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Agro-ecological aspects of groundwater utilization: A case study

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Groundwater is an important source of irrigation and public supplies in Bangladesh. It is the main source of water available in Trishal upazila during dry season. The experimental soils were heterogeneous ranging from clay to silty clay loam. The results indicated that on an average soil pH, percentage nitrogen, organic carbon and sulphur were low and phosphorous was high in all land types. The lowest water level dropped below 8 m for 2 to 3 months in almost every year for all the location studied. The depths of water table in peak period of dry season (November to March) in Sutia River and in large, medium and small ponds were 0.95, 1.33, 0.45 and 0.00 m, respectively due to lowering of groundwater table. This situation eliminated the possibility of use of shallow tube wells (STWs) or other surface mounted suction mode pumps in Trishal upazila. Due to heavy abstraction of groundwater, many environmental consequences have been encountered during 20 years. Sowing time, pisciculture and growth of aquatic plants were seriously hampered. Likewise, oxygen deficiency in ponds, scarcity of water for domestic animal, and soil cracking in critical period occurred. Due to low humidity and relatively high temperature prevailing in the study area, the shallow rooted plants and vegetation which are not irrigated were drastically affected as evidence from field survey results. This might cause ecological imbalance in Trishal upazila.

Key words: Groundwater, water quality, environment, agro-ecology, crop, soil.

INTRODUCTION

Groundwater development has become popular as a key sector for agricultural production in Bangladesh. The average annual rainfall in this country is near about 232 cm but it is not uniformly distributed all over the country (MPO, 2005). Very less amount of rainfall occurs during November through March. During these months, irrigation from surface sources is not practically possible in most cases due to scarcity of surface water. Therefore, the use of groundwater has become an increasingly important source of irrigation during dry season (November to March). Abstraction of groundwater from stream-aquifer systems reduces the surface water. Reduction of stream flow can have deleterious effect on fish growth and aquatic eco-system. Unplanned abstraction of groundwater may have drastic effects on the natural eco-system and also lead to land subsidence. Lower static water level increases the pumping cost and damage to water quality.

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In recent years, many problems e.g. groundwater table dropping below suction lift limit (8m) are being encountered in many areas of Bangladesh (Rashid et al., 1990; Talukder et al., 1990). This causes failure of some minor irrigation projects and also paucity of drinking water for rural people. Besides, the deep tube wells (DTW) also supply less water than the designed capacity when the static water levels drop much below their optimum level of pumping requirements. Unplanned development of groundwater would not only cause failure of wells but also might lead to alarming environmental situation (Khan, 1988).

Declination of groundwater table causes reduction in the amount of soil moisture available to vegetation, particularly to crops and trees. This is an unlimited impact on agro-ecological balance. Reduction of soil moisture at the top layer of the soil may make the land to become dry and sandy, which ultimately may turn the area into desert (Anik, 1984). Overdraft of groundwater may cause salt water intrusion in coasted areas. In Bangladesh, human activities already distorted the surface of the top of the

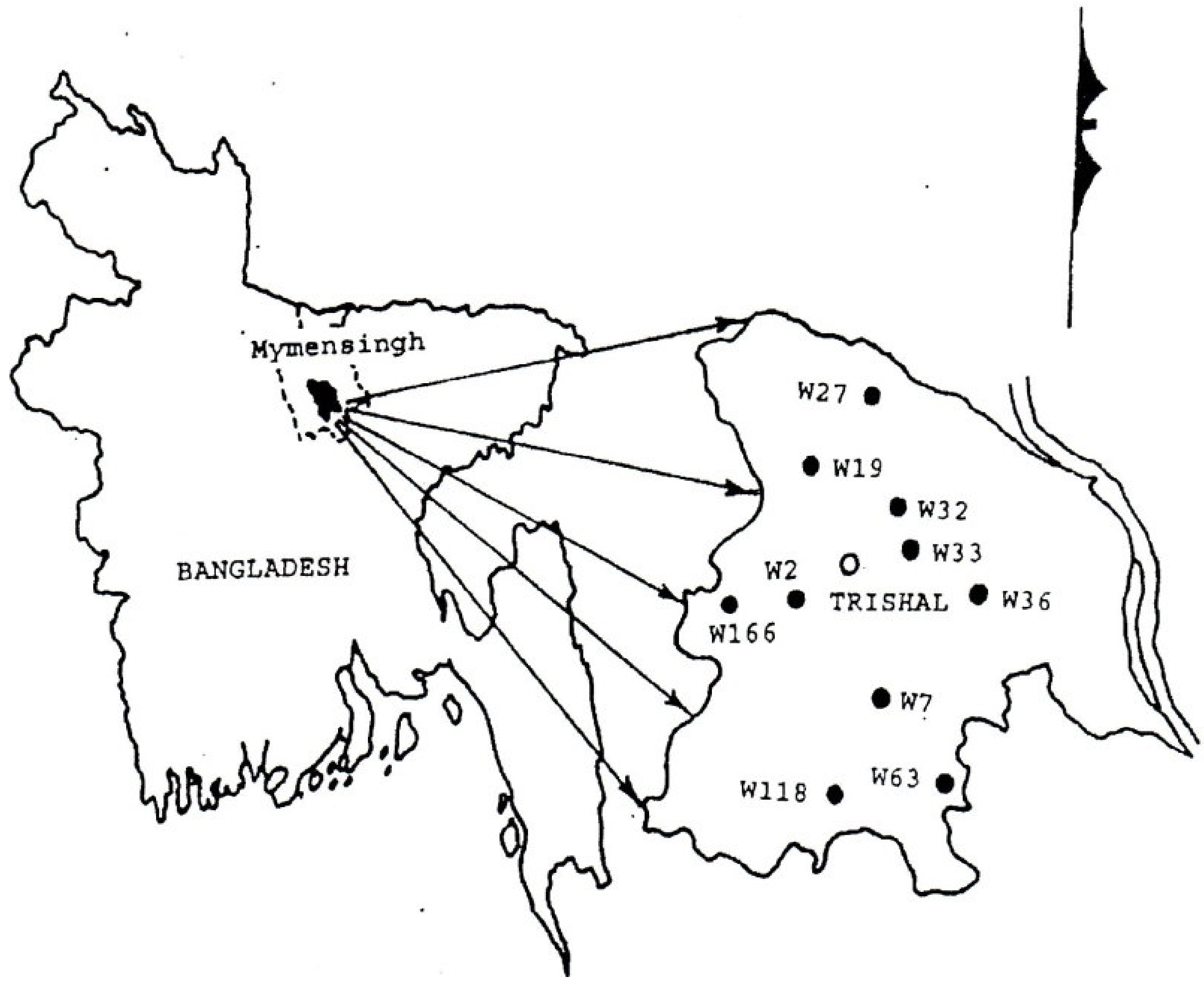

Figure 1. Location of deep tube wells used for water level fluctuation monitoring.

earth and upset many ecological systems. Many resources are being exploited either with or without little consideration of their conservation, both in quantity and quality for future use.

The quality of groundwater is a very important factor for agriculture, domestic, municipal and industrial use. Salinity of water degrades the quality requirements for irrigation, domestic and industrial uses which ultimately cause environmental hazards (Khan, 1990). Poor quality of water also damages physical properties of the irrigated soil by accumulating the harmful and toxic elements in the soil, ultimately destroying the productivity of agricultural lands (Talukder and Alam, 1995). Once the agricultural soil is affected due to the addition of deleterious components of groundwater, future utilization will make the agricultural lands non-productive which will require complex soil and water management practice (Khan, 1990). In this study, an attempt has been made to evaluate the effect of groundwater utilization on soil, available surface water resources, water level fluctuation and the growth of plants and vegetation.

METHODOLOGY

A study was conducted at Trishal upazila of Mymensingh District, Bangladesh. The location of the deep tube wells (DTW) is shown in Figure 1.The monthly data of static water levels monitored by the Bangladesh Agricultural Development Corporation (BADC) in 10 specific deep tube wells were collected from BADC office of Trishal upazila. Soil samples were collected at 20, 40 and 60 cm depths from 12 union of Trishal upazila to determine its moisture status and these samples were analyzed in the laboratory for physico-chemical properties. Water samples were also collected from 10 located DTWs and chemical properties of groundwater were determined in the same laboratory. The information about plant growth, vegetation and surface water conditions were collected from 100 randomly selected aged farmers, covering the entire Upazila using a predesigned questionnaire through on-spot visit and interviewing.

Water quality parameters

Sodium adsorption ratio

Sodium adsorption ratio (SAR) was calculated by the following equation given by Richards (1954).

Table 1. Gradual development of irrigation technologies in Trishal thana.

Irrigation technology	Year						
	1985	1988	1991	1994	1997	2000	2005
Deep tube well (DTW)	315	317	320	333	391	405	445
Shallow tube well (STW)	26	28	31	36	52	63	72
Low lift pump (LLP)	63	80	85	98	134	141	164

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

Where all ions are expressed in meq/l.

Soluble sodium percentage

The soluble sodium percentage (SSP) was calculated by the following equation (Todd, 1980)

$$SSP = \frac{Na+K}{Ca+Mg+Na+K} \times 100$$

Permeability index

The permeability Index (PI) was calculated according to Doneen (1962) by the following equation.

$$PI = \frac{Na+\sqrt{HCO_3}}{Ca+Mg+Na} \times 100$$

Residual sodium bi-carbonate

The residual sodium bi-carbonate (RSBC) was calculated by the following equation (Gupta and Gupta, 1987).

$$RSBC = HCO_3 - Ca$$

Total hardness

Total hardness (TH) was calculated by the following equation (Raghunath, 1987).

$$TH = (Ca+Mg) \times 50$$

RESULTS AND DISCUSSION

Gradual development of irrigation technologies in Trishal upazila is given in Table 1. The physico-chemical properties of soil in study area are given in Table 2. Texturally, the soils were heterogeneous having silt loam, clay loam, silty clay loam, silty clay and clay. The results indicate that on an average soil pH, %N, % organic carbon and sulphur are low and phosphorus is high in all the land types studied with respect to their standard ranges. Average soil pH, EC(µs/cm), %N, %organic carbon, phosphorus (ppm), potassium (me/100g), and sulphur (ppm) of high, medium and low lands are 6.20, 89.30, 0.08, 1.01, 19.17, 0.265, 24; 6.22, 97.67, 0.082, 0.984, 19.42, 0.257, 22 and 6.19, 102.58, 0.084, 1.11, 19.92, 0.253 and 25, respectively.

The static groundwater level gradually declines due to abstraction of groundwater by wells, effluent flow into streams and canals which intersect the water table. The monthly static water levels fluctuation patterns of DTWs located in Figure 1 of the study area are plotted graphically in Figure 2. The graphs indicate that the static water level started rising during April/May with the onset of monsoon rainfall reaching its peak in October/November, and the aquifer was fully recharged. In some cases, the static water level remains almost unchanged for one to two months, although there was sufficient rainfall to recharge the aquifer. The static water level started falling during November/December with the recession of rainfall, reaching its lowest level in March/April. The water levels drop rapidly when irrigation wells start groundwater extraction. Figure 2 shows that the dry season water level in all the 10 deep tube wells drop below suction lift limit (8 m below ground surface) of centrifugal pumps in most of the years studied. The results are in conformity with the findings of Mojid (1993) and David (1993). In dry period, groundwater level decreased due to over pumping by a large number of DTWs, STWs and low lift pumps (LLPs), which were installed scattered in the study area. This density is increasing day by day due to Government's privatization policy.

The quality of irrigation water and its classification based on various parameters are presented in Tables 3 and 4. Sodium adsorption ratio (SAR) of the groundwater samples was in the ranges of 0.98 to 3.78 (Table 3). In respect of sodium hazard, all the samples were in normal range, that is, excellent category according to Gupta (1979). The results are in conformity with the findings of Sharifullah (1990). The soluble sodium percentage (SSP) of the water sample ranged from 29.64 to 64.51 and the quality of water was excellent beyond doubt. Unsuitable water samples were not found. In terms of residual sodium bi-carbonate (RSBC) all the water samples were satisfactory, that is those having RSBC values ranging

Table 2. Physico-chemical properties of soil in Trishal upazila, Bangladesh.

Land type	S/No.	pH	Ec (µs/cm)	Nitrogen (%)	Organic carbon (%)	Phosphorus (ppm)	Potassium (me/100 g)	Sulphur (ppm)	Textural class
High	1	5.47	75	0.056	0.689	14	0.28	20	Silt loam
	2	6.46	84	0.064	0.765	14	0.25	23	Silt loam
	3	6.45	128	0.078	0.842	16	0.24	27	Silt loam
	4	6.30	69	0.089	0.995	16	0.26	12	Clay loam
	5	6.32	76	0.087	0.995	18	0.35	35	Clay loam
	6	6.08	60	0.057	0.689	14	0.20	32	Silt loam
	7	6.48	189	0.099	1.301	28	0.25	28	Silty clay
	8	6.35	110	0.103	1.606	30	0.32	22	Silty clay
	9	6.32	160	0.103	1.606	28	0.24	21	Clay loam
	10	6.06	66	0.076	0.880	16	0.29	18	Silty loam
	11	6.05	69	0.089	1.033	20	0.28	27	Silty loam
	12	5.55	75	0.067	0.727	16	0.22	23	Silty loam
Average		6.20	89.30	0.080	1.010	19.17	0.265	24	-
Medium	1	5.84	60	0.052	0.613	12	0.26	26	Silt loam
	2	6.24	98	0.094	1.033	20	0.29	25	Silt loam
	3	7.17	182	0.056	0.641	13	0.18	12	Silt loam
	4	6.78	100	0.047	0.530	12	0.28	13	Clay loam
	5	6.65	103	0.078	0.804	16	0.28	13	Clay
	6	5.57	48	0.076	0.804	16	0.20	22	Silty clay
	7	6.70	127	0.095	1.224	26	0.26	22	Silty clay
	8	6.58	130	0.098	1.186	24	0.22	20	Silty clay loam
	9	6.42	104	0.088	1.071	20	0.30	20	Silty clay loam
	10	5.57	65	0.097	1.377	26	0.28	35	Clay
	11	5.62	73	0.110	1.530	30	0.29	28	Clay loam
	12	5.86	82	0.087	0.995	18	0.24	25	Clay loam
Average		6.22	97.67	0.082	0.984	19.42	0.257	22	-
Low	1	6.24	78	0.054	0.651	13	0.30	30	Silt loam
	2	6.64	175	0.098	1.148	23	0.20	20	Silt loam
	3	6.76	172	0.087	1.003	18	0.16	13	Silt loam
	4	6.64	116	0.037	0.960	10	0.30	28	Clay loam
	5	6.23	109	0.098	1.186	24	0.24	18	Silty clay loam
	6	5.78	68	0.098	1.224	26	0.18	35	Silty clay loam
	7	6.69	117	0.082	0.957	16	0.30	30	Silty clay loam
	8	5.58	72	0.087	0.995	18	0.26	27	Clay loam
	9	6.62	126	0.097	1.148	24	0.26	16	Silty loam
	10	5.42	56	0.112	1.530	28	0.30	30	Silty loam
	11	5.43	64	0.096	1.148	24	0.26	20	Silty loam
	12	6.26	78	0.067	0.727	15	0.28	27	Silty loam
Average		6.19	102.58	0.084	1.110	19.92	0.253	25	-
Range	Low	< 6.5	-	< 0.10	-	< 10	-	< 80	-
	Medium	6.6 - 7.5	-	0.10 - 0.15	-	10 - 15	-	80 - 15-	-
	High	> 7.5	-	> 0.15	-	> 15	-	> 150	-

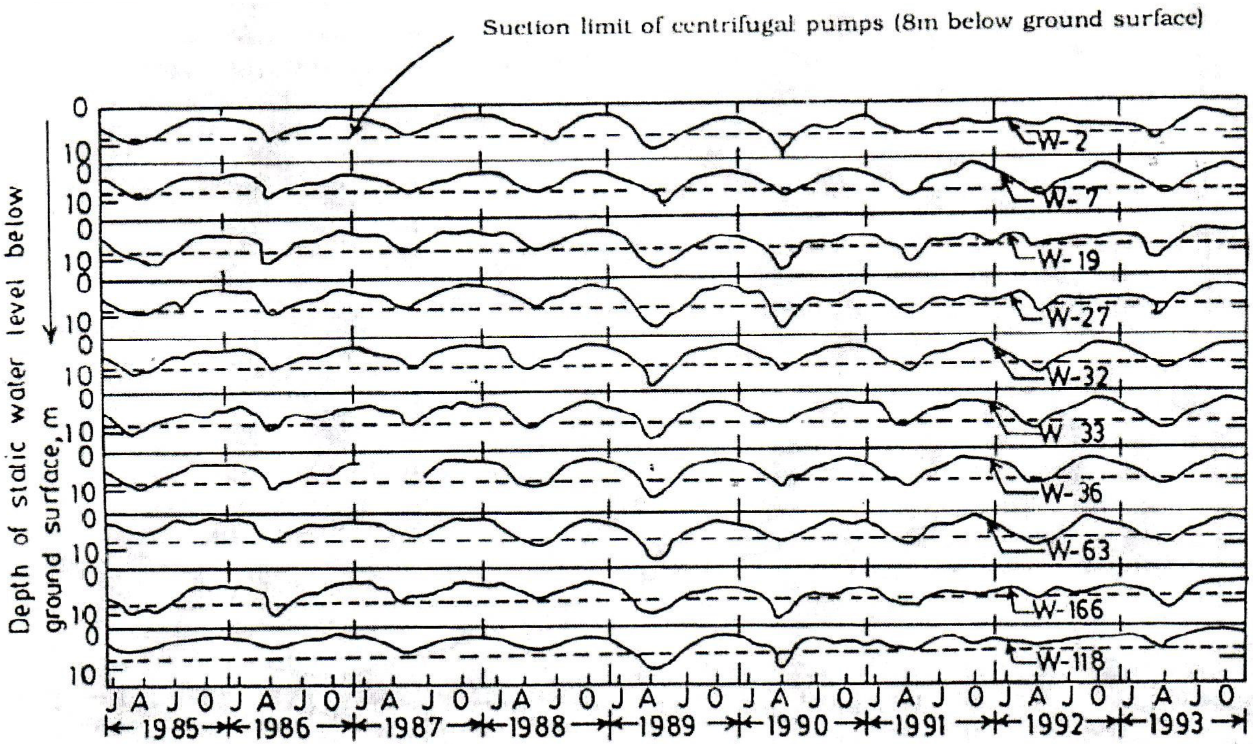

Figure 2. Groundwater level fluctuation pattern of the study area.

Table 3. Groundwater quality of the study area.

S/No.	DTW No.	SAR	SSP	RSBC	PI	TH
1	19	2.08	51.47	1.15	82.89	60.00
2	27	1.88	51.51	0.42	87.50	80.00
3	32	2.75	59.49	0.80	85.19	89.50
4	33	3.78	64.51	0.25	82.15	111.50
5	2	1.52	41.47	0.55	72.72	116.00
6	36	2.56	59.16	2.16	97.95	80.50
7	166	1.23	37.91	0.13	72.90	95.00
8	7	1.53	41.30	0.10	65.86	123.00
9	118	0.98	29.64	1.46	69.94	136.00
10	63	3.16	62.13	0.40	87.08	90.00
Average		2.15	49.86	0.74	80.43	98.15
Standard deviation		0.90	11.76	0.67	9.84	23.08

from 0.10 to 2.16 meq/l, according to Gupta and Gupta (1987). These results are supported by Islam and Farid (1991). In respect of permeability index (PI) all the water samples were good (Raghunath, 1987). Total hardness (TH) of water samples varied from 60 to 136 which were classified as slightly to moderately hard. This classification was also based on the basis of Raghunath (1987).

Relationship between depth of water table and percentage of soil moisture in the soil profile is presented in Figure 3. The depth of static water level at high land was significantly correlated (R^2=0.91) with the soil moisture. Similarly, negative correlation was found at medium (coefficient of regression, R^2=0.96) and low land (R^2=0.91) type soil. These results revealed that if the depth of static water level is increased, simultaneously the moisture percentage is decreased. The regression line between the depth of water table and soil moisture percentage also supports the statement. Generally, the groundwater rises up into the root zone due to capillary

Table 4. Water quality classification based on various parameters.

S/No.	DTW No.	Class					
		SAR	pH	SSP	PI	RSBC	TH
1	19	Normal	Alkaline	Permissible	Good	Satisfactory	Slightly hard
2	27	Normal	Slightly alkaline	Permissible	Good	Satisfactory	Slightly hard
3	32	Normal	Slightly alkaline	Permissible	Good	Satisfactory	Slightly hard
4	33	Normal	Practically neutral	Doubtful	Good	Satisfactory	Moderately hard
5	2	Normal	Slightly alkaline	Permissible	Good	Satisfactory	Slightly hard
6	36	Normal	Alkaline	Permissible	Good	Satisfactory	Slightly hard
7	166	Normal	Practically neutral	Good	Good	Satisfactory	Slightly hard
8	7	Normal	Practically neutral	Doubtful	Good	Satisfactory	Moderately hard
9	118	Normal	Practically neutral				Moderately hard
10	63	Normal	Practically neutral				Slightly hard

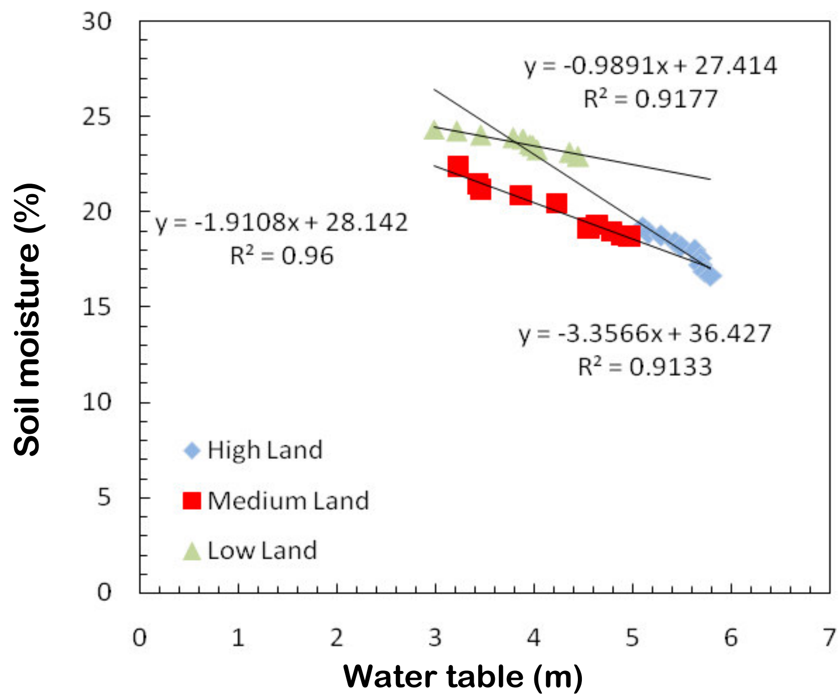

Figure 3. Relationship between depth of water table and percent soil moisture.

action but if the water level is very low, in that case water cannot rise up and this may create moisture tension and depth of capillary fringe may become higher. Due to this moisture tension soil water will go downward and for that reason root zone will run dry, which ultimately affects the crop yield. The plants and vegetation can absorb water by root hair from soil around the root zone by osmotic process when water remains in the soil at less than 15 atmospheric pressure.

The paddy yields were significantly different at different topography that is different moisture level (Figure 4). At high land the yields were strongly correlated (R^2=97) with the soil moisture percentage. The yields were also correlated with soil moisture at medium (R^2=0.91) and low land (R^2=0.89). The regression line between the paddy yields with the soil moisture percentage indicated that yield is increased with the increasing rate of soil moisture.

Average depth of surface water resources in the study area is presented in Figure 5. In the month of April 1985 the average depth of water levels of Sutia River and in the ponds of large, medium and small sizes were 1.42, 1.73, 0.62 and 0.23 m, respectively. But in April 2005, the average depths of water were 0.95, 1.33, 0.45 and 0.00 m

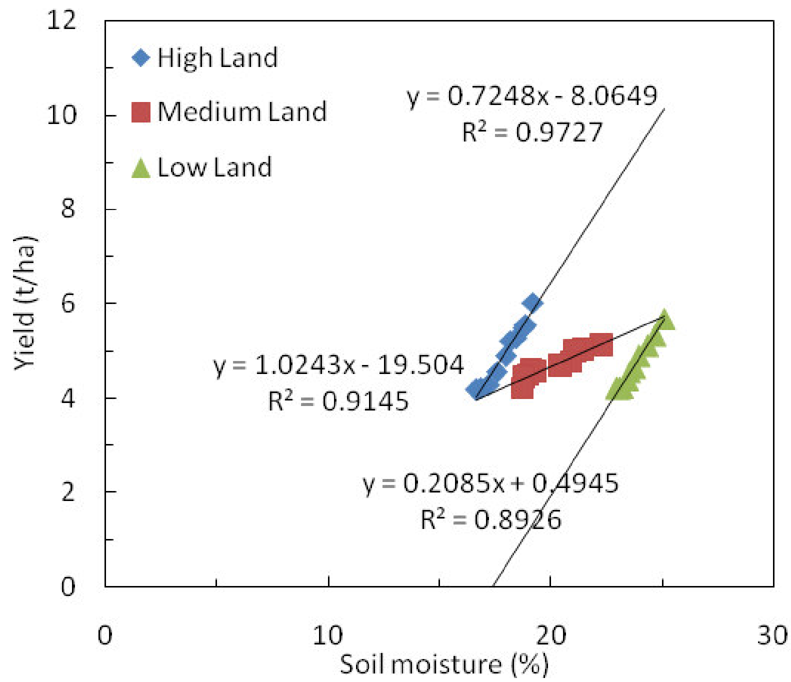

Figure 4. Relationship between percent soil moisture and paddy yield.

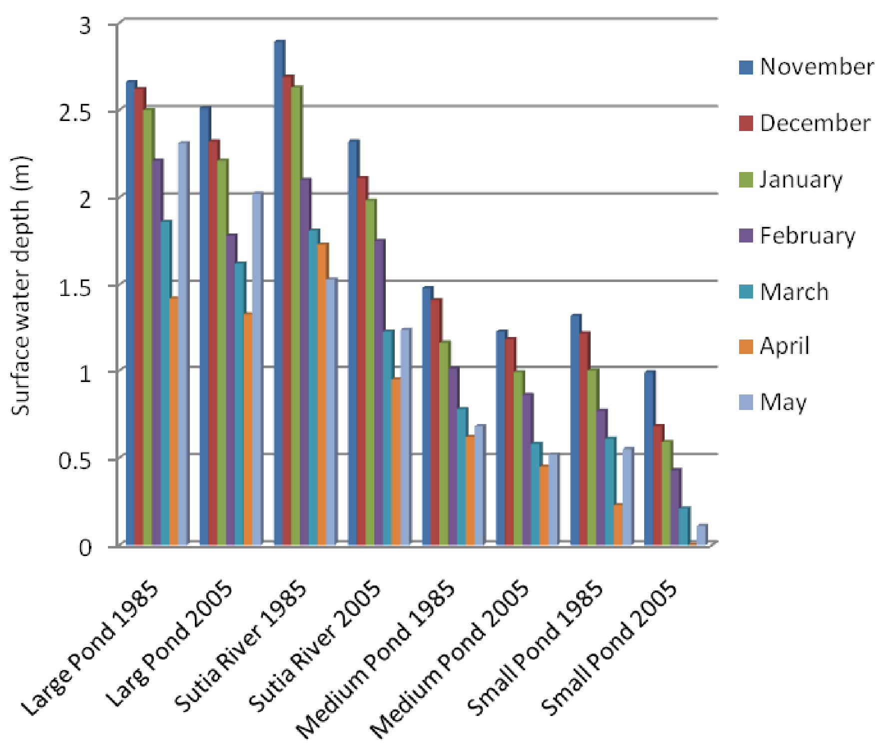

Figure 5. Average depth of surface water resources in the study area.

respectively. This indicates the gradual declination of surface water in the critical period due to lowering of groundwater. The depth of water level in the large pond is higher in comparison to the Sutia River, because in the

Table 5. Yield of boro paddy under different deep tube wells at Trishal upazila.

DTW No.	Area name	Paddy yield (t ha1)
19	Dhanikhola	5.89
27	Bailor	5.31
32	Kanthal	4.78
33	Rampur	4.89
2	Trishal	5.11
36	Kanahari-Baliapara	4.68
166	Mathbari	5.32
7	Sakura	6.02
118	Mukkhapur-Amirabari	4.75
63	Harirumpur	5.67

Least significant difference (LSD) value = 0.39 at 5% level.

Table 6. Potential depletion of crop cultivated area.

Crop	Water requirement (m)	Surface water resource (ha/m)		Water depletion (ha/m)	Depletion of potential cropped area (ha)	Total cultivated area (ha)	Depletion of cultivated area (%)
		1985	2005				
Rice	1.20	277	188.36	88.64	73.87	27589	0.27
Wheat	0.33				268.60		0.97
Potato	0.35				253.26		0.92
Pulse	0.35				253.26		0.92
Mustard	0.27				328.30		1.19

critical period irrigation was given by LLP from the Sutia River. It is noticeable that there was no water in the small pond. The lowering of water depths in ponds and the Sutia River indicate the declining of groundwater table. Evaporation from the ponds and the River Sutia, to some extent, is also responsible for lowering of water depths.

The chemical properties of groundwater, moisture status in the root zone and soil environment affect the crop production. The boro paddy yields under different deep tube wells were markedly different (Table 5). Average paddy yield at Dhanikhola, Bailor, Kantha, Rampur, Trishal, Kanahari, Muthbari, Sakura, Mukkhapur and harirumpur were 5.89, 5.31, 4.78, 4.89, 5.11, 4.68, 5.32, 6.02, 4.75 and 5.67 t ha^{-1}, respectively. The average yields of Baliapara and Amirabari union were same as the Kanahari and Mukkhapur Union. The highest yield (6.02 t ha^{-1}) was found at Shakura and the second highest yield (5.89 t ha^{-1}) was in Dhanikhola, which was significantly different at 5% level of significance. The lowest yield (4.68 t ha^{-1}) was found at Kanahari and Baliapara Area.

Potential reduction of cropping area due to surface water depletion is presented in Table 6. The surface water body of the study area was 277 ha and the average depth of surface water in 1985 and 2005 were 1 m and 0.68 m, respectively. A total 88.64 ha-m volume of water was depleted within 20 years. This results revealed that depletion of potential cropping area for rice, wheat, potato, pulses and mustered were 73.87, 268.60, 253.26, 253.26 and 328.30 ha, respectively, which is 0.27, 0.97, 0.92, 0.92 and 1.19% of the total cultivated area (27589 ha). This indicates that due to depletion of surface water, the potential cultivated area is decreasing day by day which are the consequences of groundwater depletion.

Problems on agro-ecology due to abstraction of groundwater are given in Table 7. The survey results revealed that failure of hand tube wells (HTWs) during April/May, delay in sowing time, soil cracking in critical period, acute shortage of water in the pond, deficiency of oxygen in the ponds and scarcity of water for the domestic animal were reported by 95, 90, 86, 85, 79 and 65% of the respondents. They pointed that specially sowing time, pisciculture and growth of aquatic plants and vegetation were seriously hampered. These occurred due to groundwater withdrawal and delay in rainfall. It is found from survey results that the total number of ponds in the study area is about 2188, among them derelict and perennial ponds are 1560 and 628, respectively. Due to declination of groundwater, water could not come up by capillary action and therefore would not be used by plants. Soil water would be evaporated due to low humidity and relatively high temperature prevailing in the

Table 7. Problems on agro-ecology due to abstraction of groundwater.

Item	Respondents (%)
Problems associated with plants and vegetation	
Delay of sowing time	90
More irrigation water requirement	70
Vegetation in the fallow land is not vigour	60
Problems associated with pisciculture and domestic animals	
Acute shortage of water in the pond	85
Deficiency of oxygen in pond	79
Scarcity of water for domestic animals	65
Problems associated with pumps and soil	
Partial dewatering of DTW	45
HTW failed in the month of April/May	95
Soil cracking occurred in April / May	86
Iron problem	45

study area. As a result the shallow rooted plants and vegetation which are not irrigated might die and the natural plough of farmers like earthworm and beneficial micro-organism also could not continue their life cycle. This might create ecological imbalance in the study area.

Conclusions

The lowest groundwater level dropped below 8 m for two to three months (from March to May) in almost every year for the overall study area. In the dry period 88.64 ha-m surface water depleted within 20 years and for that reason the depletion of cultivated area of rice, wheat, potato, pulses and mustard were 0.27, 0.97, 0.92 0.92 and 1.19% of the total cultivated area. The quality of irrigation water was good on the basis of EC, pH, SAR, SSP, RSBC, PI and TH values. The depth of static water level was remarkably correlated with the percentage of soil moisture and the percentage of soil moisture was correlated with the paddy yield. The soils were heterogeneous ranging from clay to silty clay loam. Sowing time of crops, pisciculture and growth of plants and vegetation were hampered due to heavy abstraction of groundwater. Conjunctive use of both surface and groundwater resources should be carried out in the study area to minimize many of the undesired consequences of groundwater abstraction.

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