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Research Article

GROUNDWATER BUDGETING IN ALLUVIAL DAMODAR FAN DELTA: A STUDY IN SEMI-CRITICAL PANDUA BLOCK OF WEST BENGAL, INDIA

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ABSTRACT
Groundwater irrigation in India has been expanding at a very rapid rate since the 1970's and the tubewells have now become the largest single source of irrigation. The groundwater level should rise to the same level as that of previous year at the end of the hydrological year to maintain its sustainability. There are 38 semi-critical blocks in West Bengal where there has been either a pre-monsoon or post-monsoon fall of static water level with respect to every preceding year. Pandua Block of Hugli District in West Bengal is semi-critical block according to the CGWB but the area entirely lies in the alluvial Damodar fan delta which is generally considered as highly potential for recharge. Hence the present study aims at groundwater budgeting of the semi-critical Pandua block to separately infer the recharge and the draft of groundwater within the study area. The static water level fluctuation method has been adopted to calculate the groundwater recharge of the area while the unit draft method and the crop water requirement method has been used to calculate the draft of the groundwater to compute the groundwater budget of the study area.

Keywords: *Static Water Level, Semi-critical Block, Specific-yield, Groundwater Recharge, Groundwater Draft*

INTRODUCTION
India is now the largest user of groundwater for agriculture in the world (Shankar *et al.*, 2011). At present 64 % of the country's population depends on agriculture for their source of livelihood (Ahmed *et al.*, 2013). Groundwater irrigation has been expanding at a very rapid rate since the 1970's and emerged as the primary democratic source for poverty reduction tool in India's rural areas (Ahmed *et al.*, 2013). The farmers have the full control over the groundwater irrigation which led to the huge withdrawal of groundwater during the last 40 years (Acharyya and Shah, 2010). According to the Agricultural Census of India (2005-06), 60.4 % of the net irrigated area is irrigated using groundwater (Sekhri, 2012). The report prepared by the Expert Group on 'Groundwater Management and Ownership' in 2007 states that 15 % of India's Blocks (nationally recognized administrative unit) in 2004 are over-exploited blocks as compared to 4 % in 1995 (Planning Commission, 2007). Hence the groundwater budgeting of a semi-critical block like Pandua in West Bengal becomes essential. The main objective of the study is to identify the stage of groundwater development of the block for adopting appropriate management measure of groundwater resources of the block.
Sustainable groundwater development in a particular area for one hydrological year envisages that the water level should rise to the same level as that of the previous year (Ahmed *et al.*, 2013). If the groundwater does not rise to the same level as that of the previous year or there is a decline of water level which makes it a water deficit area with respect to its water use. It is interesting to note that the groundwater withdrawal in a particular administrative unit or a river basin may affect the groundwater level of their adjacent administrative units or river basin as the phreatic divide normally does not coincide with the topographic divide. The Central Groundwater Board (CGWB) of India uses the norms laid by the Ground Water Estimation Resource Committee (GEC), (1997) for identification of the groundwater conditions of different blocks (administrative unit) in India. The GEC (1997) uses the water table trend

and stage of ground water development in a hydrological year for categorization of the Blocks, Mandals and Talukas in India (Mukherji, 2006). The stage of groundwater development is defined as the ratio between the existing gross groundwater draft for all uses to the net annual groundwater availability in a particular area expressed as percentage (Ground Water Resource Estimation Committee, 2009). According to the GEC, 1997 blocks are categorized as safe, semi-critical, critical and over exploited blocks (Central Ground Water Board, 2011), the definitions of which are tabulated in Table 1.a.

Table 1.a: Categorizations of Blocks

Stage of Groundwater Development	Significant Long Term Water level Decline trend		Category
	Pre-Monsoon	Post-Monsoon	
<=90%	No	No	Safe
>70% and <=100%	No	Yes	Semi-Critical
>70% and <=100%	Yes	No	Semi-Critical
>90% and <=100%	Yes	Yes	Critical
>100%	No	Yes	Over-Exploited
>100%	Yes	No	Over-Exploited
>100%	Yes	Yes	Over-Exploited

Source: Central Ground Water Board, 2009

In 2009 assessment were carried out in 5842 administrative units (Blocks, Mandals and Talukas) in India by the CGWB. It has been found that 14 % of assessment unit are over exploited, 3 % are critical, 9 % are semi-critical and 73 % of the area are safe (Central Ground Water Board, 2011).
The CGWB studied the status of 265 out of 341 blocks of West Bengal during 1994-2004. The study excluded Kolkata and South 24 Parganas district. CGWB categorized the blocks into safe, semi-critical, critical and over-exploited blocks on the basis of fall of groundwater level and stage of groundwater development.

Table 1.b: Semi-critical and Critical blocks of West Bengal (1994-2004)

Sl No.	Districts	Blocks Categorized As	
		Semi-Critrical	Critical
1	Barddhaman	6 (Bhatar, Ketugram I, Mangolkot, 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	Murshidabad	15 (Barwan, Berhampur, Bhagabangola I and II, Hariharpara, Jalangi, Lalgola, Mur-Jiagang, Nowda, Raninagar I, Bharatpur I, Suti II, Sagardighi, Domkal , Nabagram)	1 (Bharatpur II)
8	Nadia	6 (Chapra, Hanskhali, Karimpur I and II, Tehatta I and II)	
Total		37	1

Source: Ray & Shekhar, 2009

CGWB reported that there has been significant decline of groundwater level in some of the blocks and out of 341 blocks in West Bengal 38 blocks are categorized as critical or semi-critical condition (Ray and Shekhar, 2009). West Bengal has 37 semi-critical and 1 critical blocks based on the study of CGWB during 1994-2004 (Ray and Shekhar, 2009). While all the 38 blocks has been categorized as semi-critical as on March, 2009 (Central Ground Water Board, 2011). Table 1.b represents the semi-critical and critical blocks of West Bengal during 1994-2004.

Area under Study

Pandua Block of Hugli District is a semi-critical block and has been selected for the present study. The latitudinal extension of the area is 23°00'N – 23°10'N while the longitudinal extension is 88°10'E – 88°24'E. The area of the block is 280.07 square kilometers as obtained by vectorisation of block map of Pandua (Census of India, 1961) in UTM projection and WGS84 datum. The area lies within the interfluve where the river Hugli flows on the east and the river Damodar on the west as shown by Figure 1.1. The area is a meander flood plain which represents the newer alluvium (National Bureau of Soil Survey and Land Use Planning, 2001). The newer alluvium or the Holocene deposition is characteristically unoxidised and consists of sand, silt and clay mainly deposited in fluvial settings (Acharyya, 2005). Groundwater occurs within a thick zone of saturation under water table condition in the entire Hugli District excepting a small portion to the west, beyond river Darakeswar (Bhattacharjee, 1982).

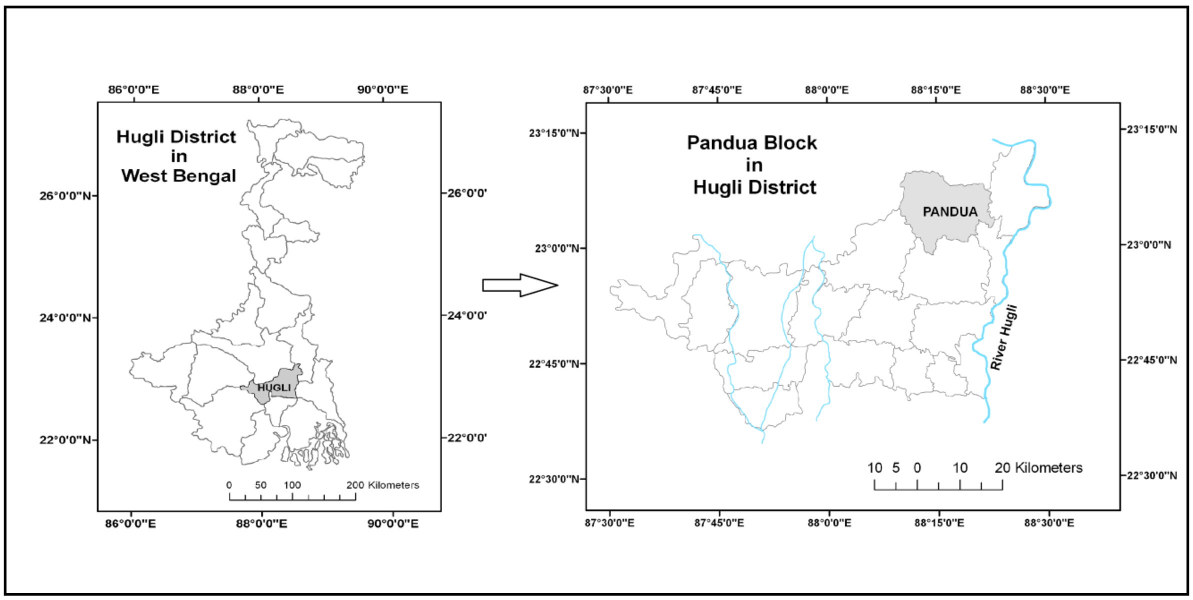

Figure 1.1: Location of Study Area

Selection of the Area under Study

Pandua Block of Hugli District of West Bengal has been selected for the study following the norms laid by the GEC (1997). According to GEC (1997) the assessment unit is a watershed in the states predominantly occupied by hard rock as the water balance equation can be better applied to the hydrological units. However, in case of the states or areas predominantly covered with alluvium the administrative blocks are chosen as assessment units. The administrative units are chosen as in alluvial areas it is difficult to identify watershed coinciding the possibility of trans-boundary aquifer system (Central Ground Water Board, 2009).

Thus this particular block has been selected for the study due to the irony of the following facts:

1. It is composed of unconsolidated Quaternary alluvium and hence considered highly conducive to groundwater recharge.

2. The block has been classified as semi-critical block by Central Groundwater Board (Central Ground Water Board, 2011).
3. The fall of static water level (SWL) is more than 10 meters during last 40 years (according to data provided by SWID).

Geographical Facets of the Study Area

Geology

The Bengal basin is a structural depression filled up by rivers during the last 150 million years (Bandyopadhyay, 2007). The river Ganga brings a lot of sediments to the Bengal basin through the Garo-Rajmahal gap. The rivers originating in the Chota-Nagpur plateau like the river Damodar and the river Ajay adds to the sedimentation on the western of river Hugli, where the study area lies as shown by Figure 1.2. The river Damodar after originating from the Chotanagpur plateau used to flow east to meet the river Hugli during the middle of the 18th century at the confluence point north of Kalna. Later the river started rotating forming an obtuse angle with its vertex at Jamalpur and shifted its mouth 128 km southwards to meet river Hugli at Garchumuk (Rudra, 2010). In the process of shifting the river Damodar has formed two alluvial fans i.e. the Memari fan trending east and the Tarakeswar fan trending south as shown by Figure 1.2 (Acharyya and Shah, 2006). The Memari fan is truncated by Younger Delta Plain (YDP) and the recent plains of the Hugli river system. The study area i.e. the Pandua Block of Hugli district entirely lies in the Memari fan. The map prepared by Mallick and Niyogi (1972) shows the presence of paleochannels (Acharyya and Shah, 2006) in the entire study area. The paleochannel explains the huge deposits of sand and the characteristics of a meander flood plain.

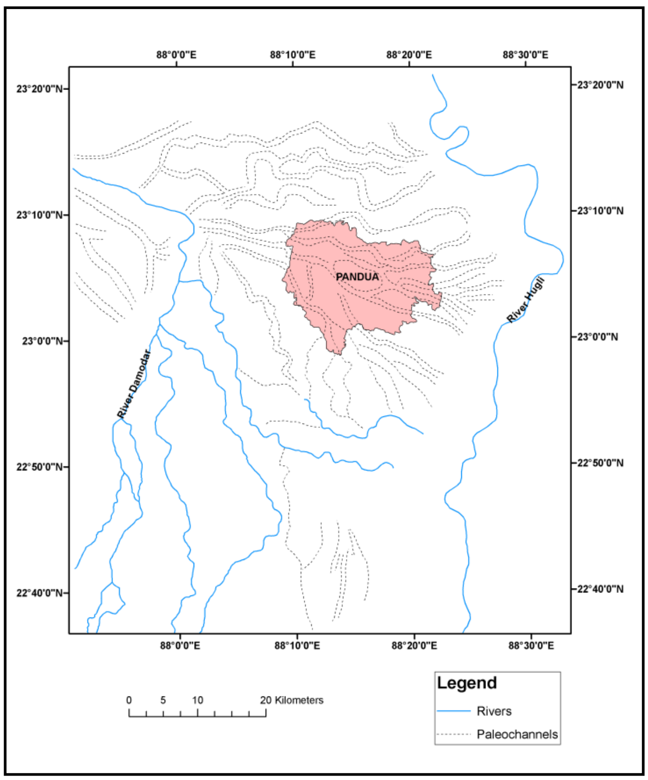

Figure 1.2: Paleochannels in the interfluves of River Damodar and River Hugli

Climate

The climate of this area is tropical humid type. The mean temperature is 26.2^{0}C as calculated on the basis of last 30 years data supplied by Indian Meteorological Department. The maximum temperature is

30.20^{0}C which occurs in the month of May, while the minimum temperature is 18.54^{0}C in the month of January. The annual rainfall of the study area is 1530.4 mm. The maximum rainfall occurs in the month of July and amounts to 297.98 mm while the minimum rainfall occurs in the month of December and amounts to 6.87 mm. Most of the rainfall takes place in the months of June, July, August and September. 71.52 % of the rainfall occurs during these four months while 88.38 % of the rainfall during the months of May, June, July, August, September and October. This signifies that 88.38 % of rainfall occurs during 6 months, i.e., from May to October while 11.61% of the rainfall occurs during the next six months.

MATERIALS AND METHODS

The present study depends on secondary data to calculate the groundwater recharge and both on primary and secondary data to calculate the groundwater draft of the study area. Static water level data has been collected from State Water Investigation Directorate, West Bengal (SWID) and borehole data has been collected from Agri-Irrigation Department, Hugli. Primary field survey has been done to collect data for calculating the groundwater draft by the shallow tubewells.

Methods of Groundwater Recharge Estimation

There has been a fall of more than 10 meters in the groundwater level of the study area during the last 40 years and the volumetric loss of groundwater from the aquifer system amounts to more than 17,500 ham (Majumder and Sivaramakrishnan, 2013). The present study aims at establishing the groundwater budget of the study area in a single year. The rise of static water level from pre monsoon to post monsoon period indicates the groundwater recharge of the study area while the draft of groundwater in the study area indicates the total groundwater use. Volumetric comparison of the net groundwater recharge and the groundwater use gives the groundwater budget of the area. The stage of groundwater development can also be very well computed from the volumetric comparison of groundwater recharge and draft.

Groundwater recharge is primarily concerned with the percolation of water through the soil down through the unsaturated zone to the water table (Misstear *et al.,* 2009). The mean value of recharge in an aquifer is equivalent to the rate of discharge, if the aquifer is not subjected to human induced groundwater extractions for sufficiently long period of time (Andreo *et al.,* 2008). According to Leaner et al 1990 there are three main types of recharge viz: direct recharge by percolation through the unsaturated zone, indirect recharge through the beds of surface water courses and the localized recharge concentrated at points (Andreo *et al.,* 2008). The factors that influence the amount and type of recharge include precipitation (volume, intensity, duration), topography, vegetation (cropping pattern, rooting depth), evapotranspiration, soil and sub-soil types, flow mechanisms in the unsaturated zone, bed rock geology and available groundwater storage (Misstear *et al.,* 2009).

Groundwater recharge can be measured by means of diverse methods but none of them are free from uncertainty (Scanlon *et al.,* 2002). Direct determination of groundwater recharge can be done by the use of lysimeter and seepagemeter but those methods are useful in case of local value than the representative of aquifer as a whole. The Darcian method is based on field measurements and the use of groundwater flow equations. Several hydrochemical and isotopic methods are also used depending on the availability of rainwater and groundwater samples. The groundwater balance equations and numerous mathematical methods are also used for estimating recharge. The water table fluctuation method is another important technique of estimating the groundwater recharge for unconfined or semi-confined aquifers (Varni *et al.,* 2013). The method is simple and easy to apply (Delin *et al.,* 2007) and based on the fact that the water table rise is due to the recharge of water reaching the water table. The estimation of the dynamic groundwater resource is based on the methodology of GEC (1997). The dynamic groundwater resource is the exploitable quantity of groundwater which is recharged annually. Hence it is also termed as annual replenishable groundwater resource (Chatterjee and Purohit, 2009). The aquifer system in Pandua Block is a semi-confined aquifer. The aquifer is overlain or underlain both by clay and sandy clay. The clay cover over the aquifer acts as the aquiclude while the sandy clay acts as the aquitard. Hence the rise of static water table from pre-monsoon season to post-monsoon season in the study area represents the dynamic groundwater volume. The rise of water table helps to estimate the annual groundwater recharge based on the principles of GEC (1997). The principle of the estimation of groundwater recharge is based on the fact that the groundwater recharge takes place from rainfall and the source including return flow from irrigation, surface water bodies, natural discharge and artificial recharge (Chatterjee and Purohit, 2009). Hence the water table fluctuation method as referred in the international literature has been adopted for estimation of groundwater recharge in Pandua Block for the year 2007. The year 2007 has been selected as it was the latest static water fluctuation database available and also the Minor Irrigation census was available for the year 2006-2007 during the course of the study. The main advantages of adopting this method is that it is relatively simple to apply, based on actual field evidence, data available from groundwater monitoring stations of government agencies over a period of time and since the monsoon rainfall is the principle source recharge. Hence the availability of the pre-monsoon and post-monsoon static water level data helps to estimate the groundwater recharge of the study area. The main equation of water table fluctuation method is as follows:

Groundwater Recharge = $Sy \times dh/dt \times A$

This equation shows that the groundwater recharge of any particular area during a particular time frame is equal to the change of storage of groundwater which is again equal to the product of specific yield (Sy), change of static water table (dh) during the given time period (dt) and the total area of the block or the study area (A).

The estimation of the recharge has been done for Pandua Block for the year 2007 i.e. the rise of static water table is considered from the pre-monsoon period to the post-monsoon period for the year 2007. Thus the formula can be written as

Groundwater Recharge = Sy× Annual Increment of SWL of 2007× Area of Pandua Block

Methods of Groundwater Draft Estimation

The groundwater draft refers to the quantity of groundwater that is being withdrawn from the aquifer. It is essential to have accurate estimation of the groundwater draft for calculating the water budget of the study area. The three methods which are used in India for estimating the groundwater draft (Ground Water Resource Estimation Committee, 2009) are as follows:

1. **Based on well Census Data *(Unit draft Method):*** In this method the groundwater draft is estimated by multiplying the number of wells with the unit draft for each type of wells in the area.
2. **Based on Electrical Power Consumption:** In this method the draft estimation is done by multiplying the number of units of power consumed for the agricultural pumpsets with that of the quantity of water pumped out for unit power consumption.
3. **Based on Water Irrigated Statistics (*Crop-water Requirement Method*):** Estimation is done by multiplying the area of different irrigated crops with that of the crop water requirement for each type of crop.

RESULTS AND DISCUSSION

Calculation of Groundwater Recharge in Pandua Block

The static water table data of Pandua Block has been collected from SWID, GoWB. The data has been obtained for the month of April, 2007 and November, 2007. The data for the month of April indicates the pre-monsoon static water table data while the data for the month of November indicates the post monsoon static water table of Pandua Block. The rise of the static water table from the pre-monsoon to the post-monsoon period signifies the annual increment of the static water table for the particular calendar year. This is because of the fact that rainfall is the main source of groundwater recharge and 93.96 % (calculated by author based on rainfall data supplied by IMD) of the rainfall occurs during this period. The volumetric estimation of the groundwater recharge of Pandua Block for the year 2007 has been done based on the water table fluctuation data following the water table fluctuation method. The aquifer system in this area is a semi-confined anisotropic type of aquifer system. Owing to anisotropy the specific yield changes both vertically and horizontally as the directional property of the aquifer exist (Todd, 2006). The horizontal hydraulic conductivity often exceeds the vertical hydraulic conductivity. Data for 65 boreholes have been collected from the Agri-Irrigation Department, GoWB for calculating the groundwater recharge of the block. The static water table data for the month of April (pre-monsoon), 2007 is 19.95 meters below ground level while the static water table data for the month of November (post-monsoon), 2007 is 12.34 meters below ground level. Thus the static water table fluctuation or the annual increment of groundwater level from pre-monsoon to post-monsoon for the year 2007 is 7.61 meters. The data for the 65 boreholes represents the lithology of a particular area. The lithology of the study area mainly consists of surface clay, clay, sandy clay, fine sand, medium to coarse sand and coarse sand. The specific yield is actually the function of these different types of textures which exist in this particular area. The 65 borehole data are thus differentiated in accordance to the specific yield of each textural class. The integration of the differentiated length of each borehole equals to 7.61 meters which range from 12.34 mbgl to 19.95 mbgl. Table 1.c shows the differentiated length (dL) of the 65 lithologs in accordance to the specific yield in between the fluctuated static water table of Pandua Block for the year 2007.

Table 1.c: Differentiated length of the lithologs

SL	TEXTURE	dL1 (meters)	TEXTURE	dL2 (meters)	TEXTURE	dL3 (meters)	TEXTURE	dL4 (meters)	TEXTURE	dL5 (meters)
1	Clay	2.91	Sandy Clay	4.7						
2	Clay	2.9	Coarse Sand	3.05	Clay	1.66				
3	Clay	7.61								
4	Clay	7.61								
5	Clay	2.9	Fine Sand	4.71						
6	Coarse Sand	7.61								
7	Clay	4.42	Fine Sand	3.19						
8	Clay	7.61								
9	Clay		Fine Sand	0.48	Sandy Clay	2.42	Clay	4.71		
10	Sandy Clay	2.9	Fine Sand	4.71						
11	Clay	5.95	Fine Sand	1.66						
12	Clay	7.61								
13	Medium Sand		Clay	7.61						
14	Clay	7.61								
15	Clay	7.61								
16	Clay	7.61								
17	Clay	2.9	Sandy Clay	4.71						
18	Clay	7.61								

19	Clay	7.61								
20	Clay	7.61								
21	Coarse Sand		Clay	5.95	Sandy Clay	1.66				
22	Clay	2.9	Medium Sand	4.71						
23	Clay		Sandy Clay	2.9	Coarse Sand	3.05	Clay	1.66		
24	Sandy Clay		Clay	7.61						
25	Fine Sand		Clay	7.61						
26	Coarse Sand		Clay	7.61						
27	Fine Sand		Clay	5.95	Medium Sand	1.66				
28	Clay	5.95	Fine Sand	1.66						
29	Clay	7.61								
30	Clay	5.95	Coarse Sand	1.66						
31	Clay	7.61								
32	Clay	7.61								
33	Clay		Medium Sand		Clay	7.61				
34	Medium Sand		Clay	7.61						
35	Clay	7.61								
36	Clay	7.61								
37	Fine Sand		Coarse Sand	7.61						
38	Clay	7.61								
39	Clay		Fine Sand		Clay	7.61				
40	Clay	2.91	Fine Sand	4.7						
41	Clay		Fine Sand		Clay	2.91	Coarse Sand	4.7		
42	Clay		Coarse Sand	2.9	Clay	4.71				
43	Coarse Sand		Fine Sand		Medium Sand	2.9	Coarse Sand	3.35	Clay	1.36
44	Clay	2.9	Fine Sand	3.05	Coarse Sand	1.66				
45	Clay	5.95	Medium Sand	1.66						
46	Clay	7.61								
47	Clay	7.61								

48	Clay	5.95	Medium Sand	1.66				
49	Clay		Medium Sand	7.61				
50	Clay	7.61						
51	Clay		Medium Sand		Clay	7.61		
52	Clay	2.9	Fine Sand	4.71				
53	Medium Sand		Coarse Sand	2.9	Clay	4.71		
54	Clay	2.9	Coarse Sand	4.71				
55	Medium Sand		Coarse Sand		Clay	2.9	Coarse Sand	4.71
56	Sandy Clay	3.2	Medium Sand	2.44	Clay	1.97		
57	Clay	7.61						
58	Fine Sand	7.61						
59	Clay	2.9	Medium Sand	4.71				
60	Fine Sand	2.9	Clay	4.71				
61	Clay	2.9	Sandy Clay	4.71				
62	Fine Sand		Coarse Sand	2.9	Clay	4.71		
63	Clay	7.61						
64	Sandy Clay		Coarse Sand	7.61				
65	Medium Sand		Coarse Sand	2.9	Medium Sand	4.71		

Source: Calculated by author based on data provided by SWID, GoWB

The values of the specific yield of different materials are already shown in Table 1.d.

Table 1.d: Specific yield values of different materials

Material	**Average Specific Yield (%)**
Clay	2
Sandy Clay	7
Fine Sand	21
Medium Sand	26
Coarse Sand	27

Source: Johnson, 1967

The area of the block is 280.07 square kilometers. Thus the equation for the water table fluctuation method is shown by the following formula:

Groundwater Recharge = Static Water Level fluctuation × Sy × Area.

The differentiated lengths of the lithologs have been multiplied by the specific yield of the respective textures. The summation of the products of differential lengths and the specific yield for each of the boreholes has been done. Finally the mean of the 65 datasets have been calculated and multiplied with the area of the block to deduce the net groundwater recharge of Pandua Block.
Substituting the values of specific yield in place of the textural classes and consequent computation of the table, the change in storage for the year 2007 from pre-monsoon to post-monsoon is obtained. Thus the total recharge of Pandua Block which amounts to 17994.50 hectare-meter (ham) for the year 2007.

Groundwater Draft

During the field survey it has been observed that there are two main sources of irrigation in Pandua Block. The two main sources of irrigation are groundwater irrigation and surface lift irrigation. Table 1.e shows the types of abstraction units and the actual area irrigated area by different sources of irrigation in Pandua Block in 2006-2007.

Table 1.e: Sources of Irrigation and Actual Area Irrigated

Type of Abstraction Units	Number of Abstraction Units	Actual Area Irrigated (Hectare)	Number of Private Ownership	Number of Government Ownership
Dug wells	0	0	0	0
Shallow tubewells	1511	11923.66	1442	69
Deep tubewells	79	4035.82	0	79
Surface flow	0	0	0	0
Surface lift	34	1064	16	18
Total		17023.48		

Source: Report on 4th Minor Irrigation Census, 2012

From Table 1.e it is seen that 17,023.48 hectares of area have been irrigated during 2006-2007. It is also observed that only 1064 hectares or 6.25% of the actual irrigated area is irrigated by surface lift irrigation. Therefore 93.75% of the actual irrigated area in Pandua Block is irrigated by groundwater source, of which 11,923.6 hectares or 70.05% of the actual irrigated area is irrigated by the shallow tubewells and 4,035.82hectares or 23.70% of actual irrigated area is served by the deep tubewells. According to the report on 4th Minor Irrigation Census most of the shallow tubewells are owned by private individuals where as all the 79 deep tubewells are owned by Government organizations and co-operative societies.

Computation of Groundwater Draft by the Deep Tubewells

The groundwater draft has been calculated separately for the shallow tube wells and the deep tubewells. According to the Agricultural-Irrigation Department, among the 79 deep tubewells, 75 deep tubewells are in use. Data of 54 deep tubewells have been collected from the Agri-Irrigation Department, Hugli. The Agri-Irrigation Department uses the electricity consumption method for determining the running hours of the deep tubewells of the study area. The 54 deeptubewells owned by Agri-Irrigation Department are categorized into 4 types. There are 36 deep tubewells, 4 heavy duty tubewells, 6 medium duty tubewells and 8 low duty tubewells. The basis of the categorization of the four types of tubewells is based on the different amount of discharge i.e. the volume of water pumped out per unit time. The unit draft method has been used for computing the groundwater draft for these four types of tubewells. The running hour of the tubewells has been multiplied with the discharge of each type of tubewells to the estimate the amount groundwater draft. The deep tubewells have mostly been constructed in 1970's and 1980's and the discharge for the deep tubewells ranges from 3.3 m^3/min to 5.96 m^3/min. Table 4.d shows the calculation of groundwater draft by the deep tubewells owned by the Agri-Irrigation Department, Hugli.
The heavy duty tubewells have a discharge of 200 m^3/hr (cubicmeter per hour), the medium duty tubewells have a discharge of 100 m^3/hr while the low duty tubewells have a discharge of 30 m^3/hr. The

running hour of each type of tubewells has been multiplied with the discharge rate of these three types of tubewells to estimate the groundwater draft by these tubewells.

There are also 21 deep tubewells in use owned by different cooperative societies whose discharge data are not available. The mean discharge and the mean running hour of the 36 deep tubewells have been adopted to estimate the groundwater draft by these 21 deep tubewells. The mean running hour of the deep tubewells is 1785.74 hours and the mean discharge is 4.35 m^3/min. Therefore the groundwater draft by the 21 deep tubewells amounts to 97, 97,942 cubicmeter or 979.8 ham.

Table 1.f shows the groundwater draft by the deep tubewells, heavy duty tubewells, medium duty tubewells and the low duty tubewells owned by the government department and co-operative societies.

Table 1.f: Calculations of Total Groundwater Draft by Deep Tubewells

Type of Tubewells	**Groundwater Draft (cubicmeter)**	**Groundwater Draft (ham)**
Deep Tubewells (A-I Dept)	16640679	1664.07
Deep Tubewells (others)	9797942	979.8
Heavy Duty Tubewells	1322600	132.26
Medium Duty Tubewells	769200	76.92
Low Duty Tubewells	823200	82.32
Total	29353621	2935.4

Source: Calculated by authors based on the data provided by Agri-Irrigation Department, GoWB

Computation of Groundwater Draft by Shallow Tubewells

The shallow tubewells irrigate 70.05 % of the actual irrigated area and consequently is the most important well distributed source of irrigation in Pandua Block. Among 1511 shallow tubewells present in the study area only 69 are owned by the government organization while the rest 1442 are under private ownership (Department of Water Resources Investigation & Development, GoWB, 2012). During field survey it was observed that the running hour of the shallow tubewells varies largely as most of the shallow tubewells are owned by the private owners. Therefore the crop water requirement method has been adopted to estimate the groundwater draft by the shallow tubewells. The two main crop types of this area are rice and potato. Rice is cultivated twice in a year, once in the monsoon season known as the *Aman* and the other in the summer known as the *Boro*. The *Aman* is sown in the month of June and harvested in the month of September. Rainfall is the principal source of water requirement for the *Aman* crops. The *Boro* rice is sown in the month of February and is harvested in the month of May. Groundwater irrigation is the main source of water for the *Boro* cultivation. The potato is sown in the month of November and harvested in the month of February and March. The groundwater irrigation is the main source of water for the potato cultivation also.

The crop water requirement has been followed for estimating the groundwater draft by shallow tubewells in Pandua Block. The mean water requirement for each type of crop is multiplied with the total cultivated area of each type of crop. A detailed field survey was conducted for estimating the mean water requirement of each type of crop cultivated per hectare. There are 158 mouzas in Pandua Block and from the field visit it has been observed that the landuse is almost homogenous in all the mouzas. A purposive sampling has been done to select 35 out of 158 mouzas for the primary field survey. Sampling is done in such a way that the mouzas are distributed in all the north, south, east and west portion of the block as shown by Figure 1.3.

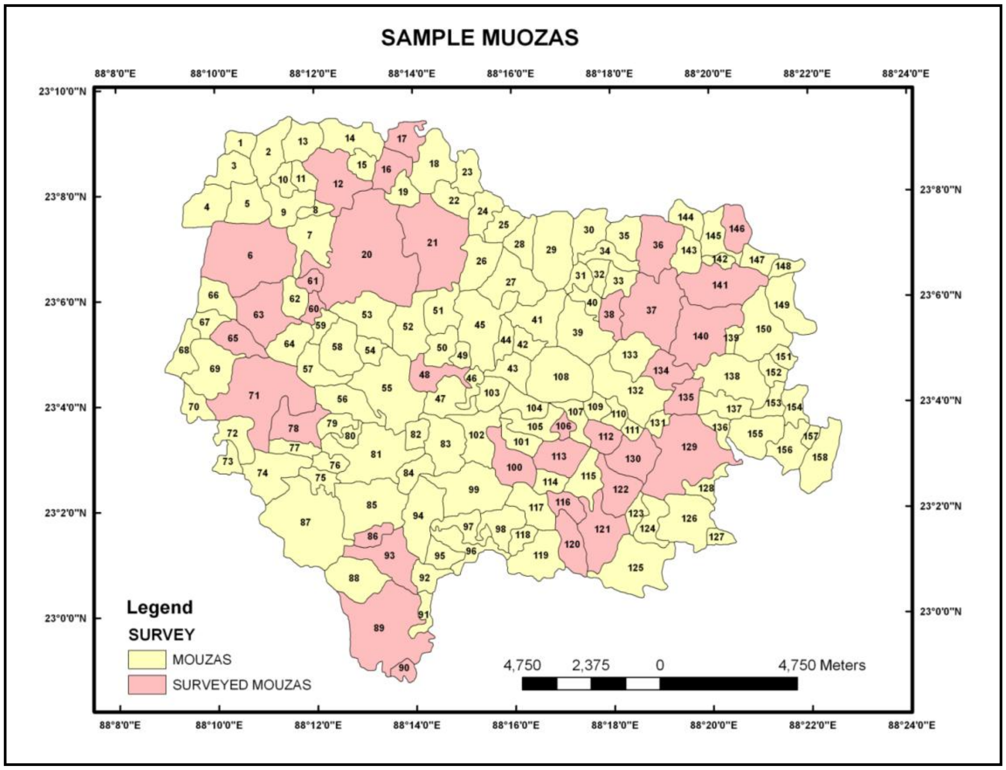

Figure 1.3: Sample Mouzas Surveyed

Questionnaire survey has been done for 80 shallow tubewells or *mini* owners. The sample has been selected based on the fact that the persons questioned are owner of shallow tubewells and at the same time is a cultivator himself so that he has enough knowledge regarding the groundwater draft by the shallow tubewells. Running hour data for each type of crop per hectare per season has been collected by the questionnaire survey. According to Report on Minor Irrigation Census, 2012 there are 1442 electric tubewells and 25 diesel tubewells during 2006-2007. During the field survey it has been found that all the electric shallow tubewells have a 5 horsepower motor for drawing the groundwater for irrigation. The discharge has been measured at field and the mean discharge amounts to 38.43 m^3/hr. The total area irrigated by groundwater in the study area during 2006-07 was 5020.14 hectares for the *Aman* (Kharif crops), 3017.69 for potato (Rabi crops) and 3876.88 hectares for the *Boro* (Other crops) (Department of Water Resources Investigation & Development, GoWB, 2012). Table 1.g represents the calculations of total groundwater draft estimation by shallow tubewells.

Table 1.g: Calculation of Total Groundwater Draft by Shallow Tubewells

Type of Crop	**Aman**	**Potato**	**Boro**
Running hour/hectare (hour)	64.86	77.90	369.94
Area Cultivated (hectare)	5020.14	3017.69	3876.88
Total Running hour (hour)	325619.75	235087.78	1434243.67
Discharge (cubicmeter/hour)	38.43	38.43	38.43
Total Draft (hectare-meter)	1251.35	903.44	5511.79

Source: Calculated by authors based on field survey

Computation of Groundwater Draft for Domestic purpose

The Public Health Engineering, GoWB has made the '*Sajal Dhara*' scheme for providing domestic water supply to this area. They supply water at a rate of 40litres/capita/day. The calculation for the groundwater budget has been done for the year 2007 and hence the population of Pandua Block has been projected to 2007 based on census data from 1961 to 2001. The projected population figures to 3,39,842 based on 2nd degree polynomial equation at r^2= 0.99. Thus the total draft for domestic purpose amounts to 497.17 ham for the year 2007.

Table 1.h shows the total amount of groundwater draft by all types of groundwater abstraction units. It shows the total groundwater draft by shallow tubewells, deep tubewells and the draft for domestic purpose.

Table 1.h: Total Groundwater Draft from All Sources

Type	Groundwater Draft (ham)
Irrigation by Shallow Tubewells	7666.59
Irrigation by Deep Tubewells	2935.4
Domestic Draft	496.17
Total	11098.16

Source: Calculated by author

Inference

The total amount of groundwater recharge in the year 2007 amounts to 17994.5 ham while the total groundwater draft from all the sources within the block amounts to 11098.16 ham. The total groundwater draft within the study area during 2006-07 hydrological year should be compensated by the recharge during 2007 (April to November when 93.96% of rainfall occurs) to maintain the groundwater budget. Thus it is essential to calculate the stage of groundwater development which indicates the of groundwater condition in the study area. The stage of groundwater development is defined as the percentage of existing gross groundwater draft for all uses to the net annual groundwater availability (Central Ground Water Board, 2011) as shown by the following equation.

Stage of Groundwater Development=

(Existing Gross Groundwater Draft for all uses/ Net Groundwater Availability) × 100

Table 1.i: Groundwater Draft during Monsoon

Type of Tubewells	Total Groundwater Draft (ham)	Groundwater Draft during Monsoon (ham)
Deep Tubewells	2643.87	431.48
Heavy Duty Tubewells	132.26	21.58
Medium Duty Tubewells	76.92	12.55
Low Duty Tubewells	82.32	13.43
Shallow Tubewells	7666.59	1251.19
Total	10601.96	1730.24

Source: Calculated by author

The net groundwater availability is equal to the change in groundwater storage. The change in groundwater storage is calculated from the result of the recharge from rainfall and all other sources during the monsoon and the gross groundwater draft during the monsoon (Central Ground Water Board, 2011). Since 93.96 % of the rainfall occurs during the period of April to November, hence the recharge during monsoon has been emphasized.

The groundwater draft from the deep tubewells and the shallow tubewells has been computed for all the existing gross draft for all type of uses. Therefore, the total existing groundwater draft for all type uses amount to 11098.16 ham. The net groundwater availability is equal to the summation of groundwater recharge and gross groundwater draft during the monsoon. The gross draft during the monsoon is mainly due to the draft for the *Aman* crops. The calculation for the draft from the shallow tubewells has been based on primary field survey. From Table 4.i it is calculated the draft of water for *Aman* is 16.32 % of the total draft of the shallow tubewells. Hence 16.32 % of the draft by the deep tubewells and the shallow tubewells during the monsoon should be added to the groundwater recharge to get the net availability of groundwater. Table 4.k shows the groundwater draft for irrigation during the monsoon season.
Thus the net groundwater availability is 19,724.74 ham and the stage of groundwater development is 56.26% (calculated by the author). The groundwater draft for domestic use within the block is also included while calculating the stage of groundwater development. The draft for domestic use contributes only 4.47 % in the stage of groundwater development. Therefore it can be concluded from the study that the fall of static water level in Pandua Block of Hugli District is not due to over-utilisation of groundwater for irrigation within the block. But still there is either a pre-monsoon or post-monsoon fall of static water level for the last 40 years. Therefore the answer to research question of this particular study is that the fall of static water level of this block is not absolutely due to the groundwater drafting for irrigation purpose within the block. From the lithological settings of this area which is completely alluvial in nature it can be concluded that the groundwater flows, following the hydraulic gradient to the adjacent blocks. Thus any decision regarding the management of groundwater of this particular block has to be taken considering the groundwater budget of this block.

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