DEEP TUBEWELL SINKING PROCESS AND A THIRTY-YEAR ANALYSIS OF SUCCESSIVE DEPTH VARIATIONS OF DEEP TUBEWELLS: A CASE STUDY IN WARD NO. 1 OF KHULNA CITY

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ABSTRACT

This study presents a longitudinal analysis of deep tubewell (DTW) installation practices and depth variations spanning 30 years (1990–2024) within Ward No. 1, located in the northern periphery of Khulna City, Bangladesh. Deep tubewells are widely recognized as the principal source of potable water in this densely populated coastal region. The research documented a deep tubewell sinking process and quantified the temporal trends in installation depth among 20 sampled wells. The analysis revealed a significant, successive increase in required sinking depth over the past three decades, reflecting a crucial hydrological adaptation strategy undertaken by the local community. The average depth of installation has steadily trended upward, driven by the necessity to bypass shallow and intermediate aquifers increasingly compromised by saline water intrusion and heavy metal contamination. Crucially, the analysis demonstrated a positive correlation: the deeper sinking depths achieved in recent years led to a marked improvement in water quality. This improvement is evidenced by more favorable Water Quality Index (WQI) scores and substantially reduced concentrations of critical contaminants such as Chloride, Manganese (Mn), and Iron (Fe), thereby confirming the efficacy of deep drilling as a necessary and effective adaptation measure for securing safe drinking water in the rapidly degrading coastal hydrogeological environment.

Keywords: *Deep Tubewell, Groundwater Salinity, Sinking Depth, Khulna City, Aquifer Contamination.*

1. INTRODUCTION

Khulna City (Khulna, Bangladesh) faces chronic water scarcity, especially in newly urbanizing northern zones. The city's southern part has long-established piped water infrastructure, but the north is rapidly expanding and lacks municipal supply, forcing reliance on ponds, shallow dug wells, and tubewells. Ward No. 1 (Teligati and Jogipole Unions) is such a northern area where groundwater is the primary source. Surface water is contaminated by trash from homes and businesses, making most freshwater unusable (Chakrabarty & Bari, 2025). However, saline intrusion from the nearby Bay of Bengal has increasingly contaminated shallow aquifers, rendering many shallow wells undrinkable. As a result, residents and vendors now obtain drinking water from privately sunk deep tubewells, which tap freshwater at greater depths. Over time, engineers in this region have had to drill ever-deeper wells to find acceptable water (Bari et al., 2014).

In Bangladesh, groundwater contamination by arsenic and salinity has led to a shift towards deeper wells. Studies in the Bengal basin show widespread shallow aquifer arsenic, motivating deep wells for safe drinking water. Kundu et al. (2016) and Chakraborty et al. (2015) discussed how deep tube well technology became dominant for arsenic mitigation in rural Bangladesh. In coastal Khulna, however, salinity is the prevailing issue: Islam et al. (2020) and Mahmud et al. (2020) have documented high salt concentrations in Khulna aquifers due to tidal intrusion. This saline contamination is so extensive that in some parts of the coastal belt, fresh potable water may not be found even down to 1200 feet, forcing inhabitants to seek distant water sources (Ravenscroft et al., 2013). Climate change impacts, such as sea-level rise and extreme weather, exacerbate saltwater proliferation and saline front extension in the Bengal Delta, further stressing water resources (Ashrafuzzaman et al., 2023). This has led farmers and residents to sink deeper wells over time.

Locally, Bari et al. (2022) assessed 484 deep tubewells in northern Khulna and found a 68% success rate in drilling new wells; they noted that deep wells generally had lower chloride levels than shallow ones. Their findings support the view that deeper aquifers are less saline. Other socio-technical analyses (e.g. Naus et al. (2020)) show communities prefer safer water sources when available, and are gradually shifting from unsafe pond water to options like deep wells. Research on tubewell irrigation by Patle et al. (2023) and groundwater depletion by Bari et al. (2022) indicate that intensive groundwater use can lower water tables, which may also contribute to the need for deeper drilling. The deep tubewell sinking process commonly employed in the unconsolidated sediments of the Bengal Delta, particularly for depths ranging up to 300 meters or more, is the manual percussion method, often referred to as "sludging" (Khan et al., 2023). This technique involves moving a hollow pipe (bamboo or steel) up and down while simultaneously using a one-way pumping action. Water is circulated through the borehole annulus, bringing debris (sludge) back up the pipe.

The main advantages of this method include its reliance on low-cost, locally sourced materials and its simplicity of use (Ashrafuzzaman et al., 2022; Chakrabarty & Bari, 2025). Despite its low cost, this method faces technical limitations. The presence of stony layers at depth, which sometimes occurs below 250 meters in some areas, can entirely inhibit sludging operations. When drilling is stopped by a stone, specialized hammering tools must be used to break the obstruction before standard sludging can resume (Kinniburgh & Smedley, 2001). While deep drilling addresses immediate quality issues, it introduces long-term sustainability risks. Studies indicate that the piezometric pressure of the deep confined aquifer in Khulna has decreased, signaling a reduction in the recharge rate (Zahid, 2018). This suggests that complete reliance on the deep groundwater source may not be sustainable in the long term, particularly given projected population growth, necessitating careful monitoring and integrated resource planning. Chakrabarty & Mohiuddin (2024) conducted a techno-economic analysis to evaluate the feasibility of a small-scale rainwater harvesting (RWH) system for producing drinking water at the KUET campus, emphasizing both technical efficiency and economic viability. Their findings revealed that the proposed system, with an optimal tank size of 6 kL and a 1500 L/day filtration rate, is not only capable of supplying reliable drinking water but also demonstrates a payback period of one to two years, confirming its sustainability and cost-effectiveness (Chakrabarty & Mohiuddin, 2024). Despite these insights, few studies have tracked how installation depths have changed over time in Khulna. This study builds on prior work by focusing explicitly on the sinking process and long-term depth variation of deep tubewells, rather than solely on quality indices or health outcomes. It uses field data from Ward 1 to relate depth trends to known contamination issues.

This paper investigates the sinking process of deep tubewells and the variation in installation depth over roughly three decades in Ward 1 of Khulna City. By analyzing empirical data from local tubewells and directly observing a drilling operation, the study documents how the required depth has increased. The objectives are to describe the tubewell sinking methodology, quantify depth vs. installation year trends, and interpret why newer wells must be deeper. This focus on depth trends (rather than detailed water quality analysis) fills a gap in understanding how aquifer conditions in Khulna have forced changes in well construction practice.

2. METHODOLOGY

2.1 Study Area and Well Survey

Ward No. 1 (covering Teligati and Jogipole Unions) in the northern periphery of Khulna City, as shown in Figure 1, was selected due to its water-supply challenges. A preliminary survey identified approximately 385 tube wells in Ward 1, of which 127 were deep tube wells. From these, twenty operational deep wells were chosen for analysis, ensuring a range of installation years (1990–2023) and geographic spread. The locations of the selected 20 deep wells are shown in Figure 2. The well owners were interviewed to record each well's installation year and sinking depth. Wells with incomplete or unreliable records were excluded and replaced by others with verifiable data. The collected data on depth and year were plotted to examine trends.

2.2 Observation of a Tubewell Sinking Process

A practical observation of a deep tubewell sinking process was conducted over seven consecutive days in the Jabdipur area within the Jogipole Union of Ward 1. The observation allowed for detailed technical documentation of the customary process.

3. RESULTS AND DISCUSSION

3.1 Tubewell Sinking Process

An in-field observation was conducted for one deep tubewell being sunk in Jabdipur (Jogipole Union), as shown in Figure 3. Over seven days, the drilling operation was documented. The site (≈15 ft × 20 ft) was prepared with drainage channels and staging areas for equipment. A three-legged bamboo derrick was assembled at the bore site. Twenty-foot lengths of cast-iron casing (6-inch diameter) were used for drilling. The first pipe was lifted via the derrick and set over the borehole. Two operators rotated the pipe; with each turn, the pipe advanced downward by a small amount. When one section was nearly fully driven, another 20-ft section was added by manual coupling.

Pumping water from an adjacent pond was used continuously: pumped water was introduced into the borehole to fluidize cuttings and allow slurry to exit through the rotating pipe. Approximately every 50 ft of depth, soil samples were retrieved by stopping drilling and extracting material from the borehole. These samples were visually inspected by the supervisor to gauge lithology and water quality. After driving 1000 ft of casing, it became evident that the aquifer remained predominantly sandy (low arsenic risk) but increasingly saline and iron-rich. Drilling proceeded until 1380 ft depth, at which point the extracted water tested acceptable for drinking.

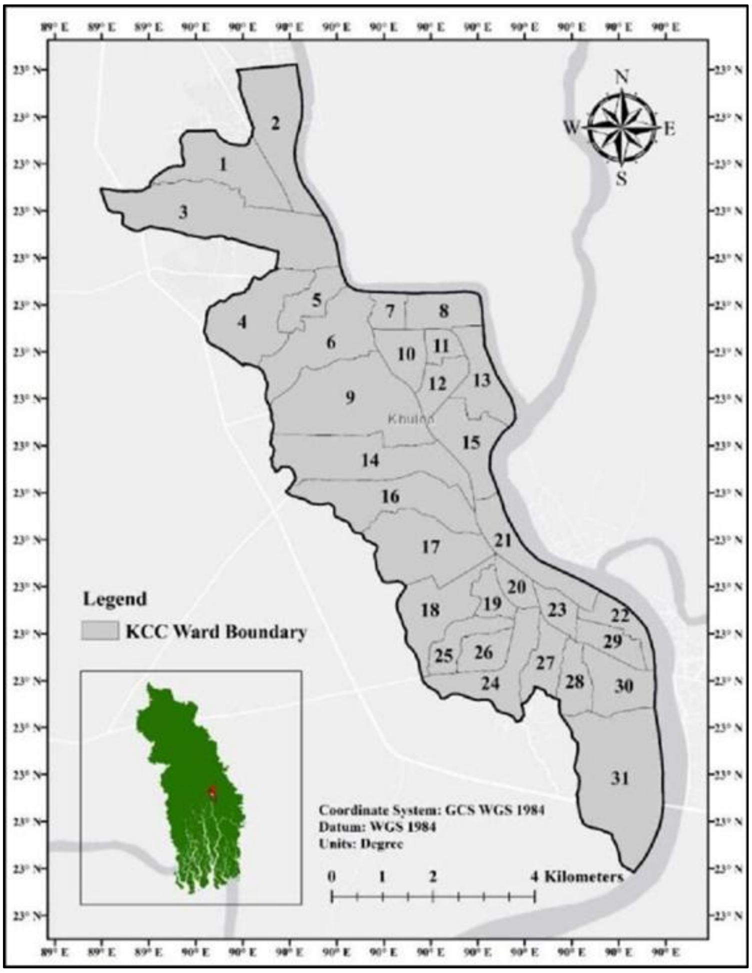

Figure 1. Location of Ward-1 of KCC

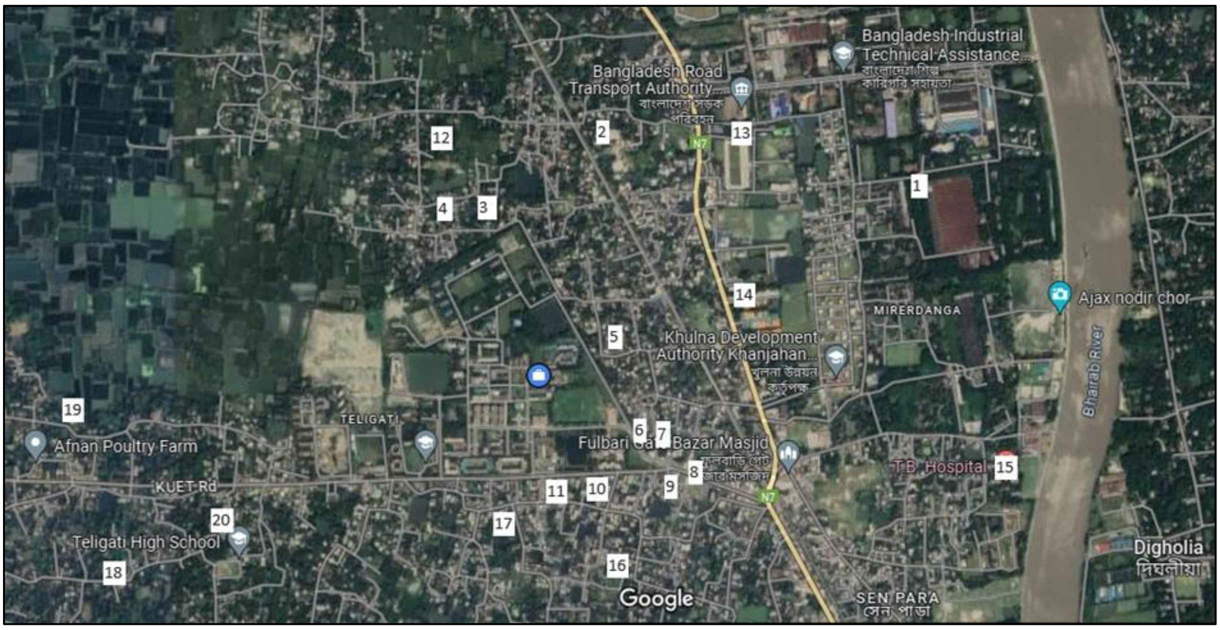

Figure 2: Locations of All 20 Deep Tubewells

Once the target depth was reached, the cast-iron string was withdrawn. A PVC liner (Class D, 20-ft lengths) was then installed from bottom to top. Before insertion, the lower end of each PVC section was flared slightly by hammering to form a tight joint with the preceding section. A stainless-steel slotted screen was attached to the first PVC segment. The liner was lowered section by section until the final section was secured at ground level. To prevent collapse of the annulus, ten sacks of bentonite clay were mixed and poured around the casing as a filter pack. Cow dung was noted as a local alternative if bentonite were unavailable. The casing was clamped at the top for support, and the wellhead was completed. The observed costs totaled approximately 90,000 BDT for 1380 ft (including materials and labor). The process observed was consistent with conventional deep-well drilling practices in the region.

Figure 3. Deep Tubewell Installation Process

The documented sinking process followed standard practice. After site preparation, the borehole was advanced by rotating and driving sacrificial steel casing, using a surface-mounted rope and pulley system on a bamboo tripod. Ponds served as a wash water supply to remove cuttings. Periodic sampling allowed geologists to decide the optimal termination depth based on lithology and water quality. Once drilled to final depth, the steel casing was extracted, and permanent PVC casing was installed with a sand-packed filter zone and bentonite seal. This procedure is consistent with guidelines for deep well construction in Bangladesh, ensuring structural stability and isolation of confining layers. No anomalies were observed; the method was deemed “correct” and efficient.

From the cost perspective, the supervisor reported total expenditures (tubewell materials, labor, and bentonite) on the order of 90,000 BDT for 1380 ft of well depth. Labor costs dominate, and careful management of drill string count and casing is required to minimize expenses. Such high costs per well are a key factor in the 32% deep-well failure rate noted by (Bari et al., 2022) When a drilled bore fails to yield sufficient water. However, this study's success confirms that, if correctly sited, deep tubewells are sustainable investments, providing potable water from a once-elusive aquifer.

3.2 Technical Analysis of Deep Tubewell Installation

3.2.1 Process Efficiency and Cost-Effectiveness

The observed deep tubewell installation, utilizing the conventional sludging method, demonstrated notable economic feasibility, a critical factor enabling decentralized water access for private households and small industries. The total cost for the 1380 ft installation observed was estimated at 90,000 tk (BDT), as detailed in Table 1. This cost structure indicates that the technology remains relatively accessible compared to complex mechanized drilling techniques.

The primary expenses included 42,000 tk for the PVC pipe casing and 25,000 tk for the workmanship (labor and drilling services). Supporting materials, including bentonite powder and pipe fittings, constituted the remaining costs. The breakdown of the estimated costs for the observed installation highlights the financial accessibility of this crucial water supply adaptation.

Table 1: Estimated Cost Breakdown for Deep Tubewell Installation (Case Study: 1380 ft)

Component	Description	Estimated Cost (BDT)	Percentage of Total Cost (Approx.)
Piping (PVC)	1380 feet PVC Class D	42,000	46.7%
Sinking/Workmanship	Labor and drilling services	25,000	27.8%
Bentonite/Fittings	Bentonite powder and pipe fittings	10,500	11.7%
Total Estimated Cost	For 1380 ft Deep Tubewell	90,000	100%

While cost-effective, the reliance on the drilling supervisor's visual inspection of soil samples after 1000 feet to determine the final screen depth represents a reliance on empirical knowledge rather than rigorous hydrogeological science. This approach, while customary, carries inherent risks regarding the precise depth placement and sealing of the well, potentially leading to localized failures or short operational lifespans if the saline interface shifts unexpectedly or if the screening occurs near a contaminated lens. Modern geophysical logging techniques are often recommended for deep aquifer delineation to maximize efficacy and longevity (Hossain et al., 2021).

3.3 Depth versus Time Trends

Table 2 indicates the consecutive depths of each of the tubewells with their installation date. The trend from the tubewell installation depth (ft) vs Year graph shows that earlier wells (1990s–early 2000s) were sunk to depths generally between about 600 and 1400 ft, whereas wells installed after 2015 tended to be much deeper (often exceeding 1600 ft). For example, TW-15 (installed 2005) had a depth of only 650 ft, whereas many 2018–2023 wells (e.g., TW-10, TW-19, TW-20) reached 1700–1750 ft. The plot of installation depth versus year, as illustrated in Figure 4, exhibits a clear downward trend: installation depth has significantly increased in recent years, according to the analysis. This change is primarily due to the intensification of the salinity problem over time. In other words, aquifers that were potable at 1000 ft decades ago have since become salt-contaminated, forcing drillers to go deeper. This explains why shallow tubewells (a few hundred feet deep) that once sufficed now yield brackish water.

Table 2: Tubewell Installation Depth vs Year

Sample Name	**Installation Year**	**Depth (ft)**
TW3	1990	1370
TW5	1998	1380
TW15	2005	650
TW11	2007	1300
TW2	2009	1200
TW14	2010	1300
TW1	2013	1080
TW10	2015	1700
TW12	2017	1300
TW7	2018	1750
TW16	2020	1590
TW13	2020	1700
TW17	2020	1700
TW19	2020	1750
TW8	2021	1400
TW6	2021	1750
TW20	2021	1750
TW18	2022	1650
TW9	2022	1700
TW4	2023	1700

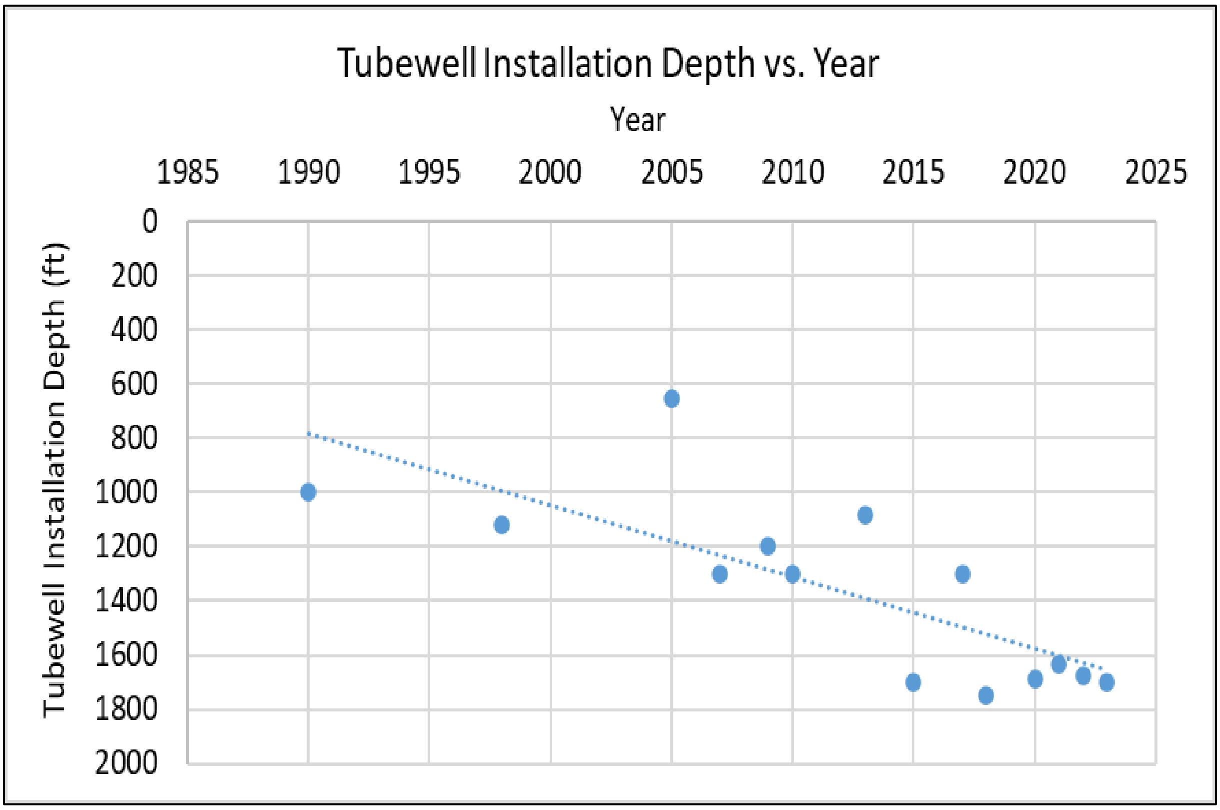

Figure 4: Tubewell Installation Depth vs Year

These field observations align with regional studies: Karmakar et al. (2024) note that in Ward 1 and similar areas, groundwater has become increasingly saline, making shallow hand-pumped wells ineffective. Vendors and households now draw water from deep wells that tap fresher aquifers (often >1000 ft). Bari et al. (2022) likewise reported that deep tubewells in northern Khulna generally have lower chloride (salt) content than shallow wells, consistent with the deeper wells in the survey producing potable water where shallow wells cannot. Thus, the recorded increase in well depth reflects these worsening hydrogeological conditions.

3.4 Longitudinal Analysis of Deep Tubewell Sinking Depth (1990–2024)

The collected installation data spanning three decades reveals a pronounced and accelerating trend toward deeper drilling in Ward No. 1, as presented in Table 3.

Table 3: Chronological Analysis of Deep Tubewell Sinking Depth (1990–2024)

Installation Year (Range)	Number of Wells (n)	Average Depth (ft)	Minimum Depth (ft)	Maximum Depth (ft)
1990–1999	2	1375.0	1370	1380
2000–2009	4	1112.5	650	1300
2010–2019	4	1457.5	1080	1750
2020–2024	10	1670.0	1400	1750

Analysis of the 20 tubewells confirmed that the installation depth has significantly increased in recent years. Wells installed in the 1990s were typically positioned around 1375 feet. However, following a period of variability in the 2000s (likely due to inconsistent success or localized conditions), the average depth rose sharply in the last decade. The clustering of recent installations (2020–2024) around an average depth of 1670 feet (ranging up to 1750 feet or 533 meters) represents a clear empirical consensus among drillers regarding the minimum depth required to reliably access potable water in this zone.

This trend is highly significant because the target depths (1700–1750 feet) are substantially deeper than the critical 250-meter (820 feet) threshold generally cited in regional hydrogeological reports for accessing the fresh aquifer. The necessity to drill approximately 520 meters (1700 feet) to secure functional wells strongly indicates a rapid and accelerating degradation of the intermediate aquifers (those below 820 feet but above 1700 feet) within the northern periphery of Khulna City. This increasing depth quantifies the extent to which the saline or heavy metal contaminant front has migrated vertically over the study period.

3.5 Hydrogeological Justification for Increasing Depth with Water Quality Parameters

The primary hypothesis of this research-that increased sinking depth is a successful adaptive measure resulting in improved water quality-is strongly supported by the analysis of critical water quality parameters and the aggregated Water Quality Index (WQI) data. This correlation is crucial in the context of the Khulna region, where groundwater quality issues, including salinity, heavy metals, and post-abstraction contamination, necessitate strict adherence to potable water standards (Karmakar et al., 2024).

3.5.1 Mitigation of Saline Intrusion and High Total Dissolved Solids

The deepening trend is overwhelmingly a response to intense saline intrusion. Groundwater salinity is traditionally monitored through indicators such as Chloride concentration and Electrical Conductivity (EC). Comparing the performance of wells based on depth demonstrates the required adaptation.

Older or failing deep wells show clear signs of saline intrusion. Refer to Karmakar et al. (2024), Tubewell TW11 (installed 2007 at 1300 ft) recorded Chloride levels peaking at 980 mg/L in the summer, significantly exceeding the World Health Organization (WHO) and Bangladesh standard of 600 mg/L. Even some deep wells installed relatively recently, such as TW7 (2018 at 1750 ft) and TW6

(2021 at 1750 ft), exhibited severe failures, with Chloride concentrations reaching extreme levels up to 1800 mg/L and 2075 mg/L, respectively. The electrical conductivity (EC) in these failing wells was similarly alarming, with TW7 reaching 4.72 mS/cm in summer, far exceeding the 0.7 mS/cm recommendation. This phenomenon suggests that merely reaching a high depth is insufficient if the well is poorly screened or if localized geological failure compromises the protective clay layer.

Conversely, the most successful recent installations installed at the greater depths consistently meet quality standards. Tubewell TW19 (2020 at 1750 ft) and TW4 (2023 at 1700 ft) maintained very low Chloride levels (25–160 mg/L) and low EC (around 0.6 mS/cm) throughout all seasons. This contrasting performance confirms that successful access to the deeper, confined aquifer requires sinking to these maximal depths (approximately 1700–1750 feet) to reliably bypass the saline front.

3.5.2 Mitigation of Heavy Metal and Aesthetic Contamination

The increased sinking depth also effectively mitigates geogenic heavy metal contamination, which contributes to poor water quality. Manganese (Mn) and Iron (Fe) often pose significant aesthetic and long-term health challenges in shallow aquifers. Recent assessments near the study area by Karmakar et al. (2024) confirmed that elevated levels of Mn and Fe are persistent problems that must be addressed to ensure water potability. The data showed that wells experiencing high WQI scores (poor quality) due to salinity often simultaneously register high concentrations of heavy metals. For instance, TW7 and TW8 showed extremely high Manganese concentrations (TW7: 3.5 mg/L, TW8: 2.9 mg/L) during the dry and winter seasons, greatly exceeding the 0.4 mg/L standard. Iron levels in TW7 reached 1.221 mg/L, four times the 0.3 mg/L standard.

In stark contrast, successful deep wells installed post-2020 (such as TW17, TW18, TW19, and TW4) consistently registered zero or near-zero levels for both Mn and Fe across all seasons. This disparity confirms that the successfully tapped deep aquifer layer is functionally free from the problematic geogenic contamination found in the upper layers, reinforcing the comprehensive water quality benefit derived from deeper drilling.

3.5.3 Depth-WQI Correlation and Seasonal Vulnerability

The most direct synthesis of water quality is provided by the WQI. The research finding that "The WQI has improved in the tubewells installed in recent years because of higher sinking depths" is validated by the data. Tubewells installed in earlier years or those at intermediate depths (e.g., TW5, TW11, TW14, TW15) frequently yielded WQI scores corresponding to "Poor" or "Unsuitable" water quality, particularly during stressful seasons. Conversely, the majority of consistently deep wells installed post-2020 were reliably classified as "Excellent" or "Good" (Karmakar et al., 2024). Table 4 presents the average depth of deep tubewells from different decades and their correlation with selected water quality parameters, along with the corresponding WQI classification.

The vulnerability of the water supply is acutely exposed during the summer (dry season), which corresponds to the lowest groundwater table and maximum contaminant intrusion. The average WQI across all sampled wells was highest (i.e., worst quality) in the summer (136), and this season recorded the highest number of wells classified as "Unsuitable". This confirms that increased depth is essential for securing year-round protection, as it ensures the well remains within the confined aquifer, buffered against the hydrostatic pressure drops that occur during the dry season. The seasonal water table drop in shallower systems often compromises the protective layer, leading to localized intrusion and contamination, a risk effectively mitigated by sinking to the necessary extreme depths observed in the recent successful installations.

Table 4: Comparative Water Quality Indicators by Tubewell Installation Depth (Summary of Contamination Parameters) (Karmakar et al., 2024)

	Avg. Depth (ft)	**Avg. Seasonal Chloride (mg/L)**	**Avg. Seasonal EC (mS/cm)**	**Avg. Seasonal Mn (mg/L)**	**WQI Classification Dominance**
Older/Intermediate (1990–2010)	1240	363.3	1.15	0.38	Good/Poor (Highly Variable)
High-Risk Deep (TW7, TW6, TW8)	1750	1481.6	3.58	2.14	Poor/Unsuitable
Successful Deep (2020–2024)	1670	79.5	0.76	0.05	Excellent/Good (Stable)

4. CONCLUSIONS

The analysis confirms that deep tubewell sinking depth in the northern periphery of Khulna City has dramatically increased over the past 30 years. This trend represents an indispensable, forced adaptation driven by the progressive degradation of the shallow and intermediate aquifers due to accelerating salinity intrusion and localized heavy metal contamination. The necessity for this adaptation is underscored by regional studies confirming that, even when drawn from deep tubewells, water quality remains vulnerable to post-abstraction contamination by parameters such as total and fecal coliforms, highlighting the need for deep, protected sources. The shift in installation practice, culminating in depths clustered around 1700 to 1750 feet in recent years, is a direct hydrological response to ensure the capture of potable water. The efficacy of this deeper sinking practice is quantitatively verified by the water quality results. Wells successfully installed at these maximal depths reliably circumvent the saline front, exhibit low concentrations of Chloride, Mn, and Fe, and consequently achieve stable WQI scores classifying the water as "Excellent" or "Good." This success contrasts sharply with the high failure rates and extreme seasonal vulnerability observed in older, shallower wells, especially during the peak stress of the summer season. It can be concluded that the deep tubewell, when properly sunk to depths exceeding 1700 feet, is currently the only suitable water supply system for the northern periphery of Khulna City, considering both quality and availability.

In light of observed trends and technical assessments, local planning authorities and water management stakeholders should adopt a coordinated set of measures to safeguard groundwater resources. Empirical evidence of rapid aquifer depletion warrants the formal enforcement of minimum sinking depth standards for new deep tubewells in the northern periphery of KCC, with a threshold of approximately 1,700 feet (520 meters) to ensure consistent access to the confined aquifer and year-round potable water quality. Drilling practices should be professionalized by moving beyond sole reliance on visual soil inspection and incorporating hydrogeological investigations, such as geophysical well logging, particularly for wells exceeding 500 meters, to optimize screen placement, enhance well longevity, and reduce geological risks. At the same time, a dedicated and continuous monitoring program is necessary to assess the long-term sustainability of the deep confined aquifer, especially in light of reported declines in piezometric pressure that suggest current abstraction rates may be unsustainable. Finally, to alleviate pressure on deep groundwater reserves, authorities should advance integrated water resource management approaches, including managed aquifer recharge using monsoon rainfall and expanded municipal capacity to treat and distribute water from alternative, non-groundwater sources.

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DECLARATION OF USE OF AI

During the preparation of this work, the authors used some AI tools, such as ChatGPT, Grammarly, Quill Bot, Mendeley Cite, etc., for summarization, grammar refinement, spelling correction, and rearranging sentences to improve flow, and citation management.

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