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RESEARCH ARTICLE

A QUANTITATIVE ANALYSIS OF GROUNDWATER STATUS OF HOOGHLY DISTRICT, WEST BENGAL, INDIA

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ABSTRACT

The present study entails groundwater level variability analysis and its relationship with groundwaterstorage change for the river-deposited plain land in Hooghly district of the Indian state of West Bengal. Various groundwaterbased maps, statistical techniques like standard deviation, groundwater storage change, etc. were adopted to analyse the status of groundwater of the district. The analysis revealed that various blocks of the Hooghly district like, Pandua, Balagrah, Singur, Chanditala II, Haripal,Chanditala I, and Tarakeswar have a sharp declined trend of average static groundwater level (mbgl) in pre-monsoon and post-monsoon conditiones. The declining trend of static groundwater level (SGWL) is more conspicuous since the district falls under the intensive agricultural practice zone. An estimation of groundwater storage change indicates that fall of SGWL in both pre-monsoon and post-monsoon condition in three blocks namely Pandua, Balagrah and Singur amounting to 15126, 12455 and 7170 Hectare-meter (ham) and 18028, 84053 and 1755 ham volume of water respectively had been actually lost from the system in 6 years of time from 2007 to 2013. A similar trend could be observed in other three nearby blocks namely, Chanditala I, Chanditala II and Tarakeswar in the same district. According to GroundwaterBlock Categorization Status, during 1994-2004 only 2 blocks, Goghat I and Pandua of Hooghly district appeared in the 'semi-critical' category. But surprisingly within a period of 6-7 years four more blocks of this district namely, Polba-Dadpur, Singur, Arambag and Chinsurah-Mogra have freshly entered in the same category by 2011.

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INTRODUCTION

Unlike many other natural resources groundwater resource is a replenishable one. But it is a finite resource (Chatterjee and Purohit, 2009). Groundwater is usually found in subsurface formations known as aquifers, which may be a significant hydrological component of watersheds and basins. The three-dimensional nature of aquifers is not generally well understood and is rarely considered in modeling for management applications. The condition and characteristics of a given aquifer are determined by the hydrologic cycle and by anthropogenic modifications in the hydrologic cycle (Burke, 1998).The quantity of water stored in an aquifer can be characterized over time by accounting for inflows and outflows according to the following expression:

Change in storage = recharge – depletion

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The amount of groundwater abstraction has been rapidly and continuously increasing worldwide (Gehrels, 2001) and excessive groundwater abstraction has caused serious groundwater-level declines in many areas (Ward and Robinson, 1990). Declining groundwater levels have a number of adverse impacts on the environment. Most directly, groundwater level decline is an indicator of groundwater depletion, which threatens aquifer sustainable development (Akther *et al.,* 2009). The world is fast running out of fresh water, our demand for this 'blue gold' is increasing at a faster pace with passing time and thousands more people are compelled to survive in a water-stressed condition. One-half and two-thirds of the global population will be put to severe fresh water crisis within next quarter century, if we do not change our present wasteful mode of water- use (Barlow and Clarke, 2003). Till the end of the last century, India was a relatively minor user of groundwater in agriculture compared to the countries like United States and Spain; by 2000, India had emerged as the global champion in groundwater irrigation, pumping around 220–230 billion m^3/year, over twice the amount the US did (Zhou *et al*., 2010). In India, groundwater has become at once critical and threatened (Shah, 2009). Decline in groundwater table has become a critical issue for sustainability of its economic growth (Saha, 2009). In recent decades, the exploitation of groundwater has increased greatly particularly for agricultural purpose, because large parts of the country have little access to rainfall due to frequent failures of monsoon. Thus the increasing population and their dependence on groundwater for irrigation are further inducing heavy stress on groundwater resources, leading to the decline of groundwater levels in this region. West Bengal covers 2.7 per cent of the national territory and renders home to 8 per cent of the Indian population. The State is endowed with 7.5 per cent of the water resource of the country and that is becoming increasingly scarce with the uncontrolled growth of population, expansion of irrigation network and developmental needs (Rudra, 2009). The Bengal Delta, which was described as areas of 'excess' water in the colonial document, now suffers from acute dearth of water during lean months. The spatial and temporal variability of rain within the State causes the twin menaces of flood and drought. Both the flood and drought isopleths are expanding with time in spite of ever-increasing investment in water management (Rudra, 2009).

Increase in population has direct impact on resource use in general and water in particular. Fast rise in population in West Bengal made a huge demand for water in agriculture and industrial sectors besides domestic consumption (Majumder, 2013). As per the report of West Bengal Pollution Control Board (2009), nearly 80 percent of the total consumption (106.18 billion cubic metres) in different sectors altogether could be made available through the annual rainfall (85.23 billion cubic meter) in the year 2001. Obviously, the deficit of about 20 percent of the total consumption could be supplemented either by trans-boundary water or by over exploitation of groundwater. Rawal (2001) pointed out the dependency of irrigation on groundwater in West Bengal by watching the increase in number of tubewells from 236432 to 545956 in a decade (1980-81 to 1990-91) period of time. Moreover, according to Census 2001, 91.4 percent of rural households and 41.2 percent of urban households in West Bengal depend on groundwater for their drinking water supply (West Bengal Pollution Control Board, 2009).

rainfall (1400-2000 mm), the maximum of the rainfalls occur during the southwest monsoon period (June to September). Its erratic temporal and spatial distribution with considerable year to year variation causes instability in agricultural production. As a result, groundwater is seemed to be the most exploited resource in West Bengal in agricultural sector. With the introduction of water intensive high yielding variety, the need for groundwater has skyrocketed. Irrigation is considered as the principal means of water loss from the natural system which leads to arid condition at downstream and groundwater depletion. Census of minor irrigation structures indicated a 64% growth in number of Shallow Tube Wells (STW) over last 16 (1995 to 2010) years,@4% annually.

Since 1970 there was the beginning of over-exploitation of the groundwater often beyond the naturally replenish able limit (Rudra, 2009). This was directly related to the introduction of high-yielding but water-intensive varieties that replaced the traditional ones. Now, more than 0.60 millions of shallow and more than 5000 deep tube wells are operating in the agricultural fields of the State (Rudra, 2009).In this perspective, the present study is an attempt to investigate the status of groundwater resource (quantitative aspect) in Hooghly district of the Indian state of West Bengal. The Hooghly district, being a river deposited plain land, is one of the regions of intense agricultural practice in West Bengal. The entire district comes under Bengal delta of the state. No other fluvio-deltaic sedimentary system in Earth is as large as the Bengal basin (Mukherjee *et al.,* 2009). The Central Alluvial Plain (covering the districts of Murshidabad, Nadia, Bardhaman, Hooghly, Howrah and Medinipur) of the state is well-known for its intensive agricultural practice regions. The Agro-Climatic Regional Planning Unit has identified this zone as having the most potential of the State, indicating promise of growth. However, fluctuations in groundwater level in major part of the region have been the subject of serious attention.

Study Area

Hooghly is one of the central districts of West Bengal extending between 20°30′32″ and 23°1′20″ of North latitude and between 87°30′20″ and 88°30′15″ East longitude. This district has a total area of 3,149 sq.km which is about 3.55 percent of total geographical area of the State.

Table 1. Categorizations of Blocks based on Stage of Groundwater Development

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

According to GroundwaterBlock Categorization Status (Table 1), out of 341 blocks in West Bengal 38 blocks are categorized as 'critical' or 'semi- critical' condition due to over-exploitation of groundwater (Ray and Sekhar, 2009).Although West Bengal receives high average annual

The district has 18 community development (CD) blocks (Fig. 1) with the head-quarter being located in Chinsurah. It is surrounded by the districts of Bankura and Burdwan at the north, Nadia and 24-Parganas in the east, Howrah in the south, and Paschim Medinipur in the west. The district is mostly bounded by its principal rivers such as the Bhagirathi (also known as Hooghly river), the Damodar and the Rupnarayan. The river Hooghly flows along the eastern boundary of the district, whereas the Rupnarayan flows from Bankura district under the name of the Dhalkisor or Dwarakeswar.

district. The older alluvium, which is mixed with kankar lateritic debris, covers the western most part of Goghat block II while the newer alluvium comprising mainly sand, silt and clay provide cover for the rest of the district.

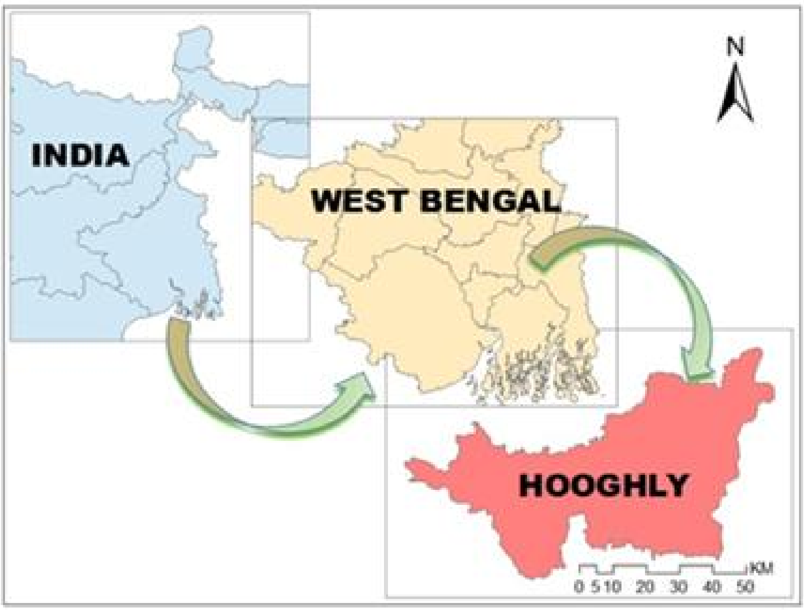

Figure 1. Location of the Study area

Physiography

The district forms a part of the flat plains of the lower Gangetic delta and there is a remarkable topographical homogeneity. It is broadly divided into two main natural divisions, the plains and the uplands, and the river Dwarakeswar forms the dividing line between the two. The flat alluvial plains may again be sub-divided into three regions, namely (i) the Dwarkeswar-

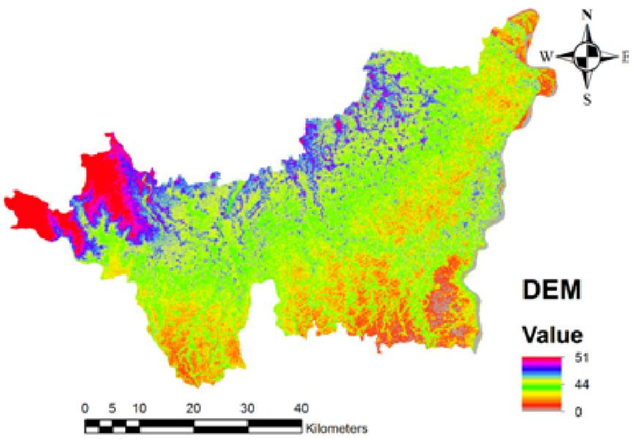

Figure 2. Digital Elevation Model

Damodar interri verine plain, (ii) the Damodar-Bhagirathi interriverine plain and (iii) the Char lands (HDRCC, 2011). The district is well watered by its principal rivers as well as by the smaller streams like the Behula, the Kananadi, the Saraswati, the Mundeswari, etc. Major portion (58.5 percent) of the district is under very gently sloping (1-3 percent) lands and remaining 41.5 percent is under nearly level (0-1 percent) lands (Fig. 2). Flooding is one of the major problems of the

The district of Hooghly represent a vast homogeneously plain with topographical variety in the form of unequal aggradations and division of old perennial intermittent and sluggish rivers sloping gradually form north-west to south-west. Groundwater in the district occurs mainly under unconfined condition in shallow aquifer and under semi confine to confine condition in deeper aquifers.

Hydrometeorology

The district of Hooghly like many other places of north Indian plain, is characterized by sub- tropical and over all humid climate. The climate of the district is hot moist sub-humid with mean annual rainfall being 1350 mm (Fig. 3). The soil moisture and temperature regimes in the district are Ustic and Hyperthermic respectively (Sarkar *et al.,* 2001).

Pedology

Soil of Hooghly district can broadly be grouped in to two principal type of soil. They are (a) Entisoils, (b) Aflisols.

Entisoils

The younger alluvium deposits, which occupy almost entire part of the district. This type of soil gets enriched by silt deposition during floods. The soil profile is immature type with irregular sequence of sandy layers. The soil is yellowish brown in colours. The area covered by the soil, is characterized by shallow water table, a heavy sub soil and occurrence of brown concentration at lower depth.

Aflisoil

These are sedimentary soils, developed on the older alluvium zone. This type of soil is confined mainly to the western extremity in part of Goghat II block of the district. These are light textured, porous, mildly acidic and poor in nitrogen, calcium, and phosphorous. The colour of the soil varies form dark brown to greyish brown. This soilis well respond to irrigation and produced good crops of winter paddy, sugarcane, wheat, gram, etc.

Nearly 30.7 percent area of the district is affected by the occasional floods, while 69.3 percent of the area is affected by moderate to severe flooding (Sarkar *et al.,* 2001). The soils of the district are dominantly loam in texture (53.9 percent) followed by silty clay (23.3 percent), silty clay loam (22.1 percent) and sandy loam (0.71 percent) (Fig. 4).

MATERIALS AND METHODS

The investigation was carried out in the whole Hooghly district of West Bengal. However, out of eighteen blocks in the district seven blocks namely, Pandua, Balagrah, Singur, Chanditala I, Chanditala II, Tarakeswar and Haripal were referred at various cases. The present study depends mainly on secondary data and maps obtained from India water tool web portal (http://www.indiawatertool.in). The India Water Tool Version 2 (IWT 2.0) is an online tool for companies and other users to understand their water-related risks and prioritize actions toward sustainable water management.

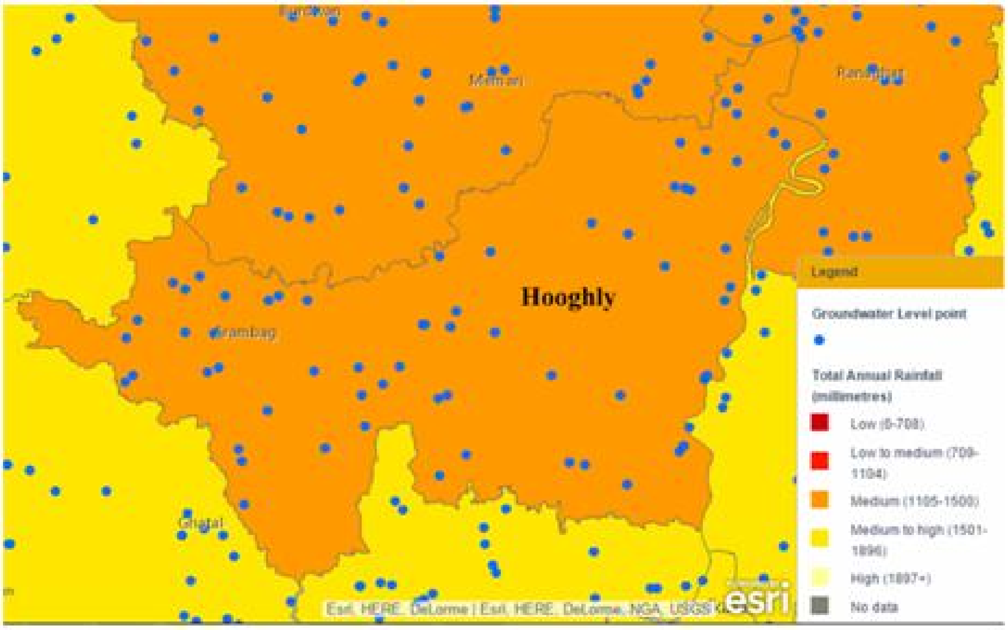

Figure 3. Annual Rainfall Map (source, http://www.indiawatertool.in)

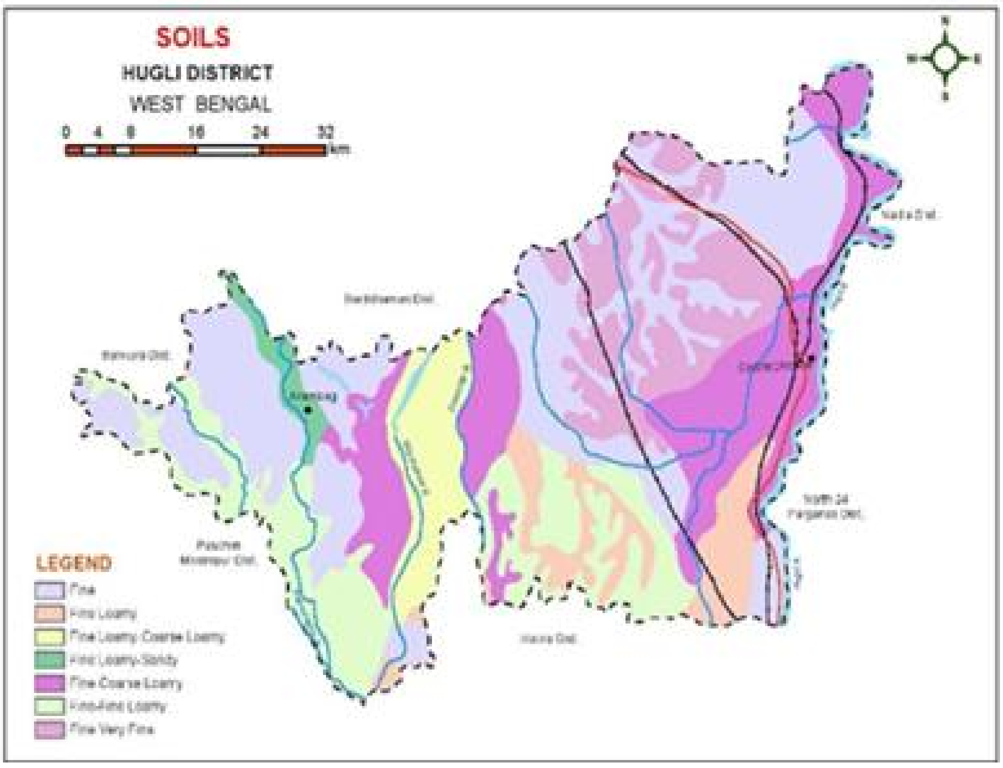

Figure 4. Soil map of Hooghly district (Source: NBSS& LUP, Regional Centre, Kolkata)

The IWT 2.0 combines 14 datasets which includes datasets from key government authorities in India such as the Central Groundwater Board (CGWB), India Meteorological Department (IMD), Ministry of Water Resources (MWR), and Central Pollution Control Board (CPCB), and best available models of water stress. The following groundwater related products were used from India water tool web portal for analyses:

- Groundwater level map (depth in mbgl),
- Block-wise groundwater level data of pre-monsoon and post monsoon,
- Groundwater block categorization map,
- Projected demand map (domestic and industrial)

Shiao *et al.* (2015), described clearly in their technical report (India Water Tool) about the methodology to produce various groundwater related products (maps). For example, groundwater block categorization map was developed on the basis of stage of groundwater development and it calculated by following procedure

$$\text{Stage of Groundwater Development} = \frac{\text{Existing Gross Draft for All Uses}}{\text{Net Annual Groundwater Availability.}}$$

In order to rationalize the projected demand of groundwater resources in overexploited areas Projected Demand (map) for Domestic and Industrial Water Use in 2025 is calculated as follows:

Case I, when GWav ≥ Dgi+ Alld

In such cases projected demand for future domestic and industrial uses = Alld

Case II, when GWav < Dgi+ Alld

In such cases, projected demand for future domestic and industrial uses = (GWav – Dgi) or Dgd, whichever is greater, where

GWav = Net Annual GroundwaterAvailability
Dgi = Existing GroundwaterDraft for Irrigation
Dgd = Existing GroundwaterDraft for Domestic Use
Dg = Existing GroundwaterDraft for All Uses
Alld = Computed Value of Allocation for Domestic Use

(Based on projected population, fractional load on groundwater, and per capita requirement)

Methods and techniques followed

- To address the set objectives, the various maps according to their constructing variables were described.
- Some statistical techniques like standard deviation to find out groundwater depth variability of pre-monsoon and post monsoon condition were also followed.
- Change of storage of groundwater of an area (block) is calculated on the basis of the following formula:

d (STORAGE) = Static Water Level Fluctuation * Area * Specific Yield[1]

The volume of groundwater storage change is expressed as Hectare-meter or ham.

RESULTS AND DISCUSSION

Static Groundwater Level

The groundwater level map of the study area is presented in fig 5 showing the depth of the static groundwater level of different blocks. It is observed from the fig.5 that the present scenario of spatio-temporal distribution of ground

1. The values of Specific yield (S) were used out of work on ‘Rainfall-recharge correlation; a method for evaluating potential groundwater’ by Bhattacharjee (1982) in Hooghly district, using the formula developed by Ramsahoye and Lanz (1961):

$$S = \frac{4Tt}{r^2}$$

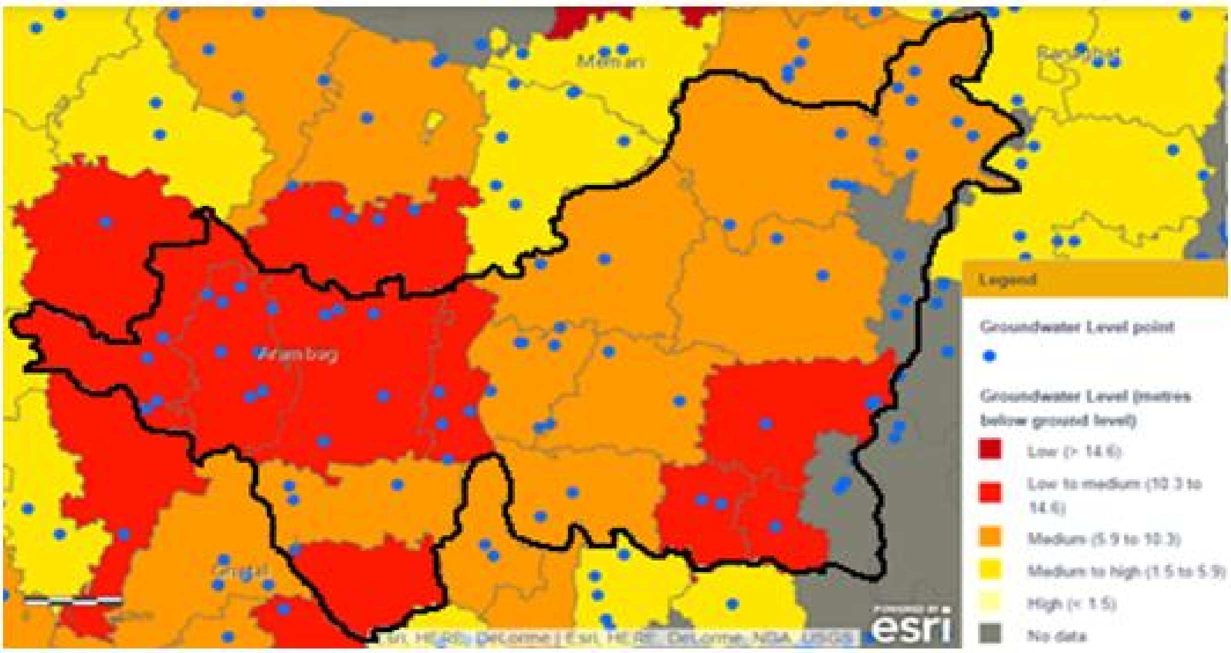

Figure 5. Block wise groundwater level (mbgl) map of the study area (source: http://www.indiawatertool.in)

S may be seen to depend on the transmissivity of the aquifer (T), the radius of influence of the test well (r), and the duration of pumping (t).

water level (mbgl) at various blocks of Hooghly district does not stand at a very good andhealthy position. Seven out of eighteen blocks(Goghat I, Goghat II, Arambag, Pursura, Chanditala I, Chanditala II, Singur) of the district show a low to medium groundwater level (varying from 10.3 to 14.6 mbgl) category, while the rest of the blocks fall under medium groundwater level (5.9 to 10.3 mbgl) category. From this information it is clear that higher depth of groundwater level of a location where the water is away from the ground surface and is less accessible. The erratic rainfall pattern; unplanned and rapid urbanization causing expansion of concrete landscape with the exchange of natural environment; structural and textural change of soil due to excessive use of chemical fertilizers resulting to reduction of infiltration rate by many times; and the poor groundwater recharge with in a spatio-temporal dimension are the probable reasons of the above. The investigation was further extended to individual block level study to account the trend of groundwater level at six blocks of Hooghly district namely, Pandua, Balagrah, Singur, Chanditala I, Chanditala II and Tarakeswar and a map was developed accordingly (Fig. 6). The figure shows that all the blocks have a sharply declined trend of average groundwater level (mbgl) in pre-monsoon and post-monsoon condition.

Block-wise groundwater storage

Table 2 represents an account of the loss of groundwater storage in various blocks of Hooghly district. A decline trend of groundwater level could be observed during 2007 to 2013 in all the study blocks. It is further observed that, a considerable fluctuation in groundwater level took place in both per-monsoon and post-monsoon readings resulting ultimately to falling of the SGWL within the study period of six years (2007-2013). Generally post-monsoon readings indicate the amount of groundwater recharge from monsoonal rainfall annually, while the pre-monsoon reading gives an account of the groundwater discharge in the year. It is found that, in the case of Pandua, Balagrah and Singur, the pre monsoon readings of SGWL in 2007 was 5.095 mbgl, 4.815 mbgl, 15.65 mbgl respectively. In 2013 it was fallen down to 9.655 mbgl, 9.216 mbgl, and 18.55 mbgl respectively. The rate of falling is 4.56 mbgl, 4.401 mbgl, 2.9 mbgl respectively.

Such fall of pre-monsoon SGWL in the above three blocks (Pandua, Balagrah and Singur) indicates that an amount of 15126, 12455 and 7170ham volume of water had been actually lost from the system in 6 years of time from 2007 to 2013.

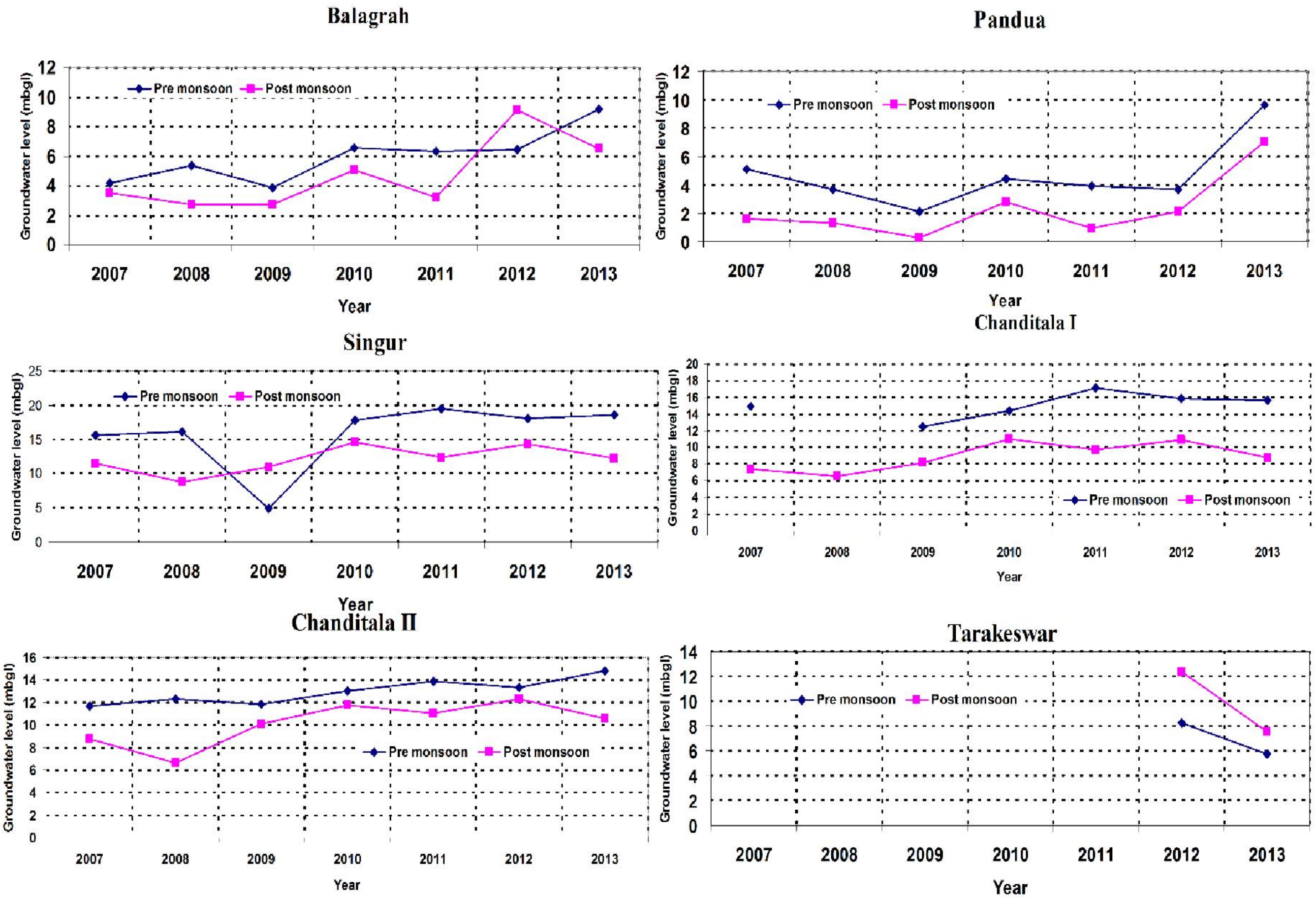

Figure 6. Average groundwater level fluctuation map of pre monsoon and post monsoon condition: (a) Pandua, (b) Balagrah, (c) Singur, (d) Chanditala I, (e) Chanditala II and (f) Tarakeswar

Table 2. Block-wise ground water storage change of Pre monsoon and Post monsoon condition

Block	Area	Pre monsoon average ground water level change (mbgl)			Post monsoon average ground water level change (mbgl)			Specific yield	d(STORAGE) (ham)	
		2007	2013	Fluctuation (mbgl)	2007	2013	Fluctuation (mbgl)		Pre monsoon fall (mbgl)	Post monsoon fall (mbgl)
Pandua	276.43	5.095	9.655	-4.56	1.605	7.04	-5.435	0.12	15126	18028
Balagrah	202.15	4.815	9.216	-4.401	3.526	6.496	-2.97	0.14	12455	84053
Singur	164.85	15.65	18.55	-2.9	11.49	12.2	-0.71	0.15	7170	1755
Chanditala I	93.45	14.96	15.71	-0.75	7.38	8.79	-1.41	0.10	700	1317
Chanditala II	70.34	11.68	14.835	-3.155	8.74	10.6	-1.86	0.10	2219	1308
Tarakeswar	119.93	8.195(2012)	12.348	-4.153	5.72 (2012)	7.52	-1.8	0.12	5976	2590

Table 3. Ground water depth variability of Pre monsoon and Post monsoon condition (2007-2013)

Block Name	Pre-monsoon ground water level change (mbgl)		Pre-monsoon average value (2007-2013)	Pre-monsoon Standard Deviation	Post- monsoon ground water level change (mbgl)		Post- monsoon average Value (2007-2013)	Post- monsoon Standard Deviation
	maximum	minimum			maximum	minimum		
Pandua	9.655	2.11	4.64	2.38720	7.04	0.24	2.29	2.24561
Balagrah	9.21	3.88	5.99	1.78269	9.12	2.72	4.77	2.38747
Singur	19.44	4.93	15.78	4.96640	14.55	8.75	12.08	2.00709
Chanditala I	17.15	12.46	15.09	1.59601	10.99	6.58	8.95	1.70493
Chanditala II	14.835	11.68	12.97	1.14351	12.31	6.59	10.15	1.95008
Haripal	10.845	6.185	8.43	1.78775	5.225	2.41	4.07	1.18074

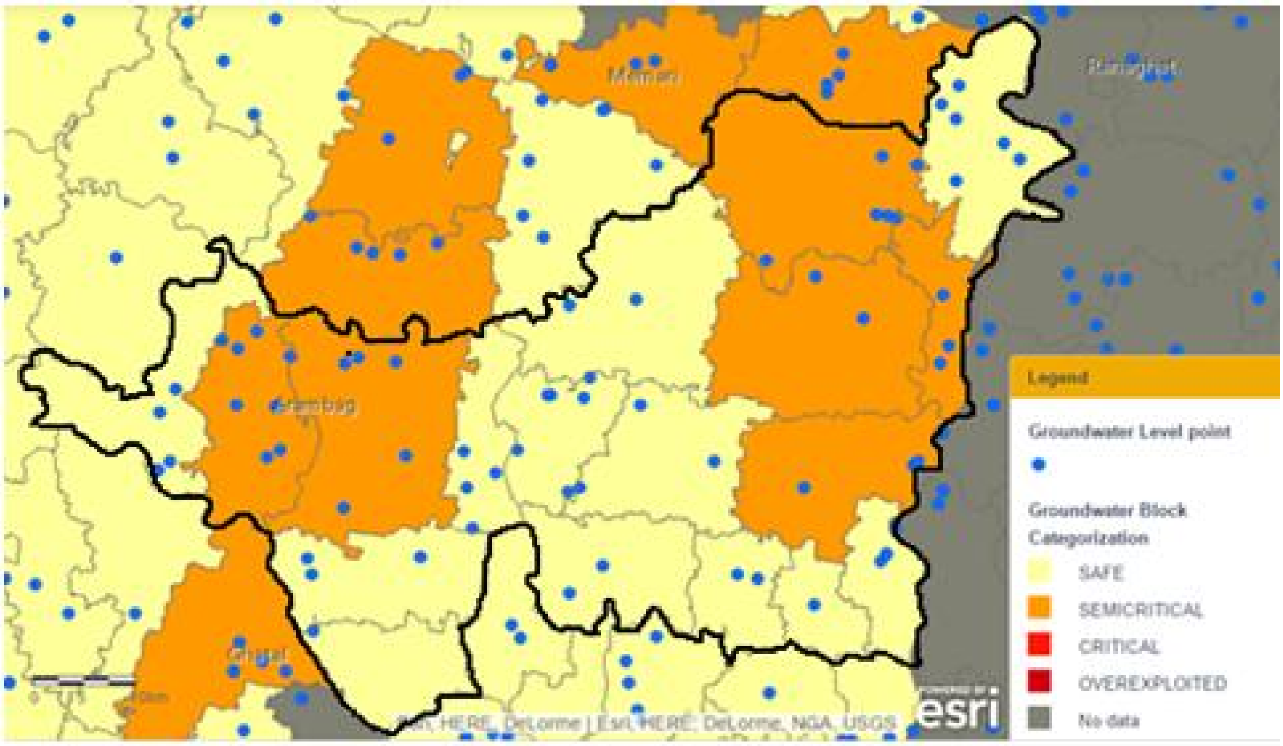

Figure 7. Block categorization map of Hooghly district (based on stage of groundwater development, source: http://www.indiawatertool.in)

Similarly, the post monsoon readings of SGWL in 2007for the three blocks were 1.605 mbgl, 3.526 mbgl, 11.490 mbgl and in 2013 those were recorded as 7.04 mbgl, 6.496 mbgl, and 12.2 mbgl resulting to the falling rates as 5.435 mbgl, 2.97 mbgl, and 0.71mbgl respectively.

The vertical fall of post-monsoon SGWL as 5.435 mbgl, 2.97 mbgl, 0.71 mbgl in the Pandua, Balagrah and Singur blocks in 6 years actually amounting to 18028, 84053 and 1755 ham volume of water had been lost from the system.

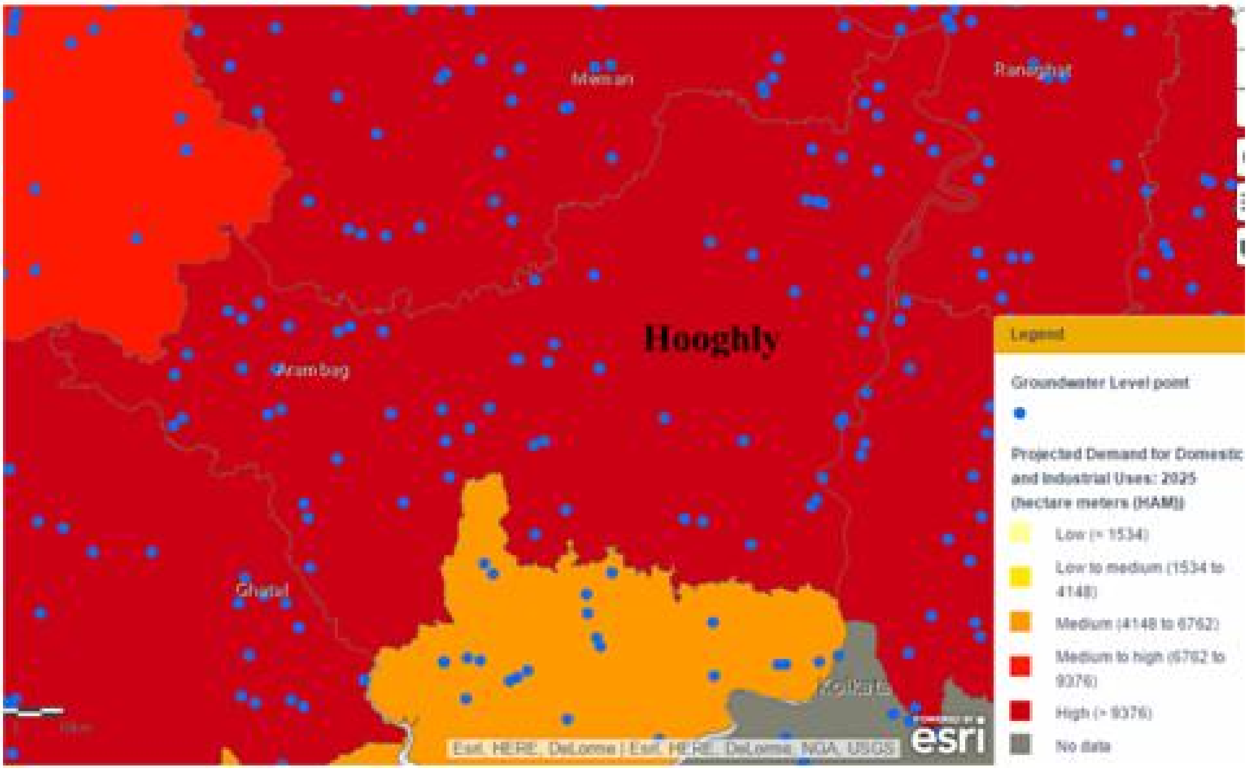

Figure 8. Projected ground water demand map of Hooghly district (based on domestic and industrial use, source: http://www.indiawatertool.in)

A similar trend could be observed in the other three blocks namely, Chanditala I, Chanditala II and Tarakeswar in the district.

The major concern is that, the decline of post monsoon groundwater level reading indicates the gradual decrease in the amount of groundwater recharge from its successive year (Table 3). On the other hand, gradual decline in pre-monsoon groundwater level also suggests that a high rate of groundwater withdrawal for domestic and agricultural and industrial purposes. So, an imbalance between groundwater recharge and discharge can be observed in these 6 blocks in Hooghly district.Based on the stage of groundwater development and long term pre and post monsoon water level trend, the blocks have been categorized as Safe, Semi-critical, Critical, and Overexploited. According to Groundwater Block Categorization Status in 2011 the 6 blocks namely, Goghat I, Pandua, Polba-Dadpur, Singur, Arambag and Chinsutah-Mogra of Hooghly district fall under semi-critical categorization (Fig. 7). Whereas, during 1994-2004 only 2 blocks, Goghat I and Pandua of Hooghly district were fallen under semi-critical categorization.

The projected demand of groundwater for industrial and domestic use for the Hooghly district is presented in Fig 8. The figure indicates that there will be a demand of groundwater as high as more than 9376 ham designating the district as ‘high’ demand of groundwater by the year 2025.From the findings of the above investigation it is clear that the falling rate of static groundwater level (SGWL) of various blocks in Hooghly district is situated in an alarming position.

Conclusion

Groundwater can be considered as a natural asset. The value of such an asset resides in its ability to create flows of services over time. In the context of changing human activities there are two principal ways, which caused to threaten the quantity of groundwater. First and foremost is excessive abstraction, which is widely termed as aquifer overexploitation. Second, and far more subtly, insofar as climate change induced by greenhouse gas emissions alters recharge rates to aquifers, it is capable of leading to depletion of groundwater resources. However, from the above discussions it is clear that in a district like Hooghly and its various blocks, empirical evidences on the groundwater resources shows a sharply declined trend of average groundwater level (mbgl) as well as storage of groundwater in pre-monsoon and post-monsoon condition. It basically refers extraction in excess of net recharge in the considerable period and leads to reduce groundwater stocks rapidly and in the future too. Evaluation should be concentratedon gathering the information like how the cost of extraction and distribution is altered by changes in groundwater stocks and hydrogeological information to assess how given pumping rates will alter the pressure head in the future. Of course, the influence of pumping on future stocks and their quality is a complex issue of hydrogeology and chemistry, since the recharge rates, the quality of the recharged water, and the aquifer capacity all are involved in it.

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