas

- Saline water overlying fresh water aquifer
- Fresh water overlying saline water
- Alternating sequence of fresh water and saline water aquifers

In the coastal tract of Medinipur ,S-24 Parganas and Haora districts of the active delta of the Ganga Bhagirathi river system, ground water in general is high in chloride content in upper aquifers (in Subarnrekha basin 8-100 m ,in Haldia area Kasai basin 40-115 m ,in South24 Parganas in Haora district 20-150 m in depth) ,the EC values are generally 1500 µS/cm. However the aquifers occurring in the depth span of 115-300 m in the Digha area ,Subarnrekha basin 125-300 m in Haldia area Kasai sub basin and 170-350 m in S-24 Parganas are relatively fresh and chloride values are generally within the permissible limit. The high concentration of chloride in ground water in these upper aquifers is probably due to estuarine environment in which the sediments were deposited . In these area ground water of four different types predominates viz. Ca-Mg-HCO_3, Na-HCO_3,Ca-Mg-Cl and Na-Cl type

The Haldia area is made of fluvio deltaic sediments of upper tertiary to quaternary age down to the explored depth of 400 m bgl. The sediments are essentially unconsolidated consisting of clay, silt, sand of various grades and gravel. The sub surface correlation indicates that there is facies variation of granular zones and /or their gradation in to silty /clayey beds towards east, south and south east. The top of tertiary sediment is gray clay which separates the upper litho system (Quaternary sediment) and lower litho system (tertiary sediment). The ground water in upper litho system indicates Ca-Mg- HCO_3 type in alluvium plane and mixed type in coastal plane but shows lot of variation in lower litho system.

The ground water occurs in confined conditions along Mahisadal-Haldia tract, brackish ground water occurs down to about 115 m depth below which fresh water bearing aquifer persists down to 300 m depth. The total dissolved solid range from 510 –1000 mg/Land Chloride between 18-360 mg/L. The Iron content in these aquifers range between 0.5 to 0.9 mg/L The chemical constituents indicate that ground water is generally potable. The upper aquifer within 120 m bgl contain saline water and the chloride range from 200 to 600 mg/L. In Digha Ramnagar area the sand dunes formed by sea contain fresh ground water.

Isotopic studies in coastal Medinipur indicated that the salinity of ground water very close to the sea coast may be due to proximity of sea, where as the ground water salinity away from sea coast (Sarda seed farm, Marisda and Nilpur) could be entrapped sea water due to the recession of shore line during the recent geological past. This has been substantiated by enriched Iodide. The chemical evolution of ground water determine on the basis of ratio Bromide/ Chloride concentration ($8.47 X 10^{-3}$ to $1.2 X10^{-2}$) and Iodide/Chloride concentration ($6.29 X10^{-6}$ to $3.58 X 10^{-3}$) indicate that ground water is under semi confined to confined condition and were deposited under marine environment.

Haora district is underlain by quaternary alluvium laid down by the south flowing Bhagirathi-Hugli river system . Entire district is occupied by unconsolidated formation. The ground water occurs under both water table and confined conditions . The aquifer occurs in the depth range of 14-300 m bgl. The sand horizon are separated by impervious clay layers. Amongst 14 block of the district, in 5 blocks ground water occurs under water table condition and is fresh down to the explored depth of 350 m bgl whereas in 9 other blocks ground water occur under semi confined to confined condition . The ground water in aquifer down to 160 m bgl are brackish to saline in nature(EC 590 – 6560 μS/cm) and the ground water in the aquifer below 160 m down to 300 m is fresh in nature.

The Kolkata metropolitan area is located on the lower deltaic plain of the composite Ganga-Bhagirathi delta and is covered by the sediment deposited by the river system flowing through the area during quaternary period. The subsurface geology of the area is completely obscured by a blanket of recent sediments. The upper 300 m of sediment are of quaternary era and consist of clay, silt, sand and occasional pebble beds, these are principal repository of ground water in the area. The clay horizon ranging generally in thickness from 30 –50 m occurs at the top of the sedimentary sequence. The principal productive aquifers generally occur within the depth of span of 60-180 m . A minor aquifer zone consisting of fine to medium sand has also been found to exist within the depth span of 20-40 m.

The chemical quality of ground water in Kolkata area in the depth range of 60-125 m bgl show variation in their chemical character. Four different species have been identified in the area viz. Ca-Mg-HCO_3, Na-HCO_3, Ca-Mg-Cl and Na-Cl type. The ground water of the northern and eastern part is brackish with chloride values and EC exceeds 500 mg/L and 2000 μS/cm respectively. The ground water in the south western part from Eden garden through Harish park to Kalighat area is of good quality and a marginal in the part of Dumdum-Maniktala-Beliaghata–Tangra, Ballygange- Kasba- Dhakuria ,Jadavpur and Tollyganj sectors. In fact several wells of Dhakuria, Jadavpur, Ranikuthi contain Sodium and Chloride above 50 % of cations and anions. The chemical characteristics gradually changes from Maidan area through

Park circus to Tangra and further south. The seqence is $HCO_3 \rightarrow HCO_3 + Cl \rightarrow Cl + HCO_3 \rightarrow Cl$. The ground water in northern part extending from Kashipur- Sinthi down to B.B.D.Bag–Sealdah contain highly mineralised water. The real ground water quality problem exists in Bidhannagar to Bagha Jatin in the east and in northern part due to high salinity and high iron. The water in south western part of the Eden garden in general is fresh.

Fluoride

Fluorine is the lightest member of the halogen group of elements. Fluorite (CaF_2) is a common fluoride mineral. This mineral has a rather low solubility and occurs in both igneous and sedimentary rock. Apatite Ca_5 (Cl, F, OH) ($PO_4)_3$, commonly contain fluoride. Most fluoride are sparingly soluble and are present in natural waters in small amounts.

The ground water is generally characterised with very low fluoride concentration viz. Cooch Bihar (0.12-0.33 mg/L) ,Darjeeling (0.01- 0.45 mg/L) Haora (0.25-0.45 mg/L. In general fluoride limit in ground water is within the permissible. The high concentration of fluoride(more than 1.5 mg/l) in ground water has been observed in parts of Barddhmna, Bankura, Birbhum, Dakshin Dinajpur, Malda, Purulia, South 24 pargana & UttarDinajpur. The high concentration of fluoride in ground water was also reported in the deep tube wells in parts of Nalhati and Rampurhat blocks of Birbhum district. A rapid assessment of fluoride concentration in ground water of West Bengal was taken up in 105 blocks of 12 districts and it is observed that ground water in 8 districts of West Bengal are affected with high fluoride. Some of the location where high cxoncentration of flouide have been reported are Khayrasol, Birbhum district(9.10mg/l), Ilambazaar Birbhum district(5.60), Gauripur, Bankura district(2.00), Dorapur, Malda district(1.80), Thanapura, Nadia district(3.00), Hariharpur, Prulia district(1.90), Durgapur, UttarDinajpur(1.90)

The high concentration of Flouride in ground water in West Bengal has been observed in :-

- Bore wells within 50-80 m depth fractured granite rock in affected block of Bankura, Birbhum and Purulia district
- Bore wells within 30 m depth in Gondwana sediment in Khyrasol block of Birbhum district ,below first coal seam
- Bore well within 50-80 m in depth in basaltic rock including intertrappean in Rampurhat I and Nalhati I blocks in Birbhum district.
- Tube wells within the depth of 20-80 m in older Alluvium in affected blocks of Bankura , U. Dinajpur, D. Dinajpur and Birbhum district.
- Tube wells within the depth of 50-70 m in recent Alluvium in Ratua II & Bamangola block of Malda district and Baruipur block of S 24 Parganas.

Arsenic

Arsenic and its compounds have been widely used in pigments as insecticides and herbicides, as an alloy in metals and as chemical warfare agents. Synthetic organic compounds have now replaced arsenic in most of the uses, arsenic is still an element of interest in terms of environmental quality. Arsenic is a naturally occurring trace element found in rocks, soils and the water in contact with them. It has been recognized as a toxic element and is considered a human health hazard.

Arsenic contamination in ground water in West Bengal came to light for the first time in early eighties when two Kolkata based institution namely Institute of Tropical Medicine confirmed a few cases of arsenic Dermatosis and subsequently All India institute of Hygiene and Public Health established that prolong uses of arsenic contaminated ground water was the cause of the disease.

At present arsenic contamination in ground water of West Bengal is restricted sporadically in 79 blocks of 8 districts in linear tract extending NNW- SSE from Kaliachak block in Malda district through the eastern part of Murshidabad, Nadia, Eastern fringe of Bardhman,Hugli,N-24 Parganas ,S 24 Parganas and Haora district. In fact the eastern part of the Bhagirathi is much more affected than the western part of the Bhagirathi. About 16 million people are in risk zone. The arsenic contamination has not been reported from the area comprising Lower Holocene to upper Pleistocene older alluvium sediments and the area occupied by hard rocks or their weathered derivatives. Ground water is also free of arsenic in the Himalayan foothills ,either in Bhabar or in Tarai area. The arsenic infested area of West Bengal forms a part of the Ganga delta, mainly in the interfluve region of Bhagirathi- Jalangi and Ichhamati in Murshidabad, Nadia, North & South 24 Parganas district comprising succession of upper Holocene Quaternary sediments . The arseniferous tract lies mainly within the upper delta plain at shallow depths (20-100 m bgl) which is mainly built of sediments deposited by meandering streams.

The exploratory drilling carried out in the districts of Murshidabad, Nadia and North 24 Parganas revealed that there are three distinct aquifers 15-80,100-160 and 200 270 m bgl. The shallow aquifer (15-100 m) is contaminated with arsenic where as the intermediate aquifer (100-160 m) and deeper aquifer(200 –270 m) are almost free from arsenic contamination. There are thick clay horizons separating shallow aquifer from intermediate aquifer and deep aquifer from intermediate aquifer. The shallow aquifer is unconfined to semi confined but intermediate aquifer and deeper aquifers are confined in nature.

In general the ground water in arsenic affected areas are Ca- HCO_3 or Ca-Mg-HCO_3 with very low sulphate ,chloride,fluoride and nitrate. In all the cases high iron has been observed in arsenic affected areas. It is observed that the presence of effective clay barrier (at least 10-15 m thick) , the deeper aquifers of the eastern part of Bhagirathi river can yield arsenic free water for the present requirement but the abstraction structures should be properly designed by cement sealing against the impervious clay layer to prevent vertical percolation of water from the top arsenic contaminated aquifers. The water quality should be monitored periodically to assure arsenic free water supply. It has been a common experience in the state that tubewell tapping deeper aquifers also some times yield arseniferous water if the tube well is not properly designed and adequate provision for insulating different aquifer is not provided. There is a concept among the experts working on arsenic problem in West Bengal that the deeper aquifer which is free of arsenic now,may get contaminated with arsenic in due course . The isotopic studies carried out by CGWB and BARC Mumbai indicates that in Murshidabad shallow ground water (up to 100m) is due to recent recharge. The Carbon –14 age of deeper aquifer in the district has been found approximately 500 years . However in South 24 Parganas shallow water is mixture of old and modern water having high arsenic where as the age of deeper aquifer water free from arsenic has been found in the range of 5000-13000 years.

Table 3. Blocks affected with Arsenic Problem in Ground water in West Bengal

S. No	District	Blocks	No. of Blocks
1.	Bardhman	Purbasthali-I, Purbasthali-II,Katwa-I, Katwa-II,Kalna-II	5
2.	Hooghly	Balagarh	1
3.	Howrah	Uluberia-II ,Shyampur-II	2
4.	Malda	English Bazar, Manikchak, Kaliachak-I, Kaliachak-II, Kaliachak-III, Ratua-I, Ratua-II	7

S. No	District	Blocks	No. of Blocks
5.	Murshidabad	Raninagar-I, Raninagar-II, Domkal, Nawda, Jalangi, Hariharpara, Beldanga-I, Suti-I, Suti-II, Bhagwangola-I, Bhagwangola-II, Berhampur, Raghunathganj-II, Murshaidabad-Jiagoan, Farakka, Samserganj, Lalgola, Beldanga-II, Raghunathganj-I	19
6.	Nadia	Karimpur-I,Karimpur-II,Tehatta-I,Tehatta-II,Kaliganj,Nakashipara,Nabadwip,Hanskhali,Kishanganj,Haringhata,Chakdaha,Santipur, Chapra,Ranaghat-I,Ranaghat-II,Krishnanagar-I,Krishnanagar-II	17
7.	North 24 Parganas	Habra-I, Habra-II, Barasat-I, Barasat-II, Deganga, Basirhat-I, Basirhat-II, Swarupnagar, Sandeshkhali-II, Baduria, Gaighata, Rajarhat, Amdanga, Bagda, Bongaon, Haroa, Hasnabad, Barackpore-II, Barackpore-I	19
8.	South 24 Parganas	Baruipur, Sonarpur, Bhangar-I, Bhangar-II, Budge Budge-II, Bishnupur-I, Bishnupur-II, Joynagar-I,Magrahat-II	9

Iron

Iron in an essential element in both plant and animal metabolism.. Both ferrous and ferric iron are wide spread minor component of most sediments. The concentration of iron in natural water are controlled by both physico chemical and microbiological factors. In aqueous solution iron is subject to hydrolysis and iron hydroxides are formed during these reactions, especially the ferric form having very low solubility. Practically all the iron is precipitated as hydroxides. To understand the behaviour of different iron species in ground water, application of chemical equilibrium is very useful and the actual solubility of iron under different condition can be calculated using Eh – pH diagram.

The Iron content of ground water in the state of West Bengal has been found mostly below 0.5 mg/L specially in dug wells which is obvious because of aeration. Some of the locations where higher concentration of iron has been reported are Bishnupr, Bankura district(4.65mg/l), Palarhati, Bardhman(7.26), Joypur, Howrah district(8.45), Gourhati, Hugli district(17.89), Rajabazar, Kolkatta(5.55), Amdanga, N-24 pargana(16.40), Ramdhari, S-24 pargana(13.03), Pingla, West Midnapur(10.94). The high concentration of iron has also been observed in deeper aquifer from the districts of Murshidabad Nadia, N –24 Parganas S- 24 Parganas and Haora.

Nitrate

The most common contaminant identified in ground water is dissolved nitrogen in the form of nitrate (NO_3). Decomposition of organic matter present in soils, leaching, of soluble synthetic and natural fertilizers, human and animal excreta are the potential source of nitrate in subsurface water. Nitrate in ground water generally originates from nitrogen sources on the land surface in the soil zone or a shallow subsoil zones where nitrogen rich wastes are buried. In some situations nitrate that enters the ground water system originates as nitrate in wastes or fertilizer applied to the land surface. These are direct nitrate sources. In other cases nitrate originates by conversion of organic nitrogen. Ammonification and nitrification are processes that normally occur above the water table generally in the soil zone, where organic matter and oxygen are abundant. In fact in nitrogen cycle various nitrogen products are available, the content of nitrate in ground water is probably controlled by nitrification which is directly related to the capacity of soil microorganism to convert ammonia to nitrate .

Concentrations of nitrate in the range commonly reported for ground water are not limited by solubility constraints.. It moves with ground water with no transformation and or no retardation. Very shallow ground water in highly permeable sediment or fractured rock commonly contains considerable. The concentration of phenolic compound (max. 0.125 mg/L), oil and grease (max. 78.80 mg/L) are found in mine seepage water Very high values of bacteriological contamination have also been observed. High concentration of Nitrate in ground water more than permissible limit(>45 mg/l) has been found in isolated pockets in Bankura, Bardhmna, Kolkata, Malda & Murshidabad.

Water Quality in Coalfield Area

The Raniganj coalfield one of the largest storehouse of coal in the country covers a total area of 1600 sq. km to the north of the Damodar river. The area extends from Barakar river in west to Andal in the east. The area is underlain by lower Gondwana group of rocks comprising alternate layers of shales and sandstones with seam of coal at places. Archean metamorphic rock comprising of granite gneiss, hornblend gneiss etc. are restricted to the north western part of the area and are overlain by Gondwana rocks .

Ground water in the area occurs under unconfined condition in the topmost weathered mantle in Archean and Gondwana rocks in the west and in the near surface aquifer in the tertiary/quaternary (depth 5.06 m to 15.20 m) sediments in the east and under semi confined to confined condition in the zone of secondary porosities like faults, fractures etc.

The huge amount of ground water (about 108 MCM/years) is being discharged in to the active mines by way of percolation through the zones of weakness. The water table recedes very much during summer in the vicinity of active mine established due to excessive percolation of ground water in to the active mines resulting in drying up of majority of open wells. The movement of ground water in general towards east and the gradient of ground water flow varies from 4 m/km in the west to 0.80 m/km in the east. The presence of both open cast and underground coalmines in the coal area have a pronounced effect on the ground water regime and modified the ground water flow pattern to a large extent. The major shallow aquifers are 9-79.5 m thick made up of yellowish gray to gray colour, fine to coarse grain tertiary sand. The deeper zone splits up into several sand layers separated by clay/sandy clay layers constitutes the deeper aquifers which are persistent throughout the area and overlies the Gondwanas in the west.

The chemical analysis of ground water from open wells and shallow tube wells shows that EC range from 97- 2570 µS/cm, chloride 11-479 mg/L ,Fluoride 0.04 to 1.3 mg/L and iron from 0.01 to 1.9 mg/L . The chemical parameter are in general within the permissible limit. The analytical results of ground water from open wells ,mines seepage water and surface water indicates the Biochemical Oxygen Demand (BOD) is high in case of surface water (10-32 mg/L) and very high in case of mine seepage water (10- 619.20 mg/L) and exceeds the limit. The open wells close to mine also shows higher values of BOD (8-14 mg/L) . Similarly Chemical Oxygen Demand (COD) is also very high in mine seepage water (18-940 mg/L) as compared to surface water (32-78 mg/L0 and open well water (28-56 mg/L).

In general ground water of the area is good for different uses except in cases where it gets contaminated with mine seepage water. In the nearby coal mines, seepage water in majority of the cases is bad and unsuitable for domestic uses. Surface water in the coal field area are mostly contaminated with mine seepage water pumped out of the mines and the industrial effluent present in the area and has become unsuitable for domestic consumption.

CONCLUSIONS

In general, the chemical quality of ground water in the major part of the state is good in shallow aquifer and the chemical constituents are well within permissible limit for human consumption. However, ground water quality problem, at places, has been noticed for salinity, high concentration of As, F and Fe etc. In some districts such as East Medinipur, S Haora, S 24 Parganas and Haora salinity problem exists at different depths. Arsenic contamination in ground water of West Bengal is restricted in 79 blocks of 8 districts, while high concentration of Flouride in ground water are observed in 8 districts of West Bengal. Suitable mitigation actions are required to be taken to use these contaminated water for different purposes.

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GROUNDWATER DEVELOPMENT IN WATER SCARCE JHARGRAM SUBDIVISION , WEST MEDINIPUR DISTRICT OF WEST BENGAL WITH REFERENCE TO APPLICATION OF ARTIFICIAL RECHARGE TECHNIQUES

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ABSTRACT

Tribal dominated Jhargram subdivision of West Medinipur District forms a part of water scarce pocket in the west of water abundant West Bengal state , which chronically suffers from drought with dwindling of monsoon. Rainfed cultivation often shatters due to monsoon failure while multiple cropping is not feasible because of lack of dependable irrigation facilities in the major part of the study area. This has caused weak rural economic status of the agrarian people of the area. The area is occupied by older alluvium underlain by Tertiary deposits, Precambrian rocks comprising Phyllite, Mica schists, Granite gneisses etc. The entire area is extensively lateritised. Subarnarekha and Kasai rivers and their tributaries drain along the area and form limited Recent inland alluvial pockets. In general, the underlying geological formations are poor water yielders barring the patchy valley fill along the rivers. Age old poverty due to absence of fertile land, lack of inherent abundances of water resources accompanied by climatic aberration, trans border infiltration, has caused infestation of extremism in the tribal dominated area. Water resources development forms one of the main infrastructural upliftment of any area to strengthen the rural economy. Keeping in view of the geology of the area, artificial recharge of ground water, rain water harvesting and conservation of water resources has been envisaged which may lead the area towards it sustainable management . Studies carried out so far in the area along with holistic development and management possibilities of water resources for societal upliftment have been discussed in paper.

INTRODUCTION

The study area (Fig-1) is encompassing a geographical area of 2556 Sq. Km. in seven CD Blocks under Jhargram subdivision which falls under West Medinipur District. This area is important as it forms a part of drought prone and water scarce patch in the western part of water abundant west Bengal state. It is already mentioned that the area faces severe water crisis both for irrigation and drinking especially in the lean period and the agriculture, the mainstay of the people, is mostly banking on monsoon rain. With the vagaries of rainfall often meager harvest is resulted. Recurrence of such failure is responsible for low economic status of the SC and ST population (Table-1) of the area who are the majority. These tribal populations used to depend on forest since time immemorial. With gradual shrinkage of dense forestry, the alternative means of livelihood other than agriculture has also been minimized.

Glimpses of studies in the area reveal that infrastructural development, especially development of water resources in the watersheds of the study area may bring some new hope for area through increase in agricultural production as also other rural development means covered under the Water shed development like Poultry, Goatery, Duckery, agro-forestry, social welfare measures through formation of Self help groups, through adoption of Joint Forest Management (JFM) practices etc. Govt. of West Bengal has already endeavored for development of water resources especially ground water for drinking in the area along with other basic

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infrastructures. Attempts are also made by the State Govt. to apply artificial recharge techniques However, some specific researches on application of artificial recharge and optimum rain water conservation have been made by the authors which are highlighted along with the hydro geological quest in the area to unravel the potentiality of various aquifers.

Table:1 Population Statistics(as per census-2001 of Jhargram Sub-division, West Medinipur District

Block	**Mouza**	**Population**						
		SC	**ST**	**Others**	**Male**	**Female**	**Total**	**Population Density (Sq.Km)**
Jhargram	629	66255	18218	69470	89688	64255	152943	285
Binpur-I	553	28113	36817	57270	62405	59795	122200	336
Binpur-II	470	20374	64760	60394	73451	72077	145528	252
Jamboni	338	16825	32675	51915	51568	49847	101415	310
Sankrail	288	18383	25761	58484	52098	50530	102628	372
Gopiballa -vpur-I	216	22206	32148	40442	48802	45994	94796	346
Gopiballa -vpur-I	192	24062	20594	48620	47813	45463	92276	462

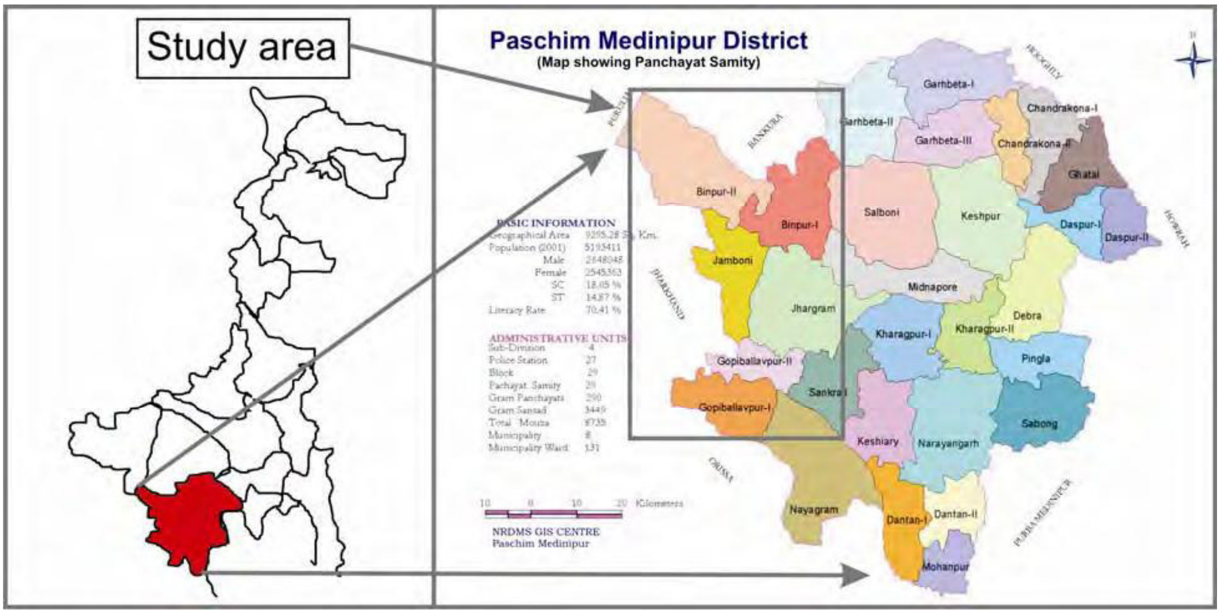

Fig.-1 Location Map

GEOMORPHOLOGY AND DRAINAGE

Geomorphologically the area can be subdivided into six geomorphic units.1. Flood plain 2. Valley fills 3. Denudational hills 4. Buried pediment 5. Lateritic uplands and 6. Paleo channels.

1. Flood plain :-Flood plains are available along the Subarnarekha and Kasai river courses available in the district and form fertile land for agriculture and these pockets are worthy for construction of shallow tube wells.

2. Valley fills:- Inland valley fills are available along tributaries of Subarnarekha and Kasai especially in their courses along the uplands underlain by colluviums , weathered and fractured basement rocks. The thickness of denudated debris, composed of laterite, quatzitic/gneissic sands and gravels as also the laterite capping over the weathered basement may vary from 0.5 to 3.5 to 4m. These areas are important recharge as also discharge zones and can be extensively utilized for artificial recharge and rainwater harvesting.
3. Denudational hills:-Denudational hills are available in the western, north western part of the district. Fractures and fissures occur in these hills and they are mainly forming the groundwater recharge areas.
4. Buried pediment:- Buried pediments are available in the undulating areas underlain by hard basement rocks where the thickness of weathering is considerable. These areas underlain by hard rock can be utilized for construction of dug wells.
5. Lateritic uplands:- Lateritic uplands are the hummocky residual landforms which are available in all geological formations i.e., older alluvium to Precambrian basement rocks. Facilitated by the climate, extensive lateritisation could be observed in the area. Thickness of lateritisation increases from west to east . Lateritisation is more extensive i.e. 15-20m or more in older alluvium-Tertiary tract while it is less i.e., 0.5-3.5-4m over Precambrian basement rocks. Laterites in general are highly porous because of its pisolitic texture and can be utilized for tapping good quantity of ground water as also as a conducive medium for holding rain water.
6. Paleo channels:-Paleo-channels are the old courses of rivers especially seen in the alluvial terrain where the river meanders. Paleo channels are the good locales for tapping copious ground water.

The area is drained by Subarnarekha, Kasai and their tributaries. A water divide runs along NNW-SSE separates the Subarnarekha basin from the Kasai sub-basin. Drainage in the district is controlled by structural weak planes i.e., lineaments and they are effluent in nature.

CLIMATE AND RAINFALL

The study area is characterized by Sub-humid to Semi-arid climate with average maximum temperature up to 40^0c. Average annual rainfall in the study area is 1546 mm. Monsoon generally sets in June and maximum downpour is received during June-September. With the delay in monsoon, the area often suffers from drought.

AGRICULTURE AND IRRIGATION

Agriculture is the mainstay of people. Major part of the study area is covered by alfisols and Ultisols. The dominant soil type of the area is sandy loam which is suitable for paddy cultivation. Colluvial soils are seen in the extreme North-west and western part of the area. Paddy is the main crop which is rainfed. In parts of the study area close to the major rivers and their potential tributaries, good cultivation could be observed. Depending upon various land type and irrigation facilities available in the study area, the following block wise cropping pattern has been suggested by the Agriculture Department, Govt. of West Bengal (Table-2).

Table: 2 Block-wise cropping pattern of Jhargram Subdivision,West Medinipur District

Block Name	Low Land	Medium Land	High Land
Jhargram	Paddy-Summer paddy-Pulses	Paddy-Summer Paddy-Mustard-Wheat	Paddy-Pulses-Maize-Kharif Veg-Mustard
Jamboni	Paddy-Summer Paddy-Pulses	Paddy-Mustard-Summer Paddy-Wheat	Paddy- Kharif Veg.-Kharif Pulses-Mustard

Block Name	Low Land	Medium Land	High Land
Binpur-I	Paddy-Summer Paddy-Pulses	Paddy- Potato-Wheat	Paddy-Potato-Wheat-Mustard
Binpur-II	Paddy-Summer Paddy-Rabi Veg.	Paddy-Rabi veg.-Wheat-Mustard-Potato	Paddy-Maize-Kharif veg.-Ground nut
Sankrail	Paddy-Summer paddy-pulses	Paddy-Mustard-Summer paddy-Wheat	Paddy-Pulses-Maize-Kharif veg-Mustard
Gopiballavpur-I	Paddy-Summer Paddy-Ground nut	Paddy-Rabi pulses-Wheat	Paddy-pulses-Wheat
Gopiballavpur-II	Paddy-Summer Paddy-Water melon-pulses	Paddy-Rabi pulses-Mustard-Water melon	Paddy-pulses-mustard

Surface water irrigation facility is very limited in the area. Because of high rate of evaporation most of the surface water sources go dry in the lean period or discharges in very low tune. In Gopiballavpur block seven Minor irrigation projects exist having an irrigation potential of 5922 Hectares. However, groundwater irrigation facility exists through shallow tubewells, deep tubewells and dugwells in various hydrogeologically favourable areas (Table-3). In addition there are good number of tanks available in the area (Table-4) which are utilized for irrigation as also for other purposes like fishery, duckery and various other community uses.

Table: 3 Irrigation details from various sources in Jhargram subdivision,West Medinipur District

Block	No. of Dugwell	CA of Dugwell (in Ha)	No of STW	CA of STW (in Ha)	No of Deep-Tubewell	CA of Deep tubewell (in Ha)
Jhargram	239	1.34	1255	1.56	7	30.28
Binpur-I	116	0.86	2320	0.90	3	26.66
Binpur-II	126	0.45	233	1.12	2	30.00
Gopiballavpur-I	227	1.39	1182	1.51	-	-
Gopiballavpur-II	267	2.28	1573	1.71	4	25.0
Sankrail	80	1.21	3075	1.12	11	25.45
Jamboni	17	0.73	692	1.52	3	40.0

CA- Command area, STW- Shallow tubewell, Ha- Hectare

Table: 4 Details of Tanks in Jhargram Subdivision, West Medinipur District

Block Name	No. of tank for irrigation purpose	No. of tank for Non- irrigation purpose
1.Binpur-I	46	580
2.Binpur-II	123	593
3.Gopiballavpur-I	17	287
4.Gopiballavpur-II	63	450
5.Jamboni	24	290
6.Jhargram	52	991
7.Sankrail	11	825

GEOLOGY AND HYDROGEOLOGY: Geology of the study area is quite diversified (Fig-2). Precambrian Group of rocks are exposed in the Northwestern , western and southern part of the subdivision while the rest part is occupied by older alluvium underlain by Tertiary deposits. Younger alluvium of Recent time occur along the river courses in the form of bar deposits.

Phyllites, Quartzites, Mica schists, Granite gneisses comprise the Precambrians. Older alluvium is often covered by laterite and it consists brown to red brown sand, sandy clay, gravels etc. Tertiary sediment consists of fine to medium sand, gravel, blueish clay with bivalve and gastropod fossils. Study of litholog of boreholes at various location reveals that a thick sequence of Clay-Silt-Sand and gravel occur down to a depth of 200-250 meters. A thick grey clay sequence separates the Tertiary sediment from older alluvium. Laterite is capping all the geological formations while it is extensive and occurs even up to 20-25m depth in the eastern side of the study area. In the areas underlain by Precambrians, the thickness of laterite is relatively less and found to occur within the depth range of 0.5- 4m below ground level.

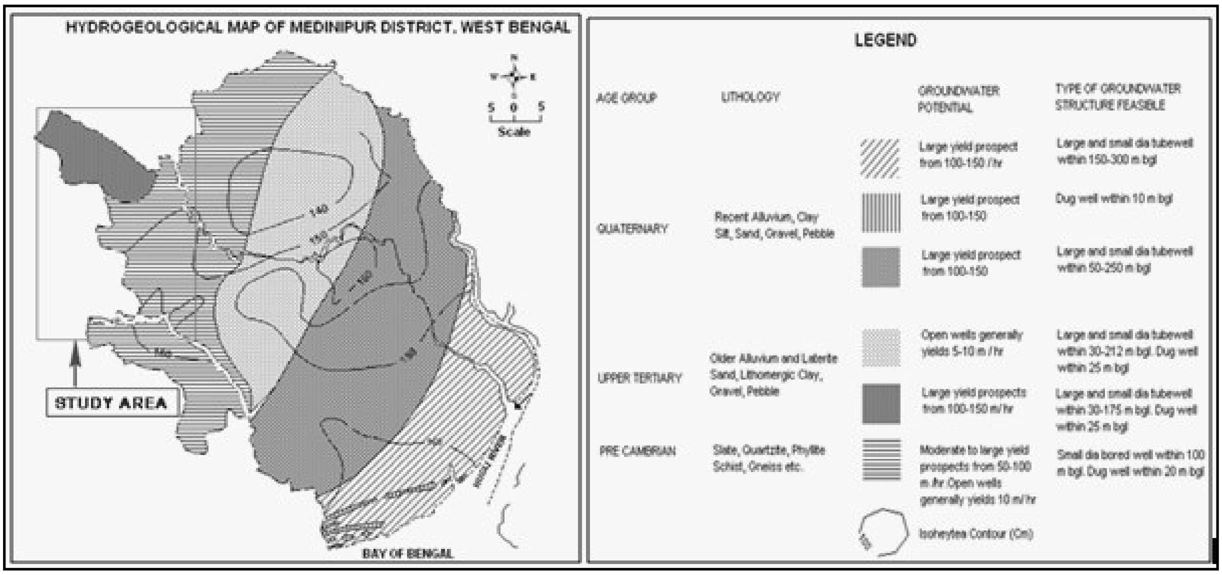

Fig- 2 Hydro-geological map of erstwhile Medinipur District where the study area is also shown

Ground water occurs under water table condition in shallow aquifers down to a depth of 60-70m from ground surface and under semi-confined to confined condition in the deeper horizons occur down to 80- 250m below ground level. Ground water in the weathered residuum in the hard rock occurs under unconfined condition while in the interconnected fractures and fissures it occurs under semi-confined to confined condition. Dug wells(2.5m dia. 6m depth) in older alluvium yields generally in the order of 5000-10,000 m^3/day while in the same formation Shallow tube wells (STW) yields sustainable for 6-8 hrs at the rate of 10-35m^3/hr. Although younger alluvium has restricted occurrences yet it yields at much higher tune ranging from 36-72m^3/hr and continues sustainable for 8-10 hrs/day. Tertiary formations occur at deeper depth are explored through CGWB drilling and found to yield from 8m^3/hr to 36m^3/hr which also can yield sustainable for 6-8 hrs/day. Dug wells (2.5m dia,6m depth) constructed in the weathered mantle of hard rock may yield 3000-4000 litres/day while the bore well may yield from negligible- 22m^3/hr which may yield sustainable for 6-8 hrs/day. The yield of bore wells in hard rocks tapping deeper fractures is revealed through the CGWB exploration carried out in the area (Table-5). Success of bore well in hard rocks depends upon proper identification of lineaments through integrated hydrogeological and geophysical studies coupled with remote sensing. Extensive exploration also reveals plethora of subsurface data for further delineation of new sites.

Transmissivity of the shallow aquifer is 96m^2/day while transmissivity of the deep aquifer ranges from 43-274m^2/day. Depth to water level in shallow aquifer varies from 4.15-16.4 metre below ground level (mbgl) in pre-monsoon while in post-monsoon depth to water level ranges from 0.7 to 9.14 mbgl in the same aquifer. Depth to water level in deeper aquifer varies from

6.61-17.36 mbgl in pre-monsoon while in post-monsoon it varies from 4.5- 11.65 mbgl. Presence of auto flowing condition has been reported from parts of Gopiballavpur-II (Recent alluvium) and Binpur-I (Tertiary) blocks and it is observed to occur within the depth range of 37-43m in recent alluvium while at depth range of 80-95m in Tertiary formation. Although dug wells constructed in pervasive lateritic formation yield considerably to the tune of 10,000-15000 litres/day, property of this porous formation has not been utilized so far for large scale conservation of ground water and rainwater through artificial recharge. A glimpse of studies carried out by the authors are presented in the following paragraphs.

GROUND WATER DEVELOPMENT AND QUALITY

Long term trend analysis of data of Pre and Post-monsoon water levels of the area shows no ground water decline in the area. This is indicative of utilization of ground water in the area in low key. This is also indicating indirectly the unubiquity of extensive ground water bearing formations in the study area. Otherwise it's an integral part of West Bengal where in spite of abundance of ground water, overdevelopment has been resulted in many blocks. Net water availability of the area is 100129.44 ham(Hectare metre)/Year of which ground water draft is 22346.66 ham/year. Stage of ground water development varies from 9.1 to 48.65%. Ground water development is done through 3095 dug wells, 11462 Shallow tube wells and 43 deep tube wells. Quality of ground water is good throughout and all the constituents are well within the permissible limit except Fe and fit for all purposes. Ground water in the area is Ca-Mg-HCo_3 type.

Why Ground water and Surface Water Sources Could Not be Properly Developed in the Area?

From the foregoing discussion it is clear that the area is dominantly covered by Precambrian basement rocks as also older alluvium underlain by Tertiary formations which do not form potential aquifers to facilitate sustainable agriculture with multiple cropping. However, from government as also through private initiative tube wells are constructed especially in the Recent alluvial tract as also in the areas underlain by older alluvium and Tertiary to tap optimum ground water. In this respect, it may be added that while exploration was attempted in such sedimentary tracts as also exploitation is in practice for quite some time, the areas underlain by hard rocks were not explored since long. However, the area has been explored during 2000-02 with nine exploratory wells only at few locations. The result was not very promising as only three out of nine exploratory bore wells were found successful. Still it was inadequate to give data based comment and for doing so extensive exploration is needed in the area to prove the extension of fractures at depth as also its interconnection. The exploration should be preceded by integrated studies of hydrogeology and geophysics coupled with remote sensing. So because of all the above valid reasons, the ground water could not be developed in the area. Similarly adverse climate, high evaporation rate, failure of monsoon makes the surface water resources in the area scarce as also undependable. In matter of ground water irrigation while the picture is not promising, in case of drinking water supply hand tube wells are constructed in the rural areas and deep tube wells and bore wells are also constructed for rural and urban piped water supply to cater potable water.

STUDIES CARRIED OUT SO FAR ON ARTIFICIAL RECHARGE AND CONSERVATION OF RAINWATER IN THE AREA

To combat with the natural unavailability of adequate surface and ground water, State water Investigation Directorate(SWID), Govt. of West Bengal had attempted to augment the groundwater resources through application of various artificial recharge techniques involving construction of Percolation Tanks, Sub-surface dams, contour bunds etc. under technical collaboration with CGWB. (Table-6,7). Impact assessment studies revealed appreciable success of the recharge structures.

Table- 5 Aquifer data from the Explorations in Jhargram Subdivision ,West Midnapur Dist.,W.B

Location/ block	Depth Drilled (mbgl)	Length Of well Constructed (m bgl)	Zone Tapped (in mtr.)	Aquifer	SWL (mbgl)	Discharge (Lps)	Draw Down (in m)	Transmissivity (m^2/day)	Storativity
Thakur Para/Binpur-I	205.3	199.0	90-96 110-114 180-183 189-197	Older alluvium/ Tertiary	4.66	10.0	-	43	$9.6x 10^{-3}$
Panchapani EW-I/ Binpur-II	100.0	100.0	14.3	Granite gneiss	-	Negligible	-	-	-
Chakadoba EW-I/ Binpur-II	122.3	122.3	5.0	Granite gneiss	-	Negligible	-	-	-
Bhula Bheda EW-I / Binpur-II	122.3	122.3	20.5	Phyllitic quatzite	-	Dry	-	-	-
Oroli Binpur-II	122.3	122.3	20.5	Phyllite	3.24	6.0 (APT)	19.95	31.64	-
Udalchua (EW-I)/ Binpur-II	169.0	169.0	6.5	Phyllite	4.27	4.27 5.8 (APT)	15.41 (APT)	22.6	-
Udalchua (EW-II)/ Binpur-II	252.2	252.2	11.0	Phyllite	4.96	5.1 6.47 (APT)	12.91 (APT)	20.26	-
Dholkat /Jhargra-m	169.0	160.0	47-59 81-84 89-95 146-158	Older Alluvium (Tertiary)	10.6	2.1	7.97	197.0	-
Shaktinagar / Jhargram	252.2	252.0	41-46 66-74 80-88 210-218 245-250	Older Alluvium (Tertiary)	-	5.83	4.62	225.10	$4.0x 10^{-2}$
Satyaban Palli/ Jhargram	241.94	118.0	78-81 103-115	Older Alluvium (Tertiary)	16.3	4.83	3.02	139.93	_

Table: 6 List of Percolation Tank constructed in Jhargram Subdivision, West Midnapur District constructed through Central Sector funds

Village Name	GramPanchayat.	Village Name	Storage Capacity(LXBXD) (In M^3)
1.Madhupur	Aguiboni	Jhargram	50X30X2=3000
2.Kashitoria	- DO-	-DO-	50X30X2=3000
3.Madhupur	-DO-	-DO-	50X30X1.2=1800
4.Belaijori	Patasimul	-DO-	61X22.6X2.5=3446.5
5.Patasimul	-DO-	-DO-	42.65X29.6X2=2524.88
6.Bagjhopa	-DO-	-DO-	15X30X2.5=1125
7.Bagjhopa	Aguiboni	-DO-	15X30X2.5 =1125
8.Andharisimul	Nedabalina	-DO-	48X30X2=2880
9.Pasro	-DO-	-DO-	50X30X3=4500
10.Nutandihi	Lalgarh	Binpur-I	50X30X3=4500
11.Nutandihi	-DO-	-DO-	50X30X3.4=5100
12.Bandhgora	-DO-	-DO-	50X30X3=4500

Table:7 Details of Sub-surface Dyke and Contour Bund Constructed in Jhargram Subdivision, West Medinipur under Central Sector Scheme

S. No	Village name	Block name	Type of structure	Dimension of the structure
1	Madhupur	Jhargram	Subsurface dyke(4 nos.)	L=1.5m,B=1.5m,D=2.5m
2	Bagjhopa	Jhargram	Subsurface dyke(2 nos.)	-DO-
3	Madhupur	Jhargram	Contour bund	L=1.5 Km, D=0.5m

STUDIES ON APPLICATION OF ARTIFICIAL RECHARGE AND OPTIMUM RAIN WATER HARVESTING IN WATER SCARCE HARD ROCK AREAS

Artificial recharge techniques and rain water harvesting can be successfully implemented in the areas having water scarcity or overexploitation . In such areas, appreciable room in the subsurface reservoir is created due to lowering of water level or piezometric(pressure) surface at appreciably deeper level . For easy recharge of ground water, porosity and permeability of the geological formations occurring in such areas should be high. Extensive experimental studies on artificial recharge and rain water harvesting have been done by several workers and plethora of literatures are available(Kar,2002a,2002b,2004a,2004b,2008; Kurien,2008; Tomar,2008; Ramaswamy et al.,2008; Vadher et al.,2008 etc.)

Experimental studies were carried out in the area to find out a solution to augment the water availability position in the water scarce parts of the subdivision with the application of various watershed management techniques and rainwater harvesting. To recommend applicable artificial recharge techniques, selected areas of the most water scarce Binpur-II block were chosen .The reasons behind selecting the area are as follows.

1. The area is underlain by hard rocks (Fig-3) having less ground water development potential as evident from the poor success rate of exploration made by CGWB.
2. Water resources development status (both surface and ground water) is very poor.
3. The area is extensively lateritised (Fig-4).

4. There are numerous small non-perennial (Fig-5) as also few perennial streams (Fig-6) available in the area.
5. Denudated lateritic sand and gravels are plentily available in the area while coarse sand could be collected at cheaper rate from the nearby Kasai and Subarnarekha rivers.
6. If the recommendations made are found successful after implementation, the same type of construction can be followed in any other block inside the study area as also elsewhere having identical hydro-geological situation.

Fig-3 Exposure of hard rock

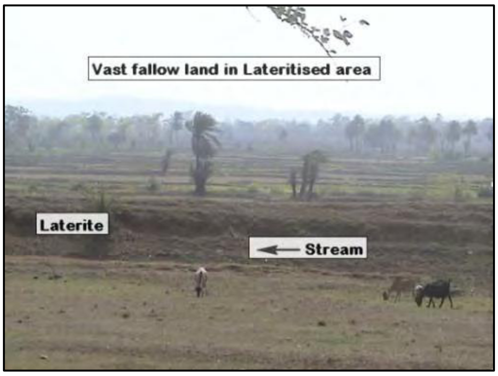

Fig-4 Vast lateritised land


Fig-5 A non perennial stream

Fig-6 One perennial stream

OBSERVATIONS AND RECOMMENDATIONS:

To properly adjudge the area, studies were carried out in peak summer (April-May) as also during post-monsoon (November-December). The Pre-monsoon study revealed that although the water level remains at much deeper level (10-12m below ground level) in the area, in specific areas especially in the topographic lows (Fig-8,13-17) ground water remains at shallow level. In such cases even the Ponds also hold some water during peak summer (Fig-7). Many traverses were made along several stream courses (Fig-5, 8). Since the area is capped by laterite , to understand the thickness of laterite over the weathered basement rocks as also to find out the hydraulic properties, yield, depth to water level, several experimental pits were constructed(Fig-10 -12) and well sections were also studied(Fig-9). From the detailed studies the following observations were made.

Fig-7 A Perennial pond

Fig-8 Look on a stream profile

Fig-9 A well section

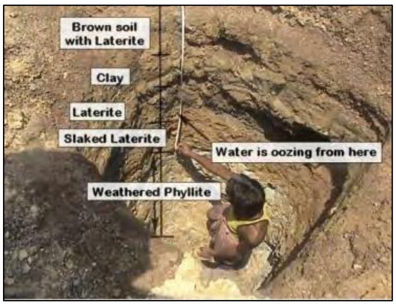

Fig-10 Experimental pit

Fig-11 Experimental pit

Fig-12 Experimental pit

1. Lateritic profile along the streams are generally 0.5 to 4m thick with intercalations of clay layer as also laterite weathered rock admixtures. Average thickness of pure laterite in the section varies from 0.5 to maximum 2.5m.
2. Thickness of laterite varies from place to place (Fig-9-12) and lateritisation is more pronounced along the streams than in the catchments i.e. in the uplands along the banks.
3. Depth to water level is very close to the bed level in many parts of the streams. Even at places water pools were also observed (Fig-13-16).
4. Laterite sand and gravels are available in the down stream of almost all the streams.
5. Permeability of the laterite found high while the weathered clayey product of pre existing rocks i.e.-phyllite, Mica schists etc. were very low and may be treated as impermeable basement.
6. Bank heights of the streams are not very high. Generally ranging from 2-3 m from bed level in majority of the streams.

Fig-13

Fig-14

Fig-15

Fig-13-15 Stagnant pool made by oozed water in the streams of water scarce Binpur-II block

In the light of above observations, the authors were prompted to recommend the following measures for optimum artificial recharge of ground water and rain water harvesting in the area to augment the water availability position in the watersheds for its development.

1. All the streams(especially non-perennial), covering the area in a reticulate fashion , may be excavated down to 5mbgl and the thickness may be packed with in situ as also local sieved lateritic gravels(Fig-18) followed by coarse lateritic sand then by medium to fine lateritic sand. In case adequate quantity of lateritic material is not available then coarse gravel, coarse to fine river sand may be brought from the local Kasai, Subarnarekha rivers.
2. Medium to fine sand at the top will arrest silts and clays to be brought by the streams during rainy season. Every year the top clay is to be removed after the cessation of rainy period and medium to fine sand is to be repacked at the top level.
3. At every 150 to 200m interval along the stream course c.c. check dams (Fig-17) are to be constructed in series for optimum rainwater harvesting and recharge . The height of the check dams should be commensurate as per the bank height and proper engineering design is to be adopted.
4. Good number of percolation tanks (Fig-17) are to be constructed in the catchment for accentuating recharge in the water shed as also for optimum rain water harvesting.
5. Small dia (1.5-2m) dug well with 5-6m depth may be constructed along the catchment (Fig-17). However, parapet of the dugwell is to be adjusted as per the height of C.C Check dam and water impounded.
6. In general subsurface dam (Fig-18) is to be constructed at the downstream of a stream having length of 2-3 km. However, if the length of the stream is too big then at 1.5 to 2 km interval it may be constructed.

Fig-16 A Spring in stream

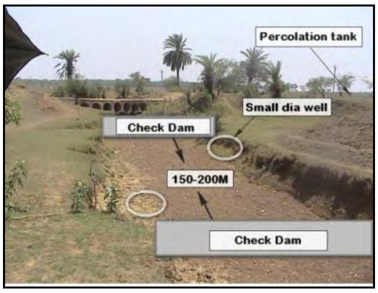

Fig-17 Scheme of check dam, well and Percolation tank in watershed

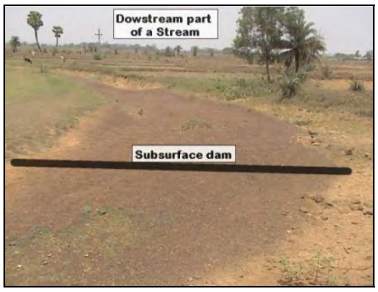

Fig-18 Subsurface dam

7. In case of perennial rivers, check dam at 150-200m interval may be constructed. However, topographical surveys would be necessary in that case to ascertain height and distance between the check dams. Subsurface dykes/dams may be constructed at 1.5 to 2 Km. interval.
8. For withdrawal of water, low duty pumps or manual methods are advisable. For management of water drip or sprinkler irrigations may be adopted.
9. Proper cropping pattern as per soil, water availability and agro-climate is to be adopted to economically use the water resources. In this regard agricultural extension services are to be geared up.
10. Impact assessment studies are to be carried out after implementation.
11. On achieving success, the structures may be followed in other areas.

CONCLUSIONS

The study area encompassing a geographical area of 2556 Sq. Km. falls under the jurisdiction of Jhargram subdivision in West Medinipur district of West Bengal. Although the West Bengal State as a whole is called water abundant, still the western part of the state containing the patch of the area under study is water scarce because of unfavorable hydrogeology, climate and non availability of prolific surface water resources. Age old poverty, paltry rainfed harvest from agriculture which is often hit hard by delay in monsoon i.e. drought, waning forest wealth, have been responsible for very poor rural economy of this tribal dominated tract. Part of the area is occupied by older alluvium underlain by Tertiary Formation while the western, north western and south western parts are covered by Precambrian basement rocks comprising Phyllite, Mica Schist, Granite gneisses etc. Recent alluvium is available in limited patches along the Kasai and Subarnarekha rivers drain along the area. In general the discharges of wells in older alluvium and Tertiary along with the Precambrian rocks are low to medium and it is ranging from 8-36 m^3/hr. The wells tapping the formations sustain the yield for 6-8 hrs/day. Although restricted, tube wells in Recent alluvium yield within 36-72m^3/hr. In the hard rock areas, maiden exploration activity produced 9 exploratory borehole during 2000-2002.However, extensive exploration preceded by Hydro-geological and geophysical surveys coupled with remote sensing should be undertaken in the area. Although, it has not become possible by the State Govt. to allocate needful irrigation water in the area, the arrangement of potable drinking water in the rural and urban areas has been done by State PHED. While scope of ground water and surface water development in the area is bleak, State Water Investigation Directorate, Govt. of West Bengal under technical guidance of CGWB have taken up various artificial recharge measures under Central Sector Scheme for augmentation of ground water recharge and rain water harvesting. The research studies carried out in the Binpur-II area have revealed scope for optimum rain water harvesting, artificial recharge and augmentation of water resources through Check dam, Percolation tank, Subsurface dam/dyke and wells. The recommendation may be expeditiously implemented through proper water shed development approach involving water resources augmentation, introduction of fishery, duckery, poultry, goatery, agro-forestry, creation of Self Help groups, Joint Forest management committee (JFMC) etc. Development of rural economy in the aforesaid way if could be achieved, this would indirectly solve the problems of insurgency in the area.

SUM UP

1. It is repeatedly discussed that the area is underdeveloped in terms of water resources. Hence to develop groundwater resources of the area, especially in the areas covered by hard rock, should be brought under extensive exploration activities preceded by combined hydro-geological-geophysical and remote sensing studies.
2. Full-fledged activities of rainwater harvesting and artificial recharge should be adopted in all macro and major water sheds of the area involving all measures of rural development as mentioned earlier in detail. The means of water resources development and various structural constructions and their recommendations are already described in the preceding paragraphs what may be followed.
3. Efforts should be made by the state government to enhance agricultural extension services.
4. The recommendation may be implemented first in one area as a pilot project, where all the structures as recommended should be constructed.
5. On successful construction and completion of the pilot scheme, the impact assessment studies should be undertaken. If it is proved worthy then the same recommendation may be implemented in all the blocks as also anywhere in the country having similar hydro-geological and climatic setting

ACKNOWLEDGEMENT

The authors express their sincere gratitude to Shri B.M. Jha, Chairman, CGWB for his kind enthusiasm to publish the paper. The authors are also grateful to Dr.S.C. Dhiman, Member(SM&L),CGWB for his kind inspiration to write the paper. The author (AK) is also thankful to Shri G.C.Saha, Regional Director, CGWB, NER, Guwahati for his enthusiasm . Regional Director, CGWB, Eastern Region is gratefully acknowledged to depute the senior author (DGD) to the area both for hydrogeological surveys and ground water exploration. The author(AK) is highly indebted to his friend Dr.A.N.Biswas, W.B.C.S(Exe.) and the then S.D.O., Jhargram, Govt. of W.B., for taking keen interest for rural development and to invite him to visit the area and to provide all infrastructural facilities. AK is also grateful to his colleague Dr. S.K.Jain, Scientist-D, HQ, Faridabad for his encouragement to submit the paper. The author (AK) would like to place on record the constant inspiration received from his colleague Dr.S.Shekhar, Scientist-B, HQ,Faridabad. Shri B.Ray, Scientist-B and Dr.D.J.Khound, Asst.Hg., CGWB,State Unit office, Itanagar, are thanked for their assistance during preparation of the manuscript.

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QUALITY OF GROUNDWATER IN PARTS OF ARSA BLOCK, PURULIA DISTRICT, WEST BENGAL

S. K. Nag*

ABSTRACT

Geochemical studies of groundwater have been performed in parts of Arsa Block, Purulia District, West Bengal. The analyses of water samples have been carried out to have an idea about physical and chemical parameters. Physical parameters include pH, Electrical conductivity (EC), Total Dissolved Solids (TDS) and chemical parameters include the elements like Ca, Mg, Na, K, HCO_3, SO_4, Cl etc. These cations and anions are correlated with standards for drinking and irrigation purposes. The U.S. salinity indicate the values of present area are of C1S1 and C2S1 types, i.e., low salinity and low sodium which is good for irrigation. Comparing the analytical results with the standard of drinking water, the present waters are also good for drinking purposes.

INTRODUCTION

Groundwater is an economic resource and most of the public water supply are obtained from wells and deep tube wells. Groundwater supplies in rural areas, particularly in villages have certain advantages over surface water. For drinking and irrigation purposes villages have to depend entirely on groundwater. The chemical composition of groundwater is related to the soluble products of rock weathering and decomposition which changes with respect to time and space. Geochemical studies provide a complete knowledge of the water resources of a hydrological regime. Geochemical studies are also of value with respect to water use. They provide a better understanding of possible changes in quality as development progresses, which may in turn provide information about the limits of total developments, or can permit planning for appropriate treatment that may be required as the result of future changes in the quality of water supply. Sampling and testing in an area with some good quality and some poor quality water should serve to differentiate areas and aquifers of varying quality. Moreover, salinity varies with specific surface area of aquifer materials, solubility of minerals and contact time.

The present investigation has been carried out in a small area which include, part of Arsa Block of Purulia district, West Bengal. The district of Purulia is one of the most drought prone areas, situated on the eastern slope of Chotanagpur plateau and forms south-eastern part of the state of West Bengal. The sources of the water supply, for example, streams, bandhs, etc., begin to dry up with approaching summer when the people have to depend entirely upon groundwater. Even the large diameter dug wells which are usually the source of groundwater in this region become almost ineffective by this time. . People have to depend on time-bound municipal water supply. The district is characterized by a dry tropical climate with a winter and a very hot summer. South-West monsoon is the principal source of rainfall in the district. However, it is erratic in nature and there is occasional drought condition in between rain spells which may last for several days. An attempt has been made to investigate the variations in geochemical characteristics of the groundwater in the area.

GENERAL GEOLOGY

The district is underlain by Precambrian metamorphic rocks barring a small patch in the north-eastern part, where sediments of Gondwana group occur. Unconsolidated sediments of

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Recent to sub-recent age are confined to narrow river channels and to the valleys. The topography of the study area is more or less flat. The ground surface is covered by thin sheet of alluvium, which are lateritic in some places. The majority of the exposed rocks are granitoid in nature. The granitoid rocks are, to some extent, weathered and show characteristics of gneissic banding. Besides these, there are patches of amphibolite, metabasics etc., intrusives within the granitoid mass. The top surface is covered by thin sheet of alluvium soil.

HYDROLOGICAL FRAMEWORK

The groundwater in the area occurs mainly in hard crystalline rocks, within weathered mantle and fracture zones of the underlying crystalline rocks. Some groundwater also occurs in narrow zones of unconsolidated deposits along the river valleys. The salient features are:-

- **The Weathered Mantle**

  The weathered mantle comprises of thin layer of top soil followed by regolith, representing the weathering product of underlying rocks.

- **Fractured Zones**

  Fractures also impart a good amount of porosity within crystalline rocks but the pattern and orientation totally governs the permeability within these rocks. Rain water percolates into the fractured zones of hard rocks through interconnected joints, fissures and other weak planes in the Precambrian areas .Intensity of joints and fractures, their interconnection, degree of penetration, etc., are the controlling factors in storage and movement of groundwater in the fractured zones.

- **Unconsolidated Sediments as Valley Fills**

  Alluvial deposits of Recent to sub-recent origin occur as discontinuous lenticular patches adjacent to major rivers and streams. The prominent alluvial zones are at and around Aharara – Sirkabad and the area to the south west of Purulia town and Belaidih in the Kasai basin.

SAMPLING

Quality of water is of paramount importance in any evaluation of groundwater resources. The physical, chemical and biological characteristics of the aquifers are of major importance in determining whether or not the water is suitable for drinking purposes, or agricultural use. An attempt has been made in order to make an estimate of and explain some major and minor inorganic constituents within the groundwater of the study area. Groundwater samples have been collected from number of dug wells and deep wells existing in the area. Polythene bottles of 1litre capacity were used for collecting the water samples. Before a sample was taken, the well was pumped for sometimes so that the sample collected, would represent the groundwater samples from which the well was fed. All bottles were rinsed with water before collecting the sample for analyses. Well location, time and date of collection of individual sample were noted down immediately on the bottles. The sample bottles were sealed well before storage and brought to the laboratory immediately for analyses.

HYDROCHEMICAL STUDIES

Quality of water is of paramount importance in any evaluation of groundwater resources. The physical, chemical and biological characteristics of the aquifers are of major importance in determining whether or not the water is suitable for domestic, industrial or agricultural use. When water infiltrates into the ground its quality is modified by a number of processes. The quality of water in the zone of saturation reflects that of the water, which has percolated into the water table and subsequent reaction between water and rock material, occur.

Table -1: Physical and Chemical parameters of groundwater samples.

Location	pH	EC (μmohs/cm)	TDS (ppm)	Cations (ppm)				Anions(ppm)		
				Ca	Mg	Na	K	HCO_3	Cl	SO_4
Senabana	6.8	198	103	16.1	6.3	26.8	0.78	79.2	21.0	5.0
Aharara	7.0	290	144	40.3	9.6	32.3	0.90	134.3	23.8	4.7
Belaidih	7.1	235	118	30.7	6.1	36.9	1.07	122.7	18.3	5.3
Lachhmanpur	7.3	268	137	34.7	7.3	23.8	1.14	137.4	20.6	4.9
Kultanr	7.1	193	114	43.8	6.7	37.2	0.87	87.2	21.5	5.6
Panrkidih	6.9	283	129	37.6	8.1	18.4	1.03	128.6	22.7	5.4

pH

The pH is a measure of hydrogen ion activity of water and is an indication of chemical equilibrium. This is usually controlled by the carbon dioxide - bicarbonate - carbonate system of the water and gives rise to different values in accordance with solubility of carbon dioxide changing with temperature and pressure. pH of water is determined by means of an electrometer and glass and different electrodes. The water samples from different wells in the area found to show pH values between 6.8 to 7.3.

Total Dissolved Solids (TDS)

The concentration of total dissolved solids (TDS) in groundwater has been determined directly by weighing the solid residue obtained by evaporating a measured volume of filtered sample to dryness. Groundwater has been classified according to its TDS content as follows (after Hem, 1970):

Fresh	<1000 ppm
Moderately saline	3000 to 10000 ppm
Very saline	10,000 to 35,000 ppm
Briny	>35,000 ppm

In the present samples TDS values range from 103.00 to 144.00 mg/liter.

Specific Electrical Conductance

Specific electrical conductance defines the conductance of a cubic centimeter of water at a standard temperature of 25^{0}C. It also depends on type and concentration of ions present. The determination of electrical conductivity has been made for the samples using Phillips Conductivity Bridge. The Water samples show specific electrical conductivity at 25^{0}C ranging from 193 to 290 μmhos/cm

Calcium and Magnesium

Calcium is widely distributed in the common minerals of rocks and is considered to be principal cations in groundwater. The feldspars, pyroxenes and amphiboles and less common minerals such as apatite and wollastonite present in igneous and metamorphic rocks are the common sources of calcium. The normal concentration of calcium in groundwater ranges from 10 to 100ppm. It may be noted from the given analytical results presented in Table-1 that calcium contents in groundwater in this study area ranges from 16.1 to 43.8 ppm. Such concentration have no effect on health.

Magnesium in groundwater is derived from ferromagnesian minerals like olivine, pyroxene, amphiboles and dark-coloured mica among igneous rocks. In metamorphic rocks, magnesium occurs in the structure of chlorite, montmorrilonite and serpentine. The reaction involving solution of magnesium is controlled by the amount of CO_2 in groundwater in dissolved state.In the present study, magnesium contents of groundwater varies from 6.1 to 9.6 ppm.

Sodium and Potassium

In igneous and metamorphic rocks sodium is chiefly derived from weathering of feldspar and mica minerals. Potassium is less common than sodium in igneous rocks. These minerals are very insoluble so that potassium level in groundwater normally are much lower than sodium concentration . The concentration of sodium in natural water is less than 200ppm and that of K is generally less than 10ppm. The water samples on analysis show that sodium content vary from 18.4 to 37.2ppm. The potassium content is very small [0.78 to 1.14ppm].

Bicarbonate and Carbonate

Bicarbonate and Carbonate usually the primary anions in groundwater are derived from CO_2 released by organic decomposition in soil. These are derived also from atmospheric CO_2 as acid rain and from solution of carbonate rocks. These ions impart exclusively the alkaline character of the groundwater and are largely controlled by the pH value of the water. The carbonate concentration of natural water is commonly less than ppm. It is found from chemical analyses that carbonate concentration ranges from 79.2 to 137.4 ppm for bore well samples and from 68 to 325 ppm for dug well samples.

Chloride

Chloride content of groundwater may be attributed to the presence of soluble chlorides from rocks, evaporates, saline intrusion, connate and juvenile water, or contamination by industrial effluent or domestic sewage. Usually the concentration of chloride in groundwater is less than 30ppm but concentration of 1000ppm or more are common in arid regions. The chloride content in the groundwater of the present study is less than 30ppm but concentration of 1000ppm or more are common in arid regions. The chloride content in the groundwater of the present study occur in the range from 18.3 to 23.8 ppm .

Sulphates

The sulphate is formed by oxidation of sulphide minerals like pyrite, sphalerite etc. In natural water the sulphate concentration does not exceed 100ppm. In the analyses of groundwater samples, the sulphate concentration is found to vary from 4.7 to 5.6 .
Indian Council of Medical Research, New Delhi 1975 has recommended the quality criteria as standard for drinking water in India. On the basis of this, the groundwater in the studied area have been classified. At the right side of the table- , maximum and minimum values of the respective constituents obtained from the present analyses have also been shown in Table

Table2 : Comparative Study between the Data obtained from Chemical Analyses of water samples with Standard for drinking water as specified by Indian Council of Medical Research, New Delhi.

Characteristics	Highest Desirable Limit	Max. Permissible Limit	Values obtained from Present Analysis Min.	Max.
pH	7.0 – 8.5	6.5 – 9.2	6.8	7.3
T.D.S	500 ppm	1500 ppm	103.0	144.0

Calcium (Ca)	75 ppm	200 ppm	16.1 43.8
Magnesium (Mg)	50 ppm	100ppm	6.1 9.6
Chloride (Cl)			
Sulphate (SO_4)	200 ppm	1000 ppm	18.3 23.8
	200 ppm	400 ppm	4.7 5.6

Total Hardness (TH) :

The hardness of water is mostly due to the presence of Ca^{2+} and Mg^{2+}. The total hardness is expressed as ppm of $CaCO_3$.

$$TH = 2.497\ Ca + 4.115\ Mg$$

where all the constituents are expressed in ppm. The calculated TH values for all samples are given in the Table 3 alongwith the range of Hardness recommended by the U.S.G.S.

Table 3: Sample location with Total Hardness (TH) and (SAR)

Sample Location	TH	SAR
Senabana	60.12	1.42
Aharara	140.13	1.18
Belaidih	101.76	1.58
Lachhmanpur	116.69	0.95
Kultanr	136.94	1.38
Panrkidih	127.22	0.85

Table 4 : The Range of Hardness of water as specified by U.S.G.S.

Class	Range of Hardness	Remarks
Soft	0 – 55	
Slightly Hard	56 – 100	Require little or no softening
Moderately Hard	101 – 200	
Very Hard	> 201	Require softening

The present samples show a range of hardness from 60.12 to 140.13. So, the water should require softening.

The Salinity Laboratory of the US Department of Agriculture recommends the Sodium Absorption Ratio (SAR) because of its direct relation to the absorption of sodium by soil. With reference to SAR as an index for alkali hazards and EC as salinity hazard, U.S.Salinity Laboratory constructed a diagram for classification of irrigation water (Richards,1954).

The SAR is defined as

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

where the concentration of the ions are expressed in milliequivalent per litre.

In the Fig.1 SAR value is plotted as the ordinate and conductivity as abscissa on the semi-log paper. The Fig.1 provides several fields defined by C_1, C_2, C_3, etc., representing progressive rise of salinity hazard from total salt concentration. Similarly S_1, S_2, S_3, etc., denote the increasing hazard due to exchangeable sodium. The total field can be subdivided into 20 different groups C_1S_1, C_2S_1,C_2S_2, etc., based on quality of water on irrigation purpose. The specific conductance value w.r.t SAR value are plotted on this Fig. It is evident from the figure that the samples are distributed within C_1S_1 and C_2S_1 field and are considered as good for irrigation purposes (Table 5).

Table 5. Quality Classification of Irrigation Water

Water Class	Salinity Hazards (EC)	Alkali Hazards (SAR)
Excellent	<250	Up to 10
Good	250 – 750	10 – 18
Medium	750 – 2250	18 – 26
Bad	2250 – 4000	> 26
Very Bad	> 4000	--
Present Samples	193 - 290	0.85 – 1.58

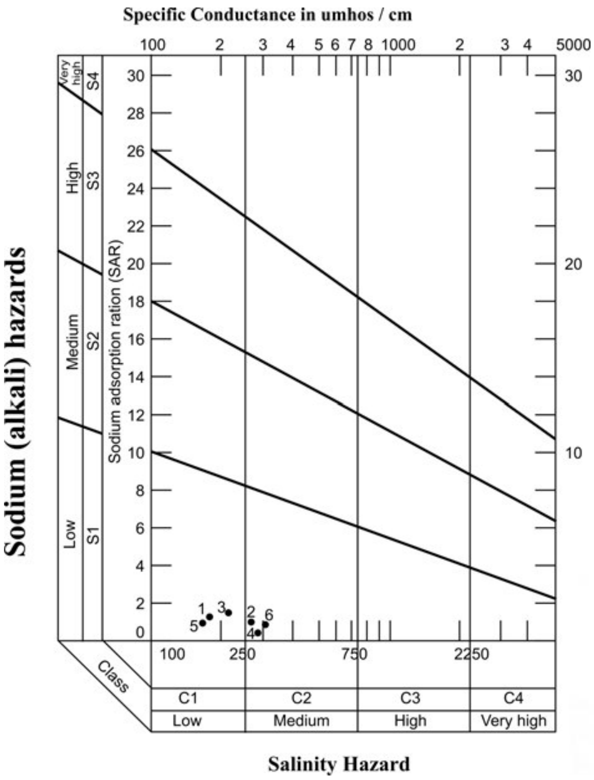

Fig.1. Plots of SAR values against EC values in the USDA diagram

The composition of groundwater are plotted in the Piper's Trilinear diagram(1953) (Fig.2) which provide facility to display analysis on a multi-coordinate field. The plotting of data in the central diamond shaped field suggest that the water samples are of alkaline character with dominance of alkaline elements and weak acids.

DISCUSSIONS

When water infiltrates into the ground its quality is modified by a number of processes. The quality of water in the zone of saturation reflects that of the water which has percolated into the water table and subsequent reaction between water and rock material occur. Residence time is an important factor in determining the dissolution of minerals to move to the point where solution is in equilibrium with the reaction. It depends upon the rate of ground water movement and is usually very slow beneath the water table. The chemical elements present in groundwater are derived from precipitation, organic processes which go on in the soil and the breakdown of the minerals in the rock through which the groundwater flows. Some of these constituents occur in significant amount, while others are of minor importance.

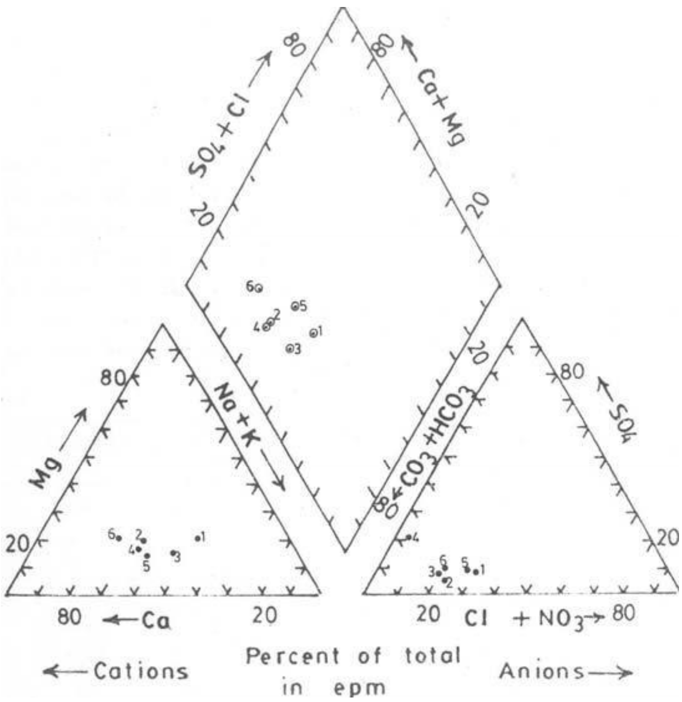

Fig.2. Piper's Trilinear Diagram showing Chemical Compositions of Water Samples

SUM UP

Ground Water in the study area is classified as C_1S_1 and C_2S_2 as per U. S. Salinity diagram i.e., low salinity and low sodium, which is good for irrigation. Also from Table-5, showing quality classification of irrigation water, the present water samples are good for irrigation. From the standard of drinking water (After Indian Council of Medical Research, 1975), the present water samples are good for drinking purposes, though stomach disorders of villagers has been reported from few villages by using the dug well water. So, for further scrutiny, intensive biological investigation, such as bacteriological study is highly needed before coming to final conclusion.

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GEOELECTRIC INVESTIGATION FOR HYDROLOGICAL CHARACTERIZATION OF SOUTHERN PART OF SAGAR ISLAND, SOUTH 24 PARGANAS, WEST BENGAL, INDIA

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ABSTRACT

Geoelectric investigation is carried out in the southern part of Sagar Island region to assess the prevailing groundwater condition. Geologically, the area is constituted of alluvial and marine sediments of quaternary age, which is underlain by the vast thickness of tertiary sediments. Landform assemblages like tidal flats, runnels, longshore bars, marshy land, sand dunes and criss-crossing tidal creeks are supportive of estuarine process under which they have been formed. Vertical electrical soundings (VES) in the area of investigation show mostly four layers consisting of topsoil, saline water, brackish water and fresh water bearing zones. The VES findings show potential freshwater bearing zone of appreciable thickness at depths from 135.3 m to 177.8 m under confined condition. The results of VES studies significantly correspond with the borehole data and a litho-resistivity relationship is established for this area. The sea water contamination (SWC) values for these water samples are significantly low. However one sample (T3), nearest to the sea, is found to exceed marginally (SWC= 0.72) the non-contaminated water (SWC $\leq$ 0.5). The Concentration of arsenic, iron, lead and mercury in the samples are below the recommended limit for drinking water of World Health Organization (WHO).

INTRODUCTION

Sagar Island, the largest island in the Ganga Delta (21° 37′ to 21° 57′ N, 88° 2′ 35″ to 88° 11′ E), is elongated in N-S direction (~30 km) and has varying width in E-W direction The southern portion of the Island widens to ~12 km (Fig.1 inset). It is bordered in the north, west and east by Hooghly, Gabtala and Muriganga river respectively (Fig. 1). In the south, lies the Bay of Bengal. Sagar Island has a flat topography with no significant variation in elevation from mean sea level (~3m). The Island of 235 square km., constitutes 46 villages with a total population of 1.75 lakh (Majumdar et. al., 2002) and offers a holy 'Kapil Muni' temple for Hindus at Gangasagar village(T1, in Fig.1) . Besides that, Gangasagar has been selected by the Government as a tourist center. For drinking water, this island is solely dependent on the deeper aquifers between 180 m to 330 m below ground level (bgl) (Das, 1991). Fresh groundwater in the deeper aquifers occurs under confined condition and is tapped by means of small diameter tubewells fitted with hand pump. Dugwells in this area produce saline water. Geoelectric (resistivity) survey has been conducted to identify various lithologic units, evaluate the groundwater condition, find potential aquifer zone and determine the possibility of sea water contamination in and around Gangasagar area.

GEOLOGY OF THE STUDY AREA

Sagar Island lies at the southermost part of the Indo-Gangetic Plain, which is the largest alluvial tract of the world, and the Quaternary alluvial fill of this plain is carried and deposited by the river Ganga and its tributaries/distributaries. Here Quaternary sediments is underlain by Tertiary sediments (upper Cretaceous to Pleistocene) indicating, an accumulation in a subsiding tectonic trough. The Quaternary sediments of the Bengal Plain are constituted of

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flood plain deposits as well as deltaic deposits and may be subdivided into two major groups (Roychoudhuri, 1974):

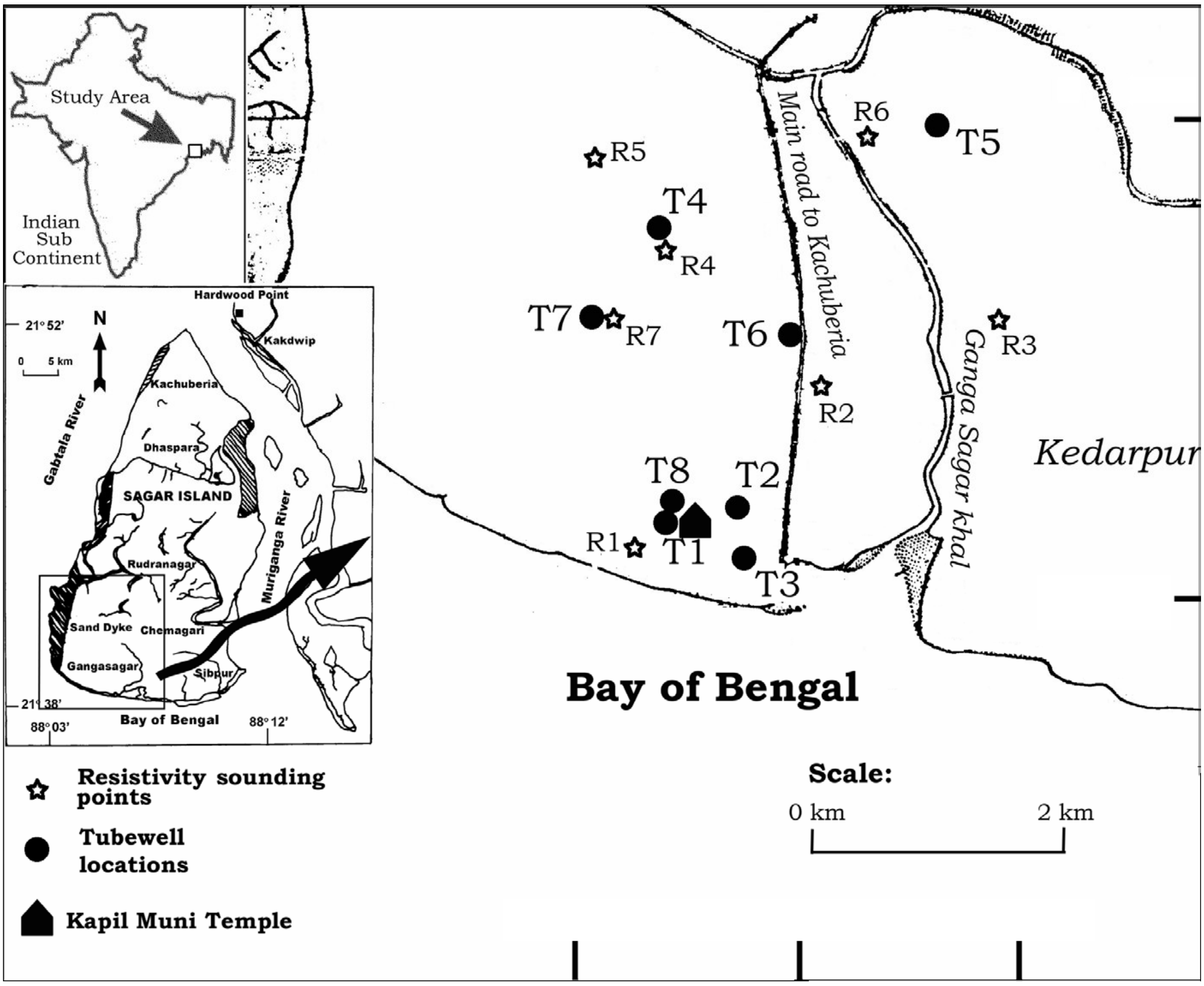


Fig. 1: Location map of the study area. Tubewell locations are as follows: T1—beside Kapil Muni Temple; T2—inside Bharat Sevashram; T3—beside Hanuman Temple; T4—northern part of Paschim Nutungheri village; T5—Lalpur village; T6—beside Sridham Gangasagar High School; T7—southern part of Paschim Nutungheri village; T8—inside Youth Hostel.

Quaternary Sediments---- (a) Newer alluvium: Recent to sub-recent
(b) Older alluvium: Pleistocene

The southern extremity of the Bengal Plain is characterized by the presence of extensive coastal belt. Chakrabarti (1995) divided this belt into two zones on the basis of coastal environment. Sagar Island, being a part of this coastal belt, falls under the 'macrotidal Hooghly estuary' zone. It has been established that Hooghly estuary is characterized by a broad expanse of syn-depositional fluviotidal and marine coastal sediments (viz. sand, silt and clay) resulting in Flandrian Transgression around 6000 years B. C. (the on-lapping sequence) and subsequent delta progradation (the off-lapping sequence) (Chakrabarti, 1995). In the present day scenario, the Hooghly estuary is the abandoned part (for the last 200 years ago) of the lower deltaic plain of Ganga-Brahmaputra. From the early part of this century, it underwent a destructive phase (Chakrabarti, 1992). The present day configuration of Sagar Island reveals that a number of small isolated islands, earlier separated by tidal creeks, are now welded almost into a single landmass due to gradual reduction of the width of the tidal creeks.

This southern stretch of coastal Quaternaries exhibits varied geomorphological signatures evolved out of dynamic and varied interactions of marine agencies like waves, tides and littoral currents, combined with fluvial and aeolian components. It is characterized by embroidery of tidal creeks, encompassing the islands and offshore linear tidal sholes, aligned perpendicular to the shoreline and separated by swales. Marine and aeolian processes are active in Ganga area. It is a tide dominated deltaic island where the high tide zone ranges from 5 to 6 m. Coastal marshes, mangrove swamps, tidal flats, mudflats, sand dunes or ridges, marine terraces, and tidal inlets are the coastal features of this island (Paul and Bandopadhyay, 1987).

HYDROGEOLOGY

Sagar Island is criss-crossed by numerous tidal creeks and man-made canals. These creeks and tanks are the main sources of surface water, which is highly saline and hard (Chakrabarti, 1995). In rainy seasons, the salinity of the water of the tanks decreases and turn to brackish water. The average annual rainfall of Sagar Island is about 200 cm with mean temperature of 22° C.The area is characterized by the presence of fluvio-tidal and marine coastal facies deposits (Chakrabarti, 1991). These deposits, being in general, porous in nature, serve as repository of potable groundwater. Freshwater group of aquifers occur within the depths of 120 to 330 m. The upper group of aquifers overlying the deep freshwater aquifers contain saline water in its upper part and brackish water in its lower part. The freshwater group of aquifers occurring beneath the brackish-water aquifer(s), are under confined condition and separated from overlying brackish aquifers by a 20 m thick impermeable clay layer. Piezometric head of freshwater group of aquifers varies from 1 to 4 m bgl with hydraulic gradient being generally towards the sea.

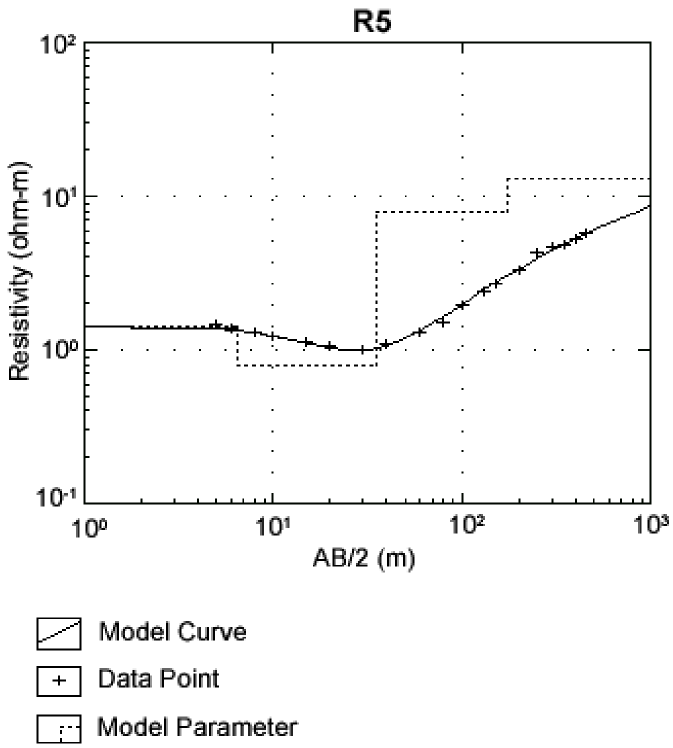
GEOELECTRIC RESISTIVITY INVESTIGATION:

Geoelectric resistivity method has been extensively used for structural, hydrological and geothermal investigation (Majumdar et al., 2000; Majumdar and Pal, 2005; Pal and Majumdar, 2001; Yadav and Abolfazli, 1998; Stewart et al., 1983). (VES) with Schlumberger configuration of electrodes was carried out in the southern part of Sagar Island region for ascertaining the vertical distribution of water bearing zones contributing the aquifer bodies in the region.

Data acquisition and interpretation

The VES investigation was conducted at seven locations with maximum current electrodes spacing (AB) of 900 m (Fig. 1) deploying resistivity meter DDR-4. The typical resistivity sounding curve for location R5 is of 'HA'type and shown in Fig. 2 and the same was interpreted by 1D inversion technique using software 'RESIST'. Preliminary values of the model parameters are obtained by matching the VES field curves with the theoretical master curves and auxiliary point charts and these model parameters are subsequently used as input (starting model) in 'RESIST' for further refinement of results of 1D inversion algorithm. The resistivities of different layers and corresponding thicknesses are reproduced by a number of iterations until the model parameters of all VES curves are totally resolved with minimum RMS error. 1D inversion reserves its importance and utility, as the interpreted model parameters can serve as starting model for 2D and 3D approaches for better approximation of the subsurface geology of an area. In such cases, 1D interpretation is usually found to be fairly consistent with those observed in 2D and 3D inversions (Monteiro Santos et al., 1997; Olayinka and Weller, 1997).

The results of VES are interpreted in terms of subsurface geology and aquifer characteristics under prevailing hydrodynamic conditions.



Model Parameters:

Resistivity (Ωm)	Thickness (m)	Depth (m)
1.4	6.4	6.4
0.8	28.7	35.1
7.9	139.5	174.6
13.1	--	--

RMS error: 1.7

Fig. 2: Typical resistivity field curve with model parameters.

Discussion of results

Inversion results for all seven VES points are interpreted and subsequently correlated to resolve the lithologic conditions in the area of investigation. The nature and distribution of different lithologic layers along the depth with variation of resistivity values are shown in Fig. 3. It reveals the presence of three to four layers in the region. The first layer is interpreted as alluvial clayey soil. The second and third layers represent saline and brackish water saturated zones. Both the layers are constituted of clay with silt and sand lenses. The most important layer is the bottommost layer, which is interpreted to be a fresh water bearing saturated sandy zone. A fence diagram is drawn to show the existing hydrological environment in the region (Fig. 4). The fresh water bearing aquifer is at depth range of 166.3 m to 177.8 m for locations R2, R3, R4, R5 and R7 and it is at 135.3 m and 93.9 m depth for locations R1 and R6 respectively. The formation of fresh water bearing aquifer shows high resistivity values (ranging from 13.1 to 41.1 Ωm) while the overlying layers with saline (ranging from 0.4 to 1.0 Ωm) and brackish water (ranging from 1.8 to 10.1 Ωm) are marked by low resistivity values. Field studies confirm the presence of saline water within a few meter below ground surface.

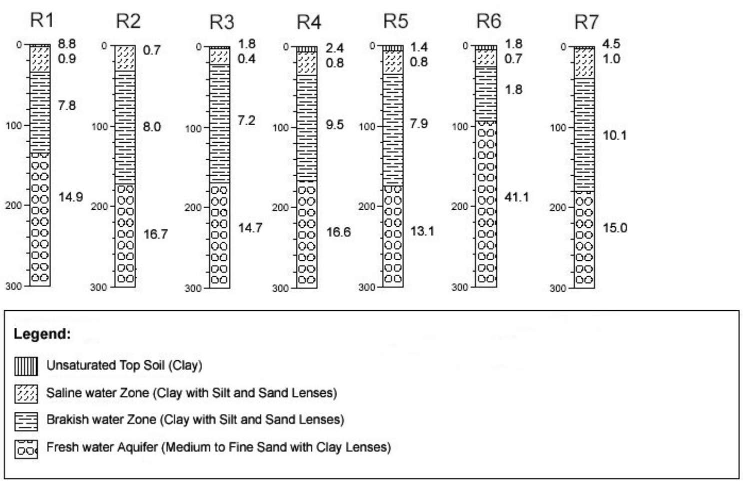


Fig. 3: Layer parameters depicting VES interpretation for different locations. Numbers in the left and right-hand side of the logs show depth from ground level (m) and true resistivity values (Ωm) respectively.

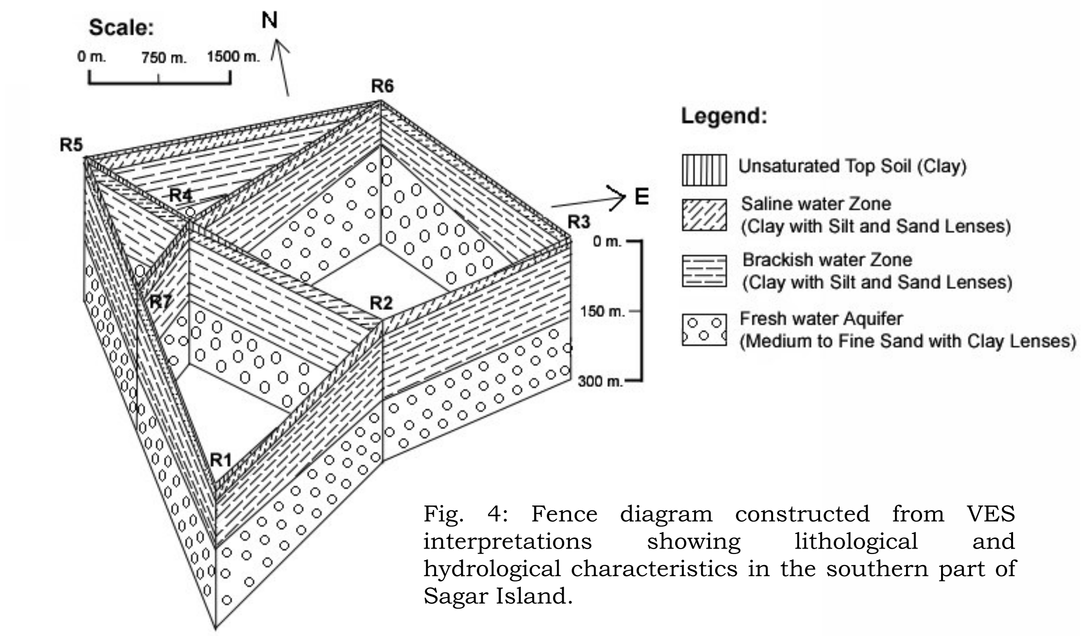


Fig. 4: Fence diagram constructed from VES interpretations showing lithological and hydrological characteristics in the southern part of Sagar Island.

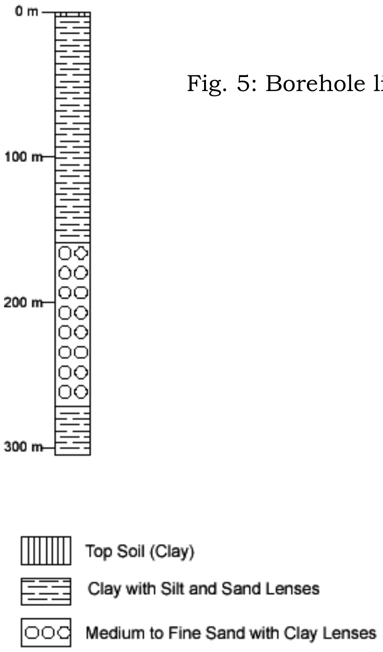


Fig. 5: Borehole litholog data of PHED near Kapil Muni Temple.

A generalized borehole lithology prescribed by the Public Health Engineering Department (PHED, 1987) near Kapil Muni Temple is shown in Fig. 5. The litholog shows the presence of clay layer with silt and sand lenses from surface to the depth level of 158.47 m. Beyond 158.47 m to 271.27 m, the formation is made up of medium to fine sand with clay intercalation which is a potential zone for fresh water bearing aquifer. The layer parameters interpreted from VES studies match significantly with the borehole data.

Comparing the results of VES and borehole lithologs, a litho-resistivity relationship has been established and is shown in (Table 1).

Table 1: Litho-resistivity relationship for the southern part of the Sagar Island.

Probable lithology	**Resistivity range**
Unsaturated top soil (Clay)	1.4 to 8.8 Ωm
Saline water zone (Clay with silt and sand lenses)	0.4 to 1.0 Ωm
Brackish water zone (Clay with silt and sand lenses)	1.8 to 10.1 Ωm
Fresh water aquifer (Medium to fine sand with clay lenses)	13.1 to 41.1 Ωm

SEA WATER CONTAMINATION TEST

The possibility of sea water contamination is examined using the ratio $Cl^-/(CO_3^{--}+HCO_3^-)$ (all values are in epm), as suggested by Revelle (1941). The ratio is about 243 for sea water from Bay of Bengal and 0.5 for fresh water (Majumdar et al., 2002). The same ratio of the water samples from the study area ranges from 0.33 to 0.72 with an average of 0.42 (Table-2). Hence, the ratio suggests that the samples, except one, are without seawater contamination. Only one sample (T3, nearest to the sea) with a ratio of 0.72 represents slightly contaminated water. Sea water contamination (SWC) ratios are plotted against Cl^- (Fig. 6) and show weak positive correlation with Cl^-. This data speak in favor of insignificant to no sea water mixing with fresh groundwater. Concentrations of arsenic, iron, lead and mercury in the water samples are found to be safe for drinking purpose. (Table-2)

Table 2: Chemical compositions of groundwater in the southern part of the Sagar Island.

Sample Nos.	Carbonate (as CaCO3, mg/L)	Bi-carbonate (as CaCO3, mg/L)	Chloride (Cl, mg/L)	Arsenic (As, mg/L)	Iron (Fe, mg/L)	Lead (Pb, mg/L)	Sea water contamination Value
T1	60	145.0	52.0	<0.01	0.39	<0.01	0.34
T2	50	152.5	58.0	<0.01	0.47	<0.01	0.39
T3	40	150.0	96.0	<0.01	0.72	<0.01	0.72
T4	80	150.0	84.0	<0.01	0.38	<0.01	0.46
T5	30	170.0	44.0	<0.01	0.39	<0.01	0.33
T6	60	127.5	50.0	<0.01	0.35	<0.01	0.34
T7	60	167.5	76.0	<0.01	0.44	<0.01	0.45
T8	80	92.5	52.0	<0.01	0.39	<0.01	0.35

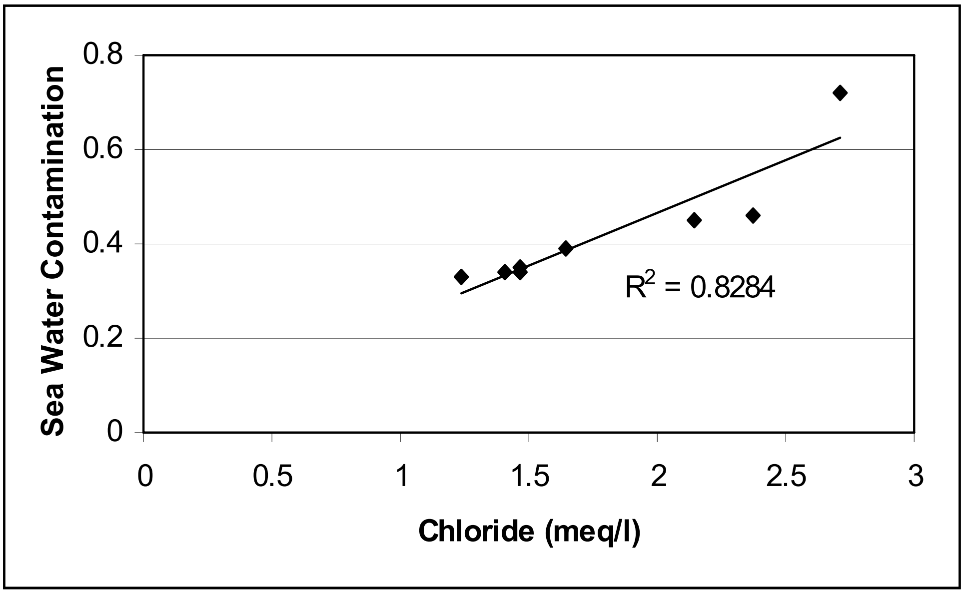


Fig. 6: Variations of the Seawater Contamination test values with chloride.

CONCLUSIONS

Following conclusions can be drawn from the integrated studies:

1. Vertical electrical soundings (VES) have delineated the topsoil, the saline/brackish ground water zones and the fresh water aquifers in subsurface geological formations. The fresh water aquifer is at depth level from 166.3 m to 177.8 m for five locations and at depths of 135.3 m and 135.5 m at two locations.
2. VES findings show promising ground water bearing zones of appreciable thickness. These zones can be tapped for drinking water purposes. The potential groundwater-bearing zone is under confined condition. The ground water conditions of the region, as discussed from the VES study significantly correspond with the bore hole data.
3. A lithoresistivity relationship is established in the area of investigation and this can be used for finding the lithology of an unknown area under similar hydrodynamic condition.
4. There is no evidence of sea water mixing with groundwater. Only one sample (T3), nearest to the sea, is slightly contaminated with seawater.
5. Concentrations of arsenic, iron, lead and mercury in the samples are below the recommended limit for drinking water of World Health Organization (WHO, 2004).

ACKNOWLEDGEMENTS

Authors are grateful to Department of Science and Technology, Government of India, for financial support and also to the Department of Geological Sciences, Jadhavpur University, for infrastructural facilities. Thanks are also due to Sri A. Das, Sri B. Das and Sri S. Das, students of the Department of Geological Sciences, Jadavpur University, for helping in survey work

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GROUNDWATER QUALITY VARIATION IN SOUTH 24-PARGANA DISTRICT, WEST BENGAL COAST, INDIA.

Saumitra Mukherjee* & Bir Abhimanyu Kumar**

ABSTRACT

The suitability of groundwater quality for the drinking and agricultural purpose was assessed in the South 24-Parganas district of West Bengal (India), based on various water quality parameters. The study area falls under a monsoon type of climate. For the present study forty-six representative groundwater samples were collected randomly from tube wells/bore wells to monitor the water chemistry of various ions, comprising of Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, CO_3^{-2}, HCO_3^{-}, SO_4^{-2}, NO_3^{-}, Cl^{-} *and* F^{-}*. The results showed that the concentrations of these ions are above the permissible limits for drinking and irrigation purposes. The pollution with respect to* Cl^{-}, NO_3^{-} *and* F^{-} *is mainly attributed to the extensive use of fertilizers and large scale discharge of municipal wastes into the open drainage system of the area. Most of the groundwater samples of the study area falls into C3-S1 (58.69%) category. According to the Wilcox irrigation water classification 46 % of the water samples falls under good to permissible category and 37 % under the permissible to doubtful category. Classification based on conductivity, shows most of the groundwater samples fall in 'tolerable' to 'safe' category. Groundwater classification based on chloride, 54.34 % of water sample falls under 'safe', to 'tolerable' and 21.74% of water samples fall under 'health hazard' category. Most of the groundwater samples of the study area fall into the category of the 'good to moderate' class (C3-S1) (58.69%) and 36.95 % under C3-S2 category.*

INTRODUCTION

Groundwater plays a pivotal role in human life and development. An understanding of chemical quality of groundwater is essential in determining its usefulness for domestic, industrial and agricultural purposes. A good quality of water has the potential to cause better crop yield under good soil and water management practices. The suitability of irrigation water depends upon many factors including the quality of water, soil type, salt tolerance characteristics of plants, climate and drainage characteristics of soil (Michael, 1990). Groundwater always contains small amount of soluble salts dissolved in it. The kind and quality of these salts depend upon the sources for recharge of the groundwater and the strata through which it flows. The excess quantity of soluble salts may be harmful for many crops. Hence, a better understanding of the chemistry of groundwater is essential to properly evaluate groundwater quality for drinking and irrigation purposes.

Presentation of geo-chemical data in the form of graphical charts such as U.S. salinity diagram and Wilcox salinity diagram help us in recognizing various hydrogeochemical types in a groundwater basin. Analysis of the chemical constituents of groundwater also sheds light on the geochemical evolution of groundwater as well as identification of recharge areas. The present study has been undertaken with the objective of (a) chemical characterization of groundwater of the study area and (b) to evaluate the suitability of groundwater in the study area for drinking and irrigation purposes. The morphological features in the district include the levees along the rivers Hooghly, Malta and Bidyadhari, the marshes bordering the levees and the islands. The district is drained by Hooghly, Malta, Bidyadhari, Thakuran rivers and their innumerable tributaries and distributaries, which form a network of rivers and tidal creeks especially in the Sundarbans region.

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Thick piles of quaternary sediments cover the whole district. Soils vary from deep fine loamy to deep fine clayey soils. In the southern part, the soil is saline in nature. The climate is characterized by hot summer, cool winter, high humidity and heavy rainfall during the monsoon. The average rainfall is 1,722 mm. Mean annual temperature ranges from 25^{O}C to 27.5^{O}C. Mean summer maximum temperature is around 40 ^{O}C and mean winter temperature is around 10^{O}C. The study area is rich in mangrove forest resources, total forest cover in the district is about 1,706 sq. km. The Sundarbans mangrove forest harbours a wide diversity of flora and fauna. It is the only mangrove tigerland on the earth.

Population is predominantly rural and agriculture is the main occupation. Net area available for cultivation is 3,928 sq. km. Rice is the main crop followed by vegetables and pulses. Orchards and gardens are localized in and around Baruipur. Only 15.25 per cent of the total geographical area is under irrigation. Important industrial centers are Bata, Budge Budge, Birlapur, Falta, Sonarpur and Baruipur. Main industries are cotton and jute textile, engineering, metallurgical, plastic and polythene, leather, drugs and pharmaceutical products.

Regional disparity in the developmental process is very prominent in this district. While the northern and northeastern parts, i.e., the area adjacent to Kolkata, have experienced marked development, the Sundarbans region shows very low level of development in all respect.

MATERIALS AND METHODS

Groundwater samples were collected from the tube wells/ bore wells and analysed for various chemical parameters as described by the American Public Health Association (APHA, 1995). These parameters includes pH, electrical conductivity, total dissolved solids, and important cations such as calcium, magnesium, sodium and potassium as well as anions such as carbonates, bicarbonates, chlorides, nitrates, sulphates and fluorides (Table I). The pH and electrical conductivity (EC) were measured in the field by means of pH meter and digital conductivity meters, respectively. Sodium and potassium were determined by flame photometer. Total hardness (TH) as $CaCO_3$, calcium (Ca^{2+}), magnesium (Mg^{2+}), carbonate(CO_3^{2-}), bicarbonate (HCO_3^-) and chloride (Cl^-) were analyzed by volumetric methods. Nitrate (NO_3^-) and fluoride (F^-) were determined using ion analyzer. Sulphates (SO_4^{2-}) were estimated by using the calorimetric technique. Groundwater quality for drinking purposes was analyzed by considering the WHO (1971) and ISI (1983) standards. The quality parameters like salinity (EC), permeability index (Doneen's Permeability Index), toxicity due to chloride and sodium (SAR), and parameters causing miscellaneous problems to soil-water-plant relationships (bicarbonate, RSC, sulphate) were determined to assess the irrigation suitability of the groundwater. The data was also plotted on Wilcox diagram and U.S. Salinity Laboratory Diagram (USSL Staff, 1954).

RESULTS AND DISCUSSION

Suitability of Ground Water for Drinking Purpose

The analytical results of different parameters of groundwater in the study area are given in the Table I. The pH values of groundwater in the study area range from 7.3 to 8.1, indicating an alkaline type of groundwater. The electrical conductivity (EC) values range from 753 to 4120 micro mho/cm at 25° C The larger variation in EC is mainly attributed to anthropogenic activities and to geochemical processes prevailing in this region. Total dissolved solids (TDS) in the study area vary in the range of 593.8-2802 mg/l. TDS values obtained in the study area are beyond the desirable limits but only two samples have TDS values more than the permissible limits (ISI, 1983), making the water unsuitable for various domestic activities. The groundwater in the study area falls under fresh (TDS<1000 mg/l) to brackish (TDS>1000 mg/l) types of water (Freeze and Cherry 1979). In the study area, the Na^+ concentration in groundwater ranges from 22-685 mg/l. The concentration of Ca^{2+} in the study area ranges from 10-146 mg/l. The major source of magnesium (Mg^{2+}) in the groundwater is due to ion exchange of minerals in rocks and soils by water. The concentration of Mg^{2+} found in the groundwater samples of the study area vary in the range of 6-98 mg/l. The concentration of K^+ in the study area varies from 1 mg/l to 50 mg/l.

Bicarbonate (HCO_3^-) is the dominant anion, followed by chloride (Cl^-) and sulphate (SO_4^{2-}). Bicarbonate in the study area ranges from 360-1080 mg/l, the source of most of the bicarbonates in the water being sewage and various human activities. Water with a high concentration of bicarbonates, if used for irrigation, may cause white deposits on fruits and leaves, which is undesirable (Subrahmanyam and Yadaiah 2001). The concentration of chloride ranges from 28-823 mg/l, the large variation is attributed to geochemical processes, and to contamination by sewage wastes. The groundwater samples no. 10, 28 and 46 showed extraordinary high values of chloride. Nitrate (NO_3^-) concentration in the study area varies in the range of 0.3-55 mg/l. Nitrate (NO_3^-) concentration of all the samples falls below the desirable limits, except the sample no. 7. The main source of Nitrate (NO_3^-) in the groundwater is attributed to decaying organic matter, sewage wastes, and increased usage of fertilizers (Karanth, 1989). Sulphate varies from 1.1-110 mg/l. The fluoride (F^-) content in the groundwater shows a range of 0.05-1.6 mg/l. The occurrence of low fluoride concentration in the groundwater may be either due to absence of fluoride containing minerals in the strata through which the groundwater is circulating. It could be also due to too rapid freshwater exchange, with the result that the normal process of concentration through evaporation or evapo-transpiration is not very effective in raising the fluoride content of the groundwater to high values prevalent in some parts of the study area.

Suitability of Groundwater for Irrigation Purpose

The irrigation water containing a high proportion of sodium will increase the exchange of sodium content of the soil, affecting the soil permeability, and the texture makes it hard to plough and unsuitable to seeding emergence (Triwedy and Goel, 1984). If the percentage of Na^+ with respect to (Ca^{2+}+ Mg^{2+} +Na^+) is above 50% in irrigation water, calcium and magnesium exchange with sodium, thus causing deflocculation and impairment of the tilth and permeability of soils (Karanth, 1987). A sodium percentage of more than 60% is considered unsafe for irrigation. The values for the percent sodium in the study area range from 11.71-93.83%. Based on conductivity classification (Table II) 52.17 % groundwater falls in 'tolerable' (1000-1500 micro mhos/cm) and 28.26 % under 'safe' (<1000 micro mhos/cm) category. Groundwater classification based on chloride (Table III), 36.95 % of water sample falls under 'safe' 17.39 % under 'tolerable' and 21.74 % of water sample fall under 'health hazard' category.

Table II. Classification of groundwater according to Electrical Conductivity

Conductivity range (micro mhos/cm)	**Quality**	**Sample no.**	**Percentage of total sample**
<1000	Safe	1,3,4,6,16,17,22,24,27,33,34,38,40,	28.26 %
1000-1500	Tolerable	5,7,8,9,12,18,19,20,21,23,25,26,29,30,31,32,35,36,37,39,42,43,44,45	52.17 %
1500-2000	Tolerable to some extent	2,11,13,41,	8.69 %
2000-2500	Intolerable	14,15,46	6.52 %
>2500	Health hazard	10,28,	4.35 %

Table III. Classification of groundwater according to chloride

Chloride range (mg/l)	Quality	Sample number	Percentage of total sample
<100	Safe	3,4,6,12,16,17,22,24,27,31, 32,33,34,35,38,40,44,	36.95 %
100-150	Tolerable	1,7,18,19,23,37,39,45	17.39 %
150-200	Tolerable to some extent	5,25,30,36,	8.69 %
200-250	Intolerable	8,9,20,26,29,42,43,	15.21 %
>250	Health hazard	2,10,11,13,14,15,21,28,41,46	21.74 %

A more detailed analysis, however, with respect to the irrigation suitability of the groundwater, was made by plotting the data in Fig.1 (SAR and salinity hazard) according to the diagram of the US Salinity Laboratory of the Department of Agriculture (US Salinity Laboratory Staff, 1954) and Wilcox classification (Fig.2). According to the RSC concentration, groundwater sample falling under different categories is given in the Table IV.

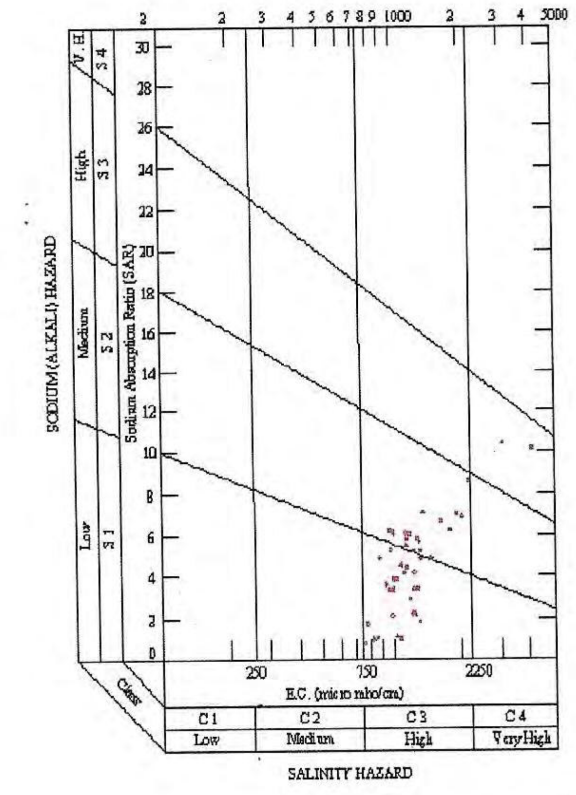

Fig.1. US.Salinity Diagram for classification of Irrigation water(After Richards,1954)

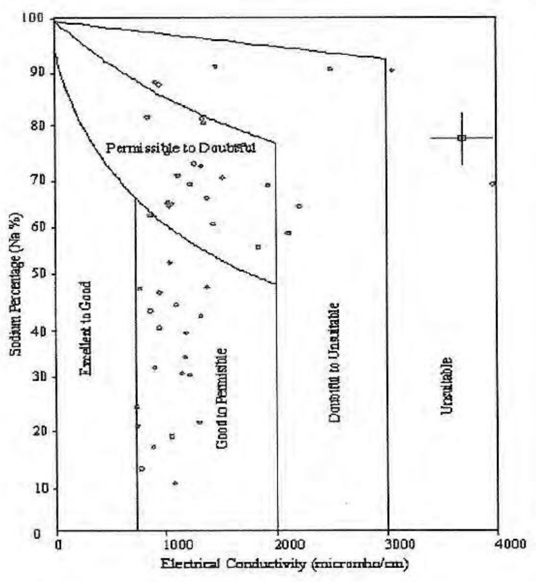

Fig-2. Wilcox Diagram for Iriigation Classification of the water

Table IV. Classification of Irrigation Water on the basis of RSC (USSL Staff, 1954)

Category	**RSC (meq/l)**	**Sample number.**	**Percentage of sample**
Safe	< 1.25	9,14,15,21,22,23,24,26,27,29,30, 35,36,38,40,41	34.78 %
Marginal	1.25-2.5	2,6,7,11,33,34,42	15.21 %
Unsuitable	>2.5	1,3,4,5,8,10,12,13,16,17,18,19, 20,25,28,31,32,37,39,43,44,45,46	50 %

Table: V. U.S. salinity laboratory classification of Irrigation water (USSL Staff, 1954).

U.S. Salinity Laboratory Classification	**Total number of samples falling**	**Percentage of total sample**
C3-S1 (high salinity-low SAR)	27 samples	58.69 %
C3-S2 (high salinity-medium SAR)	17 samples	36.95 %
C4-S3 (very high salinity-high SAR)	2 samples	4.34 %

According to this classification, low-salinity water (<200 mg/l) may be used for all types of soils. Most of the groundwater samples of the study area falls into the category of the good to moderate class (C3-S1) (58.69%) and 36.95 % under C3-S2 category (Table.V). According to the Wilcox irrigation water classification scheme majority of the water samples (46 %) falls under 'good to permissible' category and 37 % under the 'permissible to doubtful' category.

CONCLUSION

In the present study an attempt was made to analyze the groundwater quality in the South 24-Parganas and classify the groundwater samples into different categories for the drinking and irrigation purpose. The pH values of groundwater in the study area range from 7.3 to 8.1, indicating an alkaline type of groundwater. TDS values of most of the groundwater samples in the study area are beyond the desirable limits. Na^+ concentration in groundwater ranges from 22-685 mg/l and Ca^{2+} range from 10-146 mg/l. K^+ in the study are varies from 1 mg/l to 50 mg/l. Bicarbonate (HCO_3^-) is the dominant anion, followed by chloride (Cl^-) and sulphate (SO_4^{2}). Nitrate (NO_3^-) concentration of all the samples falls below the desirable limits, except the sample no. 7. The fluoride (F^-) content in the groundwater shows a range of 0.05-1.6 mg/l. The values for the percent sodium in the study area range from 11.71-93.83%. Classification based on conductivity, shows 52.17 % groundwater falls in 'tolerable' (1000-1500 micro mhos/cm) and 28.26 % under 'safe' (<1000 micro mhos/cm) category. Groundwater classification based on chloride, 36.95 % of water sample falls under 'safe', 17.39 % under 'tolerable' and 21.74% of water samples fall under 'health hazard' category. Most of the groundwater samples of the study area falls into the category of the 'good to moderate' class (C3-S1) (58.69%) and 36.95 % under C3-S2 category. According to the Wilcox irrigation water classification, majority of the water samples falls under good to permissible category (46%) and 37 % under the permissible to doubtful category.

ACKNOWLEDGEMENTS

Authors are thankful to University Grants Commission for providing necessary facilities.

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SUSTAINABLE GROUND WATER MANAGEMENT OPTIONS IN THE DELTA MOUTH AREA OF SUNDARBAN ISLANDS, WEST BENGAL

Anadi Gayen*

ABSTRACT

The 'Indian Sundarban' in West Bengal, the largest delta in the world, has it's own peculiarity in the availability of fresh ground water resource. The 'Sundarban' constituted by 54 nos. of islands spread over in 19 blocks of North & South 24 Parganas districts and covering an area of 9629 Km2. Out of the total area, only 4493 Km2 land is inhabited. The 'Sundarban' can be further divided into two portions depending upon their socio – economic condition:Islands surrounded in the Delta mouth & Islands away from the Delta mouth. Areas away from the Delta mouth have comparatively better socio-economic condition than the areas in and around the delta. The present paper deals with the hydrogeological aspects vis-a-vis substantial management option of these underdeveloped blocks situated in and around the mouth of the Delta Although, the area experiences 1770 mm. of average annual rainfall even though the surface water available in these areas are saline and fresh/portable ground water can only be available below 250 m from ground level. On the basis of the sub-surface disposition of the aquifers the area experiences two major set of aquifers, namely, Upper & Lower whose depth range varies from 100 – 160 m to 300 – 350 m below ground levels. These two aquifers are separated by numbers of clay layers having thickness varying from 40 – 150 m. In the study area, shallow and medium depth tube wells (100-160m bgl) are giving brackish to saline water (EC: 5960 – 41300 µmhos/cm at 25^{0C} and Cl: 1358 – 11,067 mg/l) and mainly used for cleaning utensils etc. The deep tube wells (300-350 m bgl) though very few in numbers are fresh in quality (EC: 915 – 4000 µmhos/cm at 25 ^{0}C and Cl: 64 – 1255 mg/l) and used for drinking purposes. Due to this peculiarity, the local people and farmers residing in these Islands are facing tremendous problems for getting potable water, So, in these Islands, availability and utilization of drinking water needs to be solved in sustainable manner. To get sufficient quantity of fresh water, Rain Water Harvesting through conservation may be adopted in these islands. The excess rainfall can be recharged through shallow tube wells in the area to dilute gradually the brackish/saline water in the upper aquifer. It may be presumed that in due course of time with the help of Rain Water Harvesting technique the quality of shallow aquifers improves considerably. If so, by utilizing ground water from shallow aquifer for agriculture and domestic purposes (other than drinking purposes), the socio-economic condition of these Islands may improve gradually.

INTRODUCTION

The 'Indian Sundarban' in West Bengal State constitutes the largest delta of the world, comprised of two southernmost districts namely North & South 24 Parganas covering 54 Islands and spread in 19 Blocks. The 'Indian Sundarbans' covers an area of 9629 Km^2, of which people inhabit in 4493 Km^2 and the rest is reserved forest. The total population was about 37.56 lakhs. Location map of Sundarban area and Islands of Sundarban region are shown in **Fig.–1** and **Fig.-2** respectively.

*Central Ground Water Board, ER, Kolkota

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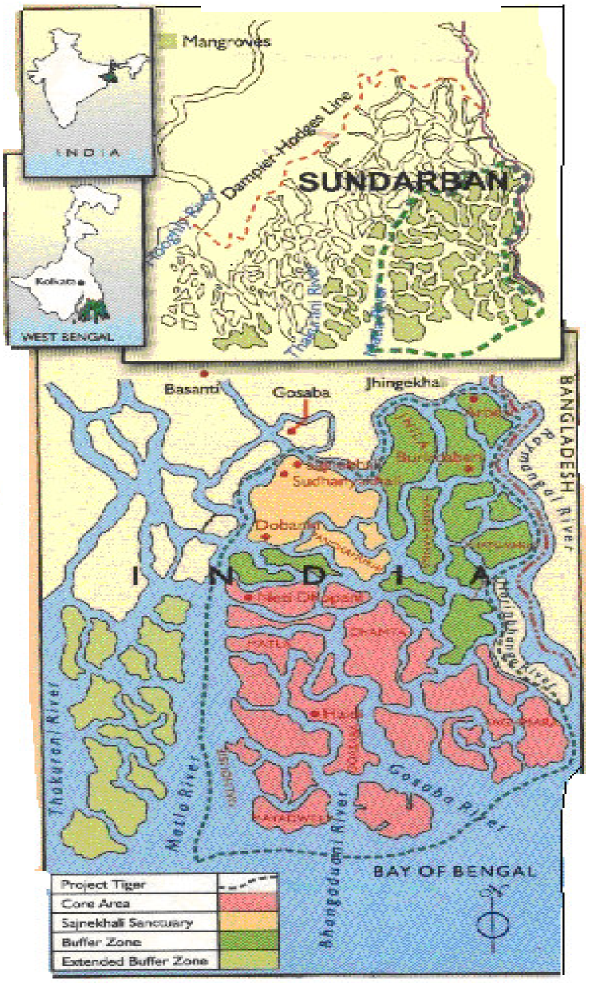

Fig.-I: Location map of Sundarban area

Out of 19 Blocks, only 6 (six) blocks namely Hingalganj, Basanti, Gosaba, Pathar pratima, Namkhana and Sagar Blocks are existing at the proximity of the river mouth and remaining 13 Blocks may be considered as inland ones. 'Sundarban' is formed by sedimentation of the Ganga and it's tributaries. In comparison to the inland blocks, the blocks at the mouth of rivers are suffering from water problem in domestic as well as agricultural sector. In spite of plenty of surface water, the availability of potable water is nil due to high salinity problem. The local people always depends on available ground water for domestic needs. Fresh ground water is only available below 300m bgl. As a matter of fact for a common person withdrawal of ground water is not easy. Present paper is dealing with the 6 Blocks located at the river mouth where accessibility as well as water quality & availability is a question mark. This paper throws light on the possible remedial measures to have an alternative method for providing potable water for the common man.

GOMORPHOLOGICAL SET UP AND DRAINAGE PATTERN

Most of the Sundarban region lies 3m below msl alongwith few hummocky grounds scatteredly distributed. The area is interlaced by innumerable creeks, channels, and tidal creeks.The huge sediments carried by all these rivers are creating acute problem of drainage.The main estuaries east to west are the Raimangal, Kalindi, Gosaba, Biyadhari, Heobhanga, Bidya, Matla, Saptamukhi, Thakurani and Hugli.The average tidal amplitude of these estuaries ranges from 3.5 to 5.0 m.

SOIL

The soil of the region is mainly clayey heavy sandy loam type along with sandy and silty nature. The northern part is considered as low salinity and southern part as high salinity area.

CLIMATE

Climate is sub-tropical. Temperatures range from 20 to $28^{\circ}C$. Annual average rainfall is around 1963 mm of which 75% occurs during June & September. The area is prone to violent storm and severe cyclones.

HYDROGEOLOGY OF SUNDARBAN AREA

The 'Sundarbans' area is occupied by recent alluvium laid down by the Ganga and it's tributaries. The top saline water bearing aquifers are generally separated from the underlying fresh water group of aquifers by a thick impermeable clay layer. The fresh ground water occurs under confined condition, where piezometric surfaces lie between 0.50-2.00m below msl and hydraulic gradient tends towards sea. Water level trends reflect a downward in nature.

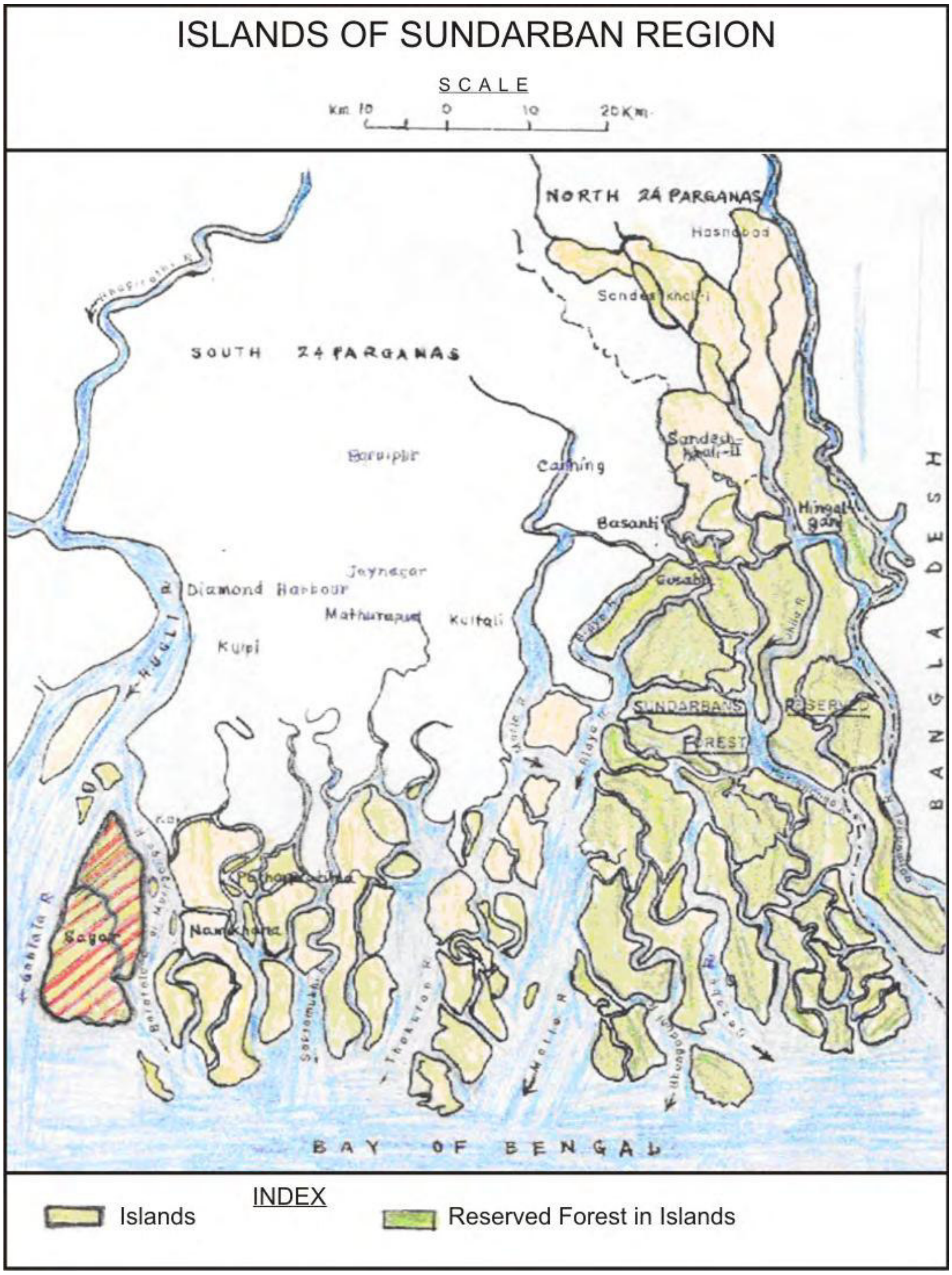

Fig.-2: Islands of Sundarban region

The upper aquifer in general occurring within 10 to 160m bgl is brackish/saline in nature. The deeper fresh group of aquifer lies beyond 160m bgl and within depth range of 160 to 490m bgl separated by clay blanket whose thickness varies from 40 to 150 m bgl in general. The tube wells tapping the fresh deeper aquifers (within 160-360m bgl), yield around 100-120m^3/hr for drawdown varying from 6-12m and having Transmissivity (T) & Storativity(S) 500-1500m^2/day and 0.15x10^{-3} to 1.0x10^{-3} respectively.

CHEMICAL QUALITY OF SURFACE AND GROUND WATER

Surface water quality is saline in nature, whose E.C ranges from 41300 – 5460 µ mhos/cm at 25^0C and Chloride (Cl) content ranges from 1358 – 11067 mg/l. Ground water is fresh & potable, whose E.C ranges from 915 – 4000 µ mhos/cm a 25^0C and Chloride (Cl) content ranges from 64 – 1255 mg/l. Rain water stored in the Reservoir Pond is having E.C - 611 µ mhos/cm at 25 ^{0} C and Chloride content - 99.3 mg/l.

DISCUSSION

Main source of drinking water is the spot source i.e, hand operated tube wells, which are tapping deep fresh ground water bearing aquifers. Detailed survey indicates that total 11161 nos. hand operated tube wells are in functioning condition in the region, out of which majority are in the inland area. Day to day population are increasing in alarming extent, so, in future this only source may not be sufficient to mitigate the water crisis. Since, the area receives sufficient rainfall in monsoon, the conservation of which may be an alternative dependable source for domestic uses as well as drinking purposes. Rain water may be conserved in the suitable structures which can be used directly for domestic purposes and after proper treatment can be used for drinking too. Rain water conservation can be done in community based way to alleviate the practical difficulties and to bring more number of people under this service. In comparison to tube well source of water, rain water conservation has so many convenient aspects. Rain water harvesting is cost-effective which helps to collect huge quantity of rain water going to sea as surface run-off and at the same time restricts use of ground water withdrawal. Specially, the areas having very less number of tube wells and not easily accessible, there rain water harvesting through conservation structures like ponds, tanks & canals etc. may help to get sufficient water for drinking round the year and specially in lean periods. The depth of the tube wells are ranging from 40-1200 (in ft) bgl & 250-1800(in ft) bgl for North & South 24 Parganas respectively. The depth range of the tube wells at the delta mouth blocks namely Sagar, Patharpratima, Namkhana, Gosaba, Basanti and Hingalganj are 240-300, 240-330, 270-325, 200-320, 240-400 and 150-270m bgl respectively.

RAIN WATER HARVESTING AND CONSTRAINTS

Rain water harvesting may be helpful to collect and store rain water. The storage structures are Reservoir Pond, Tank, Drainage Channel and Protective Bundh.These storage structures are mainly useful for agricultural purposes. Drainage Channel and Protective Bundh can be helpful to restrict rain water being wasted as surface run-off and at the same time useful to save the agricultural land from water logging. The stored rain water can be used for drinking also to mitigate the drinking water crisis in peak summers after a treatment by providing Horizontal Roughing Filter (HRF) followed by Slow Sand Filter (SSF). The depth of these structures should be restricted within 10ft. bgl, so that encounter of saline water can be avoided. The length and width can be more to store more water. The existing ponds can be desilted & renovated with effective protection measures like land sliding etc.The quality of stored rain water should be maintained as to the drinking standards. Bacteriological contamination is the alarming factor to be taken into account. Generally water borne pathogens can be reduced by slow sand filter. Chloride and other chemical constituents has to be within the acceptable limit. Disinfection of pond water has to be done with a view to improve pond water quality to potable water. The increased number of these structures can store more rain water to use in lean periods for agricultural as well as drinking purposes.

Objective of Rain Water Harvesting Structure

- To harvest rain water either from existing roof or any conservation structure
- To conserve and store rain water for future requirement
- To improve the quality of existing ground water through dilution
- To be utilized at the time of need and scarcity
- To monitor the effect and rate of ground water recharge.
- To create awareness in the society for proper management of ground water resources.
- The existing abandoned/existing shallow hand pump/ Tube wells or pond after renovation can be used for recharging the shallow brackish to saline aquifer, if the availability of water is limited. Water should pass through filter media before diverting it into Shallow tube wells.

A schematic diagram of Rainwater Harvesting through Handpump is shown in fig-3

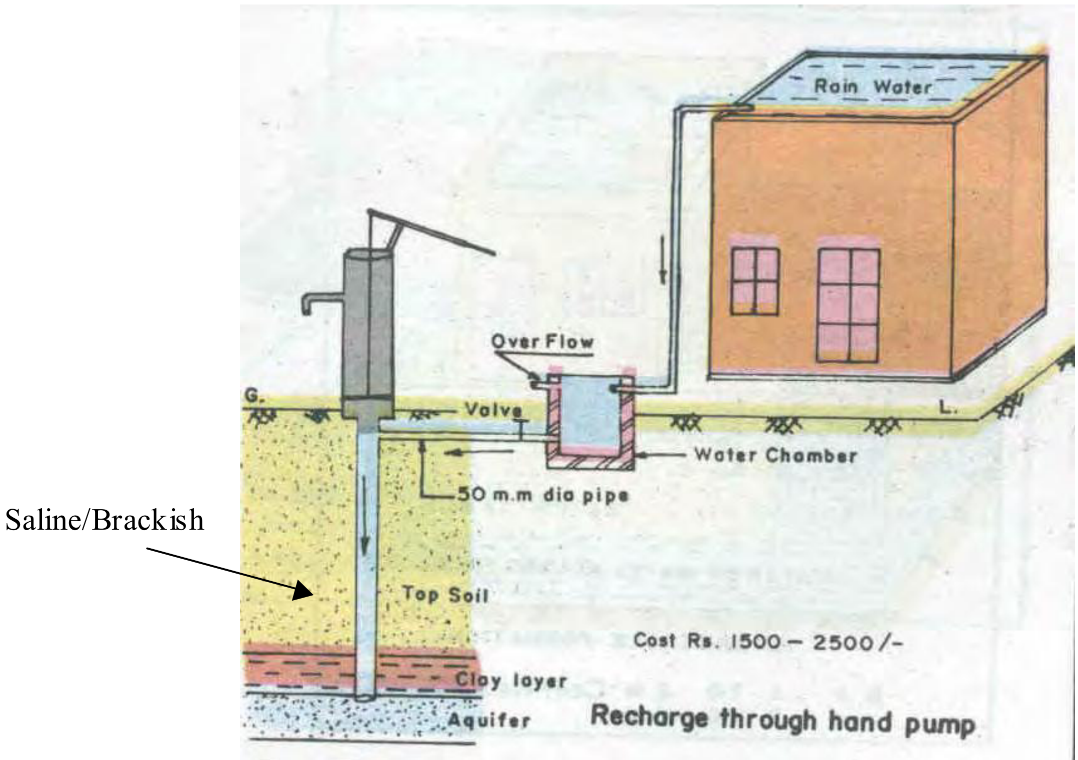

Fig-3 A Schematic Diagram of Rain Water Harvesting through Recharge Structure

CONCLUSION

- The World Heritage 'Sundarban' in West Bengal is the largest delta of the world, has it's own peculiarity in the availability of fresh ground water resource. The 'Sundarban' constituted by 54 nos. of islands spread over in 19 blocks of North & South 24 Parganas districts and covering an area of 9629 Km^2. Out of the total area only 4493 Km^2 lands are inhabited. The 'Sundarban' can be further divided into two portions depending upon their socio–economic condition:-Islands surrounded in the Delta mouth & Islands away from the Delta mouth. Areas away from the Delta mouth have comparatively better socio – economic condition than the other one which are surrounding in and around the delta.

- To get sufficient quantity of fresh water, Rain Water Harvesting through conservation may be adopted in these islands. The excess rainfall can be recharged through shallow tube wells in the area to dilute gradually the brackish/saline water in the upper aquifer. It may be presumed that in due course of time with the help of Rain Water Harvesting technique the quality of shallow aquifers improves considerably. If so, by utilizing ground water from shallow aquifer for agriculture and domestic purposes (other than drinking purposes), the socio-economic condition of these Islands may improve gradually.

ACKNOWLEDGEMENTS

The authors are highly grateful to Shri B. M. Jha, Chairman, CGWB for according kind permission for publishing the technical paper for the Bhujal News. The authors place their gratitude to Sri D.B. Saha, Regional Director, CGWB, E.R, Kolkata for providing support to bring out this paper. The authors also place their heartfelt thanks to Sri A. Ray, Superintending Hydrogeologist, CGWB, E.R, Kolkata for extending technical helps during the preparation of the paper.

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ROOF TOP RAINWATER CONSERVATION IN DARJEELING TOWN, WEST BENGAL, AN OPTION TO MITIGATE THE CRISIS OF WATER SUPPLY - A CASE STUDY AT RAJ BHAWAN, DARJEELING, WEST BENGAL

R.K.Guha* & Rose Anita Kujur*

ABSTRACT

Darjeeling, the famous hill stations in India attracts a large no of tourist both from different parts of India and abroad every year particularly in summer seasons. A large number of students from different places also come and stay here for study at various reputed institutions. The local inhabitants, students and also the tourists consume a huge quantum of water for their domestic need.

The water supply system of Darjeeling town commissioned during British period depends entirely on the spring water. During lean period discharges from the springs decrease considerably. At present water is being supplied from Sinchal Lake (North & South) and Sindhap Lake. Hydrogeological condition in Darjeeling Municipal area is such that possibilities of availability of reliable quantity of ground water are very much meager and as such the entire population of Darjeeling has to depend on spring water. During 2002, against the demand of 8.58 MLD of water (including the demand of tourists), availability of water during non-lean period was 8.28 MLD and during lean period it was 2.27 MLD. During non-lean period the shortage in water supply was 0.30 MLD and in lean period it was 6.31MLD i.e. total shortfall is 6.61 MLD (2412.65 million. litre annually).

The crisis of water supply may be tackled with the help of rainwater harvesting. Normal annual rainfall of the area is 2973mm. Considering the area of Darjeeling town as 10.57 sq.km, net annual rainwater available in Darjeeling town is 22 MCM (22000 million litre annually). The availability of rainwater is 9 times more than the shortfall in supply. The entire rainwater is flowing away downward as a waste. This rainwater, if properly harvested, can mitigate the crisis.

Hydrogeological condition does not support the artificial recharge to ground water in this hilly terrain but conservation of rainwater may be done at all level. Considering this water crisis Hon'ble Governor of West Bengal has taken initiative to conserve rainwater from the roof of the Raj Bhawan main building not only for the use of staffs of Raj Bhawan but also to create awareness among the people of Darjeeling. CGWB, ER, Kolkata was entrusted with this job for designing and technical supervision.

INTRODUCTION

Darjeeling town being a famous hill station on Darjeeling Himalaya, situated in the northern most part of West Bengal, is always an attractive tourist spot for both Indian and Foreign tourists.

At the time of the East India Company, population in Darjeeling was scanty and then with the boom in tea industry, growth of population increased many times. In 1991, total population in Darjeeling Municipality of 10.57 sq.km area was 73,062 (density of population 6,912 per

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sq.km.), which has reached to 1, 07,197 in 2001 (density of population 10,141.6 per sq.km). In addition, a large number of students from different parts of the country come for study at various reputed institutions and they stay at hostels and a large number of tourists visit this place round the year and they stay in various hotels. The local inhabitants, students and tourists consume a huge quantum of water for their domestic need.

HYDROGEOLOGY

Darjeeling Himalayas are characertised by high hills and deep valleys. It is built of a sequence of over thrust pushed southwards and dipping to the north. Darjeeling gneisses, Daling metamorphics (phyllites to quartzites) and Damuda shales and sandstones interbedded with coal seams occur successively from north to south. The network of ridges and valleys has a dendritic pattern. Slopes of the Darjeeling hills present a great diversity. Slopes are generally 1-2 km long and steep (20-48^0). Landslide is perhaps the most hazardous among all the environmental catastrophes threatening Darjeeling Himalayas. Ground water occurs under unconfined condition in the top most weathered mantle, which is 3-5m thick. The thickness decreases downward. Due to steep slopes of the land, ground water seeps out to the nearby springs and jhoras and cannot be developed by dug wells. Ground water in the deeper zones occurs under confined condition in the secondary porosities like joints, fractures and faults etc developed during tectonic activities. Due to steep slope, ground water in the joints, fractures etc gushes out in the form of springs, where the joints exposed on the surface or feed the nearby jhoras at a lower elevation. The terrain condition restricts the construction of bored wells and the development of ground water as well.

WATER MANAGEMENT IN DARJEELING TOWN

Slope instability has a direct relation to water supply in Darjeeling town. At present, the town almost wholly depends on supply of water from the three lakes on Senchal ridges. The storage capacity of lakes is as follows.

South Senchal Lake: 59,000m^3.
North Senchal Lake: 91,000m^3
Sindhap Lake: 68,000 m^3

The lakes are fed by jhoras (springs). At present during monsoon only 8 out of 26 jhoras feeding the lakes are kept alive, the rest are cut off, or there is no capacity to store.

Water demand

Demand of water for Darjeeling town 8.58 MLD (including the demand of tourists) availability of water during non-lean period was 8.29 MLD and during lean period, it is only 2.27 MLD. During non-lean period, shortage of supply is 0.30MLD and during lean period, it becomes 6.31 MLD. At present the shortfall is being met by bringing water from springs located far off from Darjeeling town by tankers and distributing it to the inhabitants by Municipality.

Due to paucity of water, selling of water from different springs, particularly during lean period becomes a profitable business. Depletion of forests and increase in average run –off has led to drying up of many local springs. The situation has deteriorated in recent years. This shortfall could be met up by construction of more reservoirs, but the Senchal ridge is hardly stable enough to stand such construction of reservoirs. Attempts are being made to construct some more reservoirs at favourable locations to enhance the supply position.

SCOPE OF ROOF TOP RAINWATER HARVESTING IN DARJEELING TOWN

- Total area of Darjeeling town: 10.57 sq.km.

- Normal annual rainfall: 2973mm.
- Net annual rainwater available in Darjeeling town: 19MCM (Considering 60% as run off coefficient).
- Annual demand of water in Darjeeling town: 3.1317 MCM i.e 16.5 % of the net annual rainwater available in Darjeeling town.
- Present utilization of rainwater: Except for a few roof top rainwater conservation, the entire quantum of rainwater is being lost as a surface run off from the town.

ROOF TOP RAINWATER CONSERVATION AT RAJ BHAWAN, DARJEELING:

Seeing the high rainfall in Darjeeling town and keeping the perpetual crisis of water supply in Darjeeling town in mind, roof top rainwater harvesting was implemented at Raj Bhawan, Darjeeling by using the roof of the main building. The main aim of the project was to create awareness among the inhabitants of Darjeeling so that they can go for roof top rainwater conservation using their own buildings and can solve the problem of water supply by themselves.

CGWB, ER, Kolkata was requested to study the feasibility of roof top rainwater conservation using the roof of the main building. Accordingly CGWB, ER, Kolkata conducted the study and based on the study, roof top rainwater conservation structures were constructed in October2005. A schematic diagram of the structure is given in Figure-1.

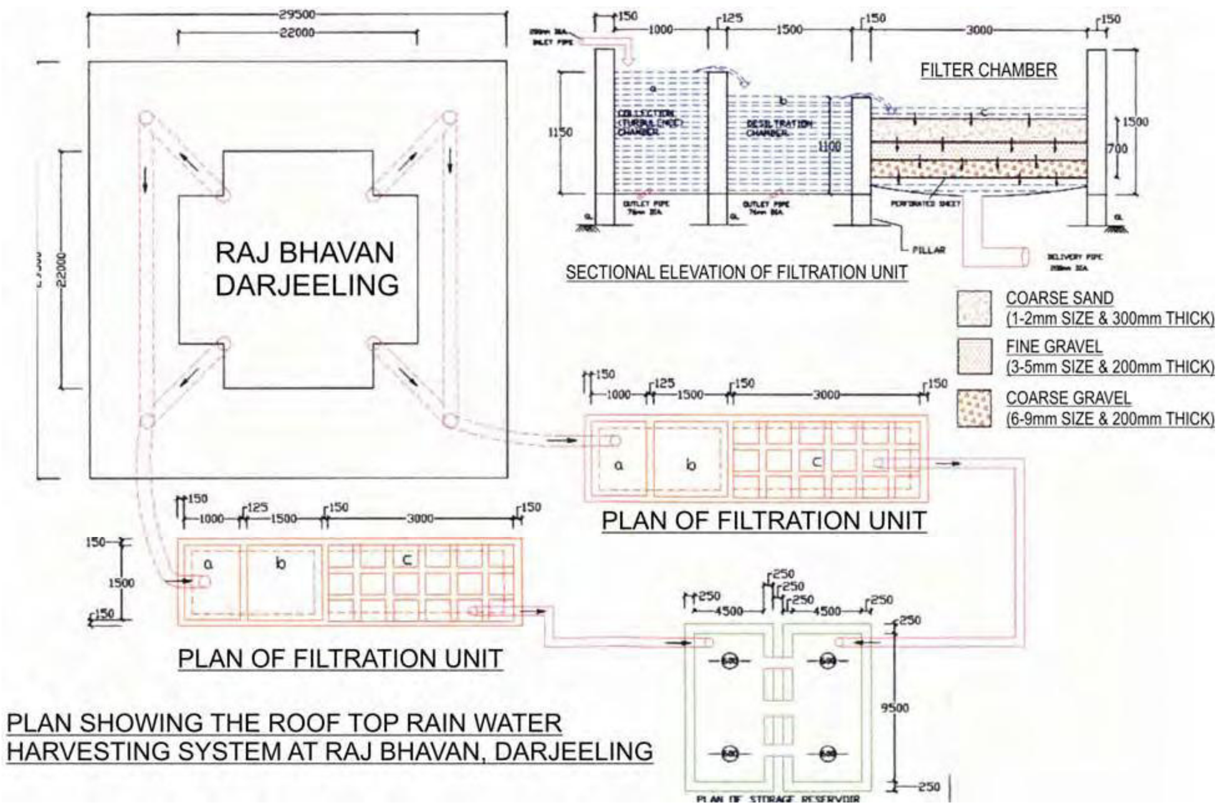

Fig-1 A schematic details of Rooftop rainwater harvesting at Rajbhawan, Darjeeling.

Availability of Roof Top Rainwater from the Raj Bhawan Main Building

- Total area of the roof: 823.69m^2.
- Normal Annual Rainfall: 2973mm (Source: DSH Book, 2003)
- Net rainwater available annually from the roof of the main building under normal rainfall (Considering 80% as run off coefficient): 1959.06 m^3.
- Normal Monsoon Rainfall (May to September): 2614mm (Source: DSH Book, 2003, BAES, Govt. of West Bengal).
- Net Monsoon rainwater available annually from the roof of the main building (Considering 80% as run off coefficient): 1722.5 m^3.
- Normal Non-monsoon Rainfall: 359mm ((Source: DSH Book, 2003, BAES, Govt. of West Bengal).
- Net Non-monsoon rainwater available annually from the roof of the main building (Considering 80% as run off Coefficient): 236.56 m^3.

After draining out the initial rainwater (First flush), the rainwater that is available from the roof of the main building of Raj Bhawan is conserved in storage tanks by passing through the filtration unit consisting of three chambers for controlling the turbulence in water, for desiltation and finally for filtration of rainwater. In the Desiltation chamber the water leaves the suspended load of silt, sand and other coarser material at the bottom of the chamber and then it enters the filtration chamber over flowing partition wall (1.10m height). To drain out the stagnant water, an outlet pipe (76mm dia) is provided at the bottom. There are two sets of filtration units with dimension of each unit as 5.5m (L) X1.5m (W) X 1.5m (D). In the Filtration Chamber water passes through a filter media made up of sand & gravel. From the top successively, it is coarse sand (1-2 mm size & 30cm thick), fine gravel (3-5mm size & 20cm thick) and coarse gravel (6-9mm size & 20 cm thick) placed on a perforated sheet (slot size-3mm) of mild steel kept at 20cm above the base of the filtration chamber (Fig-2).

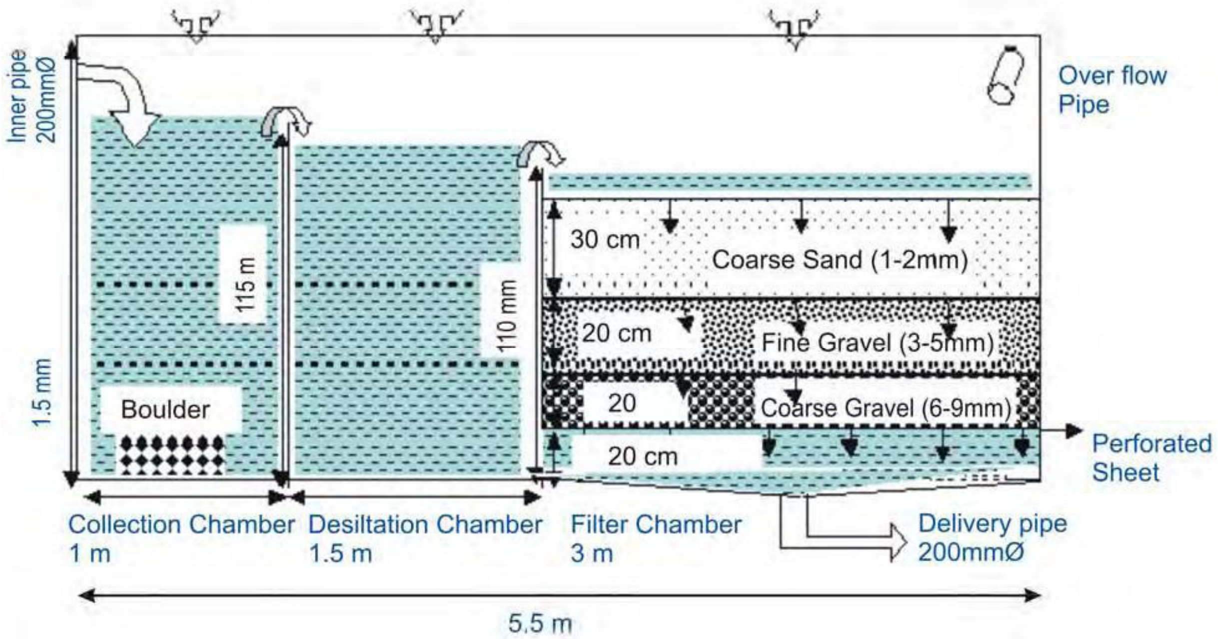

Fig-2 Details (Section) of filtration chamber

This filtration chamber is provided with a delivery pipe of 200mm diameter to deliver the filtered water from the filtration chamber to the storage tank. The filtration chamber is covered with fine net to release moisture and to avoid entry of lizards, rats, birds, insects etc. There is one overflow pipe (76mm dia) at the upper part to drain out the excess rainwater. Maximum availability of rainwater from the roof in a day to each filtration unit is 72.48 m^3. The filtered water from both the filtration chambers is taken to storage tanks by 200mm dia pipes Two separate storage tanks have been constructed considering the terrain condition and the sensitivity of the area to earth quakes.. Multi- tank system is very much convenient, as the system can remain always operational if one tank has to be shut down due to maintenance or leakage. The internal dimension of each storage tank is 9.5 (L) X 4.5 (W) X 2.35 (D). The storage capacity of each tank is 100m^3.

The filtered and the stored rainwater is at present being utilized by the staffs of Raj Bhawan for all purposes except drinking and cooking. For cooking and drinking Municipal supply water is used. The tanks are covered with the detachable slabs for periodic cleaning of the tanks and the tank is provided with T-pipes at the top cover for air pressure and to release moisture. There is an overflow pipe of 100mm dia at the upper part to drain out excess rainwater. The stagnant water from the filtration units will be drained out in the post monsoon period.

Considering the requirement of water as 40 lpcd,one person requires 14.6 m^3 of water annually. Considering the net availability of water as 1959.06 m^3 a total of 134 people can be covered annually. The total capacity of 2 storage tanks is 200 m^3 but the availability of rainwater is 9.8 times more.

DISCUSSION

Darjeeling town, being an important tourist spot and having several renowned education institutions and tea industry, is becoming over populated day by day. Density of population has increased by 46.7% from 1991 to 2001 and is still increasing and consequently demand of water is increasing. At present a total of 2, 18,000 m^3 of water is being stored from jhoras in 3 lakes and is supplied to the town. There is a shortage of supply of 0.30MLD in non-lean period and during lean period it becomes 6.31 MLD. This shortfall could be met by construction of more reservoirs, but the Senchal ridge is not favourable for construction of such reservoirs.

Considering the normal annual rainfall as 2973mm, net annual rainwater available in Darjeeling town is 19 MCM, which will spend only 16.5 % to meet up the entire annual demand of water of Darjeeling town.

The hydrogeology and terrain condition indicate that the scope for ground water development is very much meager, except for the development of springs. But depletion of forests and increase in average run –off has helped in drying up of many local springs. The only alternate to mitigate this crisis is rainwater harvesting. Roof top rainwater conservation is the best option as steep gradient of surface restricts the scope for any rainwater conservation from surface run off.

High rainfall in Darjeeling town and the perpetual crisis of water supply in Darjeeling town has led to demonstrate the roof top rainwater harvesting at Raj Bhawan, Darjeeling to create awareness among the inhabitants of Darjeeling. Roof top rainwater conservation structures at Raj Bhawan using the roof of the main building were constructed in October2005.

At the Raj Bhawan, net annual rainwater available from the roof of the main building is 1959.06 m^3, which can meet the requirement of 134 people annually. The roof top rainwater after filtration is collected in 2 storage tanks having capacity of each as 100 m^3 but the availability of rainwater is 9.8 times more. This clearly indicates that roof top rainwater conservation can easily mitigate this perpetual crisis of water supply in Darjeeling town. A small building in Darjeeling having a roof area of 50 Sq.m can get 119 m3 of rainwater, which can cater the requirement of 8 people for the entire year. Implementation of roof top rainwater conservation has already started in some other places like Louise Jubilee Complex and St. Paul's School etc. to make alternate source of supply.

ACKNOWLEDGEMENT

The authors are highly grateful to Shri B.M.Jha, Chairman, CGWB and Dr S.C.Dhiman, Member (SML) for permitting to publish this technical paper The authors place their sincere gratitude to Sri D.B.Saha, Regional Director, CGWB, E.R, Kolkata for rendering support to bring out this paper. The authors are also grateful to Sri A. Ray, Superintending Hydrogeologist, CGWB, ER, Kolkata for extending technical help needed from time to time.