Groundwater Depletion with Expansion of Irrigation in Barind Tract: A Case Study of Rajshahi District of Bangladesh

Md. Abdullah Aziz[1], Md. Abul Kashem Majumder[2], Md. Shahjahan Kabir[2], Md. Ismail Hossain[2], Niaz Md. Farhat Rahman[2], Farhana Rahman[3] and Shakir Hosen[3]

[1 & 2]Agricultural Statistics Division, Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh

[2]Director (Administration and Common Service), Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh

[2]WRP Division, Institute of Water Modelling, House # 496, Road # 32, New DOHS, Mohakhali, Dhaka-1206, Bangladesh

[3] Climate Change Specialist, Climate Change Adaptation Project, LGED-DANIDA, Project Support Unit (PSU) LGED Bhaban, Level-8, Agargaon, Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh

[3]Grain Quality and Nutrition Division, Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh

Abstract: ***The study has been described continuous declination of groundwater level with increase of groundwater irrigation in Barind Tract from mid 2000 to 2013 in the perspective of Rajshahi district which is located in severely drought prone area at Northwestern part of Bangladesh. Dry season Boro rice mainly depends on supplementary irrigation from groundwater, results in severe groundwater depletion. Main source of recharging of groundwater aquifer in this area is rainfall, but rainfall is also dropping here. Hydrographs are analyzed and groundwater level contour maps are prepared by Arc GIS version 10 software from the monitoring wells data of Bangladesh Water Development (BWDB).For aquifer geometry a subsurface geological cross section made by RockWorks software from bore log data of Department of Public Health Engineering (DPHE) and Bangladesh Water Development (BWDB).Only two aquifers exist and in NW area shows effective aquifer thickness is shorter than SE portion. Average rates of maximum depth (dry season) and minimum depth (wet season) groundwater depilation are 0.23meter/year and 0.38meter/year respectively in Rajshahi district, some upazilas these rates are much higher than that of average .Groundwater recharge condition is very poor in Tanore, Godagari, Mohanpur and Baghmara upazilas and vulnerable for Boro rice i.e. irrigated rice. A crucial relationship remain between Boro production and groundwater depletion, so crop diversification or less water consuming crops can be option for the study area.***

Keywords: Groundwater Depletion, Aquifer, GIS, RockWorks.

1. Introduction

Bangladesh is an agro-based country and rice is the main agricultural product. Rice contributes more than 80 percent to the total food supply. More than 95% of population consumes rice and it alone provides 76% of calorie and 66% of total protein requirement of daily food intake [5].The cultivation of rice in Bangladesh varies according to seasonal changes in the water supply. Rice in Bangladesh is grown in three distinct seasons, namely Boro (January to June), Aus (April to August), and Aman (August to December) covering almost 11.0 million hectares of land in Bangladesh [3].Boro rice provided 56.47% and 55.77 % of total rice in Bangladesh in the year 2009-10 and 2010-11 respectively [4].But, dry season Boro rice mainly depends on supplementary irrigation. In dry season surface water source becomes limited for irrigation so, groundwater provides the major irrigation water which are causes severe groundwater depletion and may be a great threat for future groundwater availability and irrigation ultimately Boro production specially in Barind area of Rajshahi district which is North-West part of Bangladesh. Northern part of Bangladesh is now facing water scarcity problems in both agriculture and secured livelihood [2].Groundwater recharging in Bangladesh is mainly take place by monsoon rainfall and flooding. Due to high elevation of Barind, it is located in flood free zone. So, main source of groundwater recharging in this area is rainfall, but lowest amount of rainfall occur in northwestern part of Bangladesh and the area has become very severely drought prone area. Moreover, thick sticky clay surface of Barind Tract act as aquitard which impede groundwater recharging and increase surface runoff. As a result, groundwater level in this part is successively falling by years with increasing withdrawal of water for irrigation. [7].To have proper monitoring on groundwater level and keep agriculture practice smooth, there is a need of analysis work for better crop yield it is a must to keep the water table within suction limit [1].It also needed to find out suitable and vulnerable area of irrigation. As, geological condition of an area governs the occurrence and distribution of groundwater. So, evaluation is needed to measure the geological condition in this regard.

1.1 Geography and Geology

Rajshahi has sub-tropical climate with a mean annual rainfall of 1625 mm, which is much lower than the national average of 2550 mm. During summer (March-May) temperature rises above 40°C, but falls below 5°C in midwinter (January). The mean relative humidity is low (60%) in early summer (March) and high (88%) in late monsoon (August-September) [6].

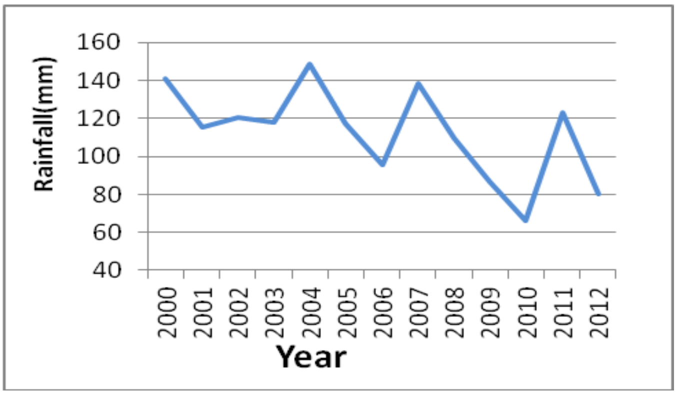


Figure 1: Rainfall graph of Rajshahi District from 2000-2012

The study area is a small part of the Ganges River basin – a flat alluvial basin. The surface geology consists mainly of sedimentary formations, mostly riverine in origin (Haque et al.,2012). Barind Tract made up of Pleistocene Alluvium also known as Older Alluvium and floored by reddish brown, sticky Pleistocene sediment; Madhupur Clay . Pleistocene Dupi Tila Sand acts as aquifer in Barind Tract [7].

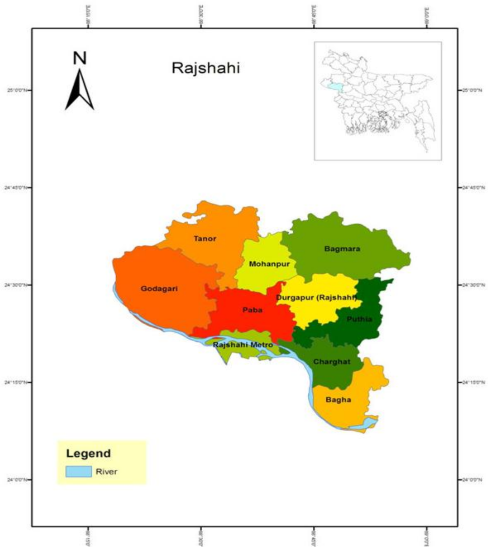


Figure 2: Upazilas of Rajshahi

1.2 Objectives

- To understand Groundwater depth and variability of study area.
- To determine the lateral and vertical extent, thickness and continuity of the aquifers.
- To identify impact of Boro rice production on groundwater depth.
- Find out suitable and vulnerable area of Boro rice with respect to groundwater fluctuation of the study area.
- The future recommendation of rice production with Groundwater fluctuation and variation.

2. Methodology

Secondary data was mainly used for this study. The study was based on groundwater monitoring wells data of Bangladesh Water Development Board (BWDB) from 2000-2013. Lithology of the study area was studied from borehole logs data collected from Public Health Engineering Department (DPHE). Rainfall data was collected from Bangladesh Meteorological Department (BMD). Boro rice area and production data were collected from Bangladesh Bureau of Statistics. Twenty eight monitoring wells data were used for mapping of contour groundwater depth (maximum, minimum, fluctuation) of study area for the year 2012-13 to evaluate the trend of the groundwater movement. Depth was calculated in meters. Mapping software ArcGIS 10 was used for contouring and others mapping. Long-terms Hydrographs were produced to measure groundwater depth and variability. Then aquifer variability map or hydro stratigraphic cross-section generated by bore log data through RockWorks software, then correlation between aquifer variability and irrigated (Boro) rice production has been conducted.

3. Result and Discussion

3.1 Water Table Contour Maps

Water table contour maps show the gradient and direction of the water flow in the study area. The attitude and direction of the water table vary with the permeability of the saturated beds and within the amount and rate of recharge and discharge. In Bangladesh two extreme trends are observed in the groundwater table throughout the year- a high water head during the wet season and a low water head during the dry season. This implies a gain or loss of water in the aquifer storage influenced by the seasonal variation. Recharge to the groundwater in the study area occurs mainly through infiltration of rainfall, stream and channel flow and percolation from pond and low lying areas. Besides, return flow from irrigated fields and inflow from adjacent areas of higher elevation also contribute minor recharge.

3.1.1 Groundwater Depth Contour Map of Minimum Depth

With the start of the monsoonal rainfall the water table is rising and reaches to the highest elevation so minimum depth. The rising of water table replenishes the discharge. Generally, the minimum depth of water table occurs from July to September. Water table depth is inversely proportional to water table elevation. So, depth is as less, elevation is as high which is good for groundwater condition. The minimum depth water table contour map is prepared with 01m interval (Figure 3).The depth increase towards from Southern to Northern part of the study area. Thus main flow is being in the Sothern portion to Northern and eastern direction. Groundwater level is high in the vicinity of Ganges River. So it implies Ganges river water recharging ground water. Minimum depth varies from 1m to17m. Depth is very high in central and North-Western part of the study area that comprised the upazilas of, Mohanpur, Tanore upazilas and very low depth in Baghmara, Puthia and Bagha Upazilas.

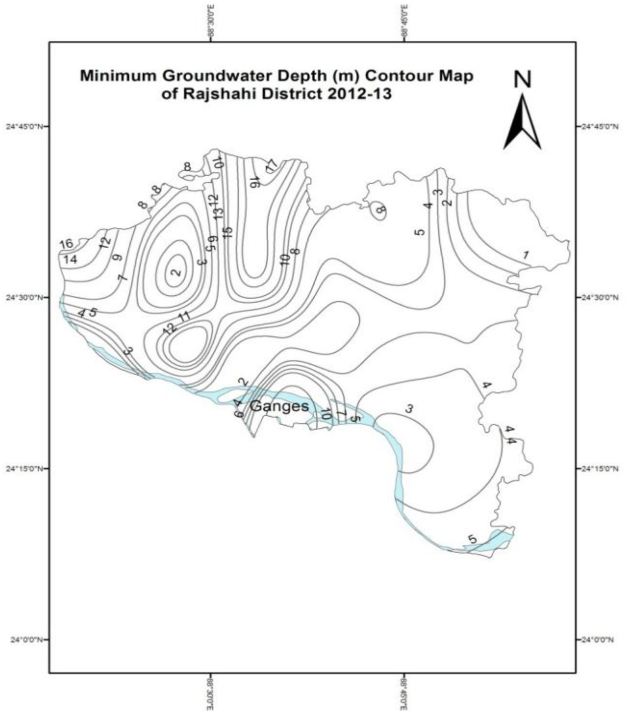


Figure 3: Minimum Groundwater Depth Contour Map of Rajshahi District (2012-13)

3.1.2 Groundwater Depth Contour Map of Maximum Depth

The Maximum depth of the water table in the study area is measured at the driest period (January to March) of the year where the maximum water is exploited by pumping through the tube wells.

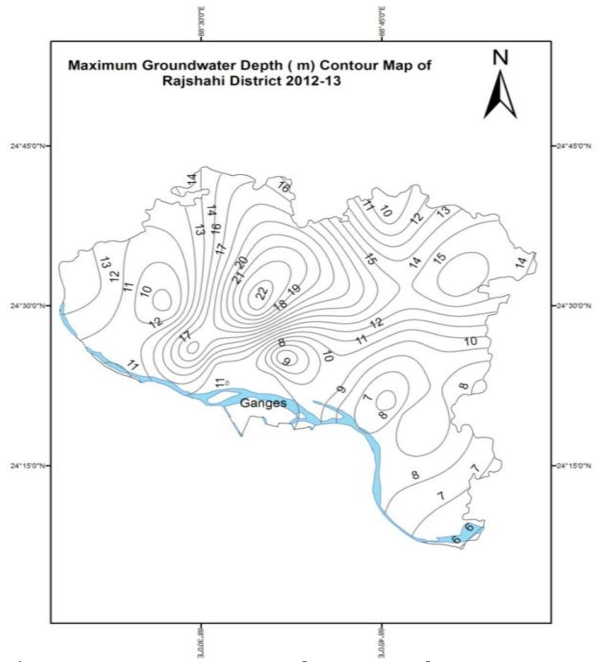


Figure 4: Maximum Groundwater Depth Contour Map of Rajshahi District (2012-13)

Groundwater depth contour map of maximum depth is prepared with 01m interval (Figure 4).The maximum depth of groundwater in the study area range from 7m to 22m. Depth is lower Southern side and high in Northern side especially central part of the study area is very high. This map also shows groundwater flows towards Southern portion to Northern and western directions. High depth areas are Tanore, Mohanpur, Baghmara upazilas; low depth areas are Puthia, Chatghat, Bagha upazilas.

3.1.3 Water Table Fluctuation depths Contour Map

Water table fluctuation is a direct response to change in groundwater storage. Generally, water levels show a seasonal pattern of fluctuation. These result form influences such as recharge from rainfall and discharge from pumping which follow well—defined seasonal cycles. Normally fluctuations are calculated differences between maximum groundwater depths to minimum ground water depth.

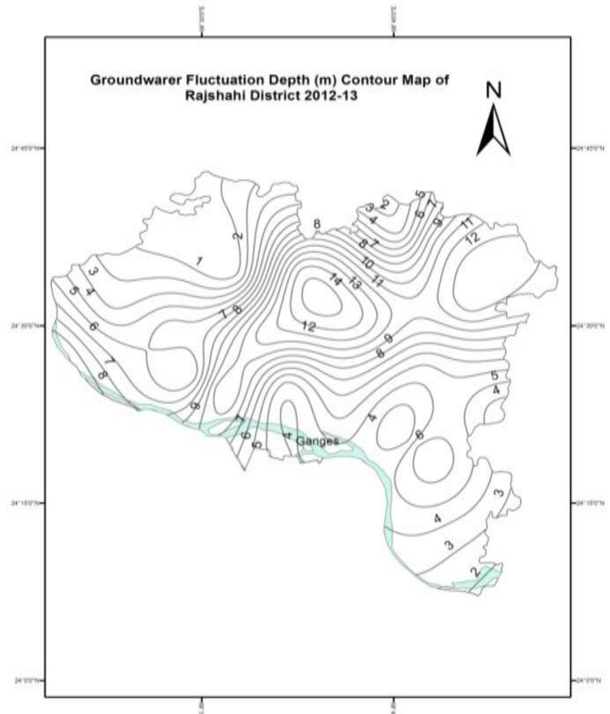


Figure 5: Groundwater Fluctuation Depth Contour Map of Rajshahi District (2012-13)

A counter map of ground water depth fluctuation of the study area has been constructed by 1m interval, within the study area, the fluctuation depth of groundwater is ranged from 1m to 14m (Figure 5).The variation depends upon the local conditions such as, the distance from river, duration of rainy season, rate of dry season and intensity of pump duration. Maximum fluctuation occurs through North Eastern area of Baghmara, mohanpur upazila and very low in puthia, charghat and bagha upalizas.

It is noticeable that Baghmara upazila maximum groundwater depth is high and minimum groundwater depth is low makes high fluctuation depth, so recharge is poor and groundwater level is declining. Mahanpur both maximum and minimum depth high but relatively higher maximum depth makes higher fluctuation so this upazila also loosing recharge ability and groundwater level, the most critical upazila is Tanore though it's fluctuation is very low, this low fluctuation due to very close maximum and minimum depth that's mean in wet season groundwater level doesn't rise high so recharge is very poor and high maximum depth causing groundwater depletion. On the other hand low fluctuation area Puthia, Charghat and Bagha upazilas have also low maximum and minimum groundwater depth so recharge of these upazilas aren't so poor.

3.2 Hydrograph Analysis

Long term groundwater level trend is observed by analysis of hydrograph from groundwater observation well data [7].

Long-term groundwater level hydrographs are prepared based on weekly-data collected from monitoring wells of BWDB from 2000 to 2013.One monitoring well is considered for each upazila, which are GT 813401 (Godagari), GT817203 (Paba) GT812200 (Rajshahi Metro), GT812500 (Charghat), GT818204 (Puthia), GT 813101 (Durgapur), GT815303 (Mohanpur), GT 811200 (Baghmara), GT 819404 (Tanore).Unfortunately well of Bagha Upazila is not considered due to unavailability of data. Fluctuations of groundwater depth are shown by hydrographs in figure (6-14).

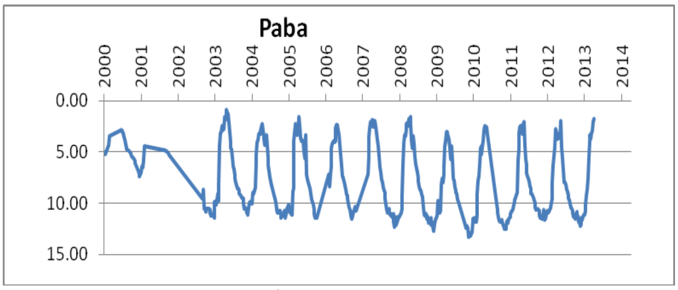


Figure 6: Hydrographs of Paba Upazila (Well ID GT817203)

Hydrigraohs of paba are more or less gentle after 2003 and fluctuation is not rapidly increasing. So groundwater recharge condition is optimal though maximum groundwater depth is slightly increasing, 2003 it was 11m and 2013 it became 12m and also minimum depth was 1m and 2 m in 2003 and 2013 respectively thus both maximum and minimum depth declination is 1m, that's why so far, declination is not high (Figure 6).

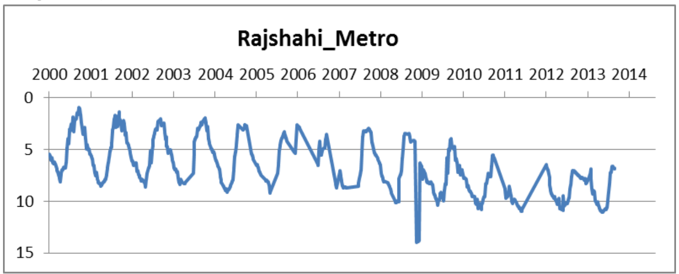


Figure7: Hydrographs of Rajshahi_Metro (Well ID GT812200)

Both maximum and minimum groundwater depth started significantly increase after 2009, when a abrupt change in maximum groundwater depth. Maximum depths were 8 m in 2000 and 11 m in 2013, i.e. declination 3m where minimum depth were 1 m and 7 m in the year 2000 and 2013 respectively i.e. declination 6m .So, recharge condition is going poor (Figure 7).

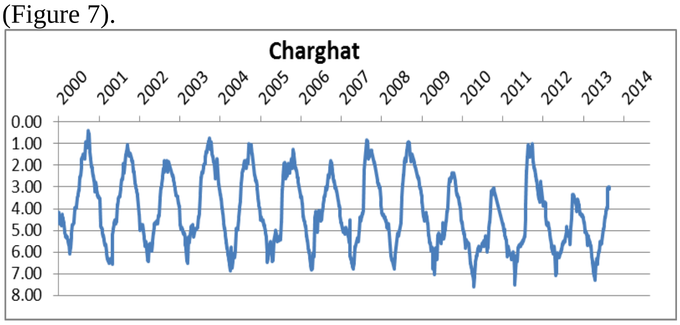


Figure 8: Hydrographs of Charghat (Well ID GT812500)

In Charghat maximum groundwater depth is gently increasing but after 2009 minimum groundwater depth is significantly increasing. In the year 2000 the maximum and minimum depths were 6 m and 0.45 m respectively where 2013 these were 7.12 m and 3 m thus groundwater is declining and these declination are maximum depth 1.12 m minimum depth 2.55 m , so the declination is in high rate.(Figure 8).

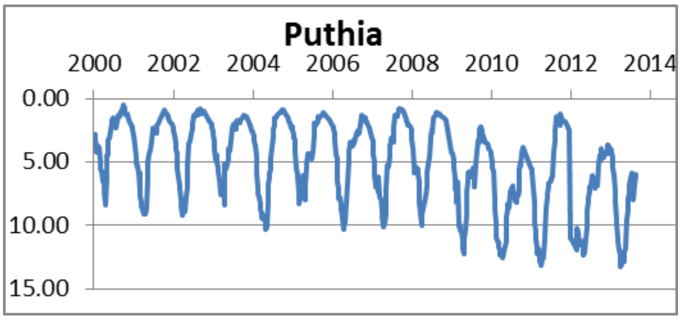
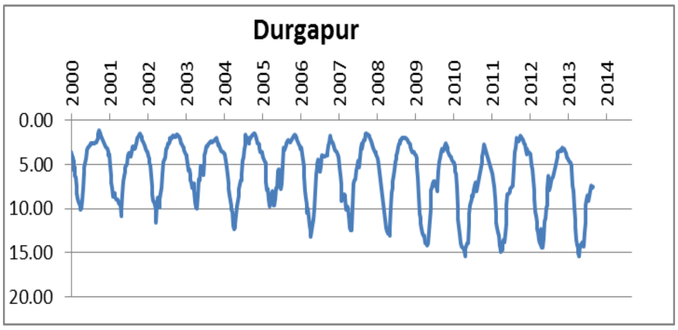


Figure 9: Hydrographs of Puthia (Well ID GT818204)

Like others upazilas hydrographs of Puthia also shows a significant change after 2009 from when both maximum and minimum depth started increase rapidly. Maximum depths were 8.5m in 2000 and 13.5m in 2013 i.e. declination is 5m. Minimum depth were 1 m and 6m in the year 2000 and 2013 respectively i.e. declination is 5m, thus both maximum and minimum depth declination is same (Figure 9).



In Durgapur both maximum and minimum depth started gently increasing after 2009 and fluctuation as well. Maximum depths of Durgapur in the year 2000 and 2013 were 10m and 14.5 m respectively and minimum depth were 1.5m and 7.5m thus declination of maximum and minimum depths were 4.5m and 6m (Figure 10).

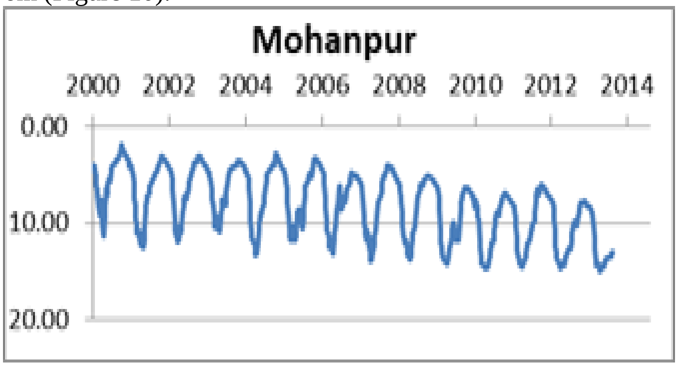


Figure 11: Hydrographs of Mohanpur (Well ID GT815303).

Hydrographs of Mohanpur are showing depths lightly increasing trend .Maximum depth were 10.5m (2000) and 15m (2013) so declined 4.5m where minimum depth 3m (2000) and 14m (2013) that means declined 11m (Figure11).

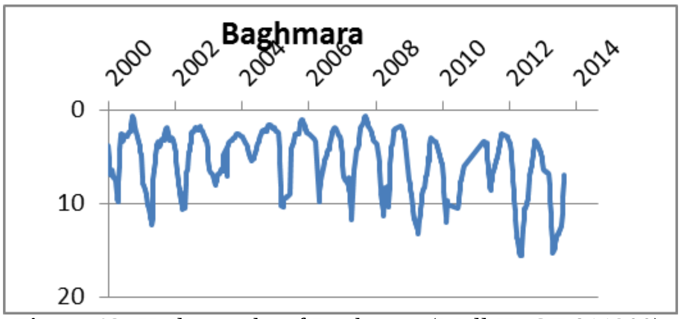


Figure 12: Hydrographs of Baghmara (Well ID GT 811200)

Though hydrographs of Baghmara shows irregular pattern both maximum and minimum depth increasing and fluctuation depth. Maximum depths were 10m (2000) and 15.25m (2013) so declination is 5.25m. Minimum depths were 0.7m (2000) and 7m (2013) thus depletion is 6.3m which is very high (Figure 12).

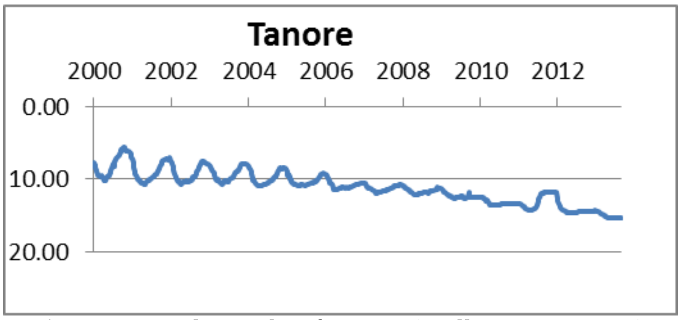


Figure 13: Hydrographs of Tanore (Well ID GT 819404)

Groundwater level depth of Tanore upazila is going down day by day but recently fluctuation is decreasing. In the year 2000 and 2013 the maximum depths were 10m and 15 m respectively that is declination of maximum depth is 5m on the other hand minimum depths were 6.3m (2000) and 14.4m (2013), so declination is 8.1m which is very high, but noticeable is recent years maximum and minimum depths are very close so it's means there have some problem in aquifer recharge. It may be withdrawal of water is very higher than recharge (Figure 13).

In Godagari maximum groundwater depth was constant though minimum groundwater depth was little bit increasing but a drastic change observed after 2009 from when minimum groundwater depth significantly started increasing, maximum Groundwater depth was also increasing already reach 20.5 m (2013) and was 17m (2000) so, maximum depth declined 3.5 m

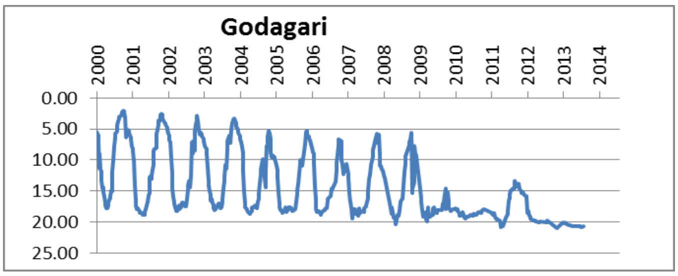


Figure 14: Hydrographs of Godagari Upazila (WellIDGT 813401)

where minimum depths were 3m (2000) and 20m (2013) that is minimum depth declined 17m and it is noticeable recently maximum and minimum depth are very close which is very alarming that's mean recently recharge condition is becoming very poor (Figure-14).

Thus, hydrographs of all upazilas show that groundwater depth is declining day by day but a significant change initiated from 2009 most of the upazilas. Rate of declination of minimum depth is higher than that of maximum which implies groundwater recharge coming down due to withdrawal of excessive groundwater. Among these upazilas condition of Godagari and Tanore are very critical, in Godagari minimum depth depleted 17m and Tanore 8.1 m since the year 2000 to 2013, moreover recently these two upazilas maximum and minimum depth come very closer so it can be said there have some problem in aquifer recharge thus the situation is very alarming and lost suitability for Boro production. Then Mohanpur, Baghmara, Durgapur and Rajshahi Metro which minimum depth declined 11m, 6.3m, 6m and 6m respectively so these upazila's quifer recharge is losing and becoming alarming for Boro production. But, some upazilas aren't not so critical stage as both maximum and minimum depth don't declined so high like Paba, Charghat Puthia.But, future high Boro production and groundwater withdrawal might become threaten for Boro production.

3.3 Aquifer Geometry

Aquifer geometry defines the lateral and vertical extent of the aquifer. Careful observation on aquifer fancies and its geometry ensures the perfect detection of the groundwater system. According to the 15 locations of boreholes along with hydrostratigraphic section, the aquifer system is classified as five zones (zone A-E). **Zone-A** is covered with grey to brown clay, silt and silty clay layer of semi impervious nature, which exhibits the typical characteristics of an aquitard. Thickness varies from 6-29m. It is distributed all over the area. Upper Sand Layer Aquifer**. Zone B** is extends throughout the area under the Zone-A and its thickness is varies from 6m – 130 m. and it consist mainly grey and light brown colored very fine to Coarse size grained. From SE to NW its thickness increases. Middle Silty- clay /Clay layer. **Zone-C** is covered with grey to grayish colored clay, silt and silty clay layer of semi impervious nature, which exhibits the typical characteristics of an aquitard of thickness, varies from 6-120m. From SE to NW its thickness and depth increases. Middle Sand Layer Aquifer, **Zone D** is throughout the area under the Zone-C and its thickness is vary from 25m – 42 m. and it consist mainly grey and grayish colored fine to coarse size and some areas found gravels size grained. From SE to NW its depth increases but NW to SE its thickness increases. Lower Silty- clay /Clay layer, Zone-**E** is the lower boundary which covered with grey colored clay, silt and silty clay layer of semi impervious nature which exhibits the typical characteristics of an aquitard. Thickness could not delineate due to non-availability bore-log data but its depth increases from SE to NW.

So, from the cross section zone B and zone D are aquifer and others are aquitard like zone A, C and E .Finally it can be said, cross section reveled that up to depth 250m only two aquifers exist and in NW area shows effective aquifer thickness is shorter than SE portion, moreover, the aquitard (zone C) between these aquifers, is thicker in NW becoming narrower in SE. Thus, the upazilas of NW are very vulnerable like, Tanore, Mohanpur. In future, it might be an alarming sign for ground water uses at NW portion and take control or planning.

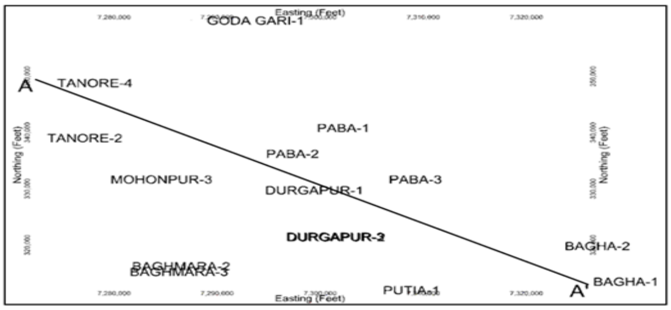


Figure 15: Location of Bore log and cross section line (A-A')

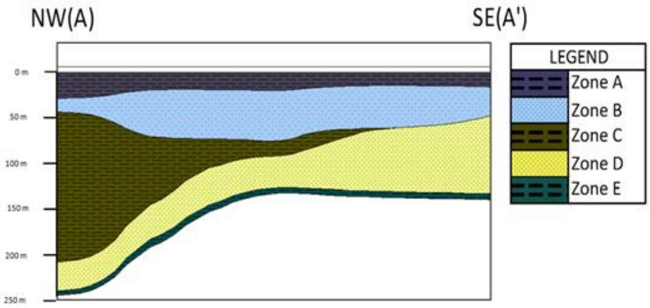


Figure 16: Cross section from NW(A) to NE(A')

3.4 Groundwater Level and Boro Production

In Rajshahi, Groundwater level is continuously going down every year. Figure 15 showing the average of nine upazila's maximum and minimum depth condition of wells of Rajshahi district (making average of nine wells from each nine Upazilas). From the graph in the year 2000-01 the maximum and minimum depths were 11 & 2 m respectively where 2012-13 these values became 14m and 7m respectively so the average rate of maximum depth (dry season) and minimum depth (wet season) groundwater depilation rates are 0.23meter/year and 0.38meter/year respectively .As rate of Minimum water level is higher which implies that recharge condition is losing day by day.

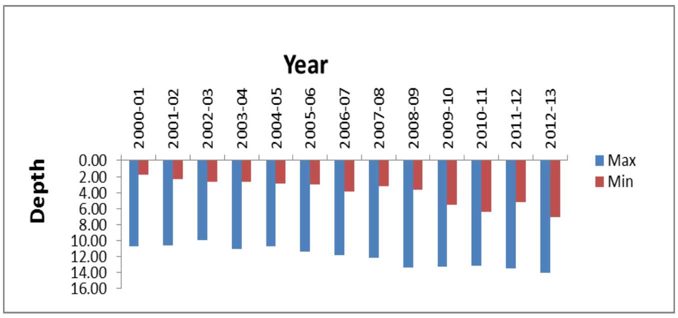


Figure 17: Average maximum and minimum groundwater depth of Rajshahi (2000-01 to 20012-13)

Recently Boro production is increasing in Rajshahi. Figure -18 shows the relationship between Boro production of greater Rajshahi district (Present Rajshahi, Noagaon,Natore, Chapainawabganj) and average maximum groundwater depth (dry season) from 2000 to 2013.

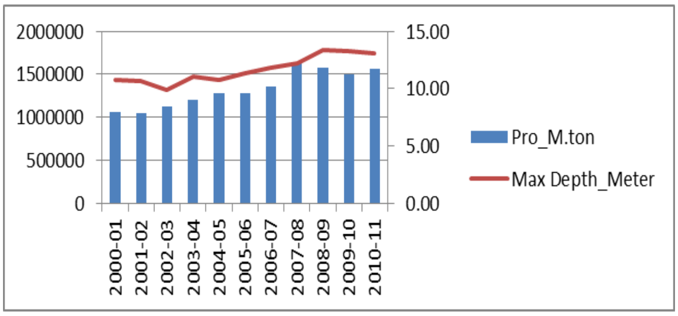


Figure 18: Relationship between max. Groundwater depth and Boro production

Graph show a clear relationship between maximum groundwater depth and development of Boro production over time. With increasing Boro production, every year the rate of depletion of groundwater level is accelerating in dry season.

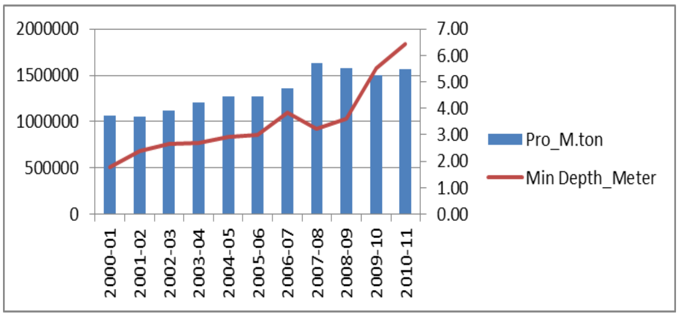


Figure 19: Relationship between min. groundwater depth and Boro production

Figure 19 graph show a clear relationship between minimum groundwater depth (wet season) and development Boro production over time. With increasing Boro production, every year the rate of depletion of groundwater level is accelerating in (wet season) especially after 2009 this rate was rapidly increased. With increasing Boro production number of DTW and STW are equivalently increasing.

4. Conclusion and recommendation

From the above study it is found groundwater is depleting due to huge withdrawal all over the Rajshahi and some areas are very critical especially Northern part of Rajshahi. Main source of recharging of groundwater in this area is rainfall which is also reducing. Average rates of maximum depth (dry season) and minimum depth (wet season) groundwater depilation are 0.23meter/year and 0.38meter/year respectively. Rate of declination of minimum depth is higher than that of maximum which implies groundwater recharge coming down due to withdrawal of excessive groundwater. A significant change of minimum water depth observed after 2009.Among the upazilas condition of Godagari and Tanore are very critical, in Godagari minimum depth depleted 17m and Tanore 8.1 m since the year 2000 to 2013, moreover recently these two upazilas maximum and minimum depth come very closer so it can be said there have some problem in aquifer recharge thus the situation is very alarming and lost suitability for Boro production. From the contour maps (maximum, minimum, fluctuation depth), groundwater level condition of Baghmara, Mohanpur and Tanore is very vulnerable and upazilas of Puthia, Charghat and Bagha so far aren't vulnerable position. Cross section of bore log data along the direction of NW to SE up to depth 250m only two aquifers exist and in NW area shows effective aquifer thickness is shorter than SE portion that means areas of NW are very vulnerable to groundwater extraction. Finally, it can be said Upazilas of Tanore, Godagari, Mohanpur and Baghmara are very vulnerable for irrigatin. There is a unblemished relation between Boro i.e. irrigated rice production and groundwater depletion thus Boro production is itself threaten for future Boro production but Boro production showing increasing treand. So, dependency of Boro of Barind area should be reduced. And groundwater depletion increased irrigation cost as water must be pumped farther to reach the surface, using more energy. In extreme cases, using such a well can be cost prohibitive .Moreover some environmental negative effect may arise like reduce surface water supplies, land subsidence, deterioration of water quality etc.

Crop variation from water consuming crop (paddy) to less water consuming crops (vegetables, fruits etc.), artificial recharging, increasing dependency on surface water, increasing irrigation efficiency including application of Alternate Wetting and Drying (AWD) method, rainwater harvesting etc. can be option for the study area.

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