



Hydrostratigraphic Evaluation using Lithological and Step-drawdown Test: A Case Study on the Aquifer of Ukhia, Cox's Bazar, Bangladesh

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ABSTRACT

Hydrogeological studies on the aquifer of Ukhia, Cox's Bazar, Bangladesh, were performed using well logs and step-drawdown tests to evaluate the aquifer's condition. In two recent boreholes (WDZ.8E.04 and WDZ.8E.02), the impacts of four single-well step-drawdown experiments were studied using Jacob and Rorabaugh's technique. The lithological data analysis of boreholes has indicated that the aquifer in the investigated area is from the early Miocene and consists of upper and middle Boka Bil Formations. Step-drawdown test results showed well losses ranging from 17% to 19.8%, with aquifer losses ranging from 82.6% to 80.2% in two wells, indicating improved efficiency. Specific capacity values ranged from 18.13 m³/day/m to 23.79 m³/day/m for two wells, whereas well-efficiency values ranged from 95.3% to 98.5%, indicating that wells are well planned and installed. The estimated aquifer transmissivity varied from 271.24 m²/day to 263.3 m²/day as measured by wells, exhibiting higher production of water from the tube wells. The existence of aquifer/well-face laminar flow is indicated in the studied area, showing that turbulent flow is negligible. The water-bearing area accumulates a large amount of water. The entire lithological and pumping test approach outlines the successful application of single-well to step-drawdown tests and predicts future safe and sustainable groundwater from well on higher production.

Introduction

The activities of urbanization, the reclamation of the land, and higher agricultural production have increased due to the incredible increase of the human population (Sawant & Shete, 2016). The heretofore unrecognized possibility has been created a harmful condition for metals on freshwater in refugee settlements in Cox's Bazar, Bangladesh (Rahman et al., 2021). Complications associated with the consumption watershed management in refugee settlements in Cox's Bazar, Bangladesh has become a critical issue (Akhter et al., 2020). Based on ethnic detoxification in Myanmar, approximately 1 million Rohingya Muslims have managed to flee to Bangladesh, where they would have found refuge (Chin et al., 2020). The displaced people are housed in the mountainous regions of Cox's Bazar, where there is an insufficient hygiene and sewerage infrastructure leading to the spread of water borne diseases such as cholera, typhoid, and diarrhea. The findings of this experimental investigation describe the potable water security issues

in two Refugee settlements that are part of a larger camp system (Sikder et al., 2020). These activities have increased the groundwater demand, which is continually increasing day by day (Tanjil et al., 2019). Now, it has become a new challenge for supplying safe groundwater according to the population's demand (Ahmed et al., 2019; Biswas et al., 2017). The authors (Hasan et al., 2016; Mahmood & Environment, 2012) have indicated that the groundwater has flowed north to south in Bangladesh. Most of the rivers in the north are connected to the Bay of Bengal (Monir et al., 2011; Monir et al., 2012), and these coastal areas are at a lower elevation compared to the northern lands (Sarker et al., 2018). The coastal area is covered by 19 districts of Bangladesh. The flow of groundwater and elevation, salinity intrusion have been considered the leading cause of potential water resources (Mahmuduzzaman et al., 2014). In the coastal regions, a higher salinity is found at shallow aquifers and as a result, irrigation activities depend on deep aquifer which is a great concern for groundwater resources reported by Rahman et al. (2012). The safe water zone is found in the higher depth of lithological distribution (Mahmood & Environment, 2012). In the dry period (March to August), the water demand became

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acute every year in Bangladesh because the water static table was low (Ahmed et al., 2021). Some researchers (Ahmed, Monir, et al., 2020; Rahman et al., 2012; Shammi et al., 2017) have investigated that this higher increased stress of water demand has been emphasized the inhabitants collect water resources from the higher depth of lithological layers. Moreover, the safe water-bearing zone or saturated zone has been found in higher depth along the coastal district's areas of Bangladesh (Hasan et al., 2016).

The step-drawdown test is considered a short process and moderately simple and cheaper than the other pumping tests because these processes are regulated the highest rate of flow water in a well (Ophey et al., 2019). The proportion of abstraction on the step-drawdown test from the well's water level increases in different numbers of steps (minimum three times) (Abdalla & Moubark, 2018). Well-performance tests have been conducted to estimate the losses of energy in the aquifer and the pumping well developed during the extraction of groundwater. The procedures of pumping well consist of increasing discharge rates (Q) stepwise. Until the drawdown stabilized, every temporary test changes in water levels at every step (Kruseman et al., 1970). Moreover, some researchers (Ahmed, Islam, et al., 2020; Gahala, 2015; Louwyck et al., 2010) studied that the analytical process of the step-drawdown test assists in identifying the quantified aquifer mechanisms that evaluate the flow rate into the well laminar/turbulent. The discharge rate (Q) and time are proportional to the formation's resistance in the water-bearing zone. The well (non-linear) loss has been considered as the parameter of difference between the immediate head of inside and the outside casing during pumping of an aquifer (Driscoll, FJpJS, St Paul, Minnesota, 1986). Jacob's method (Jacob, 1947) has been applied to determine the pumping rate, step-drawdown tests, and the specific pumping rate of an aquifer, which has been considered very easy and low expensive for calculation (Abdalla & Moubark, 2018). According to Jacob's method, Driscoll, FJSP, Minn (1986) have used aquifer loss in the laminar and turbulent period of well loss. Bierschenk (1963) also represented Jacob's method in a graphical interpretation for the determination of well loss and aquifer whereas Logan (1964) and Gabrysch (1968) have proposed the transmissivity estimation method from the loss coefficient of the aquifer. This transmissivity estimation method has been evaluated by various graphical interpretations from the coefficient on well loss. Singh (2002) has been applied this method for the determination of transmissivity (T), step-drawdown, specific recharge depending on the Jacob method (Jacob, 1947). The single-well step-drawdown test and its performance of well criteria (coefficient of well loss, the efficiency of well) provides the estimation of highest

yield under varying conditions of the water-level (Guttman et al., 2017).

The lithology of subsurface deposits, the thickness of aquifer and its depth and hydraulic properties of the aquifer are linked to the hydrogeologic characteristics and potential of groundwater resources in an area. The previous study (Ahmed et al., 2019) has investigated the distribution of groundwater quality and its evaluation on Shagordari, but there is no indicator of lithological distribution and aquifer characteristics. Another study (Chin et al., 2020) has indicated only the hydrogeological condition of Cox's Bazar, but there is no evaluation on pumping rate or well performance related to hydrochemistry. Moreover, several authors (Jahan et al., 2007; Tanvir Rahman et al., 2012) have also identified the depositional environment of the aquifer using gamma-ray well log data. However, there is no evaluation of well recharge. As the water level has been decreasing daily, the water level and the recharge rate of aquifer should be needed for water resources safety. Moreover, the authors (Abdalla & Moubark, 2018; Louwyck et al., 2010) considered the step drawdown (aquifer) pumping and performance tests as the main process to determine the sufficient and accurate assumption of groundwater resources of any aquifer.

This study attempts to evaluate the performance of wells, steps drawdown, and the pumping tests of the investigated area. The main objectives of this investigation are: identification of the safe zone according to various pumping rate, step-drawdown test and the estimation of well performance by the assessment of well loss and well efficiency, the specific capacity of well and determination of optimal pumping rate for various aquifer conditions. This study also evaluated the lithologic characteristics of the aquifer, water-bearing zone and levels of the aquifer zone from the logging data.

Study Area

Location

The study area Ukhia Upazila, Cox's Bazar, is situated beside the Bay of Bengal. The longitude and latitude of the studied area are 92°03' to 92°12' and 21°08' to 21°21', respectively. It is situated on the last corner of Ukhia Upazila, Cox's Bazar, Bangladesh (Figure 1). The well point and geological features of the study area have been plotted by using WEB GIS pattern "ArcGis, version 10.5". The humidity is very high in this area. The study area is disaster-prone. Tidal saline water intrusion is another problem in the studied area. The seasonal temperature variation is around 12 to 42 degrees. The rainy season occurs stay in high time because of the seasonal monsoon every year. Sometimes heavy rainfall is formed by the seasonal characterization of the Bay of Bengal. In summer, the temperatures are also high (over 42 degrees). The borehole areas were selected to reach the maximum water supply without

any risk of flooding away during the rainy season. In the north-western zone, this wellpoint area is one of the most readily available for the water supply in these areas for agriculture. As this area is the coastal part of Bangladesh, safe groundwater evaluation is an urgent need. For example, the water that has been used for the refugee camp for their drinking, sanitation, cooking, and other daily needs.

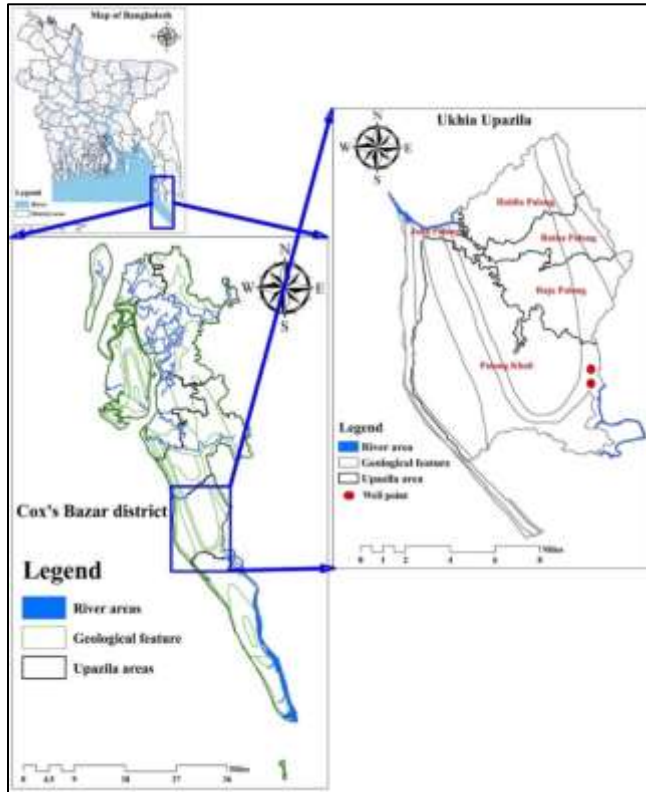


Figure 1: The well point and geological features of the study area

Geological Setting

The studied area is in the youngest structural Indo-Burman Range of the folded flank (Kresic, 2006; Nahin et al., 2019). The majority of the surface area consists of low hills. Its eastern boundary is bordered by low hill ranges (100m heights), while its western boundary is bordered by the Bay of Bengal. The Bakkhali estuary and the Maheshkhali channel are located in the northern and southern regions, respectively. The landform types in this region are classified into two categories: flood plains and coastal plains (or deltas). Dune formations, tidal rivers, and beaches have made up the coastal plain. The floodplain unit is mostly composed of sand and clay.

Methodology

This study was conducted with the Asia Arsenic Network (AAN) in Ukhia Upazila, Cox's Bazar, Bangladesh. This work was run under the technical support of the DPHE, Bangladesh. The AAN has installed two pumping wells in the study area. The field survey of

step-drawdown well tests at the well Nos. W.D.Z.8E.04 and W.D.Z.8E.02 provided static water table and higher water level depths, elevations of ground, lithological and hydrochemical data. These two wells were installed for the improvement of existing safe water supply systems. The identification of safe water, actual well construction, regulation of pumping rate, step drawdown, static water table, lithologic and geophysical setting were monitored during and before the drilling activities.

Preparation of a Well Borelog Drilling

For the drilling of wells, 30" (Well No. W.D.Z.8E.04) and 22" (Well No. W.D.Z.8E.02) temporary casing up to 3m was installed. Soil sample were collected from each 3m interval. All drilling pipes were measured, marked with red tape as an indication of soil sample collection time. These drillings were started on December 07, 2019, and October 20, 2019, respectively. They used 12" drill bit cutters, and the drilling procedure was conducted by Kazal Enterprise. 35 KW generator for power supply, 7.5 HP pump for circulating drilling fluid, semi-mechanical rotary drilling machine with 10-ton lifting capacity, and 2.5inch dia drilling pipes were used. Drilling fluids consisted of local mud and bentonite. All the collected soil samples were adequately washed and stored after marking the depth. The bore log format was observed by AAN hydrogeologist and technical supervisor by checking of collecting soil samples. For Well No. W.D.Z.8E.02, 1st cutting reached 237.80m and found a continuous fine to medium sand layer from 189.02m - 237.80m, whereas the Well No. W.D.Z.8E.04, 1st cutting reached 243.90m and found the constant medium to fine sand layer from 204.27m-243.90m. The water-bearing zone identification or simulation was developed by MATLAB (version 16), modified by Adobe Photoshop (version Ps 17).

Borehole Geophysical Logging Operation

In this study, drilling has been carried up to 244m (Well No. W.D.Z.8E.04) and 235m (Well No. W.D.Z.8E.02) depth and at every 3m interval sediment samples were collected up to drilled depth. After the completion of drilling geophysical logging was carried out in this borehole. Short (16") normal, long (64") normal resistivity (ohm-m), single-point resistance, and spontaneous potential (SP-mv) logging have been carried out. The logging data were collected using logger (MINI LOG-300M) up to the depth of 244m and 235m from the top soil for Well No. W.D.Z.8E.04 and Well No. W.D.Z.8E.02, respectively.

Interpretation of Geophysical Logging Data

The self-potential (mV) and resistivity (ohm-m) data were plotted with the recorded lithology in the log of the two-borehole correlation. In general, the long average resistivity data was found to indicate the formation resistivity of the undisturbed and disturbed

zones. In contrast, short average resistivity data were influenced by borehole wall and mud fluid. The SP and resistivity data were found indicative of lithological boundary or formation of the aquifer.

Evaluation of Pumping Unit Characterization Step-drawdown Test

Originally developed by Jacob (1947) the step-drawdown test has since been improved by Rorabaugh (1953). These investigations have been conducted on the assumption of a homogeneous and limited aquifer. It is anisotropic, with an indefinite spatial expanse and a pumping well that completely penetrates the aquifer. The thickness of the aquifer, static water table aquifers with small drawdown, and its solution has presented by Jacob (1947) and Rorabaugh (1953). Kresic (2006) has revised the full technique for the pumping test, as well as the process for analyzing the results. The step-drawdown experiments were carried out immediately after the completion of the well construction. The coefficients of B and C have been determined to assess the efficiency of the well and the transmissivity of the aquifer, respectively. In this study, the step-test results were assessed using the graphical approach developed by Rorabaugh (1953), the step draw test data have been evaluated. It is the straight-line method of adaptation of Jacob (1947) what we're talking about here. The total drill depths were 235 meters at Well No. WDZ.8E.02 and 244 meters at Well No. WDZ.8E.04. Pumping tests have been carried out at four stages. Satellite maps are developed utilizing other geological and hydrogeological data.

4.2.2. Pumping rate

Jacob (1947) mainly had proposed the relation of pumping rate and the total components of the drawdown of a pumping well by the equations.

$$S_w = (BQ + CQ^2) \quad (1)$$

Where,

S_w = whole drawdown (L; m)

Q = pumping or discharge value (L^3/T ; m^3/day)

B = loss coefficient of aquifer or formation (T/L^2 ; day/m^2)

BQ = component drawdown owing to the aquifer or formation loss with the flow of laminar in the aquifer (L; m)

C = coefficient well loss (T^2/L^5 ; day^2/m^5)

CQ^2 = drawdown component because of well loss or flow of turbulent in the early approach of the well through the gravel pack and screen (L; m)

Rorabaugh has modified the Equation (1) and it has been substituted "n" as a variable of the exponent of the equation on the turbulent flow that has been determined empirically as:

$$S_w = (BQ + CQ^n) \quad (2)$$

The parameter "n" has assumed between the ranges of values of 1.5 and 3.5, based on Q value. But Kawecki (1995) has supported widely accepted ($n=2$) which is

also accepted by Kresic (2006) originally proposed by Jacob (1947).

Specific Drawdown

To convert the Equation (1) to linear form, it has been divided both sides by the yield of Q:

$$\frac{S_w}{Q} = (B + CQ) \quad (3)$$

The specific drawdown has represented by S_w/Q , and it has plotted vs. Q. Then, the points have retreated through the line-of-best fit. The well loss has considered the equality of the slope to the line-of-best fit on the turbulent flow coefficient. The aquifer loss is equal to the line of intercept with the y-axis of loss coefficients of laminar flow in which $Q=0$.

Specific Capacity

The quantity of water is considered the specific capacity (S_c), and it is calculated per unit of drawdown in the well. The yield per unit drawdown has represented simply by it. A stable pumping level has marked it. When recharge has balanced to the discharge, it has established. The parameter of calculation has followed in such equations:

$$S_c = \left(\frac{Q}{S_w} \right) \quad (4)$$

Where,

S_c = specific capacity ($L^3/T^{-1}/L$; $m^3/day/m$)

Q = discharge or pumping rate (L^3/T ; m^3/day)

S_w = total or steady drawdown in the pumping well (L; m)

The specific capacity data has frequently been used to estimate the transmissivity of aquifer in place (Fetter, 2018; Rajmohan & Elango, 2004). Moreover, it is more expensive to regulate the total performance of aquifer tests. However, the data and equations have been applied to identify the transmissivity with its inherent limitations and errors as potential (Gahala, 2015). The partial penetration of well, well loss and hydrogeological boundaries, the values of transmissibility that have been calculated from specific capacity data by an underestimate of actual values effect on the pumping tests unfavorably (Misstear & Beeson, 2000).

Transmissibility Values

Transmissibility values have been used to the evaluation of both the aquifer and well effectiveness characteristics. The empirical relation has derived by Razack and Huntley and also assumed the values of low well loss, a homogenous and porous aquifer of isotropic. The aquifer transmissivity is estimated through the calculation of specific capacity. For porous aquifers in alluvial, Razack and Huntley (1991) provided the empirical relation with simple means of attaining the estimation on the initial stage (Eq. 5):

$$T = \left[33.6 \times \left(\frac{Q}{S_w} \right)^{.67} \right] \quad (5)$$

Where,

T= transmissivity (L^2/T ; m^2/min)

Q= discharge or pumping rate (L^3/T ; m^3/min)

S_w = total or steady drawdown in the pumping well (L; m).

4.2.6. Well efficiency

Efficiency (E_w) is considered the ratio of aquifer head loss BQ (just outside the casing of the theoretical drawdown). In contrast, the total drawdown has been measured as S_w inside the well of pumping. However, it is the ratio of head loss of the laminar flow to the total of the laminar and turbulent flow of head loss. Based on Rorabaugh (1953), it is calculated using equation 6.

$$E_w = \left[100 \times \left(\frac{Q/S_w}{Q/BQ} \right) \right] \quad (6)$$

Rewritten the equation (6), it can be formulated in the following ways:

$$E_w = \left[\left(\frac{BQ}{S_w} \right) \times 100 \right] \quad (7)$$

Values of EW have been considered acceptable as 70% satisfactory by Kresic (2006), and it has indicated in an appropriately designed and well developed. When $E_w=100\%$, the well loss term has identified the values as CQ2 is zero. Several factors have affected the efficiency of wells, the most significant being the drilling process, screen design of the screen, size of the gravel pack, and development system. When screen length is insufficient, the screen openings are too short, incomplete penetration of well in the aquifer, inadequate development of well are the leading cause of low well efficiency. The aquifer pore spaces have been plugged by the drilling fluid and silty and fine materials infiltration. The factor of well development has been indicated by Bierschenk (1963), the well loss to formation loss ratio is 100. Based on Bierschenk (1963) classification, when the development factors are <0.1 , it has represented the reflect "very effective" development, when the values are indicated the ranges 0.1 to 0.5 which means the development is "effective", when the values range is 0.5 to 1.0, it has indicated the development "fairly effective" and when the values range is >1.0 , it is indicated the development "poorly effective." The equation of the development factors on the entire range have calculated as follow:

$$\left[\left(\frac{C}{B} \right) \times 100 \right] \quad (8)$$

Results and Discussion

Evaluations of Qualitative/Quantitative Description of Lithology

Lithologic data have been collected during drilling by sampling at an interval of 1.5/3m. Data on well depths and locations, static water table have also

been collected during field observations and geophysical logging. The water-bearing zone has been identified from correlation of resistivity and self-potential logs and for higher accuracy simulation study is carried out.

Lithological Characterization

Data have been collected through sampling during the drilling and the interpretation of geophysical logging (Table 1) of two wells (Well No. WDZ.8E.02 and WDZ.8E.04). The correlation between the two log interpretations has also been demonstrated in Figure 2. The description of the litholog and the well design has been given in Figure 2(a) and Figure 2(b). From Table 1, in the Well No. WDZ.8E.02, 16 layers have been identified upto a depth of 235m, whereas in Well No. WDZ.8E.04, 10 layers have been identified to the depth of 244 m. The resistivity log values both in the clay layers and in the sand layers are found very high. But resistivity log values in the clay layers are greater than that of the sand layers. The same trend also posses for the self-potential log values (SP log) where values for sand layers are smaller than those of clay layers. Layer 3rd, 5th, 7th, 9th, and 13th of the Well No. WDZ.8E.02 are identified as clay zones. These layers are functioning as the seal of the sandstone. Layers 1st, 4th, 14th, and 18th are fine to medium sand layers and Layers 16th, 12th, and 4th are the medium to very coarse sandstone layers. The 10th and 15th are called the layers of fine sand. The (14th-16th) layers are found as the water-bearing zone of the layers (170-235) m of Well No. WDZ.8E.02, and these layers are found as high permeable fine and medium sand. Moreover, the lithology of Well No. WDZ.8E.04 (Table 1) and (Figure 2a and Figure 2b), there are found 10 layers. Layer 5th, 7th, and 9th are the clay zone with high resistivity and SP log values and are low permeable. It has been interpreted that 1st and 3rd layers are fine with very fine sand, 2nd is found fine to medium sand. In addition, the layers 4th, 6th, and 8th are found medium to fine sand. The water-bearing zone is located at the upper 10 layers of fine to medium sand (Figure 2a and Figure 2b). The main aquifer zone has been found in the 10th lithologic layer in Well No. WDZ.8E.04 and in the 14th-16th layers in Well No. WDZ.8E.02. The main aquifer zone is permeable fine to medium sandstone zone. Depth of the aquifer zone of two lithologic correlation layers are 187m-244m and 170m-135m at Well No. WDZ.8E.04 and Well No. WDZ.8E.02 correspondingly (Figure 2a and Figure 3b).

Table 1: Subsurface lithology with depth range for Well No. Wdz.8E.02 and Wdz.8E.04

Well No.	Layers SI	Depth (m)	Lithology
		From-To	By Layers
Wdz.8E.02	1	25-39.5	Fine to Medium sand
	2	39.5-85.5	Medium to fine sand
	3	85.5-88.5	Clay zone
	4	88.5-100.5	Fine to Medium sand
	5	100.5-103.5	Clay zone
	6	103.5-106.5	Coarse sand
	7	106.5-110.0	Clay zone
	8	110.0-122.0	Coarse sand
	9	122.0-128.0	Clay zone
	10	128.0-143.0	Very fine to fine sand
	11	143.0-149.5	Clay zone
	12	149.5-167.5	Fine to Medium sand
	13	167.5-170.5	Clay zone
	14	170.5-183.0	Fine to Medium sand
	15	183.0-189.0	Very fine to fine sand
	16	189.0-235.0	Fine to Medium sand
Wdz.8E.04	1	15-49	Fine with very fine sand
	2	49-67	Fine to medium sand
	3	67.6-112	Fine sand
	4	112-140	Medium sand
	5	140-152	Clay zone
	6	152-161	Medium sand
	7	161-173	Clay zone
	8	173-183	Medium to fine sand
	9	183-187	Clay zone
	10	187-244	Fine to medium sand

Stratigraphy of the Study Area

The Bengal Basin of the eastern folded belt portion has exposed the molasses sediments of geosynclinals since the age of Neocene, and it has consisted of varying proportions on the shale, mudstone, siltstone, and sandstone. This lithological succession has been subdivided into Surma (Bhuban and Bokabil), Tipam, and Dupi Tila Groups according to the classification reported by Alam (1989). Most of the portions of Bangladesh have been covered by the sedimentary deposits of the Tertiary and Quaternary that thicken larger portions to the south. Cox's Bazar, Ukhia Upazila zone, has been found in the same category (Curry, 1991). The strata of Cox's Bazar has considered as the last part of deltaic Bangladesh. The study area has covered mostly by sandstone and clay layers (Table 2). The southern part of Cox's Bazar city (Ukhia Upazila) has consisted of the sedimentary deposit of Bokabil Formation. However, the majority of this area is covered by Dupi Tila (DT) formation. The 2nd lithological zone of the aquifer is the Girujan Clay of the

Middle Miocene age with constricted extent of subsurface area (Figure 2). The 3rd lithological formation of the aquifer is Tipam Sandstone formation with a larger extent and have been sealed by the clay layers from the both sides (Figure 2). Boka Bil Formation unconformably underlies Tipam group. Boka Bil Formation is considered as the oldest formation exposed in the area (Zakaria et al., 2015). It is found from the field observation and data measurement (Figure 2) that the thickness of the upper sandstone Dupi Tila (DT) formation has expanded from 20m to 140m (sandstone), the formation of Girujan Clay has expanded from 140m to 152m (clay zone). Moreover, the formation of Tipam Sandstone is extended from 152 m to about 183m (Sandstone with clay). The oldest exposed Upper Boka Bil (siltstone with clay or shale) formation and Middle Boka Bil (fine to medium grained sandstone) continues from 183 m to 187m and from 187 to 244 m. The last zone (massive medium grained sandstone) is considered as the water-bearing zone of higher permeability and is covered by upper clay layer.

Table 2: The stratigraphic succession of Ukhia Upazila, Cox's Bazar from two wells (Alam, 1989; Zakaria et al., 2015)

Age	Formation	Litho-Colors	Lithological Description
Mio-Pliocene	DupiTila (DT)	Light, brownish, yellowish and whitish grey.	Sandstone; Medium to coarse grained, massive, ill sorted, highly porous.
Late Miocene	Girujan Clay	Bluish, earthy and whitish grey	Clay; Soft and sticky.
Middle Miocene	Tipam Sandstone	Light brownish, brownish and sometimes bluish grey.	Sandstone with clay; Fine to medium grained.
Early Miocene	Upper Boka Bil (BB)	Bluish to earthy grey.	Siltstone with clay or shale; siltstone tabular concretion.
	Middle Boka Bil (BB)	Bluish grey to grey.	Sandstone; Medium to fine grained, massive.

Characteristics of the Water-bearing Zone

A huge difference is observed between hydrogeological conditions of the study area from other coastal regions of Bangladesh. Transmissivity of the main coastal aquifers has been found in the range of 250 m²/day to 10000 m²/day with an average of 1000 m²/day (Figure 3). Generally, the aquifer storage capacity increases with depth as the grain size of aquifer materials increases. It is suggested (Zakaria et al., 2015) that the thickness of aquifer at different depths and actual hydrogeology of the study area as complex. From Figure 2, hydrostratigraphic (Table 2) sections have been divided into five lithologic parts with the correlation of two wells: (a) sandstone and topsoil, (b) claystone zone, (c) sandstone with clay (d) shale (siltstone and clay) and last (e) sandstone. The main aquifer is of Early Miocene age of the Middle Boka Bil Formation (Figure 2b). The resistivity log responses shows resistivity in the range from 35.6 ohmm to 42.7 ohmm. The cross sections of the actual water-bearing zone of the two different wells have been divided depending on their hydrostratigraphy. The aquifer geometry has been divided into 4 parts from the top to bottom according to the water-bearing condition Figure 2 (a): (1) water table (2) aquiclude (3) aquitard (4) aquifer. The aquifer of the Middle Boka Bil of the Early Miocene age on 184m to 244m depth has been defined as the main aquifer zone of safe groundwater based on the lithological analysis of individual logs (resistivity and SP log).

Pump Installation Characteristics Production Well Design and Development

The proper efficiency of designed well production is depended on well yield, on the construction materials, on casing diameter, on depth of wells and on the screening interval. Lower maintenance and operation costs are the prevailing factors for selection of well design with proper efficiency (Naggar, 2005). The selected diameter of wells is 160 mm which provides the desired percentage of the slotted (open) area in the screen (14% to 19%). It ensures the desired velocity of the pumped groundwater near the screen for minimizing the drawdown and losses of well (Figure 3). It also prevents the migration of sand and clay- or silt-sized particles due to usage of 150mm piping (Smith, 1966). The grain size of the penetrated beds is and selection of slot sizes are depended on the appropriate screen slot size. These prevents entrance of at least 90% of the aquifer substances from the well at the time of pumping. The filter or artificial gravel pack (clean, uniform-sized, well-rounded grains) must be used around the casing and screen of the well (Naggar, 2005). Then it should be sealed so that clogging of the screen can prevent entrance of the fine material in to the well. The well screen design is the determining factors for well productivity and efficiency (Zakaria et al., 2015). The features of the design include screen diameter, length, slot size, and material. The amount of water entering the pipes can be maximized by the proper screen designs and can be minimized by entrance of sediments to the screen (Naggar, 2005). The screen is placed where permeable layers are found. Both the wells at 4th aquifer zone has been found as the confined aquifer with high thickness and been characterized as homogeneous water-bearing zone.

Flow of Groundwater and Water Table of the Study Area

The study area, which is situated adjacent to the Bay of Bangla, has been shown in Figure 1. It is indicated by different authors (Curray, 1991; Zakaria et al., 2015) that the water level is lower in the coastal areas of Bangladesh. The water table has found in the shallowest depth of 28.5m in the study area (Table 1). The water level of Well No. Wdz.8E.04 has been found in moderate depth. On the other hand, the water level of Well No. Wdz.8E.02 has been found in lower depth. The groundwater flow of Bangladesh is directed from north to the south. The safe water-bearing zone has been detected in higher depth due to the topographic variation of surroundings of the study area (Figure 2 (a and b)).

Calculation of Well Loss and Aquifer Loss Coefficient

The aquifer loss coefficient of two wells has been investigated for the study area based on Walton’s classification (Nahin et al., 2019; Walton, 1962). Four

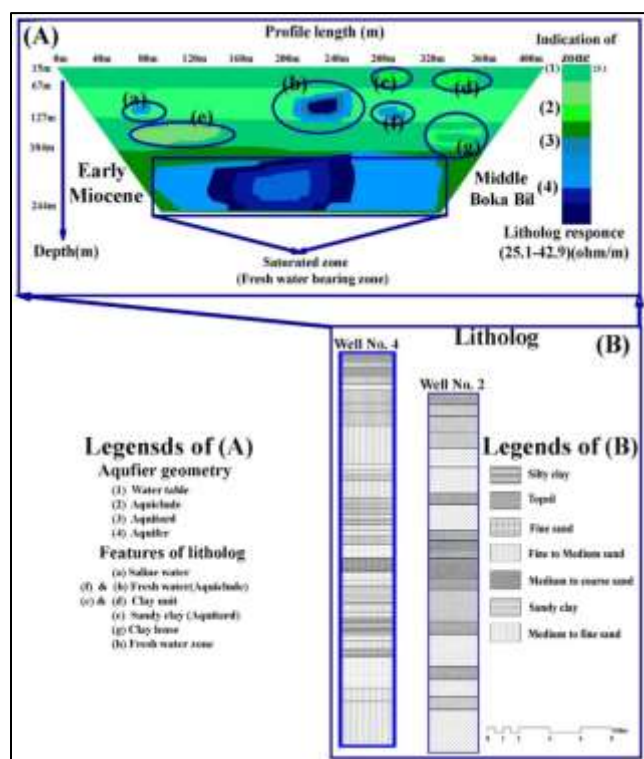


Figure 2: Water bearing zone and aquifer geometry with the lithologic correlation of two wells

steps calculation has been made for the determination of the average loss coefficients (C) of aquifer. The average loss coefficients of aquifer has been calculated as 41.45min/m² and 41.64 min/m² for Well No. Wdz.8E.04 and Well No. Wdz.8E.02, respectively (Table 3 and Figure 3). However, formation loss has been found as 98.95% on average for Well No. Wdz.8E.04 and 99.42% on average for Well No. Wdz.8E.02 (Table 3). Values for loss formation percentages are found higher

than the average well efficiencies percentages for the both well (Table 3). Values of Well efficiencies show existence of streaming flow and laminar of the turbulent flow between the well face and the aquifer area for the both wells. Result predominantly shows that aquifer efficiency is adequate for pumping for the both wells. The well loss for the both pump has been found lower which prove that the step drawdown and specific capacity of pumps is effective.

Table 3: Calculation of hydraulic factors/parameters from step-drawdown pumping tests in Well No. Wdz.8E.02 and Well No. Wdz.8E.04

Step No.	Discharge (Q) [L/min]	Pumping Water level [m]	Observed Drawdown (S)[m]	Specific Capacity Sc (Q/Sw) [L/min/m]	Specific Drawdown (Sw/Q) [min/m ²]	Aquifer Loss BQ	Well Loss CQ ²	Calculated Drawdown (BQ + CQ ²) [m]	Well Efficiency Ew %	Aquifer Transmissivity (T) (m ² /day) (Avg.)
Well No. Wdz.8E.02										
0th										
1st	62	30.14	2.74	22.62	43.19	8.638	0.01	8.651	82.66	
2nd	134	35.48	5.78	20.18	49.64	9.928	0.01	9.94	95	263.3
3rd	174	38.94	8.64	18.13	50.83	10.166	0.02	10.183	97.28	
4th	241	40.53	9.13	21.39	51.23	10.246	0.02	10.263	98.04	
Well No. Wdz.8E.04										
0th										
1st	62	31.14	2.74	22.45	44.19	8.838	1.29	10.13	88.55	
2nd	125	34.48	6.08	20.59	48.64	9.728	1.25	10.98	97.47	271.24
3rd	185	37.94	9.54	20.41	48.13	9.626	0.89	10.516	96.45	
4th	252	40.53	10.13	23.79	49.57	9.84	1.55	11.388	98.59	

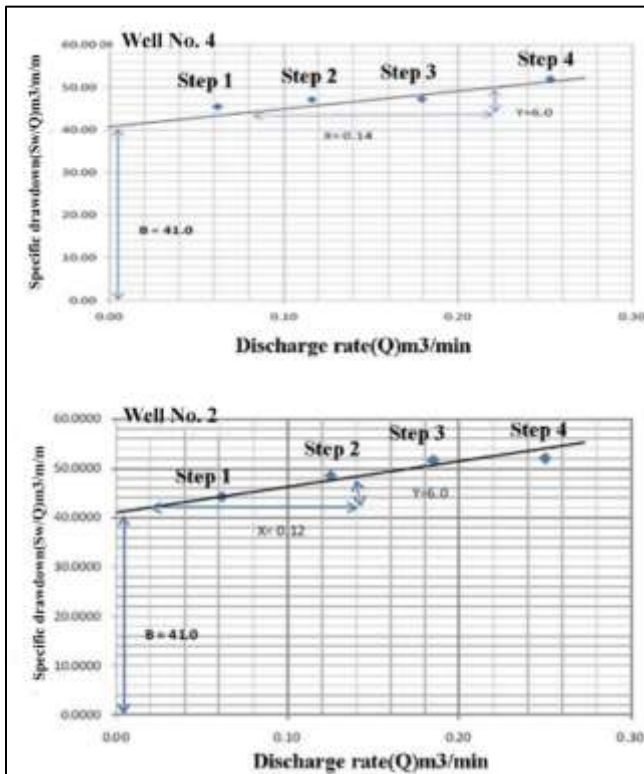


Figure 3: Graphical evaluation of B and C from step-drawdown pumping of test analyses by Sw/Q versus Q graph in Well No. Wdz.8E.04 and Well No. Wdz.8E.02

The Calculation of Specific Capacity and Aquifer Transmissivity

From Table 3, it is apparent that the specific capacity of average step-down test for the both wells has been determined through calculation of Q/Sw max. The specific capacity is inversely proportional to increasing well loss. The particular capacity has been found as 21.81 m³/day/m and 20.56 m³/day/m for Well No. Wdz.8E.04 and Well No. Wdz.8E.02, respectively. Particular Capacity values indicate the shallow levels of pumping water in the study area, which ultimately causes lower cost for pumping.

The values of transmissivity have been calculated from the specific-capacity data 271.24 (m²/day) and 263.3 (m²/day) for Well No. Wdz.8E.04 and Well No. Wdz.8E.02, respectively (Table 3). These values have reflected a very good productivity of aquifer (higher yields) and the high groundwater accessibility by the pumping wells. There are found the smaller differences of transmissivity between two wells, and these wells are found in the same sedimentary facies in different thicknesses and same water-bearing bed. It has been mentioned that values transmissivity has been calculated by specific capacity data and evaluated by the actual (true) values. Therefore, partially penetrating production well, the quantity of well loss, and the presence of hydro-geologic boundaries have been affected.

Well Efficiency Characterization

The average values for well efficiencies are found 95.26% for well No. WDZ.8E.04 and 93.25% Well No. WDZ.8E.02. The higher efficiency of the well reduces the costs of pumping. According to Kresic (2006), the values more than 70% is acceptable for the excellent production of water. The rate of well efficiency is properly designed and developed. The development factor for Well No. WDZ.8E.04 is found 0.0005 and for Well No. WDZ.8E.02 is 0.00725. Both of the wells have been found as very effective in accordance with the Bierschenk's classification (Bierschenk, 1963).

Conclusions

The investigation of the hydrogeologic characterization has been included two single-well pumping tests design. It also indicates the formation (Early Miocene age and Boka Bil Formation) and the safe water zone by the lithologic interpretation. The pumping test has also stated the performance of well criteria and aquifer characteristics. The well performance has been evaluated by applying the graphical analysis of the Jacob methods of formation and well losses from drawdown analysis. The ideal design of the two wells has been developed for groundwater exploration by choosing the accurate model of the screen and the well casing. The pumping test results have also shown the aquifer flow is mainly laminar, but the turbulent flow is highly negligible because the well loss is much lower than the formation loss. The test of two wells has been adequately developed for optimizing the greater effectiveness by removing fine materials from the face of the two wells. The pumping test has helped to build transmission as much of the aquifer's wideness as possible. Higher specific capacity values and transmissivity values (evaluated from the test of particular capacity data) have indicated that the aquifer has higher water productivity. The total efficiency of the two wells ranges from 95.3% to 98.5% suggests that the well designs are proper for higher water production.

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