SUCCESS RATE IN SINKING DEEP TUBE-WELLS TO SEARCH NEW WATER SOURCE IN THE NORTHERN PERIPHERY OF KHULNA CITY

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ABSTRACT

Water is abundantly available in and around Khulna City for serving several limited domestic purposes depending on the quality assessed by the users of the specific areas. The scarcity of quality drinking water has been prevailing in the human settlement areas of Khulna from time immemorial. There is an old fashion of collecting water from a far distance of about 2 to 3 km due to an inadequate nearby potable source within the city boundary. Historically, the people of the selected area were using water from the ponds, dug-wells, shallow tubewells (ST), and finally deep tubewells (DT) for all the domestic purposes. For the last 40 to 50 years, few shallow tubewells (120 to 400 feet) placed on comparatively better-quality pocket aquifers, are used for drinking purpose. The northern part of Ward No. 1 of Khulna City Corporation (KCC) and Teligati union did not have such good tubewells before 10 to 12 years and the people depended on bad STs or STs of Khulna University of Engineering & Technology (KUET) campus, Fulbarigate, the northern part of Jogipole union and other nearby places. There was a continuous search to bore deeper aquifer for better quality water. In this research, the success rate of sinking deep tubewells, investment and causes of unsuccessful cases were assessed. Further the depth of boring for present and past 10 years were compared. Individual household surveys and focus group discussions (FGD) were conducted in the research which covered the northern boundary of ward no 1 and other two unions namely, Teligati and Jogipole, to fulfill the prime objectives. The investment was compared with the shallow tubewells. Quality drinking water of few selected deep and shallow tubewells were furnished for comparison. The findings show that, the success rate of DTs depending on the right drilling of an aquifer with available storage is 68 (87%) in the study area. The success rate of DTs depending on the quality of drinking water is 55 (81%) for all types such as public, private or community DT. The reasons for the unsuccessful drillings are mainly the poor quality of water and very fine sand in the aquifer. The sinking cost of deep tubewells are ranged between 65,000 to 300,000 BDT respectively depending on the depth of boring and diameter of the tubewell. In case of unsuccessful drilling, 20 to 40% of the total cost is to be spent. The chloride value varies for DT from 21 to 300 with an average of 90 mg/L. Most of the DTs found to contain very less chloride than STs. The chloride content for ST varies from 72 to 2063 with an average of 997 mg/L. In Teligati area 88% of the STs are bad due to very high salinity, Fe, and Mn concentration. The scenario is almost the opposite for Jabdipur and Jogipole areas where 81% of the STs are good to very good category. Excellent WQI is found in most of the DTs having depth more than 1150 ft. Most of the shallow tubewells of depth from 80 to 400 ft have very poor WQI value over 200 due to very high concentration of Fe, Mn, hardness and chloride content. Finally, the successful sinking of deep tubewell is sharply increasing the living standards of the dwellers and growing more confidence to stay.

Keywords: Deep tubewells, shallow tubewells, drinking water, investment, success.

1. INTRODUCTION

Water is abundantly available in and around Khulna City for serving several limited domestic purposes such as bathing, cleaning, washing, depending on the quality assessed by the users of the specific areas. The users usually assess the quality of water by physical test, odor and staining on fixtures, utensils etc. The scarcity of quality water including drinking need have been prevailing in the human settlement areas of Khulna from time immemorial. There is an old fashion of collecting water from a far distance of about 2 to 3 km in absence of any nearby potable water source within the city boundary. Historically, the people of the selected area were collecting water by themselves or by vendors from the ponds, dug-wells, shallow tubewells (ST), and finally after 2010 from deep tubewells (DT) for all domestic uses. For the last 40 to 50 years, few shallow tubewells (120 to 200 feet) with comparatively better quality, placed on pocket aquifer, are used for drinking purpose. The northern part of ward no. 1 of KCC, Teligati union and southern part of Jogipole union did not have such good tubewells before 10 to 12 years and the people depended on bad STs or STs of KUET, Fulbarigate, the northern part of Jogipole union and other places. There was a continuous search to bore deeper aquifer in the above problematic areas for better quality water. In this path of searching better source of water a systematic water quality analysis is necessary by collecting water samples from both DTs and STs. Water Quality Index (WQI) are needed to be determined and compared for the study area. The water quality index (WQI) is a mathematical method used to facilitate water quality explanation (Al-Omran et al., 2015). Water quality indices are suitable tools used for assessing water quality because of their capacity to reduce a large number of water quality indicators into one value which defines the water quality class (Calmuc et al., 2020). The WQI can be calculated for several sources of water including ground water aquifer, surface water and other sources (Naubi et al., 2016; Karim et al., 2018; Mutea et al., 2021). The WQI was considered using several physico-chemical parameters of the collected water samples both from DTs and STs. In this research, the success rate of sinking deep tubewells, investment and cause of unsuccessful cases was assessed. A suitability analysis on shallow tubewells was also discussed.

2. METHODOLOGY

2.1 Selection of study area

The northern part of ward no. 1 of KCC, Teligati union and southern part of Jogipole union did not have any good tubewells before 10 to 12 years and the people of those area depended on bad STs or STs of KUET, Fulbarigate and northern part of Jogipole union. There was a continuous search to bore deeper aquifers in the above problematic areas for better quality water. The search has been found to be successful since 10 to 12 years. Therefore, the northern part of ward no. 1 and 2 of KCC, Teligati union and Jogipole union were selected to study a complete history of success rate in sinking deep tubewells. The success rate was justified in two ways, firstly successful drilling of deep tubewells for good quality of water and secondly high yield of the aquifers. The detail of the study area is shown in Figure 1. The area is very clearly divided as left and right side by a straight line (Rail way line) in Figures 1 and 2. Almost 50% of the left area of Figure 1 was selected for total counting together of DTs and STs to formulate Table 3, and where D1, D5, D6, D7, D8 and D9 are located. The total counting of both DTs and STs to formulate Table 3 were done by household survey and FGD.

2.2 Collection of water sample

Monthly samples of deep tubewell water were collected from 9 locations designated as D1 to D9. Similarly, monthly samples of shallow tubewell water were collected from 9 locations designated as S1 to S9. Most of the pairs of DT and ST locations were very close to each other designated as D1, S1. All the samples of DT and ST were collected on the same day.

2.3 Laboratory Analysis

The water qualities of all the selected deep and shallow tubewells were furnished for comparison. Water quality variations in aquifers were also compared. The monthly water quality parameters including pH, Color, Turbidity, Temperature, Iron, Manganese, Arsenic, Hardness, Chloride, Total dissolved solids, and Conductivity were measured just after collection of the samples. All the analyses were done according to the standard methods in the Environmental Engineering laboratory of the Department of Civil Engineering of KUET.

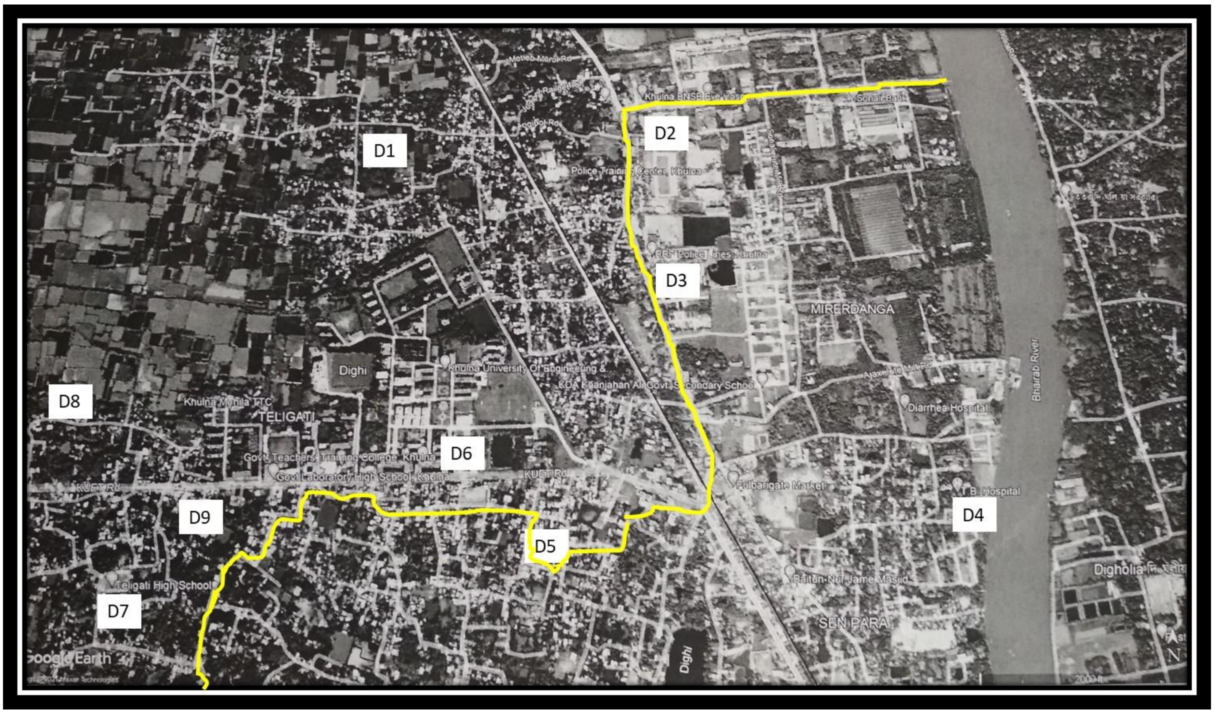

Figure 1: Study area, yellow color is city boundary of ward no 1 and 2. 'D' is the sampling location for both deep and shallow tubewell. The map is collected from google map and modified by the authors as required.

2.4 Water Quality Index (WQI)

There are different types of methods to calculate and compare the WQI. Most of the methods were developed by considering the physio-chemical properties of water. All the available methods published in the literatures were carefully examined and finally the following method was selected.

Water quality index (WQI) can be calculated in different ways for different objectives as extensively mention in the literature (Akter et al., 2016; Sharma and Chhipa, 2016; Mohamed, 2020). In this research the WQI was analyzed for all locations both for deep and shallow tubewells using sample equations as proposed by (Yisa and Jimoh, 2010; Tyagi et al., 2014).

The equations to calculate the relative weight are:

$$\boldsymbol{qi} = (\, \boldsymbol{ci}/\boldsymbol{si}) * \mathbf{100}$$

$$\boldsymbol{wi} = \mathbf{1}/\boldsymbol{si}$$

Where, qi = quality rating scale

ci = concentration of i parameter and

si = standard value of i parameter

Finally, overall WQI was calculated according to the following expression

$$\boldsymbol{WQI} = \frac{\sum(\boldsymbol{qi} * \boldsymbol{wi})}{\sum \boldsymbol{wi}}$$

WQI classifications are expressed as, <50 excellent; 50-100 good water; 101-200 poor water; 201-300 very poor water and >300 water unsuitable for use.

2.5 Household survey and FGD

Individual household surveys and focus group discussions (FGD) were conducted in the study area covering the boundary of ward no 1 and 2 and other two unions namely, Teligati and Jogipole, to fulfill the prime objectives.

The investment was compared with the shallow tubewells. The depth of boring for the present and past 10 years were collected by FGD and compared.

3. RESULTS AND DISCUSSIONS

3.1 Physical and chemical Parameters

The average value of monthly water quality parameters namely pH, Color, Turbidity, Temperature, Iron, Manganese, Arsenic, Hardness, Chloride, Total dissolved solids, and Conductivity are shown in Table 1. The pH value varied for DT from 7.0 to 8.1 and for ST from 5.5 to 7.5. Most of the DTs and STs contained color near the standard value of 15 Pt. Co. The S2, S4 and S8 contained very high color. The turbidity values were within the standard value of 15 NTU for drinking purposes. The shallow tubewells S2, S4 and S8 also contained very high turbidity. The water of DT (average temperature 29.5ºC) was found to be warmer than ST (average temperature 29.2ºC) in the study area. The Fe value varied for DT from 0.06 to 0.29 with an average of 0.2 mg/L and for ST from 0.13 to 3.27 with an average of 1.3 mg/L. The DTs were found to contain lower iron than STs. The manganese value varied for DT from 0.03 to 0.8 with an average of 0.2 mg/L and for ST from 0.08 to 3.15 with an average of 0.8 mg/L. The DTs were found to contain lesser Manganese than STs. Arsenic was found to be nil in all of the DT and ST under observation except ST8. The hardness was comparatively less in DTs than STs. The hardness value varied for DT from 25 to 154 with an average of 56 mg/L and for ST from 63 to 196 with an average of 132 mg/L. Overall, it can be concluded that the hardness is not a problem in the studied area as both DTs and STs contain hardness far below the standard.

The most important parameter of discussion is chloride content in the DTs and STs. The chloride value varied for DT from 21 to 300 with an average of 90 mg/L except DT5, which contained 1384 mg/L. Most of the DTs were found to contain very less chloride than STs. The users of DT5 copiously use the water for all domestic purposes except Drinking. It is reported that, no staining problem has been found on utensils, fixtures and on tiles since 2013 as the average value of turbidity, iron and hardness were far below the standard. The accelerated corrosion problems have been identified on GI pipes especially on joints due to high chloride content. The chloride content for ST varied from 72 to 2063 with an average of 997 mg/L. There are hundreds of STs in the study area containing similar results. The average value of color, turbidity, iron and manganese exceeded the standard range including salinity content as chloride. The users of the STs have been using the water for all domestic purposes including drinking since the 1970s to 2010. In case of drinking, they could carry water from nearby good ST. Sometimes they would carry water from sources 2 to 3 km away from their houses and usually this job is conducted by a paid vendor locally called Paniwala.

The total dissolved solids (TDS) value varied for DT from 355 to 818 with an average of 480 mg/L except DT5, which contained 2555 mg/L. The TDS content for ST varied from 477 to 3935 with an average of 2135 mg/L. The conductivity value varied for DT from 765 to 1600 with an average of 1002 µcm/S except DT5, which contained 3168 µcm/S. The conductivity value for ST varied from 1008 to 6915 with an average of 3925 µcm/S. The chloride values show similarity with TDS and conductivity values and detailed correlations are performed in the future articles.

The users identified some specific major problems while using the water like staining or corrosion on all types of utensils, floor, fixtures etc. due to the high values of chloride, TDS and conductivity specifically in the STs. Using STs water in civil constructions have been creating long term problems on buildings and ultimately it become severe. It is identified that the building masonry surface got efflorescence and MS bars got corroded and finally cracks are formed in concrete. There are lot of incidences of falling pieces of spoiled concrete from slabs and beams of buildings in this study area.

Table 1. Average water quality parameters of 16 sampling points from 28/08/2021 to 10/11/2021.

Sampl-	pH	Color	Turbidity	Temp.	Iron	Mn	As	Hardness	Cl-	TDS	Conductivity
ing Point	-	mg/l*	NTU	ºC	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µS/cm
D1	7.8	35	1.4	29.5	0.09	0.10	0.00	25	36	360	800
D2	7.6	13	1.2	32.4	0.27	0.08	0.00	32	33	365	853
D3	7.0	13	1.1	29.2	0.17	0.80	0.00	76	90	560	1080
D4	7.6	27	2.2	29.7	0.29	0.08	0.00	61	300	818	1605
D5	7.5	38	6.1	30.2	0.21	0.55	0.00	154	1384	2555	3168
D6	7.9	18	2.2	29.1	0.08	0.23	0.00	45	104	485	1043
D7	7.9	14	2.5	27.9	0.10	0.03	0.00	30	43	420	870
D8	8.1	8	2.0	28.0	0.06	0.10	0.00	29	21	355	765
S1	7.0	17	1.1	28.6	0.13	0.83	0.00	93	496	1475	2895
S2	6.6	424	97.9	30.7	3.27	3.15	0.00	174	1320	2750	5225
S3	7.0	13	2.1	29.0	0.16	0.83	0.00	63	72	477	1008
S4	7.2	996	235.0	31.2	2.89	0.10	0.10	116	290	1010	1880
S5	7.1	48	7.9	29.1	0.17	0.68	0.00	161	1515	2345	4303
S6	6.9	16	2.3	29.1	0.17	0.08	0.00	196	1575	3588	6405
S7	7.5	67	7.4	28.5	0.96	0.35	0.06	179	2063	3935	6915
S8	6.5	239	29.0	27.6	2.44	0.30	0.01	79	650	1500	2770

D = Deep tubewell; S = Shallow tubewell; *Pt. Co; Bangladesh Standard si is given in Table 2.

3.2 Water Quality Index (WQI)

The WQI for all DTs and STs were calculated and the results are shown in Table 2 for the sampling point D1. Average water quality parameters of four months data were considered for the calculation. Water Quality Index (WQI) and all other necessary information of all sampling locations for DTs and STs of the study area are illustrated in Figure 2. The information in the upper line of the text box adjacent to D1 is for deep tubewells, the year of sinking, depth in ft, WQI considering ECR 1997 and in bracket (WQI considering Mn standard as 0.4 mg/L according to WHO guidelines). The information in the lower line of the text box adjacent to D1 is for shallow tubewells of S1. A similar explanation is valid for all other locations of D2, D3, D4, D5, D6, D7 and D8 respectively. The text box for KUET shows the information of shallow tubewells of depth 400 ft in upper and lower lines. According to WQI classification, Figure 2 is discussed. Excellent WQI is found in all DTs having depth more than 1150 ft except DT6 with good values. The DT5 with poor WQI with depth 1380 may be in a pocket of bad water formation. The users of DT5 copiously use the water for all domestic purposes except drinking as the average value of turbidity, iron and hardness are far below the standard and collect drinking water from nearby DT with excellent WQI by vendors. Most of the shallow tubewells of depth from 80 to 400 ft have very poor WQI value over 200 due to very high concentration of Fe, Mn, hardness and chloride content of the water as shown in Table 1. One can compare two shallow tubewells of KUET of same depth of 400 ft having WQI of 48 (excellent) and 336 (unsuitable for use) which imply that the existence of small pocket aquifer in KUET area.

Table 2. Example calculation of water quality index (WQI) for the sampling point D1. Units of all parameters are shown in table 1.

Date	pH	Color	Turbidity	Temp.	Iron	Mn	As	Hardness	Cl-	TDS
28/08/2021	8.23	53	1.52	30.1	0.13	0.00	0	27.78	35	260
12/09/2021	7.1	28	0.91	29.8	0.09	0.10	0	23.15	37.5	280
18/10/2021	8.1	36	2.15	29	0.10	0.00	0	23.15	30	410
10/11/2021	7.95	23	1.00	29.2	0.03	0.30	0	27.78	40	490
Average	7.85	35.00	1.40	29.53	0.09	0.10	0	25.47	35.63	360.00
Median	8.03	32.00	1.26	29.50	0.10	0.05	0	25.47	36.25	345.00
Stdva	0.51	13.14	0.57	0.51	0.04	0.14	0	2.67	4.27	109.24
si	8.5	15	10	25	1	0.4	0.05	500	600	1000
qi=ci/si	92.29	233.3	13.95	118.1	8.75	25	0	5.09	5.94	36
wi=1/si	0.12	0.07	0.10	0.04	1.00	2.50	20.00	0.00	0.00	0.00
qi*wi	10.86	15.56	1.40	4.72	8.75	62.50	0.00	0.01	0.01	0.04
∑(qi*wi)/∑wi										4.36

In continuous search for the quality aquifer, after 2010, most of the DTs were installed. It can be seen from Figure 2 that out of nine DT, six are installed after 2010 with a depth of more than 1380 ft. Most of the WQI values considering Mn as 0.4 mg/L according to WHO guidelines instead of 0.1 mg/L (ECR 1997) show theoretically excellent category except ST7, although the user perception does not support this point.

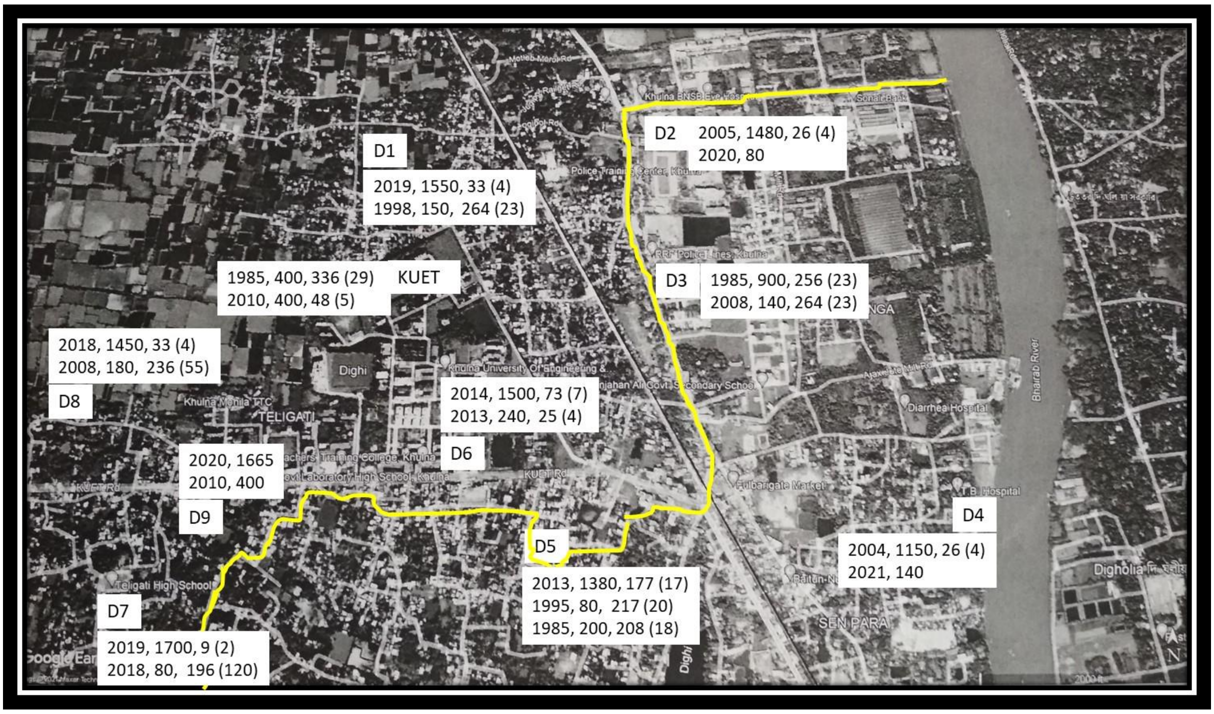

Figure 2: Water Quality Index (WQI) in all sampling locations of the study area. D is sampling point. Year of sinking tubewells, depth in ft, WQI, (WQI WHO for Mn). First line in all text box in figure for deep tubewells and 2nd, 3rd lines for shallow tubewells near to respective ST.

3.3 Details of DT and ST sinking

The details of DT and ST sinking in KUET Campus, Taligati, Taligati maddaha Para, Jabdipur, Jogipole and North Banikpara under the study area are illustrated in Table 3, which roughly cover 50% of the study area. Total DTs and STs in the left area, as shown in Figure 1 and 2, were found to be 68 and 347 numbers respectively as performed by household survey and FGD in the study area. The different quality indicates that the aquifer is not continuous in both shallow and deep levels.

3.3.1 Discussion on DT

The DTs are installed by private owners in their personal yards and by different organizations in private on other lands which are easily accessible to all the inhabitants in the area.

Table 3. Details of DT and ST sinking in KUET Campus, Taligati, Taligati Maddaha Para, Jabdipur, Jogipole and North Banikpara under study area.

	KUET Campus						
	Total No.	No. Bad	Depth ft	Cost in TK	Period day	Person required	Turn to bad
Deep, 2010-2021	5 (3)	0	1300	80000, 150000	8, 10	6, 10	--
Deep, >2010	1	0	480*	--	--	--	--
Shallow	24	20	180, 200	5500, 7000	1,	3,	--
	Taligati						
Deep, 2010-2021	16 (4)	4	1300, 1800	65000, 160000	8, 10	6, 10	--
Deep, >2010	1		1400	35000	8, 10	6, 12	--
Shallow	65	54	125, 600	3000, 25000	2, 6	4, 8	--
	Taligati maddaha Para						
Deep, 2010-2021	21	3	800, 1560	95000, 180000	7, 10	10, 15	2
Deep, >2010	0	0	0	0	0	0	--
Shallow	257	232	300, 400	8500, 115000	1, 2	3, 4	3
	Jabdipur						
Deep, 2010-2021	13	1	1350, 1400	70000, 75000	8, 10	6, 7	--
Deep, >2010	1		1400	35000	8, 10	6,	--
Shallow	70	10	130, 140	5500, 7000	1,	3,	--
	Jogipole						
Deep, 2010-2021	8 (3)	2	1300, 1520	90000, 300000	8, 10	7, 8	--
Deep, >2010	2		1350, 1470	90000, 91000	8, 10	7, 8	--
Shallow	37	10	135, 140	7500, 9500	1,	5	--
	Norht Banikpara						
Deep, 2010-2021	5	0	1275 - 1400	160000	15	15	1
Deep, >2010	0	0	0	0	0	0	--
Shallow	25	20	170 -200	12000	1	5	--

The private owners are also kind enough to give access to others to collect the drinking water from their DTs. From 2010 to 2021 eight points were drilled for deep tubewells in KUET and five were successful. In Teligati twenty points were drilled for deep tubewells and sixteen were successful. After running, four turned bad out of this sixteen. In Jogipole eleven points were drilled for deep tubewells and eight were successful. In Taligati maddaha Para, Jabdipur, and North Banikpara, 21, 13 and 5 points respectively were drilled for deep tubewells and all were successful. The depth of DTs ranged between

800 to 1800 feet depending on the existence of the desired aquifer, mostly settled by the experience of the technicians of the drilling party and finally by the laboratory testing. Among 73 DTs only 5 were installed before 2010 due to less availability of the drilling technology and the cost of installation. Generally, the cost was 35,000 to 90,000 BDT at that time, depending on the depth and diameter of the boreholes. The cost from 2010 to now is 65,000 to 300,000 BDT depending on the depth and diameter of the boreholes. In case of unsuccessful drilling, 20 to 40% of the total costs are to be spent. The number of workers needed to drill DTs vary from 6 to 15 persons. The time needed for boring the DTs varies from 7 to 15 days, depending on the depth, diameter and location of the boreholes. Three DTs had turned bad after use for a time, probably due to saline intrusion in the aquifer. The success rate of DTs depending on right drilling of an aquifer with available storage is 68 (78-10) and 87% (78-10/78) in the study area. The success rate of DTs depending on the quality of drinking water is 81% (68-13/68) in the area. Once the sinking of production deep tubewell is successful, it sharply increases the living standards of the dwellers and grows more confidence to stay.

3.3.2 Discussion on ST

The STs are installed by private owners in their personal yards and by different organizations in private on other lands which are easily accessible to all the inhabitants in the area. The private owners are also kind enough to give access to others to collect the drinking water from their STs. There are 24 STs in KUET and only four have excellent quality. This four have been serving since last 50 years to most of the population of KUET and nearby areas 3 to 4 km apart. In most cases the vendors use Rickshaw van to supply drinking water door to door for 20 to 30 BDT per container of 25 liters. In Taligati, Taligati maddaha Para, and North Banikpara, there are a total of 347 (65+257+25) STs and among them 42 (11+26+5) STs are moderately good. Before 2010, many people of Taligati, Taligati maddaha Para, and North Banikpara used to collect water from STs of KUET, Fulbarigate, northern part of Jogipole union and other nearby sources. Therefore, 88% of the STs in the above areas are bad due to very high salinity, Fe, and Mn concentration till now and the other 12% is only moderately good. The scenario is almost the opposite for Jabdipur and Jogipole area. There are a total of 107 (70+37) STs and most of them are good to very good category and among them 20 (10+10) STs are bad. In this area 81% of the STs are good to very good category and the other 19% are bad. The depth of STs ranged between 125 to 600 feet depending on the existence of the desired aquifer, mostly settled by the experience. Although, a tubewell having a depth of over 500 ft is considered as DT, however, in Taligati there are some STs having depths up to 600 ft with better quality compared to other STs. In sum, the quality of those are also not good. Generally, the cost was 5,000 to 12,000 (25,000 for STs of 600 ft) BDT at the time of installation, depending on the depth of the boreholes. The number of workers needed to drill STs vary from 3 to 5 persons. The time needed for boring the DTs varies from 1 to 2 days (4 to 8 days for STs of 600 ft), depending on the depth and location of the boreholes. Three STs in Taligati maddaha Para had turned bad after use for a time, probably due to a similar cause as saline intrusion in the shallow aquifer.

4. CONCLUSIONS

The chloride value varied for DT from 21 to 300 with an average of 90 mg/L. Most of the DTs were found to contain very less chloride than STs. The chloride content for ST varied from 72 to 2063 with an average of 997 mg/L. There are hundreds of STs in the study area that contain similar results like the above range. The average value of color, turbidity, iron and manganese exceeded the standard range including salinity content as chloride. The users of the STs have been using the water for all domestic purposes including drinking since the 1970s to 2010. In case of drinking, they could carry water from nearby good ST. Sometimes they would have to bring drinking water from 2 to 3 km away from their houses and usually this job is conducted by a paid vendor locally called Paniwala.

The findings show that, the success rate of DTs depending on the right drilling of an aquifer with available storage is 68 (87%) in the study area. The success rate of DTs depending on the quality of drinking water is 55 (81%). The sinking cost of DTs are 65,000 to 300,000 BDT depending on the depth and diameter of the boreholes. The number of workers needed to drill DTs vary from 6 to 15 persons. The time needed for boring the DTs varies from 7 to 15 days, depending on the depth, diameter and location of the boreholes. There are evidences of salinity intrusion in the deep aquifers as some DTs have turned bad later but was initially good. In Teligati area, 88% of the STs are bad due to very high salinity, Fe, and Mn concentrations. The scenario is almost the opposite for Jabdipur and Jogipole area where 81% of the STs are of good to very good category.

Excellent WQI is found in all the DTs having depths more than 1150 ft, except DT5 with poor WQI having depth 1380, which may be in a pocket of bad water formation. The users of DT5 copiously use the water for all domestic purposes except drinking as the average value of turbidity, iron and hardness are far below the standard. Most of the shallow tubewells of depth from 80 to 400 ft have very poor WQI value over 200 due to very high concentrations of Fe, Mn, hardness and chloride content.

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