Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains

Pond and groundwater resources for irrigation intensification

Working Paper

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Table of Contents

List of Figures

List of Tables

List of Photographs

1. Objectives

Eastern Gangetic Plains of Nepal and India have been noted to receive substantial monsoonal rains but still lag behind in its ability to utilize its water resources for agricultural production. It has been shown that the seasonality of the monsoon rains, on which a major portion of the agricultural population is the leading cause for the low agricultural intensification of these high potential areas. This study thus aimed at assessing the water resources available from alternative sources, specifically groundwater and surface storages (ponds) that can be tapped for dry season irrigation.

This assessment aimed at answering the following research questions:

a) What is the areal and temporal status of water availability in ponds within the target villages?
b) What is the temporal status of water availability in shallow groundwater aquifer within the target villages?
c) What are the potential irrigation demands (crop water requirements) of the main crops grown within the target villages?
d) What is the state of water quality for both surface and groundwater resources?

This study was based on data collection from field walkthroughs, remote sensing, household surveys and secondary data from previously published resources. Climatic data and cropping patterns were then used to model crop water demands for the major crops based on optimal cultural practices to estimate the potential yields under optimal water supply for all crops across the different seasons.

2. Methodology

Target villages were selected based on a criteria developed by a multidisciplinary team based on social, economic, cultural and biophysical characteristics. The two villages selected in Saptari District, Nepal were Koiladi and Khoksar Parbaha villages.

Ponds were mapped, at district level, through remote sensing, backed by groundtruthing to determine number and areal extents. A sample of the identified ponds were selected and groundtruthing survey/walkthrough carried out. During the survey of the ponds the depths were also recorded based on interview information from owners and/or residents within the vicinity of the ponds with knowledge of the ponds. Temporal pond water availability was determined from weekly monitoring of the storage depth changes from a reference point from the tops of the ponds.

Groundwater status was determined through the monitoring of groundwater tables from representative open dug wells and tube wells within the villages. The temporal depth changes were recorded on a weekly basis to evaluate the aquifer storage depths over time.

Using the average district level groundwater tables and the district level cropping patterns an AquaCrop modeling of irrigation water requirement and yield potentials of the major seasonal crops were determined. The modeling was carried out on the assumption of optimal field cultural practices (optimal fertilization, weed and pest control, 70% irrigation efficiency by flooding and mulching of vegetable crops).

This assessment also reviewed published data on groundwater quality for arsenic, fluoride and iron. Primary data on pH and EC of the pond and groundwater was also monitored on a monthly basis to assess any changes during across the year.

3. Saptari District

Study Sites

Saptari District lies in the Nepal Terai with a small northern portion extending into the Babar and siwalik zones.

Bio-physical Background

Saptari District is geographically located in the latitude of 26.417^0 to 26.783^0 N and the longitude 86.467^0 to 87.117^0 E. The district is generally flat but with a general altitude variation between 61 m to 610m. The climate is generally sub-tropical to tropical climate with average temperatures varying from 7^0C in winter to 46^0C in the summer and average rainfall of between 1588 mm to 2096 mm.

The aquifer underlying the district is variable along the north-south transect with relatively higher water tables to the south and lower water tables to the north. This variability is also influenced by specific aquifer materials across different parts of the district.

Despite the high precipitation and high water tables across the district, drought is a common challenge as much of the precipitation is received within the monsoon period from June to September with the rest of the year being generally dry.

Cropping Pattern

Across Saptari the cropping pattern generally fall into two main seasons; kharif and rabi. The two seasons run from May to October and November to April. Apart from these two main seasons, a small number of farmers grow vegetables and other crops in between the main seasons by either changing the planting/harvesting dates of the main crops and/or foregoing a season of the main crops.

Findings at study village level Koiladi

Village

Koiladi Village study area is located around latitude 26.484^0 N and longitude 86.809^0 E. Koiladi Village is mapped on a Gleysol (GLe) soil material with a loam clay soil structure.

Ponds

A remote sensing of the ponds in Koiladi Village (Figure 1) identified 37 permanent ponds with areal areas ranging from 350 – 50675m^2. There were 15 temporary ponds with areal sizes ranging from 150 – 13450m^2.

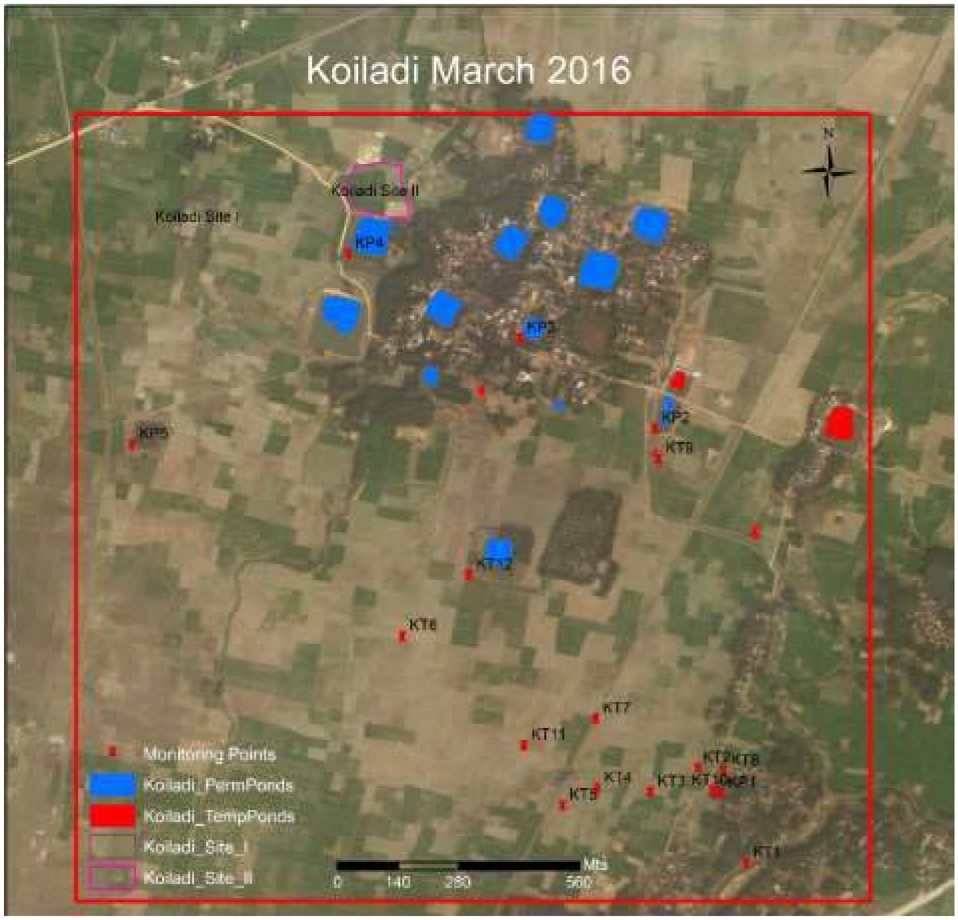

Figure 1: Study intervention sites, ponds and groundwater monitoring points in Koiladi Village

Most of the ponds surveyed were found to be used mainly for fishery and domestic water supply (Photo 1). The domestic uses were mainly for washing and bathing and animal watering. Domestic water for cooking and drinking is mainly sourced from shallow tube wells. A number of the ponds were also used for religious purposes, especially during religious celebrations. Use of ponds for irrigation was found to be minimal and usually only during droughts and/or to supplement groundwater during land preparation for nursery establishment of vegetables and paddy.

Photo 1: A pond in Koiladi Village used for fishery and domestic purposes

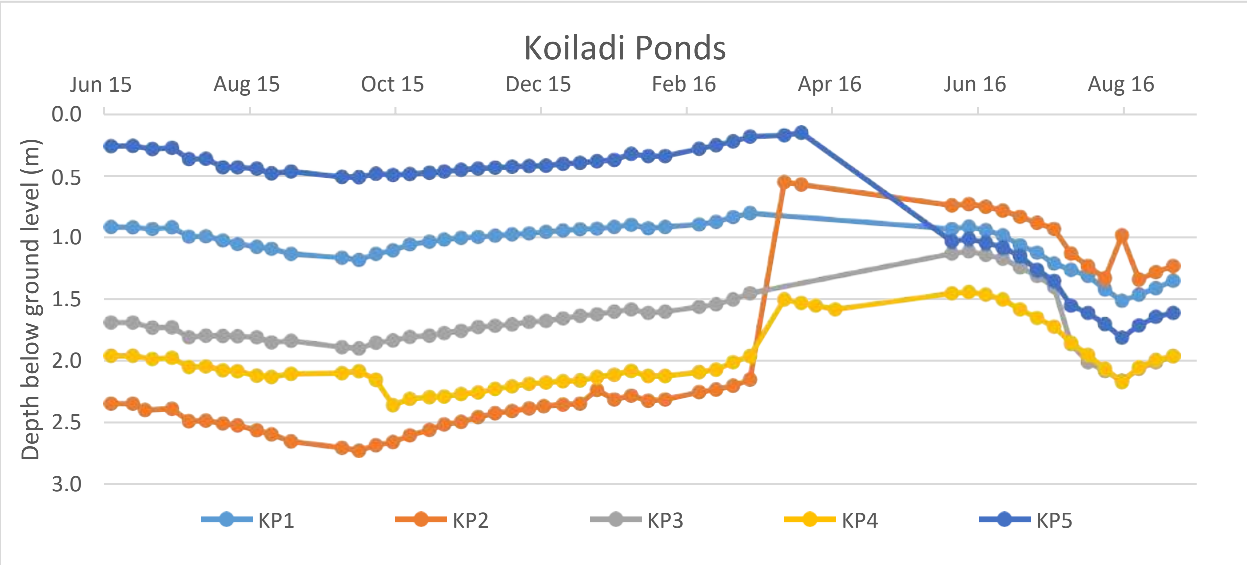

Figure 2: Monitored pond water levels in Koiladi Village

A plot of pond water levels (Figure 2) shows that all the ponds have similar temporal trends of water levels. The spatial variability is fairly low (considering plot points between May-September 2016) suggesting that this variability is likely an artifact of topographical variation between various datum of pond measurements. This is supported by the plot points between June 2015 and March 2016, period during which a different set of datum was used (in-pond gauge instead of on-the-bank gauge used for the later period). Based on the more accurate on-the-bank datum, pond water levels are estimated to range between 0.75m to 2.25m below ridge of bank, post- and pre-monsoon periods, respectively. The lowest pond storages are noted in August-September whereas lowest storage depths are recorded in March.

Photo 2: Pond drained for fishery in Koiladi Site I

Groundwater

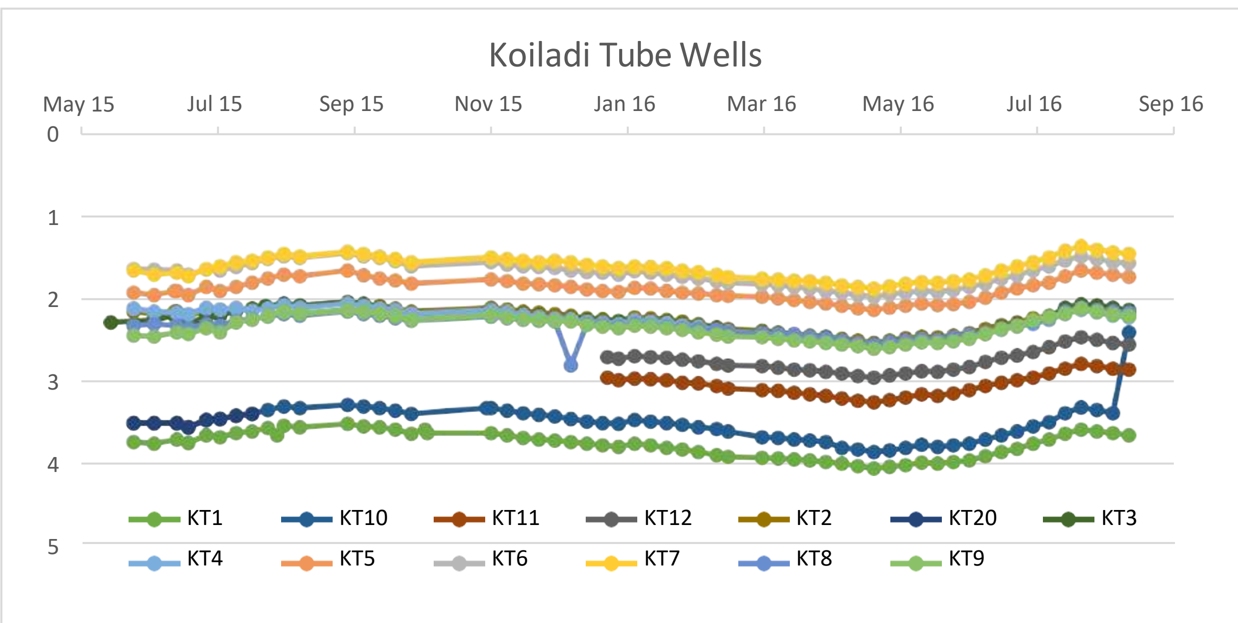

Figure 3: Groundwater tables on monitored shallow tube wells (TW) and dug well (DW) in Koiladi Village

Groundwater levels measured from tube wells (Figure 3) show spatial variability of between 1.5 and 3.75m below ground level. This spatial variability is not corrected for topography hence is likely due to physiographic variation rather than hydrologic variability. The temporal trends of water tables show similarity across all measuring points suggesting that temporal groundwater response to natural and human factors are well averaged across the village. The lowering or rising of groundwater table is thus smoothed out over the weekly monitoring period implying full recovering of cones of depression from pumping activities in the community.

Crop water requirements and production

AquaCrop modeling of crop production based on generalized cropping pattern and optimal management based on a rice cropping system are presented in Table 1 below. It is noted that for all crops, except rice paddy, irrigation is critical for production, contributing the major portion of evapotranspiration crop water demand.

Crop	Planting	Harvest	Cycle	Rain, mm	ETo, mm	GD, °C.day	Irri, mm	BioMass, ton/ha	HI, %	Yield, ton/ha
Cucumber	01/30/15	04/07/15	63	52	442	934	492	8.44	85	7.17
Onion	02/14/15	04/30/15	113	247	802	1767	642	12.782	50	6.39
Early Paddy	06/23/15	09/30/15	98	855	614	1839	17	12.324	50	6.16
Monsoon Paddy	06/29/15	10/30/15	98	803	596	1821	14	12.324	50	6.16
Chilli II	08/23/15	12/22/15	193	353	939	2371	682	22.473	85	19.10
Brinjal I	08/30/15	11/14/15	63	287	369	1128	215	8.169	85	6.94
Early Cauliflower	09/15/15	12/23/15	133	198	633	1599	544	14.709	85	12.50
Tomato I	10/07/15	03/23/16	106	55	474	1390	536	12.224	63	7.70
Cauliflower	10/30/15	02/14/16	133	48	624	1358	661	14.709	85	12.50
Potato	12/16/15	03/30/16	105	54	601	2066	772	15.613	75	11.71
Raddish	12/16/15	01/30/16	33	11	149	264	237	3.25	50	1.63
Wheat	12/16/15	04/15/16	116	59	631	2402	768	13.797	48	6.62
Tomato II	01/05/16	07/15/16	129	135	783	1939	767	13.578	63	8.55

Table 1: Water requirements for main seasonal crops grown in Koiladi Village modeled by AquaCrop (Steduto, et al. 2009)

A tailored cropping pattern meeting agronomic, field management constraints and water availability can potentially lead to greater intensification of cropping through supplementary and full irrigation of various crops.

Water quality

On-going monitoring of pH and electrical conductivity (EC) of pond and dug well water is being implemented in this study area. Iron has been noted, especially in the dry season along surface water sources such as streams and springs within the study area. No quantitative data on extent and severity of this has been documented but the visual occurrence of iron is critically highlighted as risk indicator for low buffering of the aquifer with potential of fluoride and arsenic with increased groundwater pumping.

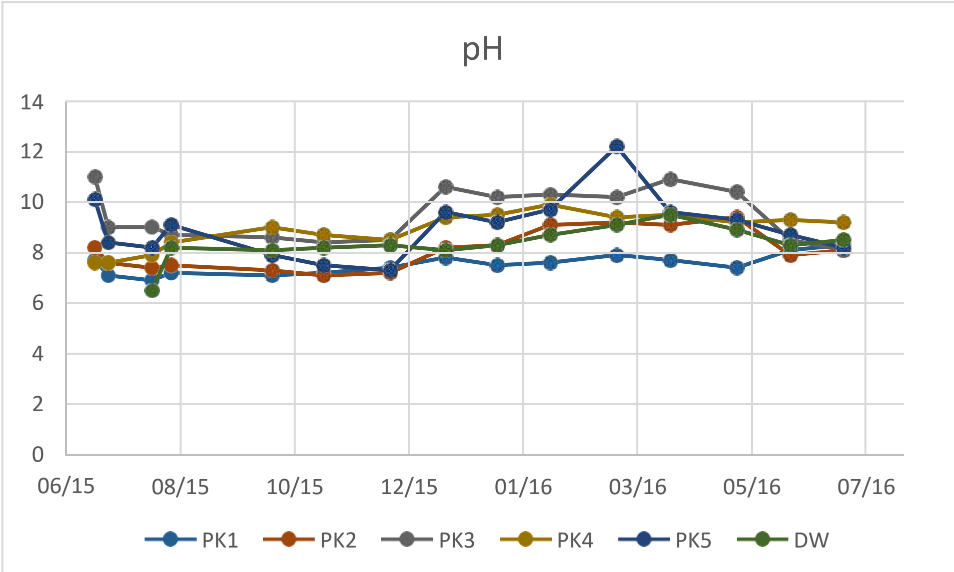

Figure 4: Temporal pH levels of pond (P) and dug well (DW) water (June 2015 – July 2016) in Koiladi

The pH records (Figure 4) show stable levels between June and November at levels between 7 and 9. The readings then start fluctuating between December and June (dry/irrigation periods). The pH during the dry season also show elevated values of between 7.5 and 11 suggesting that pond water tends to alkaline during this period. The highest changes are noted from PK3 and PK5, which are located within the community (with high domestic use) and agricultural area (and is used for supplemental irrigation), respectively. This suggests that the increased pumping with consequent reduced storage depth tends to reduce the acidity of the pond water.

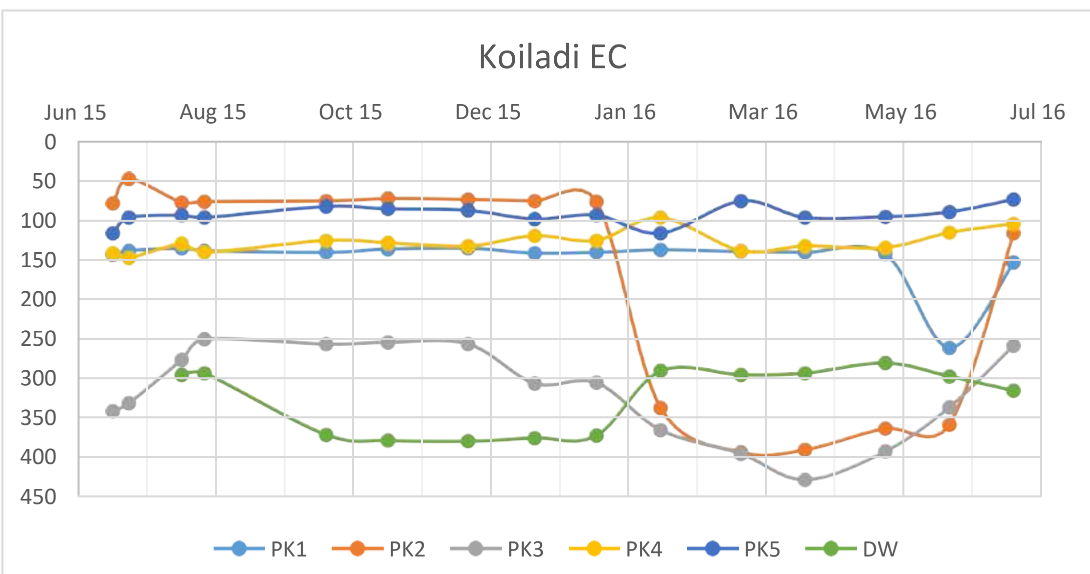

Figure 5: Temporal electrical conductivity (EC) values for pond and dug well waters (June 2015-July 2016) in Koiladi

As for pH, the electrical conductivity of the pond and dug well waters show stable constant values during the monsoon period and variable values during the dry season (Figure 5). Readings from the dug well and PK3 show elevated EC levels across the season suggesting anthropogenic effects. PK2 shows extremely elevated values between February and July compared to other similar ponds. This pond is situated within the residential area with a lot of domestic waste water discharge into the pond. It can thus be presumed that these streams of anthropogenic contaminants are the cause for the elevated EC during the dry season when no monsoonal dilution is available.

4. Khoksar Parbaha Village

Ponds

Based on remote sensing, the greater Khoksar Parbaha village is noted to have 10 permanent ponds with surface areas ranging from 150-8250m^2 and 11 temporary ponds of sizes 275-3125m^2. It is however noted that most of the temporary ponds are actually flooded areas occurring during the monsoon season.

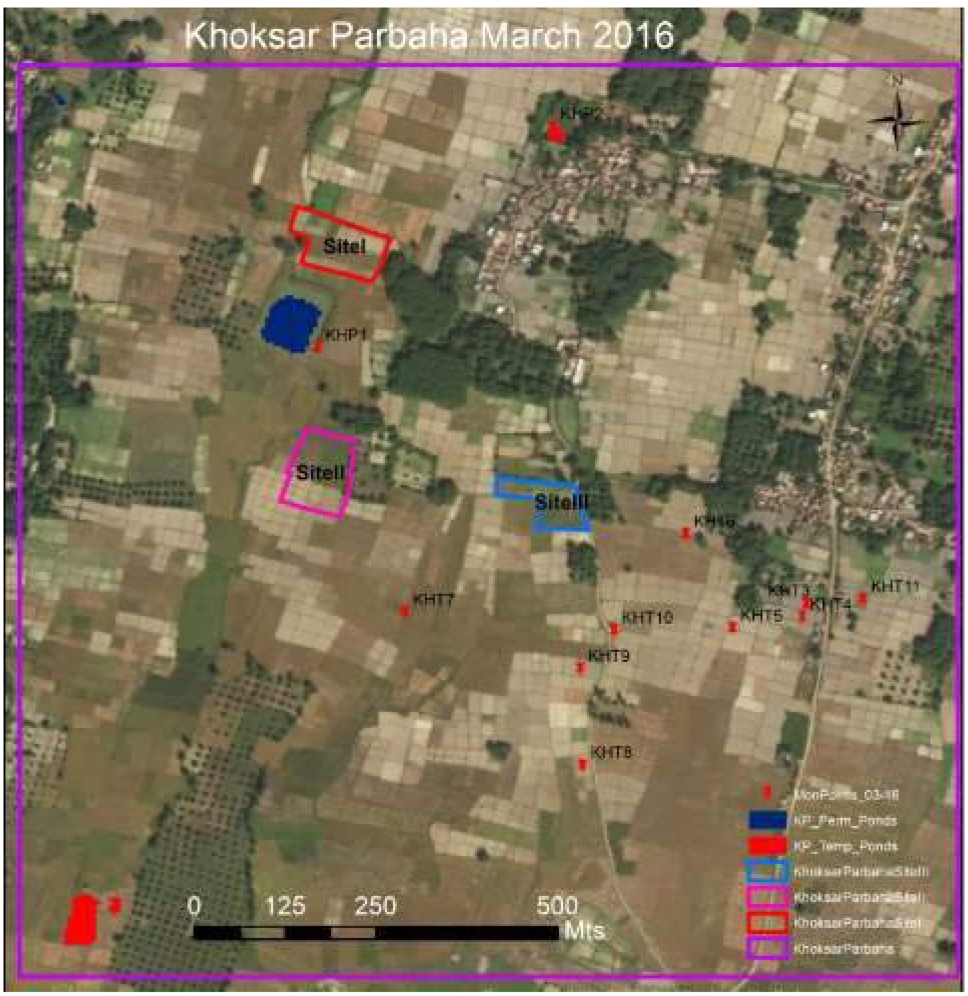

Figure 6: Locations of study sites, ponds and groundwater monitoring points in Khoksar Parbaha Village

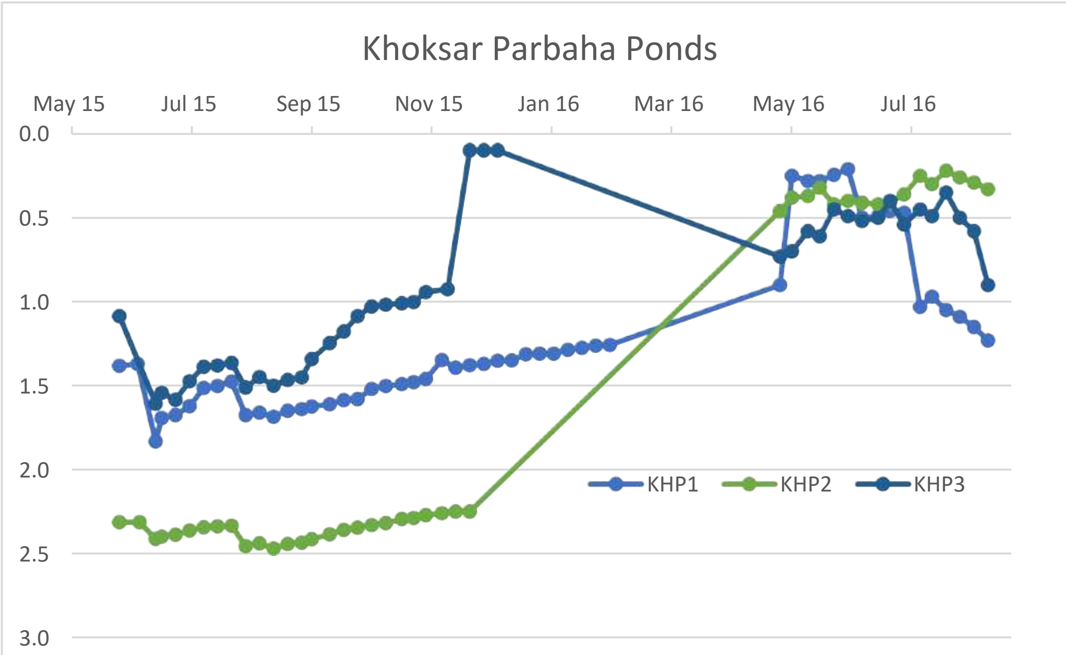

Figure 7: Pond water levels in Khoksar Parbaha village

Three ponds were monitored from Khoksar Parbaha village (Figure 7). KHP1 is located within the agricultural area of pilot study Site I, KHP2 is located within the village while KHP3 is located at the base of the Babar hills. KHP1 and KHP2 show similar trends of water levels between September and February overall difference in recorded water levels. The effect of topography can thus be surmised to be the source of the overall variation of about 1m between the water levels at the two ponds. KHP1 and KHP2 show water level values ranging from a low of 1.7m and 2.5m respectively to a high of 0.25m above ground level. KHP3. KHP3 on the other hand show same water level as KHP2 at the pre-monsoon period but shows faster refill with water levels topping off at about 0.1m below ground level. This quick refill is due to the location of the pond at the base of the hills within the catchment area of an upland watershed draining through the pond area. Despite the fast refill with monsoon rains KHP3 experiences faster recession of water level following the monsoon rains.

The slower refill (0.083m/month) during August-December period suggests that the inflow into the ponds is likely from groundwater rather than direct rainfall. This is supplemented with opening of the banks at the peak of the season to allow flood waters into the ponds by the pond owners.

Groundwater

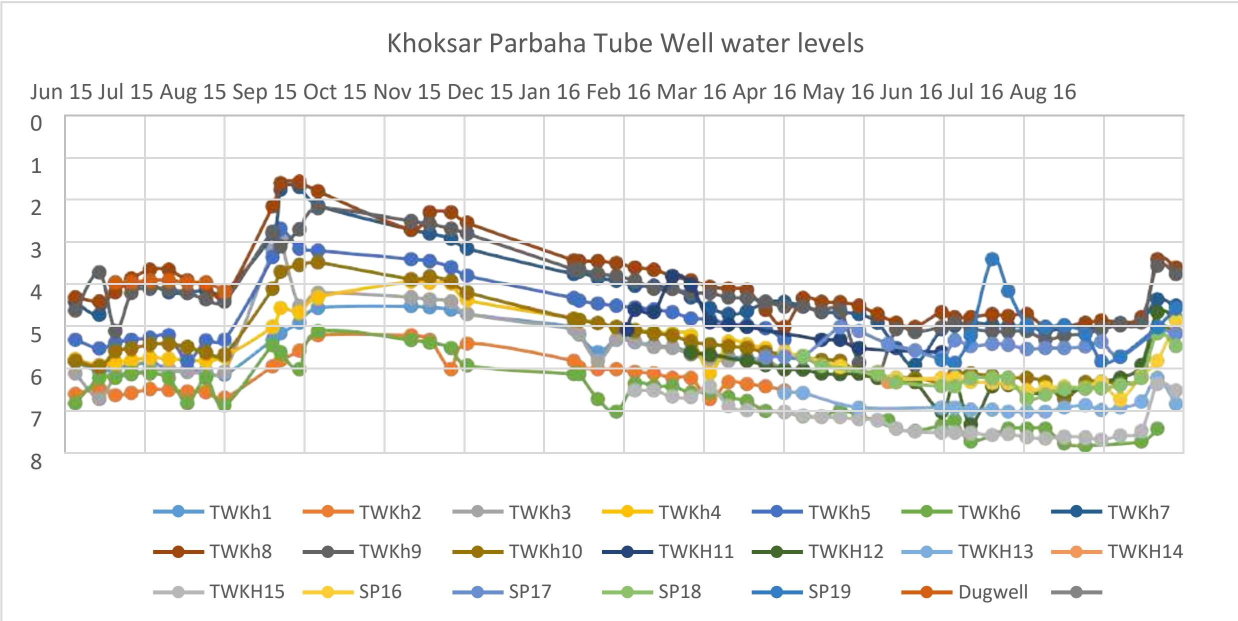

Figure 8: Groundwater levels in Khoksar Parbaha Village

A plot of ground water levels monitored from various tube wells, piezometers and an open dug well are presented in Figure 8. The water levels range from depths of 1.5-5m below ground level in September (post-monsoon) to 4-7.5m in May (pre-monsoon). The spatial variability maps both geological heterogeneity as well as the topographical variations in the village.

Despite these variations between points of measurements all points of measurement show similar temporal trends indicating the interconnectedness of the various underlying aquifer materials. Sharp drops in water table levels are noted around point measurements suggesting temporal pumping. The residual slow recovery in such points highlight the differences in the aquifer materials that influence the movement of groundwater over the spatial space of the study area.

Crop water requirement and production

A number of commonly grown crops were modeled based on optimal growing conditions under paddy field infrastructure with irrigation and yield potentials presented in Table 2. Except for crops grown around the monsoon period (May – September), irrigation is a major input to achieve the projected production potentials. The harvest index (HI) is noted to be quite variable between different crops. This is premised to be a consequence of management constraints encountered in modifying the paddy-based field structures to the vegetable crops, mainly grown in winter and summer seasons.

Table 2: Water requirements for main seasonal crops grown in Khoksar Parbaha Village modeled by AquaCrop

Crop	Planting	Harvest	Cycle	Rain, mm	ETo, mm	GD, °C.day	Irri, mm	BioMass, ton/ha	HI, %	Yield, ton/ha
Cucumber	01/31/15	04/07/15	63	35	395	827	466	8.44	85	7.17
Chilli I	03/17/15	09/10/15	193	1107	1282	3337	497	22.47	85	19.10

Cabbage II	03/30/15	06/15/15	68	213	541	1209	425	8.62	85	7.32
Early Paddy	05/30/15	09/30/15	98	840	642	1842	43	12.32	50	6.16
Raddish Elevated	06/15/15	08/15/15	33	391	252	703	81	3.25	50	1.63
Monsoon Paddy	07/23/15	10/31/15	98	663	584	1787	67	12.32	50	6.16
Cabbage I	07/30/15	10/30/15	68	469	413	1293	72	8.62	85	7.32
Tomato I	10/07/15	03/23/16	106	669	610	2079	98	12.25	63	7.72
Wheat	10/30/15	04/29/16	122	43	557	2410	707	15.00	48	7.20
Brinjal	10/30/15	12/31/15	63	21	298	709	384	8.17	85	6.94
Onion	10/30/15	02/22/16	113	39	507	1108	549	12.78	50	6.39
Potato	11/07/15	03/16/16	105	35	520	1990	686	15.61	75	11.71
Cabbage I	11/07/15	01/21/16	68	17	299	627	392	8.62	85	7.32
Cauliflower	11/14/15	02/22/16	133	48	652	1364	698	14.71	85	12.50
Raddish	11/14/15	01/08/16	33	7	168	407	257	3.25	50	1.63
Oilseed	12/15/15	03/15/16	83	31	390	762	363	11.07	50	5.54
Lentils	12/16/15	02/22/16	120	102	779	1585	691	15.34	45	6.90
Tomato II	01/08/16	07/16/16	127	141	779	1934	760	13.49	63	8.50

Water quality

Three ponds were monitored for electrical conductivity during the period of July 2015 and August 2016 (Figure 9). The EC records show distinctive spatial variability between the ponds. Pond KHP1 and KHP3, which are located in more agricultural or natural surroundings show lower electrical conductivity levels of between 75-220 µS/cm while KHP2 that is located within the village shows levels ranging from 100-300 µS/cm. These variability is notable during the post-monsoon dry periods when minimal dilution occurs to the pond water but with higher inflow of domestic pollutants into KHP2.

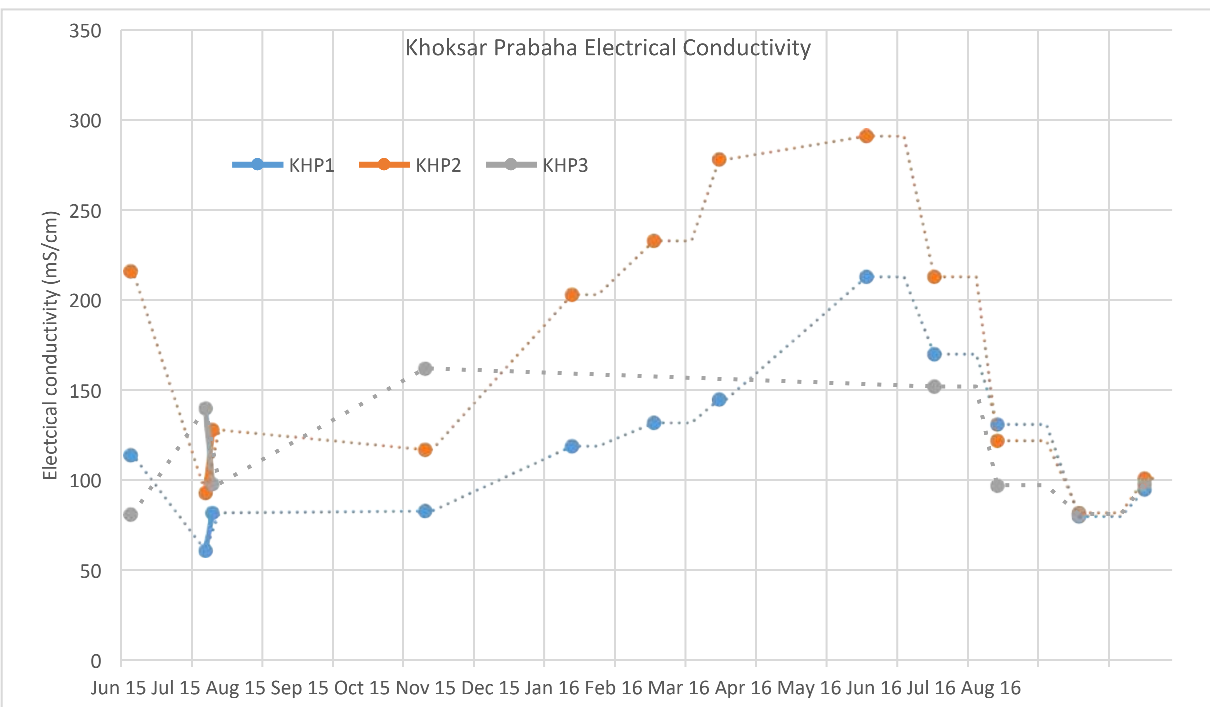

Figure 9: Electrical Conductivity of pond water in khoksar Parbaha

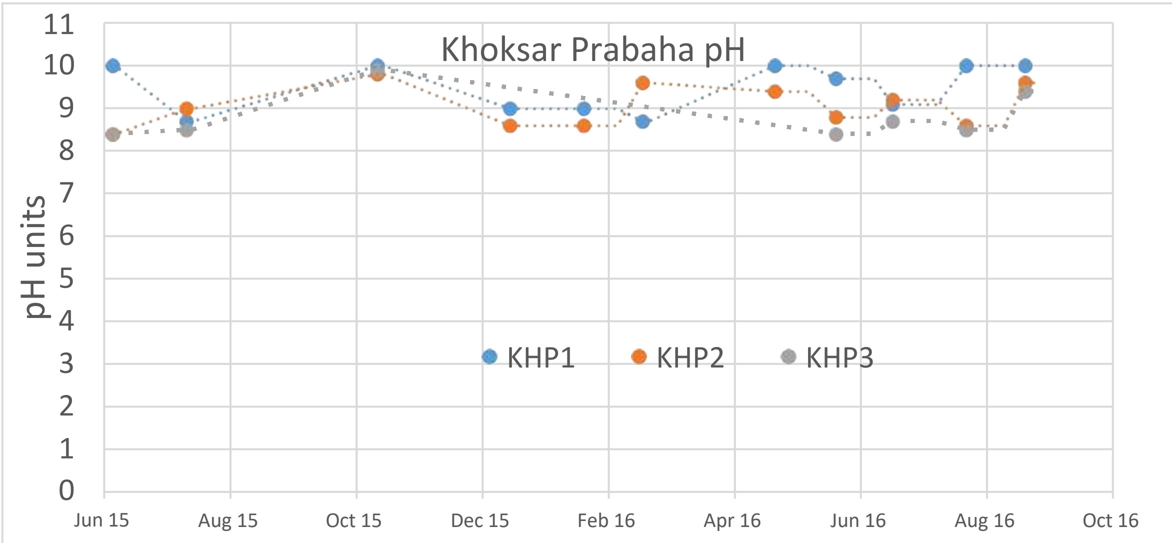

Figure 10: Hydrogen potentials (pH) of water samples from Khoksar Parbaha ponds

The pH levels show (Figure 10) slight temporal and spatial variation between ponds, except between May and September. The ponds water is generally alkaline with values ranging from 8.5 to 10. The ponds are used for various purposes; KHP1 for domestic and irrigation, KHP2 for domestic and fishery and KHP3 for irrigation. The ponds, except for KHP1 retain water all year round.

Discussion

Study sites in Saptari District are shown to have significant groundwater storages. The existence of ponds was noted to be mainly useful for supplementary irrigation in drought years and/or to facilitate paddy field preparation. The major use of permanent ponds was noted to be for fishery due to the higher economic returns achieved in comparison to crop production.

Koiladi pilot site shows a generally more homogeneous soil/aquifer whereas the Khoksar Parbaha site has greater heterogeneity of aquifer characteristics. The result is that spatial and temporal access to groundwater is much more extensive than in Khoksar Parbaha where greater sensitivity to local variations is critical in siting shallow tube wells.

Water quality in so far as irrigation is concerned is generally good, even though on-going monitoring of iron, as a precursor of more serious water quality minerals such as fluoride and arsenic should be considered.

Research suggestions

1. Lack of locally accurate data on aquifer properties and characterization is noted as a major constraint in accurately assessing the storage potential and thus the long term sustainability of groundwater pumping to support irrigation needs long term planning

2. Limited agronomic and crop development data of common crops is a singularly limiting factor in the use of crop growth modeling that would be useful in the development of an upscaling/out scaling strategy of the proposed intensive irrigated cropping system.

5. State of West Bengal

The study sites of Dholaguri, Cooch Behar District and Uttar Chakoakheti, Alipurduar District are located in the State of West Bengal. These two study sites encompass both the pure terai sites of Dholaguri to the south and the hill areas of Uttar Chakoakheti to the north.

These two villages though different in topographical, cultural and social characteristics are agriculturally similar with Kharif paddy as the dominant crop grown. Due to the cultural agricultural background, Dholaguri has a more robust crop production system than Uttar Chakoakheti where the residents still consider forest product harvesting a major activity outside the monsoon growing seasons.

A generalized modeling of crop production across the two communities under optimal management and input provision is presented in Table 3.

Cropping Pattern

Table 3: Water requirements for main seasonal crops grown in West Bengal as modeled by AquaCrop (Steduto, et al. 2009)

Crop	Planting	Harvest	Cycle	Rain, mm	ETo, mm	GD, °C.day	Irri, mm	BioMass, ton/ha	HI, %	Yield, ton/ha
Kharif paddy	07/15/16	11/10/16	96	1719	482	1906	0	14.52	43	6.24
Cucumber	06/29/16	10/15/16	63	1607	328	1225	1	8.44	85	7.17
Cow pea	02/28/16	06/20/16	93	707	673	1473	313	12.26	50	6.13
Cucumber	02/28/16	06/20/16	63	242	490	982	293	8.44	85	7.17
Rapeseed Mustard	11/25/16	03/05/16	83	21	406	703	421	11.07	50	5.54
Potato	11/25/16	03/20/16	70	17	364	1283	450	10.40	75	7.80
Maize	11/30/16	04/30/16	136	138	781	1702	812	29.88	48	14.35
Wheat	11/25/16	03/30/16	121	71	666	2407	672	14.76	48	7.08
Boro paddy	01/30/16	05/20/16	83	176	577	1086	459	11.92	50	5.96
Lentil	11/26/16	04/10/16	120	128	786	1426	593	15.09	45	6.79
Tomato	11/02/16	02/20/16	152	92	806	1935	751	18.60	63	11.72
Brinjal	11/02/16	02/20/16	63	20	323	655	344	8.17	85	6.94
Chilli	11/02/16	02/20/16	193	423	1120	2204	796	22.47	85	19.10
Cabbage	11/02/16	02/20/16	158	125	880	1653	739	18.91	85	16.07
Cauliflower	11/02/16	02/20/16	133	61	698	1297	641	14.71	85	12.50
Onion	11/02/16	02/20/16	113	40	565	1050	530	12.78	50	6.39
Pea	11/07/16	02/20/16	93	23	456	842	480	9.31	50	4.65
Raddish	11/07/16	02/20/16	33	9	195	416	206	3.25	50	1.63
Carrot	11/07/16	02/20/16	149	88	787	2208	728	19.83	70.1	13.89

It is observed that outside of Kharif Paddy, crop production in West Bengal is highly dependent on irrigation with over 50% of water requirement for all crops being derived from irrigation sources

6. Dholaguri Village - Cooch Behar District

Study Sites

Dholaguri pilot site lies around Lon 89.493^{0}N and Lat 26.428^{0}E. The area is characterized with Eutric Haplic Gleysols with slightly acidic pH of around 5.7. the soil texture is identified as sandy clay loam

The minimum and maximum temperatures across the region is averagely 3.9^{0}C and 39.9^{0}C, respectively. The average annual rainfall is about 5300mm, mainly from the South-West monsoon (NIC 2002)

DholaguriThe village is rich in both surface and subsurface water resources. There is one perennial river called Ghargharia flowing through the village. However, most of the ponds are seasonal and only 20-25 ponds retain water throughout the year. The groundwater table is available at about 1.5 to 4.5 m below ground level. The quality of groundwater resources is good.

Ponds

Dholaguri Village (Figure 11) is quite well endowed with surface water resources. The perennial river Ghargharia flows through the village, with an in-construction river-lift irrigation system being developed. The village has numerous ponds; about 25 permanent ponds () have been identified within the larger Dholaguri Village area. Despite the existence of this many ponds the majority are used for fishery with only supplementary usage in drought years and/or for paddy land preparation.

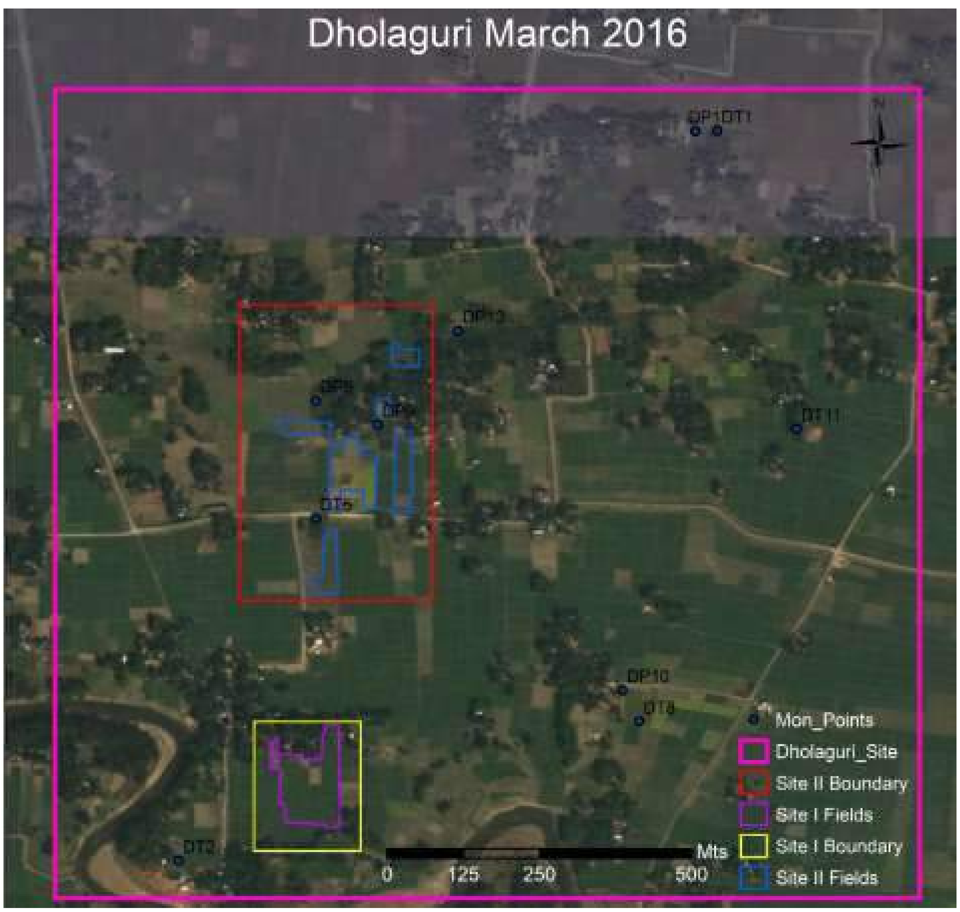

Figure 11: Locations of study sites, ponds and groundwater monitoring points in Dholaguri Village

Photo 3: A pond in Dholaguri Village

A selection of representative ponds was identified and are being monitored for seasonal and spatial storage changes to evaluate the storage potential of these water sources for optional irrigation use. The results of storage depth changes over the period of August 2015 through September 2016 is presented in Figure 12.

It is observed that the pond water depths ranged from a high of 0.2m below ground level in the peak of monsoon to a low of 2.5m at the end of the dry season. The sharp drop in pond water levels in March-April indicates a localized supplementary pumping for Kharif Paddy nursery bed planting and land preparation. Subsequent rise in storage depth suggests a recharge from the high groundwater table before eventual drop with increased dry season pumping of groundwater (gradual fall of pond water depth between July and September).

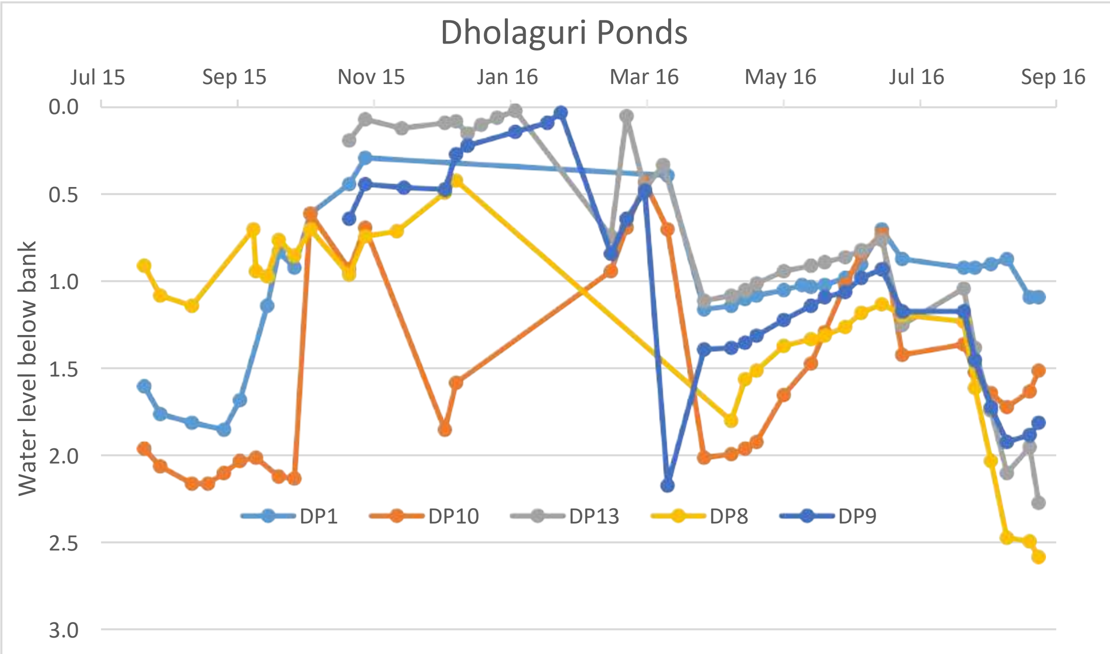

Figure 12: Monitored pond water levels in Dholaguri Village

Groundwater

Dholaguri village is noted to have a high density of shallow tube wells for both domestic and agricultural use. The high dependence of the community to groundwater resources is quite notable from the limited access to selected monitoring tube wells between early January and June when all tube wells were actively being pumped, especially for irrigation purposes (Figure 13).

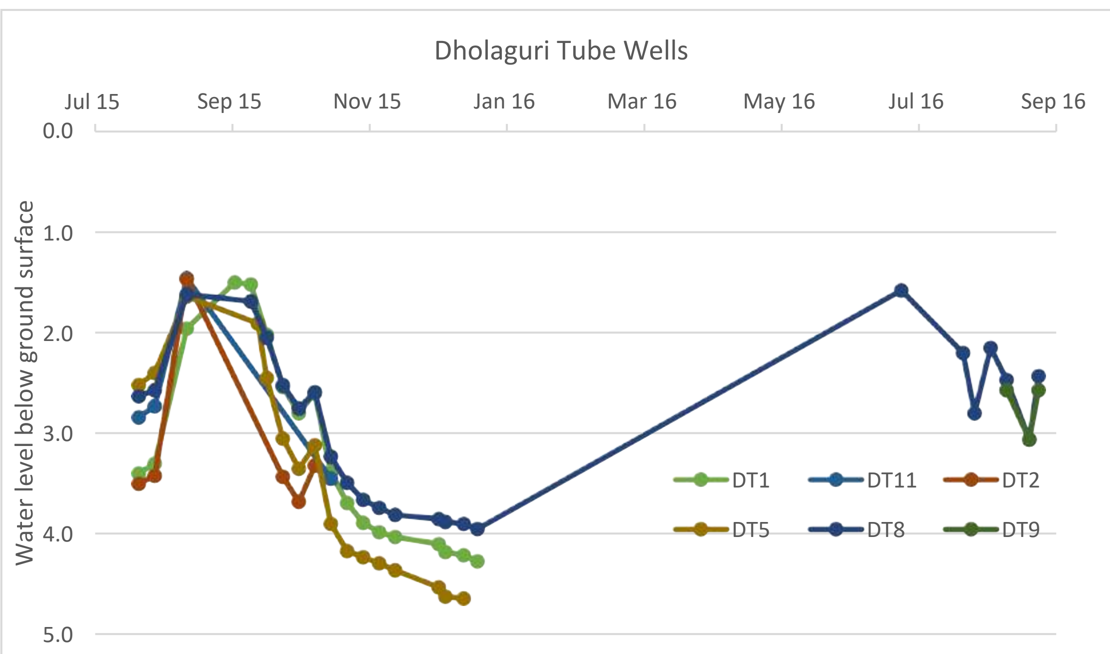

Figure 13: Groundwater tables on monitored shallow tube wells (TW) in Dholaguri Village

Ground water level was monitored across six shallow tube wells located within Dholaguri Village to monitor the static water table. Due to on-going use of the same tubewells for irrigation it was not possible to perform the weekly monitoring between January and July 2016. Thus, for the periods of data collection (Figure 13) the ground water table was found to vary from a high of 1.5m below ground surface in August-September to a low of 4.75m in January. For the period between July 2015 and January 2016 the monitoring data show similar levels and trends of ground water level both temporarly and spatially. It can thus be presumed that a full recharge recovery as noted for DT8 should occur for all monitored wells proceeding from July 2016.

Water quality

The water quality in Dholaguri village was generally found to be good with limited concern of water use for both domestic and agricultural use across shallow tube wells.

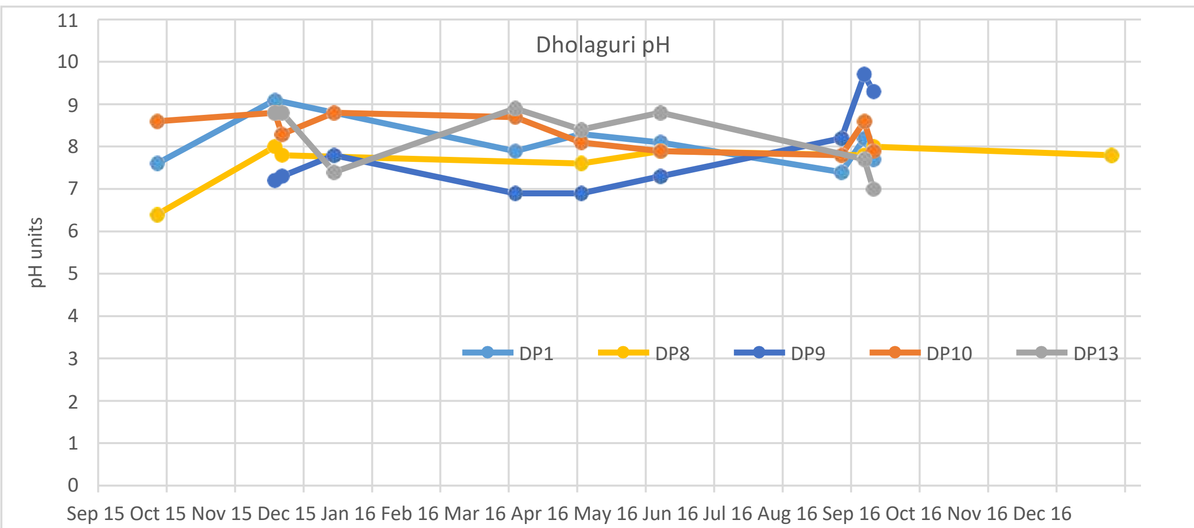

Figure 14: Temporal pH levels of pond water (June 2015 – July 2016) in Dholaguri

The pH levels of pond water were monitored for five ponds across Dholaguri Village (Figure 14). The pH values ranged from 7 to 9, indicating neutral to slight alkaline conditions. This is to be expected as these ponds are predominantly used for fishery. There was minimal spatial and temporal variability over the duration of current monitoring suggesting a homogeneity of the pond water quality. The marginal variability is likely due to temporary artifacts such as time of day when monitoring is carried out and/or other anthropogenic treatments given towards the fishery purposes.

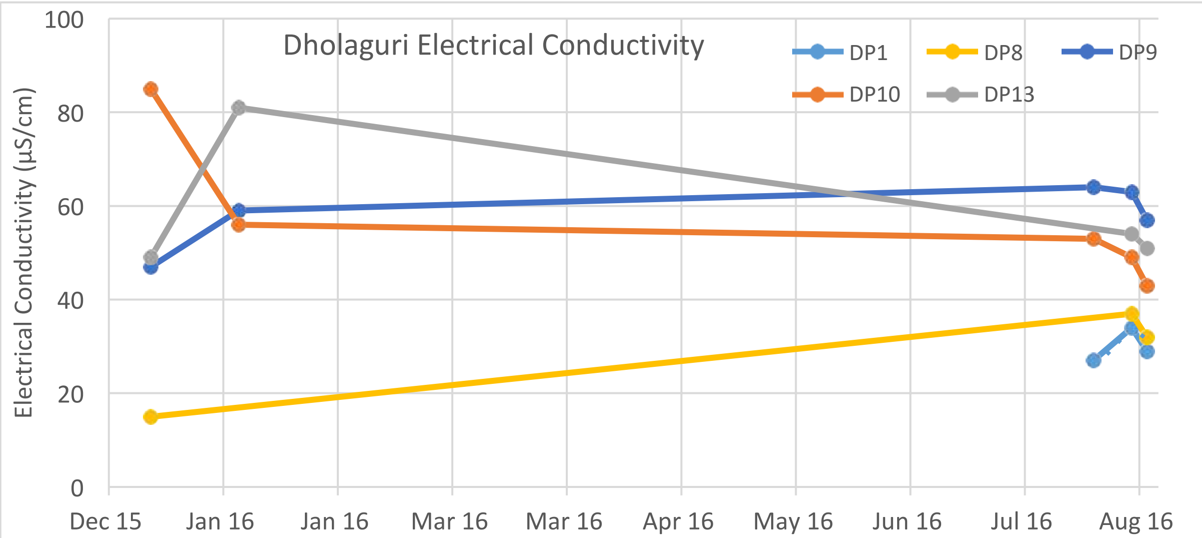

Figure 15: Temporal electrical conductivity (EC) values for pond and dug well waters (June 2015-July 2016) in Dholaguri

Due to failure of electrical conductivity instrumentation no EC data was collected between January 2016 and August 2016 (Figure 15). Despite this limitation it is observed that the EC levels are all within a range of 15 – 85 µS/cm between December 2015 and August 2016. The stability of the pond water EC can be surmised to be controlled towards the fishery purpose.

7. Uttar Chakoakheti Village – Alipurduar District

Study Sites

The Uttar Chakoakheti study site is located in Alipurduar District, West Bengal around Lon 89.401^{0}N and Lat 26.547^{0}E. the area is generally of Haplic Gleysol soil materials with sandy clay loam soil structure with high infiltration capacity.

Alipurduar District is characterized with a warm and humid climate. Its summer temperatures range from 25-37^{0}C with winters from 18 – 6^{0}C (Climate of West Bengal 2016).

Ponds

Due to the location of this village no remote sensed pond data was collected for assessment. Manual mapping of the available ponds was thus carried out and six ponds identified within the project target area. Due to the high infiltration capacity of the heavily sandy soil material no substantial surface water storages exist for summer irrigation though some pond water is accessed for post monsoon field preparation. Figure 16 shows the temporal variation of pond water storage as monitored between August 2015 and August 2016.

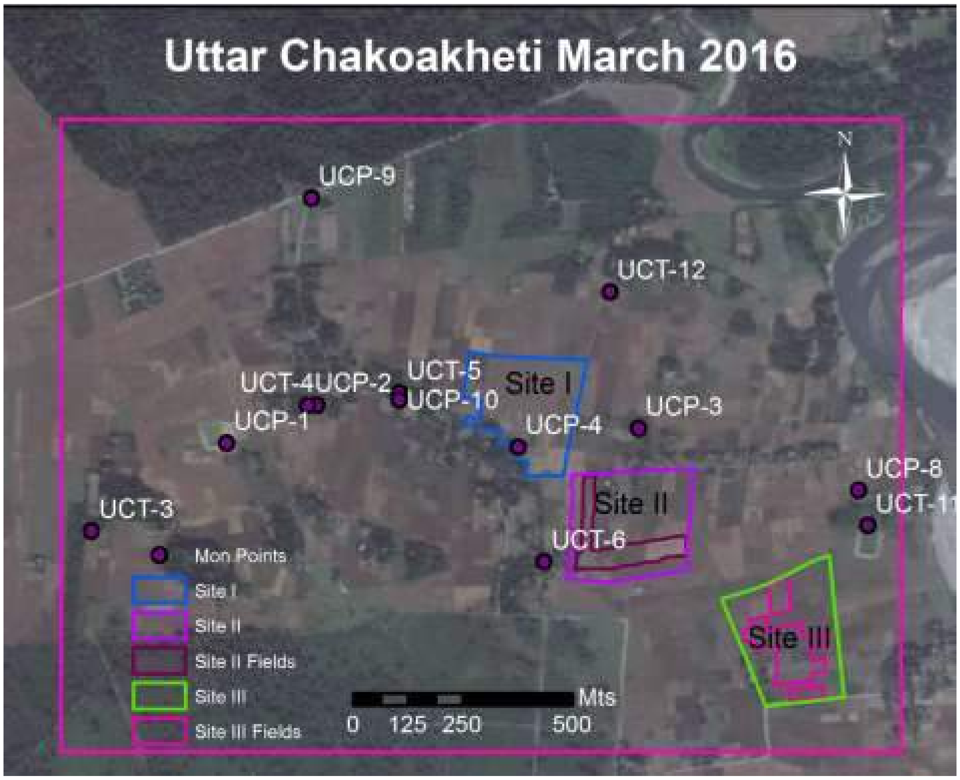

Figure 16: Locations of study sites, ponds and groundwater monitoring points in Uttar Chakoakheti Village

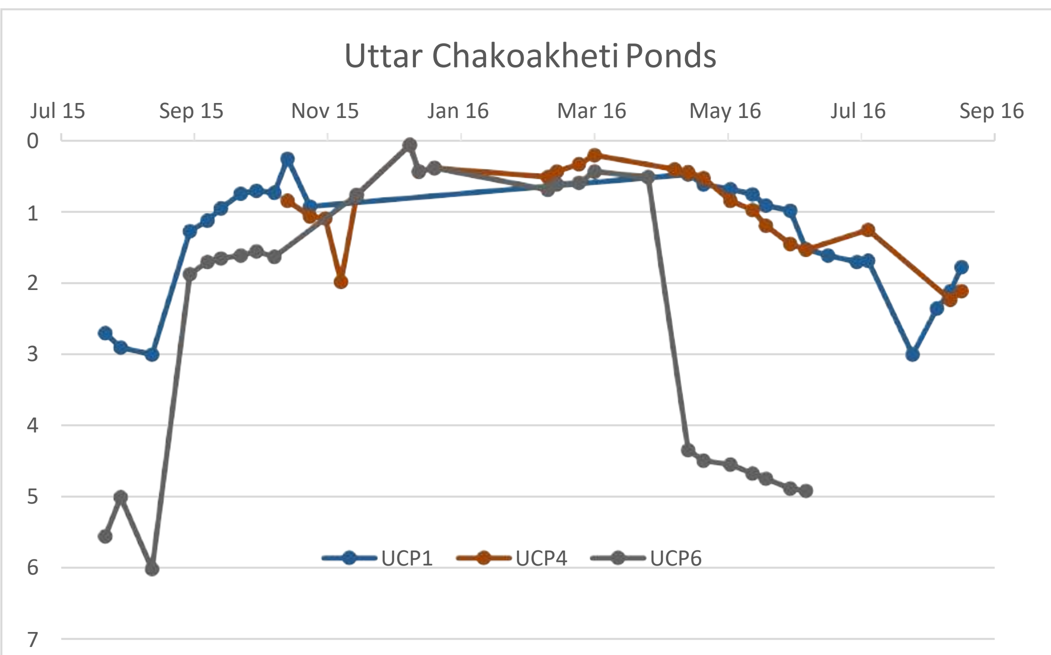

Figure 17: Pond water levels in Uttar Chakoakheti

Of the six ponds mapped, UCP1 UCP4 and UCP6 were monitored between July 2015 and September 2016 (Figure 17). The water level data show that UCP1 and UCP4 contained storage depths of 0.5 to 3m between the post monsoon period and the following pre monsoon.

UCP6 on the other hand is set at a level with banks well above the ground level hence having total storage depth of nearly 6m. UCP6 shows a fast refill between July and September followed by a period of nearly stable storage until March when the storage was drained down to 4.5m. A base discharge flow is noted between April-June 2016 showing that an approximate natural discharge (deep percolation and evaporation) of about 0.35m/month. It should be noted that UCP6 is located about 10m from the local river hence facilitating the fast refill during monsoon flooding and consequently the fast discharge as the river water recedes to base flow.

Groundwater

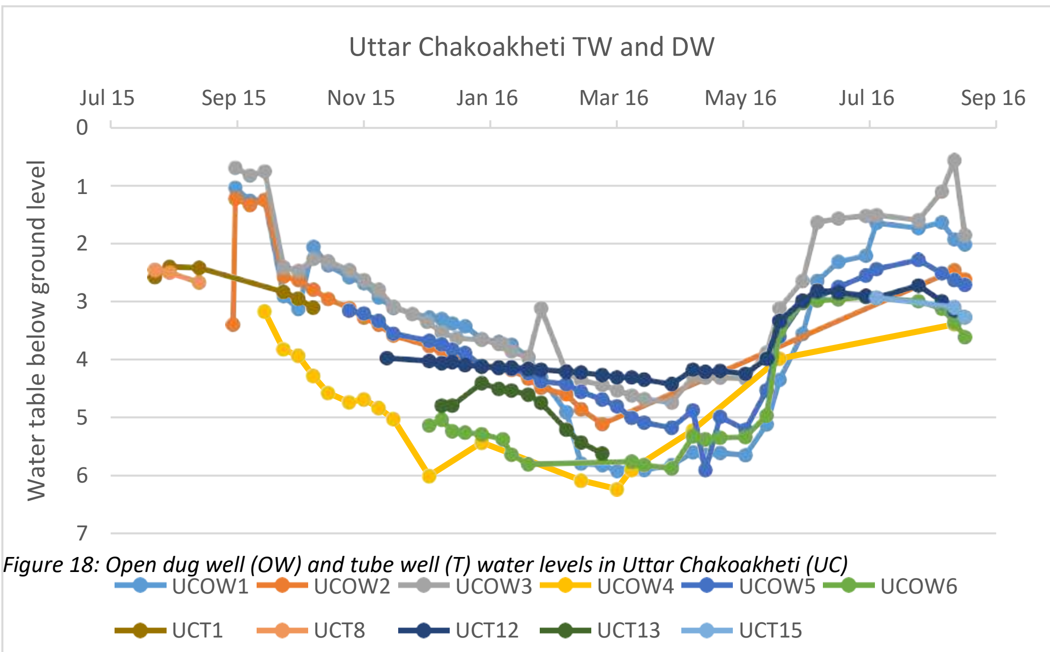

Figure 18: Open dug well (OW) and tube well (T) water levels in Uttar Chakoakheti (UC)

Groundwater table was monitored in Uttar Chakoakheti through six open dug wells (DW) and five shallow tube wells (TW) (Figure 18.). The data plots show slight spatial variability across monitoring points with all monitoring locations showing similar general trends of water table levels. Peak groundwater storage is recorded in July-September period with water table levels between 0.5 – 3.0m below ground surface. Between November and May, a gradual fall in water table indicates a combined effect of natural and pumped discharge with water table reaching the lowest levels in May at 4-6m below ground level. The monsoon-driven recharge occurred between May and June with average recharge rates of 1.5m/month.

Photo 4: Observing an electric-pumped shallow tube well in Uttar Chakoakheti Village

Water quality

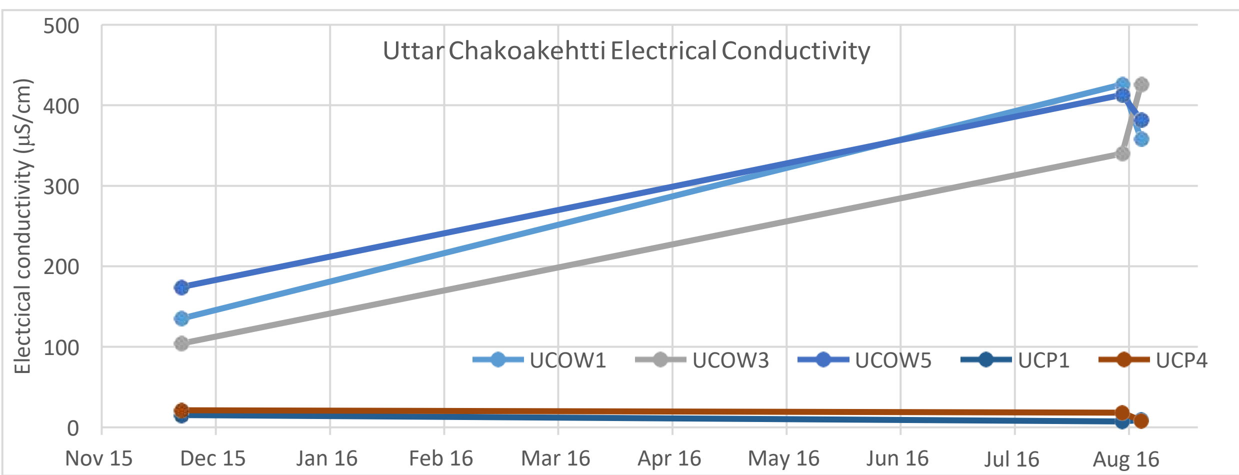

Figure 19: Monitored electrical conductivity in Uttar Chakoakheti Village

Electrical conductivity of two ponds and three open dug wells was tested in December 2015 and again in August 2016 (Figure 19). The testing in December was to obtain post monsoon information whereas the August reading was to assess the monsoon status. As shown in Figure 19, the electrical conductivity of pond water was similar at below 20 µS/cm at both times whereas the EC for open dug wells shows August values of 300-400 µS/cm and December values of 100-175 µS/cm. the unchanged values of EC in ponds is supposed to be due to the temporary nature of the ponds such that no longterm accumulation of contaminants occur in the ponds. The dug wells on the other hand show higher EC during the monsoon period suggesting increased mobilization of aquifer contaminants into this water sources with the monsoon flooding. These results show a good match to previous studies of water quality of the region (CGWB 2009).

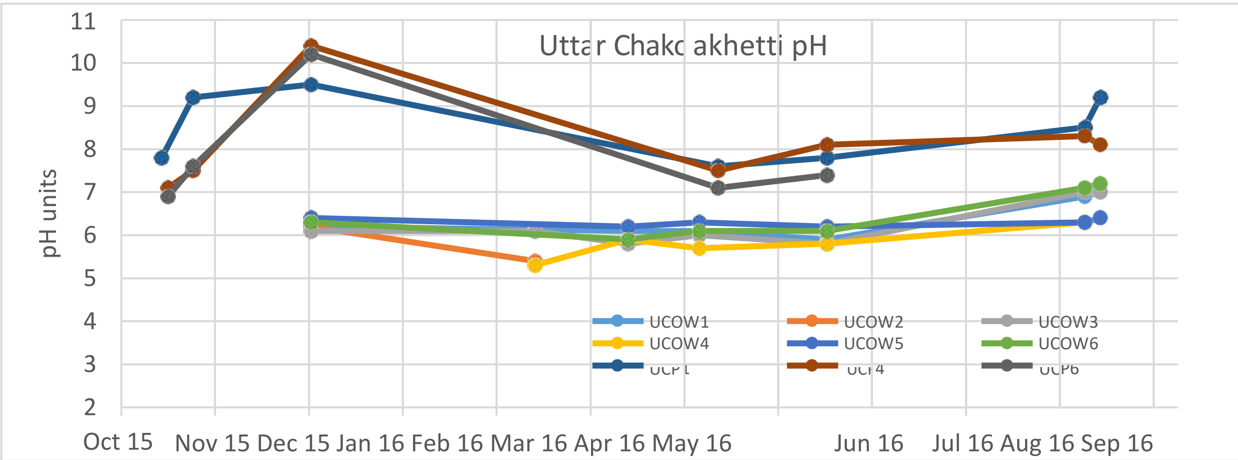

Figure 20: Monitored pH in Uttar Chakoakheti

The pond water show slightly elevated pH values than the open dug wells (Figure 20). The pH of pond waters ranges from 7 to 10.5, but generally lie between 7 and 8.5 for the 5 months of monitoring. Dug well water on the other hand show generally stable pH values around 6 with slight rise in August-September, probably due to the monsoon rain recharge.

General water quality across Cooch Behar District, and Alipurduar District, indicate that groundwater is of good quality for both domestic and agricultural use (CGWB 2010). This report further indicated that Cooch Behar has high iron content ranging from 0.04 – 10.2 mg/l; which raises the concerns for other risks such as arsenic enrichments ((NRDWP 2014);. (Sengupta, Hossain and Ahamed 2009) noted that Cooch Behar is mildly affected by high arsenic concentrations though their areas of study are not near this study's sites. It is thus important that the status of iron and arsenic concentrations be closely monitored to curb any chances of increased contamination. Fluoride has also been detected in groundwater sources in the region though at levels of 0.12 – 0.37 mg/l are considered not hazardous ((CGWB 2009); (ENVIS 2009)).

Discussion

Uttar Chakoakheti is shown to have high water tables and full pond storages at the peak of the monsoon. These storages are generally naturally drained through deep percolation and horizontal movement to surface water streams with subsequent low groundwater tables in the dry season. With good management of both the cropping pattern and the crop types it is possible to achieve two-cropping seasons in Uttar Chakoakheti, at large scale. But this intensive irrigation will require significant sustainability assessment in view of competing domestic water needs that may be compromised with greater groundwater pumping.

Research suggestions

Groundwater percolation from shallow aquifers to deep aquifers and surface water channels coupled with the high infiltration capacity of the soils is a limiting factor to aquifer storage of the study site. A detailed spatial and temporal assessment of the aquifer structure is thus critical to fully inform a sustainable development of intensive irrigation system.

It is further noted that the temporal availability of groundwater, and conjunctive use of surface water, would be better informed with accurate understanding of the agronomic options for crop production. The understanding of the flexibility possible in the planting calendar may enable adjusted cropping to make optimal use of the temporal availability of groundwater and pond water resources.

8. Madhubani District

Madhubani District lies between latitude 26.65^0 and 26.98^0 N and longitude 85.72^0 and 86.70^0 E. with an average annual rainfall of 1290mm and minimum and maximum temperatures of 13^{0}C and 42^{0}C it is considered sub-tropical climate area. Most of the rains are monsoonal, and is received between July and August. Madhubani, geologically lies along the alluvial plains of the north terai characterized by low-lying waterlogged areas, classified within the entisols.

Cropping Pattern

The yield potential of major crops grown in Madhubani District was modeled based on optimal on-farm cultural management and no limiting crop production factors. The crop associated production (biomass production and yield) with related irrigation water requirements and harvest indices are shown in Table 4. The irrigation demands for the summer and winter production is shown to range from 500 to almost 1000mm. To achieve a three-crop intensification is thus dependent on ability to efficiently manage the groundwater withdrawals coupled with some surface water resources in a conjunctive use pattern. It is also suggested that a modified planting calendar be implemented to enable both optimal irrigation water access and achievement of sufficient growing degree days for each crop.

Table 4: Water requirements for main seasonal crops grown in Madhubani District as modeled by AquaCrop (Steduto, et al. 2009)

Crop	Planting	Harvest	Cycle	Rain, mm	ETo, mm	GD, °C.day	Irri, mm	BioMass, ton/ha	HI, %	Yield, ton/ha
Paddy	08/15/16	11/15/16	70	436	419	1398	112	11.49	4.1	0.47
Brinjal	06/15/16	07/01/16	63	661	406	1253	64	8.17	85	6.94
Bitter Guard	06/15/16	07/01/16	63	661	406	1253	64	8.44	85	7.17
Cucumber	06/15/16	07/01/16	63	642	416	1253	93	8.44	85	7.17
Wheat	12/30/16	04/15/16	113	52	849	2413	981	13.36	48	6.41
Lentil	11/30/16	03/15/16	120	52	939	1458	816	15.03	45	6.77
Mustard	11/30/16	03/15/16	83	28	444	682	523	11.07	50	5.54
Cauliflower	11/30/16	12/15/16	133	49	888	1377	921	14.71	85	12.50
Cabbage	11/30/16	12/15/16	68	21	351	543	432	8.62	85	7.32
Potato	12/15/16	01/15/17	105	45	773	2054	952	15.61	75	11.71
Tomato	12/15/16	01/15/17	106	41	665	1310	749	12.24	63	7.71
Moong Beans	04/15/16	05/30/16	120	906	1042	2545	458	15.62	45	7.03
Onion	02/15/16	03/15/16	113	155	1046	1795	947	12.76	50	6.39
Cucumber	02/15/16	03/15/16	63	32	596	931	656	8.44	85	7.17
Tomato	02/15/16	03/15/16	111	130	1009	1951	970	12.00	63	7.56

Water Quality

The groundwater quality in Madhubani District is generally considered suitable for irrigation purposes. Most of groundwater chemical elements have been determined to be within permissible limits of international standards (Table 5). The study by Central Ground Water board (CGWB 2009) noted that groundwater in Madhubani District varies with depth. Shallow aquifers have high electrical conductivity (EC), chloride, sodium and potassium levels compared to the deeper aquifers. Iron is also encountered in the shallow aquifers (in levels exceeding drinking water standards).

An effort by India's Ministry of Drinking Water and Sanitation has been monitoring the groundwater quality in Madhubani through its National Rural Drinking Water Programme (NRDWP 2014) (PHED 2014). The program evaluated groundwater samples from across Madhubani District for selected parameters, especially iron, arsenic and fluoride. Their results indicated that arsenic contamination was absent/below detection limit in their sampled sources. Iron content varied from 0.10 mg/l to 0.79 mg/l with a mean value of 0.24 mg/l with 98% of samples within desirable limit (Fe < 0.3 mg/l) of Indian drinking water standards (Table 5). The highest average concentration of iron in drinking water was recorded in Madhwapur (0.35 mg/l) and Babubarthi blocks (0.28 mg/l).

Table 5: Groundwater quality in Madhubani District (CGWB 2009)

Chemical constituents*	Deeper Aquifer	Shallow Aquifer	Drinking Water Standard (As per BIS norms)	
			Highest desirable	Maximum Permissible
pH	7.0	7.42 – 8.91	6.5 – 8.5	No relaxation
EC (μS/cm)	564 - 734	500 - 2000	500	2000
Total Hardness ($CaCO_3$)	235 - 280	110 - 380	300	600
Bicarbonate	378 - 445	177 - 476	200	600
Calcium	52 - 80	12 - 44	75	200
Magnesium	16 - 35	12 - 66	30	100
Chloride	3.55 – 10.60	14 - 263	250	1000
Sulphate	< 1.0	-	200	Up to 400 if Mg<30
Nitrate	< 1.0	-	45	100
Fluoride	0.2 – 0.25	0.41 – 0.76	0.6 – 1.2	1.5
Iron	<0.1 – 3.20	-	0.30	1.0
Sodium	22 - 45	75 - 246		
Potassium	1.40	2.70	1.90 - 50	

*All units are in mg/l except EC and pH

Another study (MPA 2012) carried out quality tests of water samples from hand pumps, dug wells, ponds and chaurs. Though their sample size was much smaller they reported that hand pumps had higher iron content compared to dug wells and over 50% of the samples exceeded desirable limit of iron for drinking water. Arsenic contamination exceeding drinking water standards was also recorded in hand pumps of three of the five panchayats from where water samples were collected. This study does not correlate with (NRDWP 2014) due to the localized occurrence of the contaminants as well as temporal variation of sample collections. A strong correlation between iron and arsenic occurrence has been reported, especially in the terai areas. Thus high iron in groundwater expresses that the aquifer is in an anaerobic condition which enhances reduction processes with an increased possibility of enrichment of metals to groundwater. Such an anaerobic condition is favorable for arsenic mobilization and release to groundwater. This is especially of concern under increased groundwater pumping condition.

Fluoride screening has been carried out ((ENVIS 2009); (NRDWP 2014)) for groundwater from different sources in Madhubani District. Fluoride ranges from 0.11 to 1.30 mg/l with a mean value of 0.70 mg/l were found.

It is important that though only localized records of iron, fluoride and arsenic have been recorded (CGWB 2013), the presence of these chemical constituents at levels more than permissible limits should not be ignored.

9. Findings at study village level

Bhagwatipur Village

Bhagwatipur study site is located at longitude 86.340^{0}N and latitude 26.352^{0}E. The area is composed of Haplic Vertisols with high clay contents (around 33%). The soils are generally neutral with soil pH of around 6.6. the soils within 90cm of ground surface are generally of clay loam structure.

Ponds

Across the greater Bhagwatipur village (Figure 21**Error! Reference source not found.**) 16 permanent and 9 temporary ponds were identified. The sizes of the ponds, as mapped from remote sensing images, ranged from 100 – 17227 m^2 and 250 – 2675 m^2 for permanent and temporary ponds, respectively.

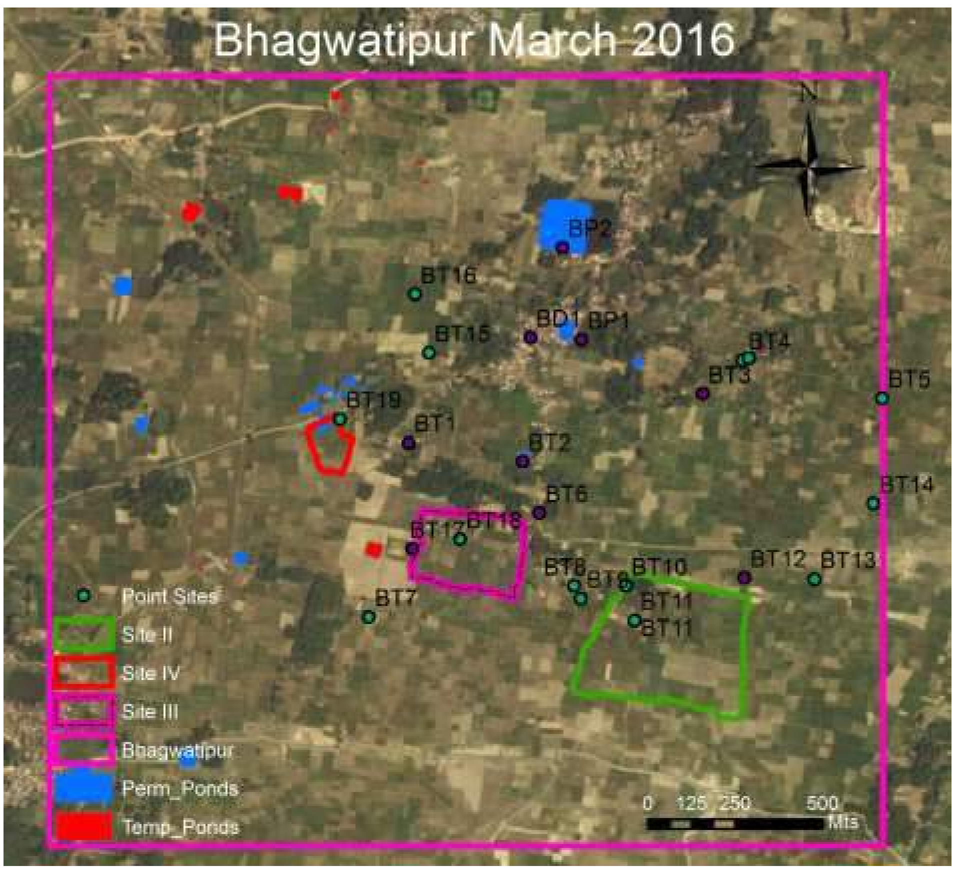

Figure 21: Locations of study sites, ponds and groundwater monitoring points in Bhagwatipur Village

Most of the ponds are presently used for fishery and domestic use, though a few were noted as used for supplementary irrigation, especially during land preparation and minimal dry season vegetable cropping.

Photo 5: A new fishery/irrigation pond in Bhagwatipur Village

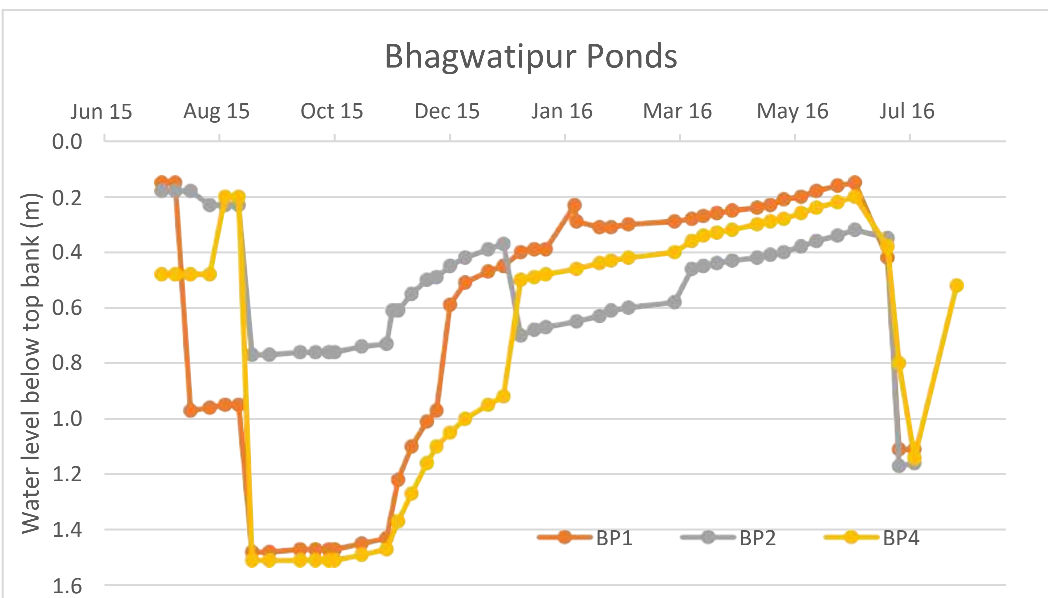

Figure 22: Monitored pond water levels in Bhagwatipur Village

High pond water levels of 0.2m bgl recorded in August and lows of up to 1.5m bgl in September (Figure 22). The sharp drop of water levels in July-September is due to supplementary irrigation for seedbed preparation for paddy planting. Pond BP2, the largest pond in the village, shows greater storage depth during the period of post-monsoon to winter but a greater drawdown in January, indicating its greater value as a source of supplementary irrigation water for the winter cropping. Gradual refill of all monitored ponds is noted from October through May from groundwater recharge of the ponds.

Groundwater

Groundwater table was monitored through a weekly monitoring of static water levels in one open dug well and nine shallow tube wells (*Figure 23*).

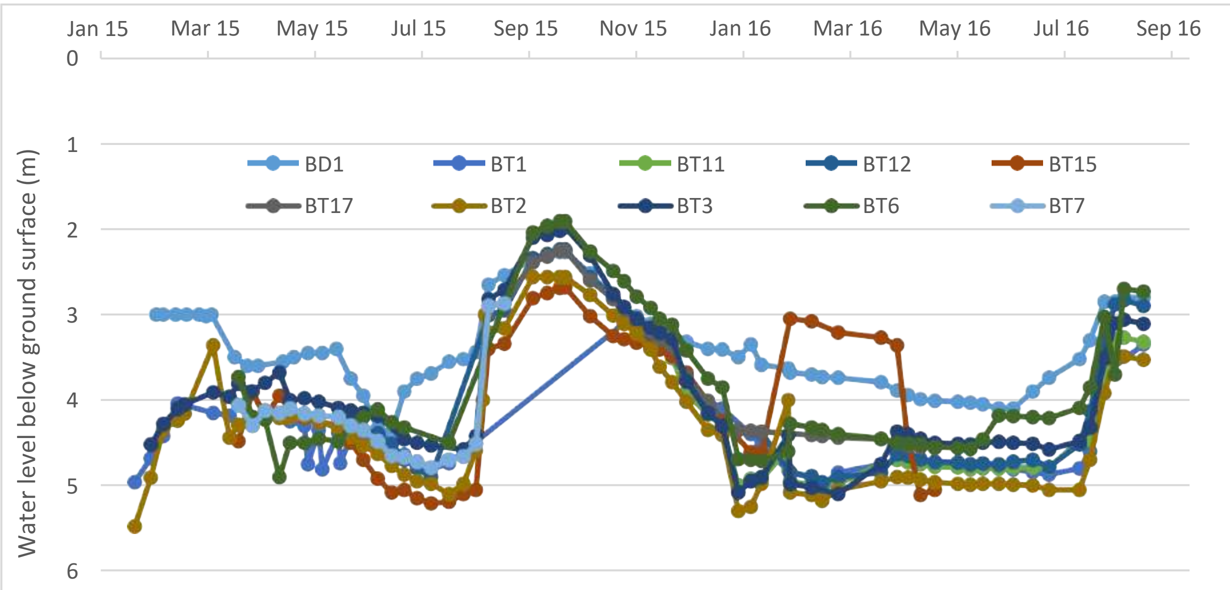

Figure 23: Groundwater tables on monitored shallow tube wells (BT) and dug well (BD) in Bhagwatipur Village

Groundwater levels as reflected from tubewells indicate high levels of 2-3m below ground level in September and low levels of 4-5m bgl in July. These results closely match the average values obtained across Maddubani District (CGWB 2013). It is noted that though the trend of dug well water level and tube well water levels are similar the dug well response during both discharge and recharge is slower. This is likely due to the fact that the dug well is inoperational and thus the water movement into and out of the well could be restricted by waste material settling into the dug wells walls.

Water quality

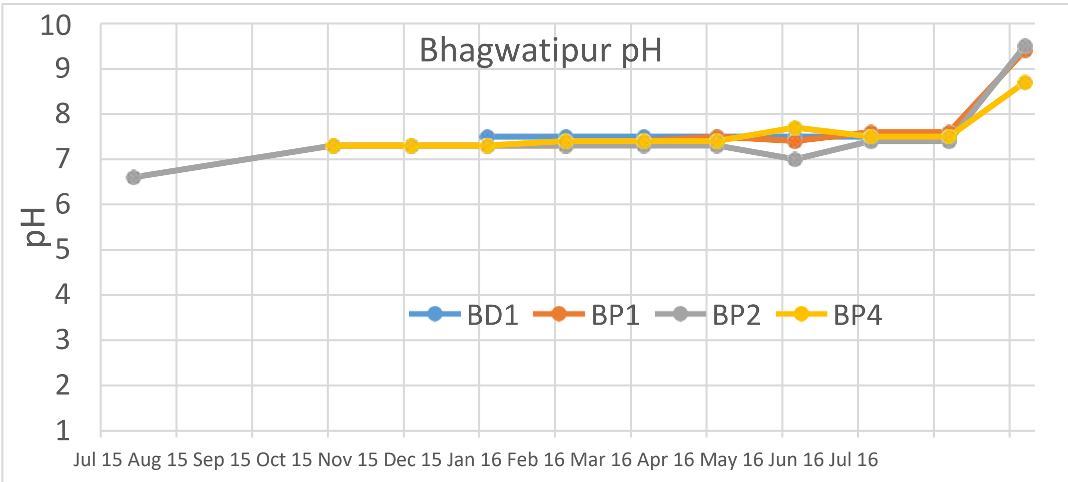

Figure 24: Temporal pH levels of pond (BP) and dug well (BD) water (June 2015 – July 2016) in Bhagwatipur

The pH levels of three ponds and one dug well were monitored over the period of August 2015 until July 2016 (Figure 24). For most of the monitoring period the pH values were stable between 6.5 and 7.5 for all sources. a spike on the pH of all the sources was observed for the July 2016 reading up to about 9. It was observed that rains were received in the area 3 days prior (data not presented here) suggesting that this spike in pH could be as a result of the weather artifact through fresh recharge of the sources through runoffs and/or groundwater percolation.

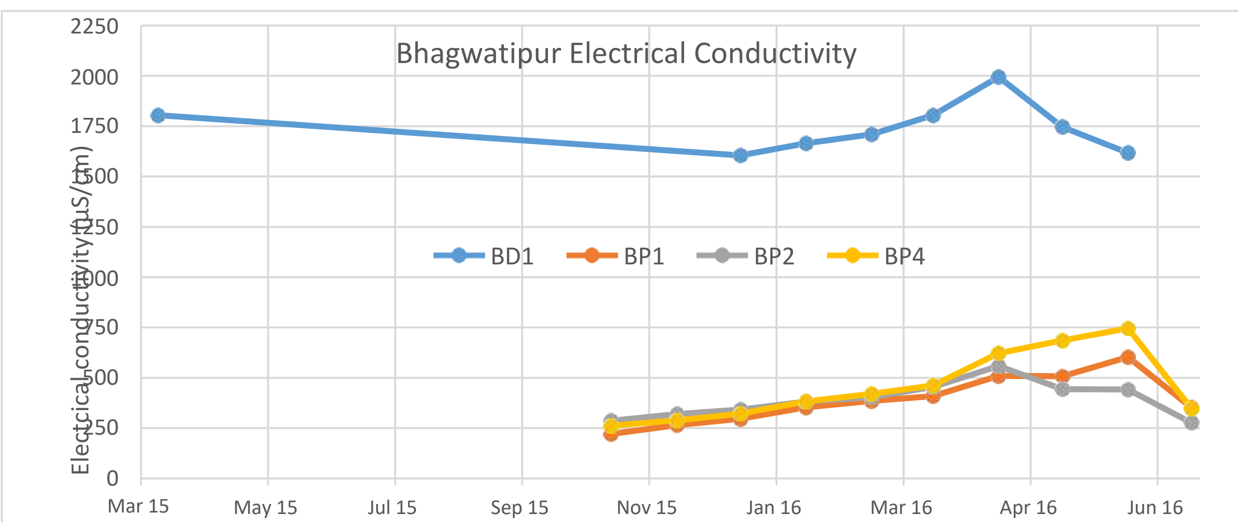

Figure 25: Temporal electrical conductivity (EC) values for pond and dug well waters (June 2015-July 2016) - Bhagwatipur

A monitoring of the electrical conductivity shows a very substantial and clear distinction between the dug well water and the pond waters (Figure 25). The dug well shows higher EC levels ranging from a low of about 1600 µS/cm in December to a high of 2000 µS/cm in April. The high EC values in the dug well is a direct indication of the anthropogenic contamination of the source. This dug well has been out of operation for several years and been a dumping place of On the other hand, the electrical conductivity of the ponds' waters are closely similar with a low of about 250 µS/cm in July-October period and a high of

500 – 750 μS/cm in May. The gradual increase in EC between October and May, though inconclusive suggests a concentration of contaminants in the ponds with progression of the dry season followed by a lowering at the start of the rains.

Mauahi Village

Mauahi Village study site is located at longitude 86.298^0N and latitude 26.442^0E. Based on the Predicted (World Reference Base 2006) soil classes the soils in this area is classified as Haplic Vertisols (Hengl, et al. 2014) with high clay contents (33%). The soils are generally neutral with soil pH of around 6.6. The soils within 90cm of ground surface are generally of clay loam structure.

Ponds

A remote sensing mapping of the ponds in the greater Mauahi Village identified 17 temporary ponds and 24 permanent ponds ranging in sizes from 100-14877 m^2 and 175-5476 m^2, respectively. Of these ponds, only 7 permanent ponds (no temporary ponds) were located within the pilot intervention site (Figure 26). The permanent ponds mapped within the intervention site area ranged in sizes from 175 – 5476 m^2.

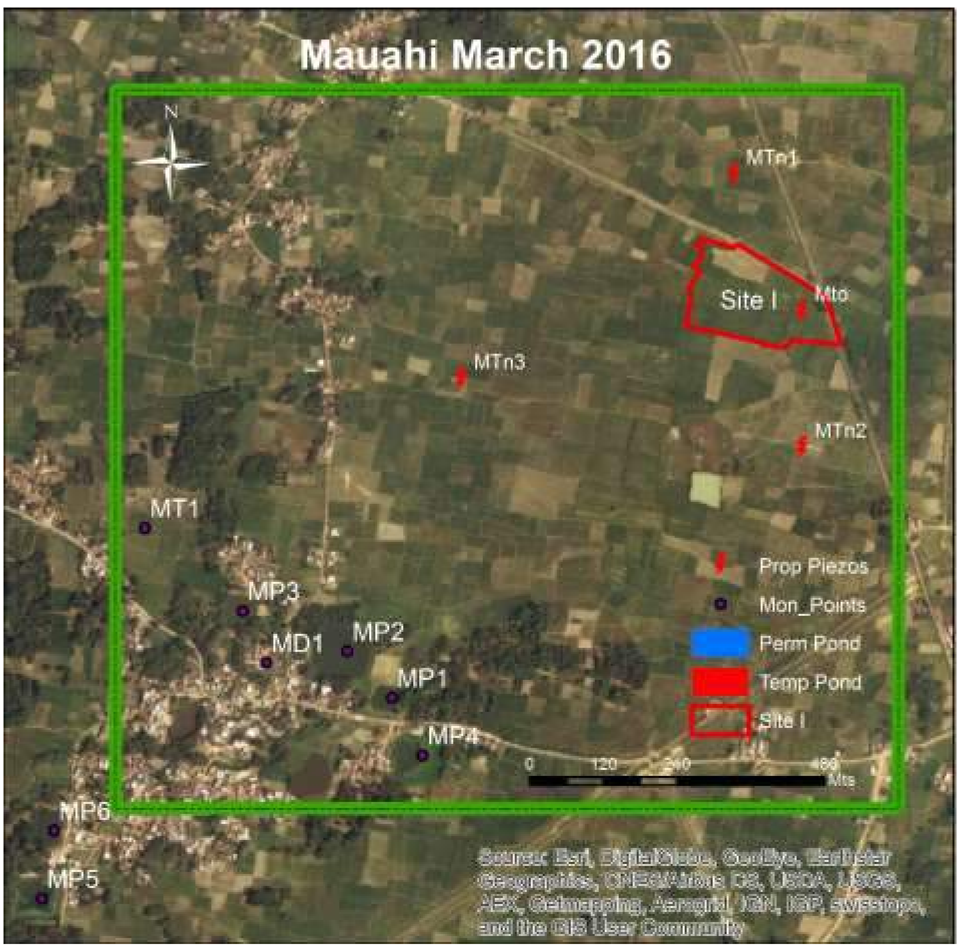

Figure 26: Locations of study sites, ponds and groundwater monitoring points in Mauahi Village

Five ponds were monitored across Mauahi village starting July 2015 through August 2016 (Figure 27). The results show that monsoonal recharge does raise the pond water levels to within 0.2m of the ground surface. A sharp drop in the water levels of all the bonds to between 1 and 2m in August 2015. This was a consequent of irrigation pumping for supplementary irrigation for paddy field preparations. Even though all ponds were pumped for this purpose consequent months saw gradual refill of the ponds at a rate of about 0.1m/month until June 2016 indicating the dominance of groundwater recharge of the ponds rather than flooding and/or direct precipitation. The temporal variability of pond water levels suggests a strong influence of the hydrogeology rather than topography in the water circulation into the ponds (water levels).

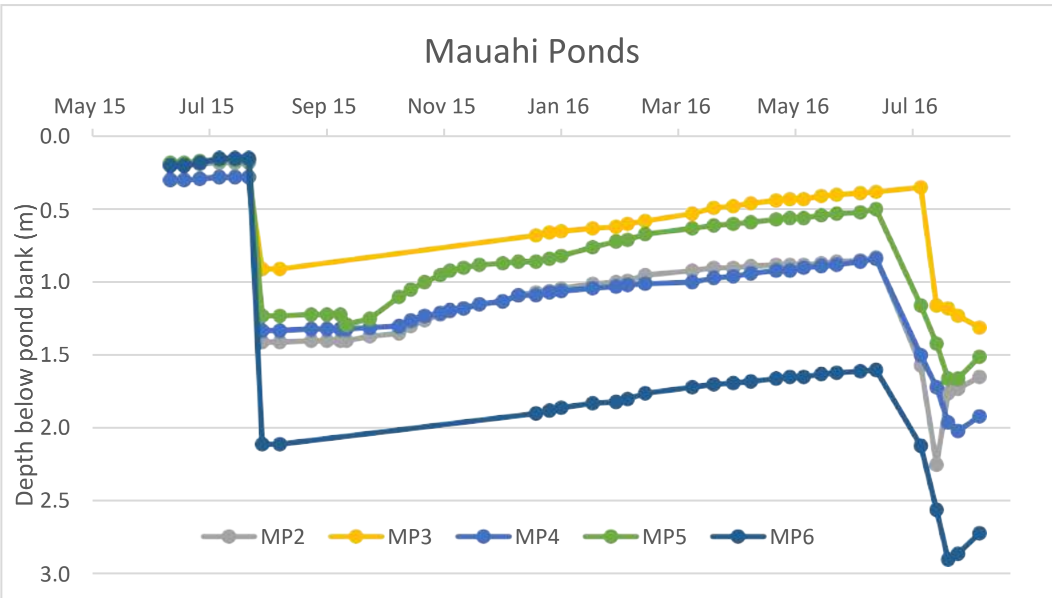

Figure 27: Monitored pond water levels in Mauahi Village

Groundwater

The groundwater level variability in Mauahi Village is quite significant both temporally and spatially. Groundwater levels were monitored from three tube wells and one dug well as shown in Figure 28.

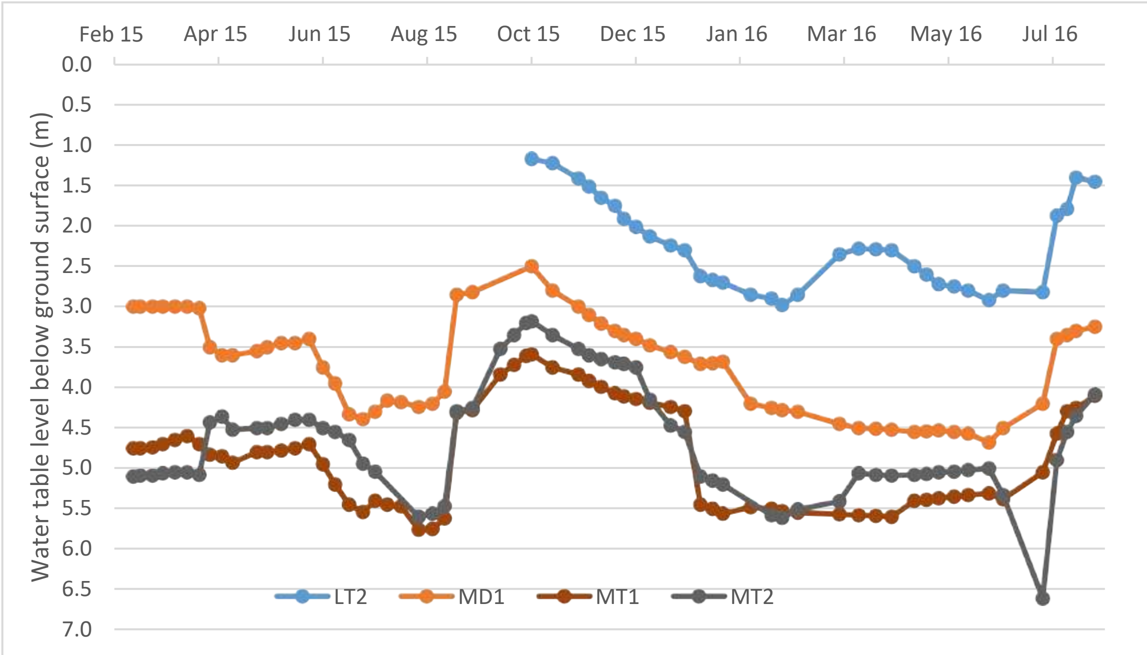

Figure 28: Monitored groundwater tables in Mauahi Village

The results indicate that the water table is generally deeper within the agricultural areas than in the village settlement. The pumped tube wells MT1 and MT2 are located to the North and South West of the village while LT2 is located to the North East. The dug well (MD1) is located within the village settlement. All monitoring locations show similar temporal trends with highest water levels occurring in September-October and the lowest levels occurring in June-August period. Highest water table level was recorded in LT2 in October 2015 likely due to the high flooding of the fields in this area. Lowest water tables of about 6m were recorded in MT1 and MT2 in August, likely following pre-monsoon pumping for paddy field seedbed and field preparations.

Water quality

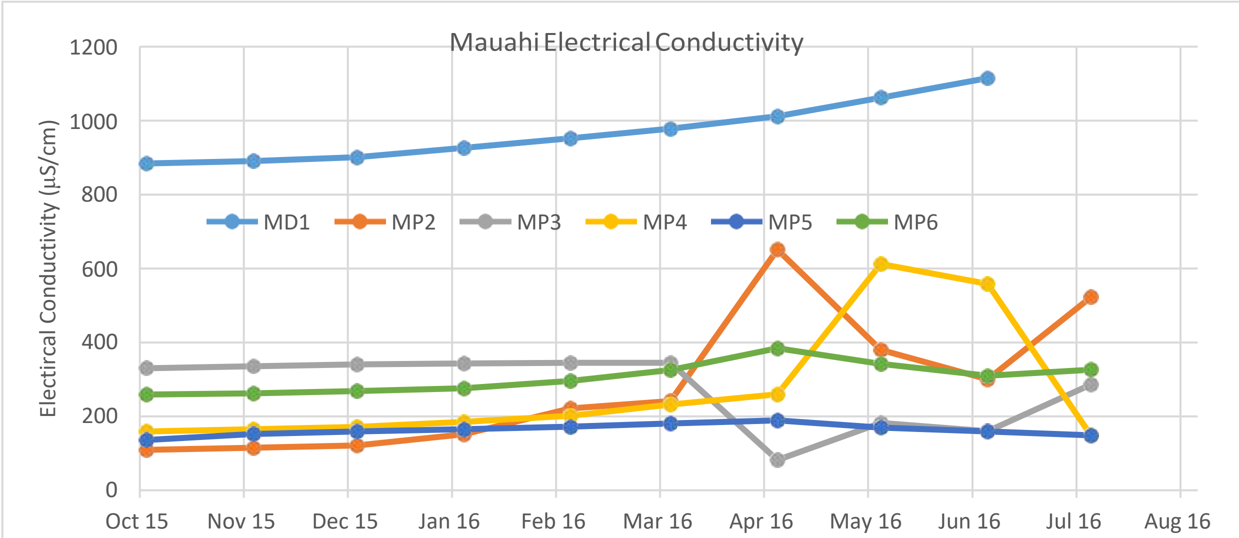

Figure 29: Monitored electrical conductivity trends of dug well (MD) and pond (MP) waters in Mauahi

The electrical conductivity of ponds and dug well in Mauahi village are presented in Figure 29 above. All water sources show an increasing trend of EC concentration from October 2015 through July 2016. Pond water show small temporal variability with ranges of about 200 – 300 µS/cm during th monitoring period. Spatial variability is more pronounced, with values of 110-330 µS/cm in October to 150-500 µS/cm in July. The period between March and July shows significant fluctuations in measured EC levels of ponds (except MP6) indicating temporary pertubations to the water system. From an evaluation of the locations and uses of these ponds it is surmissed that the pertubations impacting the EC are due to pumpage from these ponds for irrigation. Pond MP6 is used for fishery hence the stable EC values over the same period.

The dug well (MD1) on the other hand shows constant increasing trends of concentration from 900 to 1100 µS/cm between October and June. This indicates the hydrologic changes in the groundwater with deeper withdrawals of water as previously noted with falling water table level (Figure 29).

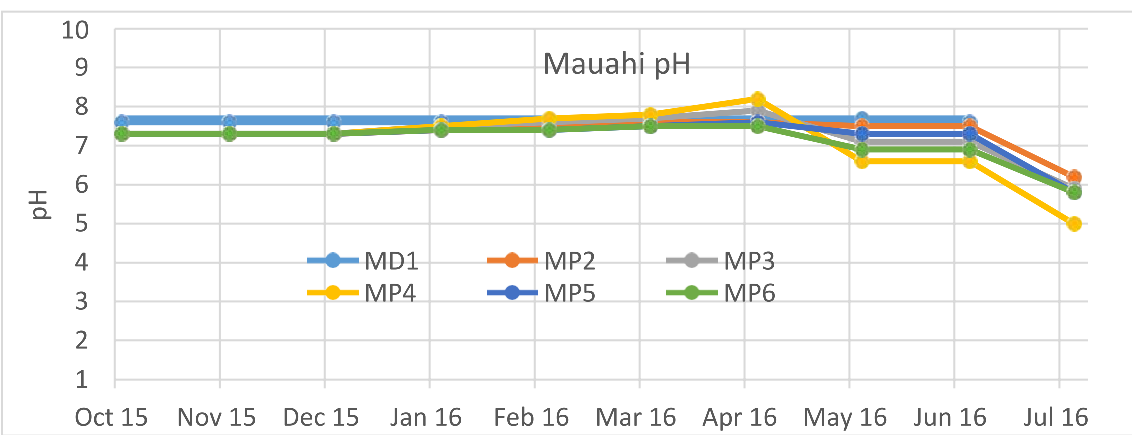

Figure 30: Monitored pH trends on dug well (MD) and pond water (MP) from Mauahi Village

Hydrogen potential (pH) was monitored from five ponds and one dug well (Figure 30) for the period of October 2015 until June 2016. The pH levels of all the water sources range from around 7.5 to 5. The sources are thus generally neutral, tending to acid with increased pumping/groundwater depletion. The results show low spatial or temporal variations from october 2015 through March 2016. This constant level period is followed by a gradual acidifaction of water from all the sources between March and June 2016. The period of increasing acidification also shows increased spatial variability between sources with MP4 showing the greatest difference.

With very limited ground water irrigation in the period between September and March and supplementary irrigation in April to June it is surmised that the decreased pH of the water sources is occasioned by the increased groundwater withdrawals from the surrounding aquifer.

Discussion

The assessment of groundwater and pond water resources indicate substantial potential for increased cropping intensity. The achievement of this noble target would require greater monitoring of the groundwater-surface water interactions and especially local level aquifer characteristics to guide the optimal planning for the access and use of these water resources without compromising domestic uses. Though the areas of this study do not show any mineral contaminations it has been shown that Madhubani District is subject to occurrence of arsenic and iron contamination. These contaminations are brought about with increase in the intensity of groundwater pumping hence an on-going monitoring of the water sources in the study sites is highly advised to avoid risk of inducing conditions that may arise in the contamination of these areas under the projected intensive irrigation driven by groundwater pumping.

Research suggestions

Targeted studies to assess the potentials of withdrawals that will not induce iron and arsenic contamination in this high risk area of the terai

Can a modified cropping pattern, facilitated through shifted planting dates and supplementary irrigation provide enough growing degree days for three-crop consecutive cropping system?

10. General Conclusions

District level water resources assessment, supported by local pilot area assessments indicate that the three general areas of this research study has great potentials for intensive irrigated agriculture. Availability and access to these water resources are still limited with groundwater depletion ranging from a low of 4m in Koiladi and a high of 7m in Khoksar Parbaha. These depletions, though not clearly attributable to any specific processes are strongly likely due to natural deep percolation and lateral flows to surface water systems (rivers) and hence not fully utilized. a planned temporal arrangement to harness these depletions for productive uses would thus be greatly impactful to the development of the agricultural sectors in these regions.

Despite these current levels of groundwater depletions, dry season storages of 3 to 6m of groundwater aquifers are available for surface pumping for irrigation development. It is suggested that a detailed assessment of the actual storage potential of the aquifers be determined to comprehensively advice on the available pumping potentials for dry season irrigation.

The presence of ponds and associated storages in noted to be an unused resource across all sites. It is noted that the ponds are generally used for fishery due to the higher economic returns, relative to traditional agricultural systems. Despite this use constraint, it is also noted that most ponds are available for supplementary irrigation during drought years and for some instances of nursery beds and even pre-monsoon land preparations. They thus provide a substantial resource that can augment groundwater resources under extreme uncertain conditions.

The groundwater and pond water quality in all the study areas indicate fair to good quality. This assessment is based solely on pH and electrical conductivity as surrogates of irrigation water quality hence is not comprehensive for all potential mineral hazards. Reports from other areas within the districts of concern indicate occurrence and/or potentials of iron, fluoride and arsenic contamination, among other chemical risks. This study, thus though noting unrestrained use of groundwater and pond water for irrigation notes the concern of increased risks of contamination. It is thus strongly suggested that on-going monitoring, both spatial and temporal be facilitated to avoid the worsening of the soil and water chemical balances under changed agricultural developments.

At the agronomic level, it is noted that for all the region’s main cropping patterns are for two cropping systems. This study notes the potential for a three-crop system when water is the sole constraining factor. But since water access/availability is not the only factor in irrigated agriculture this study suggests an agronomic assessment to review the cropping calendar against limiting other factors such as growing degree days, weather conditions, pest and disease factors in order to evaluate a large scale promotion of a potential three-crop system. Further assessments on other social and cultural constraints to increased labor and time demands of an intensive irrigated cropping system would also require further consideration.

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