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Subsurface Lithology and Sediment Texture as Indicators of Groundwater Potential in the Inani Anticline Cox's Bazar

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ABSTRACT

The exploration of groundwater in the coastal folded country should be sensitive to the texture of sediment and continuity of the confining layers. This paper assesses a 240 ft borehole in Inani Anticline region of Cox's Bazar in Bangladesh through lithological log of the borehole, 24 depth-indexed grain-size samples and consistency testing on some samples. Beds of sand are thick within the interval between about 20 to 90 ft. thin sand layers are found at depths of about 100 to 120 ft, with the log fraction varying widely, between about 8.50% and 46.02%. The sample at 170-190 ft and 220-240 ft have comparatively low pan fractions, whereas the 200 ft sample has 32.61%, indicating that the sequence at the bottom is heterogeneous. In the equation in the published values of the plastic limit, the plastic limit is greater than the value of the liquid limit, which provides nonsense positive plasticity indices; the indices produced in the consistency approach cannot be used to aid classification. The log and texture data together identify the candidate deeper sand targets, which are subject to verification by other boreholes, hydraulic tests and analysis of groundwater-quality. The work illustrates the importance of the combination of depth-resolved observations and maintaining a clear line between inferred aquifer potential and measured well performance.

INTRODUCTION

In the coastal region of Bangladesh, there is a need to have reliable supply of groundwater as domestic demand, land use change, and seasonal variability strain the available freshwater resources. In topographical situations, aquifers cannot be modeled as horizontal sheets that are laterally continuous. An effective episode at a single point can end against a clay bed or can jump abruptly in thickness along a branch of an anticline (Sarkar, Alshehri, *et al.*, 2022). In the context of local exploration, the question is thus not just whether or not the sand is below the ground. Whether a sufficiently connected and pervious saturated sand body can be located that can be safeguarded against poor-quality water and drilled to a defensible yield. The interpretation based on the geometry and texture of the sediments is a starting point in hydrogeological interpretation, yet it must be confirmed by hydraulic and chemical methods before quantifying the water resource is made possible (Isa *et al.*, 2022).

The Inani Anticline is a coastal belt fold, which is located in south-eastern Bangladesh. Its tectonic environment, stratism between arenaceous and argillaceous rocks and closeness to marine and estuarine conditions have local groundwater evaluation unusually vulnerable to stratigraphic detail (Sresto *et al.*, 2021). Vertical flow can be delayed by clay and silty clay and form confining conditions. Sand beds can conduct groundwater, but their real conductivities are determined by sorting, packing, cementation as well as the connected pore continuity. The water levels also vary in a well due to natural recharge and abstraction. As a result, a unit of sand is not a pointer

to the existence of sustainable supply of water directly but just a pointer to the potential material of the aquifer. Regional mapping and coastal geology will provide the larger context but in themselves will not identify a screened interval at a given borehole. The interchange of clay, sandy silt and sand tens of feet in depth is an issue which requires resolution through borehole-scale observations (M. Rahman *et al.*, 2021). Grain-size measurements provide a completely independent account of the texture of sediment and can be used to detect changes that lithological labels obscure. When the measurements meet the elementary readings of liquid and plastic limits, engineering consistency tests may be used to complement this interpretation in case the material is fine-grained. The mixed method proves to be particularly beneficial when few field observations are required to make an initial decision regarding the further exploration. This paper transforms a thesis inquiry into a narrow examination of one borehole which was sunk to 240 ft in the site of Bangladesh Oceanographic Research Institute (Sarkar, Esraz-Ul-Zannat, *et al.*, 2022). It addresses three questions. First, what depths are characterized as being mostly fine grained, or sand-laden in the recorded log? Second, the distribution of measured particle-size is sensitive, how does it change with depth and does it favor the log interpretation? Third, what can the reported tests of consistency legitimately contribute to an evaluation of groundwater potential? The contribution is a transparent, depth resolved synthesis that leaves inconsistencies in the underlying records, rather than hides them in a simplified classification of aquifers.

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The discussion differentiates between geological plausibility on the one hand and proven productivity on the other hand. It is a self-assessment of the intervals of candidates instead of estimating transmissivity, storage or sustainable yield. The difference is important in coastal environments: a seemingly beautiful layer of sand may be salty, discontinuous, poorly interconnected or too thin to be reliably abstracted (Alao *et al.*, 2023). On the other hand, a finer unit might have resolved, permselective, laminae that are not distinguished in a sampling interval of ten feet. The study thus considers the borehole as a beginning of a testable hydrostratigraphic model and outlines the measurements required to test that model. The resultant paper is applicable in the well planning of the Coss Bazar coastal belt and other structurally complex aquifers of the same nature.

Geological Context and Analytical Framework

The Inani structure is a part of the Chittagong-Tripura Fold Belt, which is an eastern boundary of the Bengal basin and the compressional deformation (Pande *et al.*, 2021). The thesis outlines a long, asymmetrical anticline that has an approximate northnorthwest to southsoutheast direction. Exposures of sandstones, siltstone and shale are regular with a highly heterogeneous underlying terrain. Fold geometry will be able to change the perceived depth and lateral persistence of individual units. Faults, fractures, bedding contacts could be productive of movement or compartmentalize flow. This architecture is not a map of the whole anticline but a single vertical trajectory that is recorded by a single borehole (Daruwati *et al.*, 2023).

There is a second set of controls which is Geomorphology. The tidal environments and uplands differ with regard to draining and opportunities of infiltration and exposure to saline water in coastal plains (Hsu *et al.*, 2023). Recharge can be provided by seasonal rainfall, but the pathway between the land surface and a deep sand bed is a factor of intervening layers, and the spatial distribution of permeable pathways. A clay dominated cap can shield a deeper aquifer against a faster surface pollution as well as retard local recharge. These two implications cannot be summed up in a single observation of good or bad groundwater potential. Evaluation should be based on the use and time span of abstraction proposed (Mo *et al.*, 2020).

The conceptual hydrostratigraphic interpretation starts with the separation of three properties. Lithology determines the types of strata, and their depth. The texture is a term that defines the composition and sorting of particles sizes on sampled intervals. Hydraulic behavior deals with the flow and retention of water in interconnected pores (Nascimento *et al.*, 2023). The initial two are noticeable by the thesis record. The third is inferential since there are no credible depth-specific hydraulic tests. This division helps avoid one of the most frequent mistakes, to transform textual description into a quantitative statement of well yield without having quantified either discharge or drawdown (Shishaye, 2023).

The anticipated influence of the grain size is conditional. In a relatively clean coarse sand deposit where the beds are unconsolidated, connected pore throats may be larger than a fine particle-filled matrix. Most people are deterred by fines which increase the permeability by stuffing the pore spaces (Sarker *et al.*, 2021). But a fine sand can be well sorted, and still permeable, and cementation may slow down flow through a unit which is nominally coarse. Usable yield is also controlled by layer thickness, extent of saturation and attachment to recharge. Because of this, the existence of even a conspicuous signal of change between clay and sand can only be described as an exploration signal instead of a production estimate.

The shape of distributions is summarized by graphical grain-size statistics. Graphic mean is the average particle size expressed in phi units with the larger the phi the finer the material. Sorting describes spread (Md. M. Rahman *et al.*, 2022). Skew gives an indication of the tail of the distribution toward finer or coarser classes; kurtosis of the distribution describes the concentration in the middle of the distribution. Such statistics can be used to make comparisons across depths, but are affected by the resolution of measurements, the treatment of the fine tail and the percentile interpolation used. Their depositional interpretations are tentative and they should not have the presence of sedimentary structures or lateral facies observations (Thongley *et al.*, 2023).

Measures in the source investigation were put in terms of work on the Bengal Basin and coast-fold belt at the regional scales. This kind of work offers arguments to anticipate lithological difference, yet the local aquifer behavior needs to be validated on site. Regional correlation of sand facies and greater yield is beneficial in the choice of test locations (Hardanto *et al.*, 2023). It does not determine that the sand in this borehole hole is carrying fresh water or that it can support a certain rate of pumping. The existing analytical model thus combines the litholog and sieve outcomes, indicates instances of inconsistency between them and prioritizes intervals solely as subjects of the further testing (Olawuyi, 2021). There is a functional and lithological difference between an aquifer and an aquitard. A clay zone can be more or less effective as a confining unit compared to a nearby sand, but continuity and defects determine its effectiveness as a confining unit (Diallo *et al.*, 2022). In places where coarser laminae are present a sandy silt can convey small amounts of water. Hydraulic continuity cannot be proven by the descriptions of a single log. Thus, the terms aquitard and candidate aquifer in this paper refer to plausible relative positions based on the record available, and not formally tested hydraulic classifications.

The source thesis is also based on research of the coastal groundwater quality and stressed groundwater systems. Those are the topics that are applicable to interpretation but are out of the measured variables in this case (Suliman *et al.*, 2021). The reported tables are not accompanied by any measured salinity profile, major-ion chemistry, bacteriology, series of groundwater-level, or history of

abstraction. The coastal location is not used as evidence of intrusion in the paper. Rather, closeness to saline sources is perceived as an excuse to test the water quality prior to advising on potable use (Fajriati *et al.*, 2022).

MATERIALS AND METHODS

Study site and observational design

It is stated to be located at 21.2995 ° N and 92.0518 ° E in the area of Bangladesh Oceanographic Research institute in the Ramu region of Cox's Bazar. The thesis links the location to the Inani Anticline and outlines a coastal landscape that borders the Bay of Bengal. The method is a single site vertical evaluation. It is unable to generate spatial differences among various limbs or along the axis of the folds. The report of results is in feet to keep the units of the starting log; 240 ft is about 73.2 m.

Borehole logging and collection

The thesis presents a report of percussion drilling of borehole BH1 to 240 ft and collecting 24 depth-index samples at nominal ten-foot depths. Around 0.5 kg of sediment was harvested at a time and bagged to be analyzed in the lab. The lithological table reported has 24 rows with a span of ten feet each. The 110-120 row is marked as 110-1120 which is clearly the typographical oddity considering the previous ones: 100-110 and 120-130. The paper will use 110- 120 ft as the target interval and indicate that. It does not re-interpret the drilled depth to be the row of 230- 240 ft.

Particle-size analysis

The described preparation used consisted of drying samples, followed by pretreatment with hydrochloric acid to eliminate carbonates and hydrogen peroxide to eliminate organic matter, and subsequent oven drying the product. Nominal 100 g subsample was sieved at particle size-distribution limits of about 1, 0.5, 0.25 and 0.125 and 0.063 mm. The mass remaining was weighed in the pan (Hossain *et al.*, 2023). In this paper, pan fraction refers to the material less than 0.063 mm as indicated by the sieve values; it does not differentiate between silt and clay. Even though the methodology states sieve and hydrometer procedures, the depth-based fraction of the tables is sieving classes and a pan class. There are no independent tabulated percentages of hydrometer derived clay percentages.

Sediment statistics

The thesis also reports phi percentiles and calculated graphical mean, sorting, skewness and kurtosis of 24 samples. The following analysis presents reported values as opposed to recalculating them by using raw cumulative curves (Khan *et al.*, 2022). It verifies the consistency between the narrative statements about depth and the tabulated fractions and also whether a result that is claimed to be coarse is upheld by the measured class distribution. Since the records in the sample have rounding and some totals other than 100 g, measurements published are maintained at their quoted accuracy. This is a descriptive

synthesis, without confidence intervals or hypothesis tests.

Consistency measurements

Measurements of liquid-limit and plastic-limit are given at eight different depths, including 10, 20, 80, 90, 120, 130, 140 and 160 ft. The nominal procedure is given to ASTM D4318 and the traditional plasticity index, $PI = LL - PL$. The liquid limit must be no less than the plastic limit of an applicable plastic soil in accordance with standard interpretation. The plastic-limit values provided exceed the liquid limits in all the listed samples (Halder *et al.*, 2021). Moreover, the plastic-limit mean, which is reported to be 120 ft, does not correlate with the individual duplicates on the plastic-limit table. The given PI values can be interpreted as the positive differences in opposite sides to the given equation. To this end, none of the derived liquidity, consistency, toughness or activity indices can be believed to be an interpretable soil property in this manuscript.

Criteria for preliminary interval ranking

The time interval is a better target in follow-up situations when the material in the recorded log consists of sand-dominated material, the fraction below 0.063 mm material is relatively thin and there is sufficient apparent thickness to warrant testing (He *et al.*, 2021). The rank is qualitative. There is depth changes with inconsistent evidence observed in the analysis as well. The criteria are not a substitute for measured hydraulic conductivity, pumping response, grain packing, lithological correlation between holes or water chemistry. This is a conservative method that is relevant in situations where aim is to find out where to explore next instead of asserting an established aquifer.

RESULTS AND DISCUSSION

Borehole lithology

The top 0-10 ft is reported as fine sand containing clay then at a depth of 10-20 ft there is silty clay. Between 20 and 90 ft. here is a continuous zone of logged clay; between 90 and 100 ft. fine sand with hard rock; the account of how it might have been calcareous cemented was not in any way determined (Akinyemi, 2022). Fine to medium sand is approximately timbered at 110-120ft. The bottom of this narrow sandy interval is sloped by 120 to 130 ft of clay and the finer material of the greater part of the interval below the clay. Its thinness on record and an unknown lateral extent preclude a solid conclusion regarding the possibility of extraction.

Between 120 and 190 ft the log varies between clay, clay and fine sand, sandy silt and silty clay. Specifically, clay is recorded at 120–130, 150–160, 160–170 and 170–180 ft, while sandy silt is recorded at 140–150 ft. The 180-190 ft layer is silty clay. This fragment is thus not a unitary continuous clay seal. Field descriptions are lithological categories and could be different to laboratory descriptions of the individual collected samples.

The succession that is the most heavily logged begins with

190-200 ft sandy silt. It continues through coarse sand at 200–210 ft, fine sand at 210–220 ft, fine to medium sand at 220–230 ft and coarse sand at 230–240 ft. The source story transfers these depth assignments by ten feet in one line and cites the material more than 240 ft. The layer table is chosen as the main depth record, as it has 24 successive intervals

that add to the given depth drilled. The bottom 50 ft is thus a sequence of sand-bearing, a sandy silt on the top, not a uniform clean sand.

Downhole distribution of grain-size fractions

The results of the sieve demonstrate significant differences

Table 1: Selected intervals from the BH1 lithological log

Depth (ft)	Logged material	Preliminary significance
0–20	Fine sand with clay; silty clay	Mixed near-surface cover
20–90	Clay	Thick fine-grained interval
90–100	Silty clay	Fine-grained boundary
100–120	Fine sand with hard material; fine to medium sand	Thin candidate sand lenses
120–190	Clay, sandy silt and silty clay	Heterogeneous, largely fine-grained
190–200	Sandy silt	Transition to lower sand sequence
200–240	Coarse, fine and fine to medium sand	Priority interval for testing

Note: Based on the source thesis log; descriptions indicate lithology, not measured groundwater yield.

among and within the logged units. The pan fraction at 10 ft, is 23.58 % of the nominal sample and the fine and very fine sand combined contain about 50.56 %. At 20 ft the pan fraction rises to 39.92%. Through much of 30–160 ft it remains above 30%, reaching 46.02% at 140 ft. The sample at these depths has a significant fine tail in the laboratory sample that agrees with the description that fine-grained lithologies occur in the field, but a sieve pan fraction cannot measure the content of clay mineral by itself.

A drastic fall in the fraction of the pan takes place at 170-190 ft. The recorded values are 20.69% at 170 ft, 9.97% at 180 ft and 9.57% at 190 ft. The 170 ft reading is a bit higher than the 20% and this is not true to the general statement of source where all the samples below 170 ft have less than 20% fines. Further, 170 -180 ft clay and 180 -190 ft silty clay are similarly identified by the labels on the field log and the sieve samples of this area contain fairly low pan fractions

with very large percentages in the 0.063 mm class. The visible disagreement might indicate mixed cuts, variation of depth attribution or disparity in visual descriptions and in laboratory descriptions. The record at hand is unable to tell which of these may or may not be.

The pan fraction returns to 32.61% at 200 ft, although the log places the sandy-silt transition near 190–200 ft and coarse sand at 200–210 ft. At 210 ft the fraction is 16.45%, at 220 ft it is 15.05%, at 230 ft it is 8.50%, and at 240 ft it is 18.69%. These statistics favour a decreasing sequence that is in many cases cleaner than the thick shallow fine-rich interval, but not a monotonic increase with depth. Moreover, the sieve table preponderantly consists of very fine and large sand, even at lower levels. The field designation of the coarse sand at certain depths should thus be verified against the representative core or the cuttings prior to actual screen selection.

Table 2: Selected reported grain-size observations

Sample depth (ft)	Fine + very fine sand (g)	Pan below 0.063 mm (g)
10	49.91	21.15
20	26.40	22.07
80	31.40	23.27
90	31.99	18.25
120	30.43	16.55
140	10.58	32.17
160	28.72	19.08
170	8.95	69.80
180	34.55	54.18
190	32.72	55.56
200	22.94	41.12
210	38.91	40.14
220	16.34	64.18
230	28.22	62.69
240	10.10	70.19

Note. Each laboratory sample was nominally 100 g. Masses are those in the thesis sieve table; proportions are approximate because sample weights and retained totals are not identical.

Reported grain-size statistics

The given values of the graphical means are between 2.52 and 3.61 phi. Majority of the rows are identified using very fine sand and some of them using fine sand. This behaviour is not incompatible with the sieve evidence that the deepest units are not necessarily made out of coarse grains only. The sorting of the reported samples is principally poor in the upper and middle succession, with values of the numerical sorting approaching nearly all between 10 and 160 ft. in the range 170 to 240 ft. the values of the numerical sorting are generally lower with a range of about 0.65 to 1.05 phi. The row of 210 ft is still considered poorly sorted. So, the bottom part is inclined to a broad tendency in the way of better sorting, though the depths of individuals do not follow a simple tendency (Basri *et al.*, 2023).

The majority of the samples have a negative graphic skew, with the 10 ft being slightly positive. Having a negative distributional skew may be defined as a coarseness tail towards larger sizes in the adopted convention. It is not a direct indication of a specific transport mechanism, depositional energy or recharge pathway. The kurtosis values are very scattered, with 4.25 at 230 ft, and 2.69 at 240 ft, which are extremely or very leptokurtic in the source. Peaked distributions of this kind can be consistent with a narrow dominant mode of grain-size distribution, although the given graphic classifications/percentile calculations would have to be checked by the actual original size distributions before one can deduce a particular depositional environment (Ravi *et al.*, 2021). Field and laboratory evidence are most instructive when compared where there is uncertainty in the evidence. The bottom sand layer in the log is associated with bottom pan materials at 210, 240ft and 230ft in particular. The 200 ft pan content and the grain sizes dominated by fine grains complicate any generalization of the fact that the

whole lower unit is a course, uniformly transmissive body. Similarly, low pan percentages at 180 and 190 ft are inconsistencies with fine-grained field labels. Such instances should be repeatedly sampled and better depth controlled. They are conclusions regarding a pact of data; they are not organizational nuisances that have to be left out of the answer.

Consistency tests and validity checks

In the table of derived-properties, eight samples have cited liquid limits of 10-24 % and plastic limits of 94.02-169.27 percent. All the plastic limits recorded are greater than the corresponding liquid limits. Subtracting the standard definition $PI = LL - PL$ results in negative values in every row whereas the source table gives positive values of around 71-170%. The reported derived-properties plastic limit at 120 ft is 185.92% as compared to the duplicate table which reports an average of 92.99%. The single 120 ft values and shown mean in the duplicate table alone begs an independent test with superimposed laboratory worksheets. The use of the derivative indices and classifications is undermined by these problems.

The source thesis uses reported activity and toughness values that are positive as evidence of a soil behavior. Because they are based on an invalid calculation of plasticity-index and (in the case of activity) an unverified clay fraction, they cannot be understood to be measurements of expansive behavior or shear strength. There are no direct shear, consolidation, permeability, porosity or unit-weight results provided in the major tables. In this way, the statements concerning the foundation suitability, compressibility or numerical hydraulic conductivity cannot be determined based on the tests at hand. The samples, chosen with fine-bearing, are to be retested using the laboratory procedure and their raw weights checked.

Table 3: Internal validity check for the reported consistency measurements

Depth (ft)	LL (%)	Reported PL (%)	LL – PL (%)	Assessment
10	18	115.19	-97.19	Invalid ordering
20	23	169.27	-146.27	Invalid ordering
80	10	151.59	-141.59	Invalid ordering
90	16	148.2	-132.2	Invalid ordering
120	16	185.92	-169.92	Invalid ordering
130	24	117.39	-93.39	Invalid ordering
140	17	137.37	-120.37	Invalid ordering
160	23	94.02	-71.02	Invalid ordering

Note: Reported PL values are drawn from the thesis derived-properties table. Negative differences show why the published positive PI and secondary indices cannot be interpreted.

Discussion

What the combined record supports

The strongest observation is the comparison between the upper clay-rich layer which is a thick zone and the deeper layer which shows several logged sand beds. The seven consecutive entries in the field-log between 20

and 90 ft, relate to clay. We have here, due to this long fine-grained succession, a productive shallow screened interval at the borehole in question less plausible than a target in the underlying sand-bearing sequence (Ravi *et al.*, 2021). At around 100-120 ft, there are discontinuities in the succession caused by two descriptions of sand. Their

thinness and their potential to be hard or cemented invite certain tests before they are devised to be developed. An ideal lower first test interval is in the sand-bearing 200-240 ft sequence, where repeat logging proves the material, the material can be separated by screening and water chemistry should be satisfactory.

This ordering is only qualitatively supported by texture. Between 20 and 160 ft the pan fraction is frequently large, and some of the lower samples contain much less material less than 0.063 mm. Fine and very fine sand happen to prevail in many samples, at least those that are considered coarse sand in the field (Naus *et al.*, 2021). The actual exploration program must thus also be on the compatibility of log and sample evidence of each of the planned screens instead of assuming that all the deeper sand labels are such that high permeability is expected. The sample size (200 ft) makes the point. Its comparatively high fraction of its pan could indicate a layer that is high in silt or a problem with the sampling or the designation of depth is required, either of which could be important to a screen set near that depth.

The lithological structure might result in localized or semi-localized conditions in the event that the fine beds are lateral. Continuity or the relationships between hydraulic heads across them cannot be determined on the basis of a single profile (Priya *et al.*, 2022). Neither can it determine recharge areas nor can it differentiate between fresh ground water and saline ground water. The semi-confined term used in the 100 120 ft interval in the thesis is just a hypothesis. It would be necessary to confirm by either separate observation or piezometric measurements above and below the putative confining beds preferably at multiple locations throughout the structure.

Strength and limitations of the grain-size evidence

Grain-size data also offer a handy cross check of qualitative logging. The 24 depth-indexed samples cover the full sequence investigated and reveal within-profile variation which would otherwise be obscured by a plain sand-versus-clay column. They also allow the transparent examination of the fine tail at a certain depth (Sarkar, Alshehri, *et al.*, 2022). Their principal weaknesses are a very sparse vertical sampling compared to potential thin laminae, uncertainty over the true sample provenance during percussion drilling and the use of sieve pan mass and no independent silt and clay separation. Sample mass may also be changed by pretreatment with acid and peroxide and this should be captured with a complete mass balance to be reproducible.

A unique sieve curve cannot be used to deduce the hydraulic conductivity. Empirical grain-size relations have specific requirements, and tend to work disproportionately in nonhomogenous or mixed sediments (Isa *et al.*, 2022). There is no measured conductivity or estimate of the conductivity introduced in the thesis results. The paper thus does not make any numerical classes of permeability, yields or pumping rates of the aquifer. This discipline is particularly crucial whereby there are significant pan

material in some deep samples and the log and sieve ratifications do not agree. The gap should be closed in the next measurement, using slug tests, pumping tests and recovery observations on screened intervals (Sresto *et al.*, 2021).

Interpreting the invalid Atterberg data

Liquid and plastic limits are limits of consistency of a material on which the test can be applied. Any plastic limit exceeding the liquid limit means that at least one of the determinations, unit conversion, label or calculation is on the wrong one. The values of the thesis cannot support the low to medium plasticity values, high positive PI, high activity or weak foundation performance (Alao *et al.*, 2023). The fact of most of the samples chosen being finer than others, does not arithmetically eliminate the problem. Audit should be done on laboratory worksheets, balance readings, moisture-content formula, curve-fitting assumptions and transcription of the date (Pande *et al.*, 2021). Retesting must be directed at the fraction to be used in the standard procedure and note whether a sample is nonplastic at the necessary points.

Another problem is the utilization of the pan fraction as a substitute of the clay percentage. A material with less than 0.063 mm contains both silt and clay and a sieve does not recognize mineralogy. Determined soil activity must have a justifiable clay-size fraction and a legitimate plasticity index. Neither can be found here in a form that upholds the values of the thesis activity (Daruwati *et al.*, 2023). As a result, the evaluation of the ground water needs to be based on the more interpretable log and sieve observations until the geotechnical aspect is rectified. Well construction and near-surface engineering may still have valid use of valid geotechnical testing; only it does not give a confirmed hydraulic estimate in the current record.

Implications for groundwater development

It is a logical site in the lower sand beds where a pilot borehole or targeted well completion could be done. An effective program commences with a repeat lithological log and samples taken with known depth control. Correlation of contacts and determination of appropriate screen intervals may be facilitated with the help of downhole geophysics (Nascimento *et al.*, 2023). There should be at least one nearby borehole to determine the continuity of the candidate unit laterally. The design of the screen needs to differentiate the chosen sand among the fine-rich or salty intervals and consider potential sediment generation. Then step-drawdown and constant-rate pumping tests, followed by recovery monitoring would yield evidence of well efficiency, and transmissivity and operational performance.

Hydraulic testing should be accompanied by water-quality testing. The completed well and, where feasible, depth-isolated samples should be analyzed with respect to salinity, electrical conductivity, major ions and other contaminants of interest (Mo *et al.*, 2020). Monitoring

on a seasonal basis would assist in identifying whether quality and head change with recharge and abstraction. The basis of any recommendation of drinking use should be on actual analysis results, treatment requirements and available standards. Freshwater cannot be guaranteed by either of the two textures or a deeper screen. Once observed, extraction management is to depict observed drawdown, recovery and neighboring users.

Scope and uncertainty

It is one-hole research founded on an internally discrepant thesis. It does not determine the potential of fold-wide groundwater, map the geometry of a regional aquifer or determine the amount of water (Shishaye, 2023). The reported series of samples are useful in determining testable depth targets though the exact depth of each contact can vary when sampled and recorded using more controlled techniques. Field terms like coarse sand are also mixed in the source tables with laboratory distributions having large roots of very fine sand, and the source narrative has some shifted depths descriptions. These are observed differences not averaged.

The substantive contribution of the study is that the chain of inferences is made clear. The description of observed sediments and the mass of the sediments are first compared; only after this, plausible hydraulic roles are attributed. A candidate aquifer is thus a suggestion to further measurement (Sarker *et al.*, 2021). This open chain has the capacity to enhance reporting of research in the small-data coastal studies, when seemingly decisive classification is typically based on unproved jump of grain size to well productivity. It further clarifies if the priorities of further fieldwork: depth control, repeated stratigraphic correlation, hydraulic testing, water quality and corrected consistency measurements.

Depth-specific synthesis of the borehole

The upper ten feet cannot be defined as either an aquifer or an aquitard. The fine sand with clay field description indicates a mixed material whereas the pan mass in the laboratory at the 10 ft sample is less than at various successive depths. Near-surface permeability can be highly fluctuating where weathering, soil formation and movement of seasonal water-table takes place (Md. M. Rahman *et al.*, 2022). All these mechanisms are not measured at this site. The implication of this finding is that the former interval is dissimilar to the thick clay-dominated succession below it, and therefore should not be combined into a broad shallow clay unit. The presence of a shallow domestic supply would also be subject to the questions of seasonal saturation and vulnerability which would not be answered by the current measurements (Hardanto *et al.*, 2023).

The most powerful indication of a fine-grained interval is the seven successive entries of logs taken between 20 and 90 ft. The proportion of pan in tracked samples depths over that range are large, even though not all the material in the samples is less than 0.063 mm. This difference is not

surprising where samples are a mixture of components and field classification involves a dominant lithology label. In case the clay bed proceeds laterally, then it might retard infiltration and might isolate superficial ground water and deeper aquifers. Its restraining influence, however, can be broken down by fractures, or by sand stringers or local thinning (Olawuyi, 2021). That role can be determined only by several logs, piezometric observations.

The range between 90 and 120 ft is more complicated. At 90-100 ft, there is a layer of silty clay and then two sand beds that have been logged. Their environment gives a possible local water-bearing lens, but the data does not indicate whether both beds are wet, or to what extent water can be carried by the hard part of the 100-110 ft description, or whether the hardness decreases the connectivity of the pores. In the table of sources, the pan fractions of the samples that are supposedly collected at 100, 110, and 120 ft are relatively elevated, which are about 40.19%, 41.85%, and 31.42%. These values render the definition of a clean, possibly productive, sand lens particularly unpredictable. A screened test in the future would require a close separation of the clay above and below through proper documentation of the sample source during the drilled sample.

Between 120 and 160 ft the log passes through clay, clay with fine sand, sandy silt and clay. In the sieve series depicted, the 140 ft sample has a large pan fraction (Diallo *et al.*, 2022). The existence of a sandy silt at one depth does not mean that all the intervening profile will have similar hydraulic behavior. Bed alternation can induce vertical anisotropy, whereby flow across layers is more difficult than flow along bedding. The present data do not quantify anisotropy. They do show why a development plan founded on an average value of grain-size in the entire depth would mask the pertinent stratification.

Between 160 and 200 ft, these two types of evidence are the most visibly contradictory. At 190 ft and 190-200 ft, there is a log of clay or silted clay and sandy silt, respectively. The sieve data indicate that pan material decreases dramatically at 170 ft, and that the pan values are fairly low at 180 and 190 ft, after which they switch to a downward trend at 200 ft. One theory is a compensatory relationship between logged depth intervals and sampled depth points; the other includes mixing during percussion drilling (Suliman *et al.*, 2021). The third one is that field-described clayey beds contain sand-sized material. The explanations predict varying screen positions. The proper answer to this is to get a more dependable depth-resolved record instead of choosing the explanation that suits best a model that one may be inclined to favor.

The last 40 ft is the part of the log which is most uniformly described as sand. However, the classes of description are rough, fine and medium sand (Fajriati *et al.*, 2022). Fractions of the sample measured indicate a high concentration of fine and very fine material, especially at 220-240 ft. It might still work fine in well-sorted fine sand and a screened well might work well where sufficient saturated thickness and lateral continuity

exist, but these have not been quantified. Rude field labels must be checked and aperture of the screens should be constructed out of the actual grain-size distribution at the effective depth of construction. Inadequate choice of the screens might allow fines to be infiltrated into the well despite having sufficient water in the regional aquifer.

Measurement priorities for a confirmatory study

The first step is a confirmatory campaign that should determine what was actually drilled and sampled. The changes to the drilling rate, cuttings recovery, flushing, and overlay strata and depth contamination should be noted in the revised log along with the depth of each sample (Motlagh, 2022). The major clay and sand boundaries could be correlated by a second nearby borehole, which would make clear whether the apparent sequence of sand that starts at 200 and ends at 240 ft would continue beyond BH1. A third site that would be particularly helpful in testing the impact of structure would lie along an alternate section of the fold, but the number of holes required would be determined by the accessibility of a site, and the desired volume of abstraction.

Sediment testing must document original mass, mass post-pretreatment, mass retained on each sieve and total recovery in each depth. In cases where the pan component is material to interpretation, there should be a separation of the silt and clay component by sedimentation analysis, or some other suitable technique (Khan *et al.*, 2022). Replicate samples at the controversial 170-210 ft transition may establish whether the sudden changes are reproducible. The mass balance recorded should be used to calculate grain-size curves. independent recalculation of percentiles and graphical statistics could then be made, the interpolation method mentioned. This would provide a more solid ground in the comparisons between the nominal depth points as well as in the choice of a filter pack.

There is a need to have an independent audit of the consistency program. Determinations of liquid-limit and plastic-limit have to be matched on material in the same prepared sample and their unrefined moisture calculations saved. The apparent nonplastic samples should be reported as such and not given a numerical limit (Khan *et al.*, 2022). Should a valid plasticity range be determined, it should be classified in terms of the resulting PI, actual clay fraction and the applicable classification chart. The compressibility or bearing behavior engineering choices would still require tests that were aimed at the properties. Limit consistency indicators are indirect descriptors; they cannot substitute a permeability test, or demonstrate a groundwater yield.

The hydraulic tests must isolate the candidate sand zone and take the pumping rate, water-level response, recovery and test time. When screening upper and lower zones are involved, screened intervals should be closed to avoid cross-flow between (Halder *et al.*, 2021). They could be observed in observation wells to enable a more defensible evaluation of boundary effects and hydraulic

connection. The report of test interpretation should include assumptions and uncertainty since an anticline can have discontinuities which cannot be modeled using homogeneous aquifer model (He *et al.*, 2021). Pre- and post-pumping monitoring would also be able to detect any sluggish reaction in adjacent layers.

Lastly a well to be used as a water supply must be water-quality-analyzed prior to and during trial pumping. Initial overview of salinity can be provided by conductivity and chloride, whereas microbiological and other chemical indicators are based on the intended use and exposure pathways in the area (Akinyemi, 2022). Confounding by drilling fluids or static water in the well should be avoided by sampling. Reoccurrence of the observations at these seasons would be more conclusive than just one observation. The outcome would be that acceptable discharge, water quality and long-term impacts were assessed jointly.

Relevance to coastal aquifer assessment

The Inani example demonstrates the way, preliminary geological evidence can be effective, despite the incompleteness of the evidence (Basri *et al.*, 2023). It reduces the search to an undifferentiated 240 ft profile to only a few intervals into which further testing maximally valuable. The heavy logged clay between 20 and 90 ft, the dubious thin sand beds between 100 and 120 ft and the lower sand-bearing succession are too distinct to direct a step-by-step investigation. However, their ranking is also contingent on the real hydraulic and chemical characteristics of the water bearing formations (Ravi *et al.*, 2021). This conditional interpretation is more helpful to decision makers compared to a numerical rating whose inputs are thus not proven.

Attempts to transfer a well design between another location of Cox's Bazar may also be complicated by local stratigraphy. Where there are variations in fold geometry, a target unit can dip, become narrow/grade to another sedimentary facies. The wells at the same surface elevation can access various levels at the same depth of drilling (Priya *et al.*, 2022). Regional map can be used to frame expectation; however, depth of the screen should come after the unit that is being observed at the specific site. Correspondingly a seemingly protecting layer of clay can possess varying hydraulic continuity around a fault, fold hinge or an eroded surface. These features are not detailed enough in the thesis to be quantified in terms of their effects.

The snapshot of sediment texture does not provide information on sustainable use. The water available over time varies with recharge, neighbour pumping and wet-season and dry-season conditions and potential seawater movement. An effective pumping test would offer crucial information because long-term monitoring would be required in case abstraction is important (Sarkar, Alshehri, *et al.*, 2022). The quality and quantity of water must be looked into together: well, dug technically productively can produce water that is not suitable to its intended use.

The analysis of the sediment thus takes a definite position in the chain of evidence, between the geological context of the region and evaluation of operations.

The data checks in the article are applicable outside this site. A huge typographical mistake like a misplaced zero may be taken up in a log; this mistake can alter the apparent depth of an entire unit. The tabulated index may be of the wrong sign with a narrative nevertheless interpreting it as physically meaningful (Isa *et al.*, 2022). It is possible that a general statement of all samples, below a threshold, may fail at one or more of recorded depths. Such issues can be diagnosed by clear contrasting the initial tables. Their correction strengthens the claim of the research without the need to make an assumption that the entire field program was not valuable. In the present case, the sound portion of the evidence justifies a tentative but operative question, which is, is there a continuous freshwater-bearing unit in the lower sand beds that has an adequate hydraulic performance?

Interpretation of uncertainty and practical decision thresholds

A justifiable exploration decision must provide an indication of what evidence would shift the prevailing position. Repeat logging would make the deep interval a realistic production goal, provided there was connected, thick enough sand, and interval-specific pumping demonstrated reasonable drawdown and recovery; and representative water samples were of the desired quality (Sresto *et al.*, 2021). On the contrary, coarse content of the proposed screen, fast minimal duration of draw down, continued formation of sediment or intolerable salinity would undermine the argument. They are quantifiable and not qualitative statements of confidence. They also show the argument not to be circular in the sense that a unit of sand is referred to as an aquifer simply because we had anticipated an aquifer.

The uncertainty can be classified as observation, interpretation and extrapolation. Sample mixing, weighing and ambiguous depth labels are some of the uncertainties of observation. The issue of interpretation uncertainty is on the relationship between a measured size distribution and the associated pore space and whether the lithological name is representative of the same material as the sample. Extrapolation uncertainty starts as a borehole is moved to depict the larger anticline. The former can be minimized using better collection and laboratory controls; the latter using direct hydraulic tests; the third by further spatial sampling (M. Rahman *et al.*, 2021). Every remedial measure must be selected according to the uncertainty that it deals with. Redoing the sieve interpretation at a single depth, such as, would not indicate continuity laterally.

The ranking proposed is also responsive to the extent of saturation of the lower interval. The depth of drilling cannot determine the level of water, or the hydraulic head of a closed unit (Alao *et al.*, 2023). A 40 ft sand carrying section is not required to provide 40 ft of effective saturated thickness in a finished well. Neither can the

levels of water in an open borehole be safely attributed to any of a number of intersected layers. Piezometers would be used separately or independent interval to explain head distribution. Information of this kind can be used in understanding possible leakage over fine beds and in the interpretation of any response of pumping.

Another group of choices that the thesis could not answer is that made by well construction (Pande *et al.*, 2021). The screen can be positioned between layers of varying quality or mobilize the fines of the least stable layer, by placing the screen across several layers. Note should be taken after a confirmation of the depth-specific distribution of the grain that the screen and filter pack are to be specified, rather than based on a single average particle size of the entire lower sequence. Seals and screened lengths must be documented on completion records to allow future interpretation of water-quality changes or drawdown changes. A pilot well that is well documented can thus work as a test of supply as well as an observation point to be used later on the investigation.

Management wise, the first evidence will be best suited to be prioritized. The BH1 outcome can be used by a public or institutional water-supply project to warrant investigations of the lower portion of the section in detail, and to prevent treating the thick upper clay as a self-evident shallow object. It is unable to make use of these findings to guarantee a day supply quantity or potable water. Such commitments must be based on test data, which is verified, service demand and continuous monitoring (Daruwati *et al.*, 2023). Explicitly establishing the boundary of this study renders the study more practical in application since it can determine the conditions within which an initial geological discovery can justify a definitive investment decision.

Research reporting implications

We can also learn in this case that computed indices ought to be verified by their respective equations before they get into an abstract or conclusion. A derived number may seem accurate but be invalidated by an elementary inconsistency in its inputs (Hsu *et al.*, 2023). The issue can be exposed by reporting the liquid and plastic limits and the index derived; it will be hidden by indicating the index only. It is the same with depth assignments. The description (graphical or narrative) must be compared to the original row intervals, especially those where the reported borehole depth and the estimated aquifer boundary are separated by one sampling interval.

An updated field report must maintain the original measurements but reflect the corrections separately, indicate the evidence of the correction and its impact on interpretation (Mo *et al.*, 2020). An unambiguous typographic correction should be accompanied by an explanation. Unclear laboratory findings, as opposed to them being just quietly overwritten with reasonable figures. This will assist future researchers in the determination of a real geological boundary and an error that has occurred during the recording or writing of the manuscript. It

also enables a subsequent result of a pumping-test to be compared with the original stratigraphic hypothesis without altering the historical record.

The current analysis possesses a certain evidentiary power: the depth pattern in question may be reconstructed based on the registered tables. The numerical description is not provided as evidence of hydraulic performance. It is given as an imprintable excuse to evaluate specific periods and to reconsider certain inconsistencies (Shishaye, 2023). That difference is central to a considering journal record of an investigative borehole. A more robust publication in the future might combine refined texture and consistency tests to mapped geological segments, screened-well tests and chemical profiles to determine whether the considered lower unit is coherent and useful.

CONCLUSION

The BH1 log outlines a thick clay-based interval between some 20 and 90 ft, a thin sand-bearing interval between 100 and 120 ft and a lower sand bearing succession between about 190 and 240 ft. The sieve record in general encourages the investigation of the deeper sequence, albeit with significant heterogeneity, such as a higher fraction of fine sand at 200 ft, and nonconcurrence with the field log at other depths. The deeper sand beds are not candidate targets to be verified as a high yield or potable aquifer.

There is an inherent ordering error in the reported Atterberg measurements, all of the eight samples have higher plastic limits than liquid limits. The positive indices of plasticity and the dependent calculations obtained are invalid concerning the given equation. They should be verified with original laboratory records and recalculated prior to being placed in any type of geotechnical classification. The high priorities in the immediate field include a second borehole correlated, controlled depth sampling, interval specific hydraulic tests and water-quality test. These would transform a plausible lithological interpretation - into a defensible well siting and management in the Inani coastal environment.

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