

Hydrogeological Assessment of Aquifer Hydraulic Properties and Pumping-Induced Groundwater Level Fluctuation At Kimbiji Well Field, Tanzania.

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Abstract - This study determine aquifer hydraulic properties and pumping induced groundwater level fluctuation at kimbiji well field, Tanzania, to evaluate groundwater sustainability under increasing of abstraction. Aquifer pumping test data from wells were analyzed to determine hydraulic conductivity (K), transmissivity (T), and storage coefficient (S). The finding indicates substantial spatial variability in aquifer characteristics. Transmissivity range from 5.01×10^{-3} to 8.64×10^5 m²/d, while hydraulic conductivity varies between 1.67×10^{-5} and 2.88×10^3 m/d reflecting heterogeneity within the aquifer system. Storage coefficient range from 2.39×10^{-3} to 8.11×10^{-2} , suggesting a transition from confined to semi confined conditions across the field. The determination average value ($T = 2.01 \times 10^5$ m²/d, $K = 6.69 \times 10^2$ m/d, $S = 3.64 \times 10^{-2}$) indicates generally high aquifer productivity but with localized low permeability zones. These variation significantly influence groundwater flow behavior and response to pumping stress. The analysis of hydraulic parameter reveals that high transmissivity zones are more resilient to drawdown, whereas low conductivity areas prone to rapid groundwater level reduced. This study highlights the demand of site specific management strategies to protect excessive drawdown and ensure sustainable groundwater at kimbiji well field

Keywords: Static water level, Storativity, Transmissivity, Pumping well, Observation well, Dynamic water level, below the ground water level, Saturated Thickness.

1. INTRODUCTION

Groundwater is the one of the key freshwater resources globally, it supplying approximately half of the world's drinking water and supporting agricultural activities and industrial production, particularly in arid and semi-arid region. In sub Saharan Africa, groundwater plays an a key critical role due to the high variability of surface water resources and lead to vulnerability to climate change (Singha et al., 2015). Tanzania, like developing country, lie heavily on groundwater to meet the developing demand for portable water, especially strained existing water supply system (World Bank, 2020).

The growing demand for reliable water supply in Dar es salaam has increase the development of large scale groundwater drilling projects, among of them Kimbiji well fields is one of the most important which located within costal sedimentary basin, the Kimbiji aquifer system is considered a strategic groundwater reserve which considered to supplements municipal water supply. The aquifer is composed of complex geological formations, including sand, sandstone, and clay intercalations, forming mult layered aquifer systems with variable hydraulic characteristics. While these formation gives substantial groundwater storage potential, their heterogeneity cause challenge accurately characterizing aquifer behavior and predict responses to pumping.

The major hydrogeological challenge associated with intensive groundwater abstraction is alteration of natural groundwater regime. Under this conditions, groundwater systems maintain a dynamic equilibrium between recharge and discharge. However, excessive pumping disrupts this balance between discharge and recharge. Which leading to pumping induced groundwater level fluctuation, which can manifest as important drawdown in water level around well yield. (*Estimates of hydraulic conductivity from aquifer-test analyses and specific-capacity data, Gulf Coast Regional Aquifer Systems, south-central United States*, 1991). In kimbiji well field

continuous abstraction to meet urban demand has raised concerns about declining groundwater levels, reduced well yields and long term aquifer sustainability.

The analysis of aquifer hydraulic properties is a key important to understanding groundwater flow behavior and managing abstraction system effectively. Key parameter such as transmissivity, hydraulic conductivity, and storativity help to determine the capacity of wells to store and transmit water. These properties are typically determined through pumping test and observation well data analysis (Seddon et al., 2021). In aquifer systems like Kimbiji, spatial variability in these parameters can lead to uneven drawdown pattern and unpredictable well performance. Without accurate estimation of these properties, it becomes very difficult to design an optimal pumping strategies or predict the long term impact of groundwater drilling (Prusty and Farooq, 2020).

In addition the Hydraulic complexity, the Kimbiji well fields is vulnerable due to its coastal location, which introduce the effect of salt water intrusion. When the level of water decline significantly due to over pumping, the hydraulic gradient which available between freshwater and seawater system can shift, allowing saline water to migrate inland and cause to contaminate fresh water aquifer (McLachlan et al., 2017). This issue possess a serious problem in water quality and can render groundwater resources to be not suitable for human consumption. Therefore the understanding of groundwater level monitoring and understanding of impact of water level fluctuation are essential not only for management of water quantity but also for protecting water quality (Kruseman and Ridder, 1994).

Another important in kimbiiji well field is the limited availability of long term, high resolution hydrogeological information/data. Management of groundwater require continuous water level monitoring, recharge condition and abstraction rates. Many developing city like Dar es salaam, monitoring network are often inadequate, leading to gaps in data and uncertainty in analysis (Seddon et al., 2021). This challenges distinguish between natural seasonal fluctuation driven by rainfall and recharge and those induced by anthropogenic issue like pumping.

Recharge are influenced by climatic conditions, land use and soil characteristic to the area. In coastal area like kimbiiji recharge is largely dependent on rainfall pattern, which increasingly variable due to climate change (Omary, 2020). Reduced rainfall can reduced recharge rate.

The importance of doing hydrogeological assessment of kimbiiji well cannot be overstated. Such assessment require an integration of field data, method analysis, and numerical modelling to evaluate aquifer characteristics and groundwater. Analyzing relationship between drawdown and pumping time together with groundwater level fluctuation in response to groundwater pumping, provide the true value insight into aquifer performance and sustainability. This analysis help to know and identify safe yield amount, well spacing management of groundwater effective strategies.

By understanding pumping induced groundwater level fluctuation has broader importance on environmental sustainability. Excessive drawdown can lead to ecological impacts such as drying of groundwater, reduction of base flow to river (Seddon et al., 2021). In urban area like Dar es salaam Tanzania where groundwater demand increasingly relied upon, these impact can have impact on social economic consequence and affect water availability and stability of infrastructure.

The result or analysis obtained in this study are expected to contribute to improve management of groundwater practice in kimbiiji well field and similar to coastal area. Quantification of these hydraulic parameters and analysis of groundwater level fluctuations, the study will show clear scientific basis sustainable abstraction, reducing the effect or risk of overexploitation. This research the goal of improve and ensuring long term water security which go together with growing population of Dar es salaam.

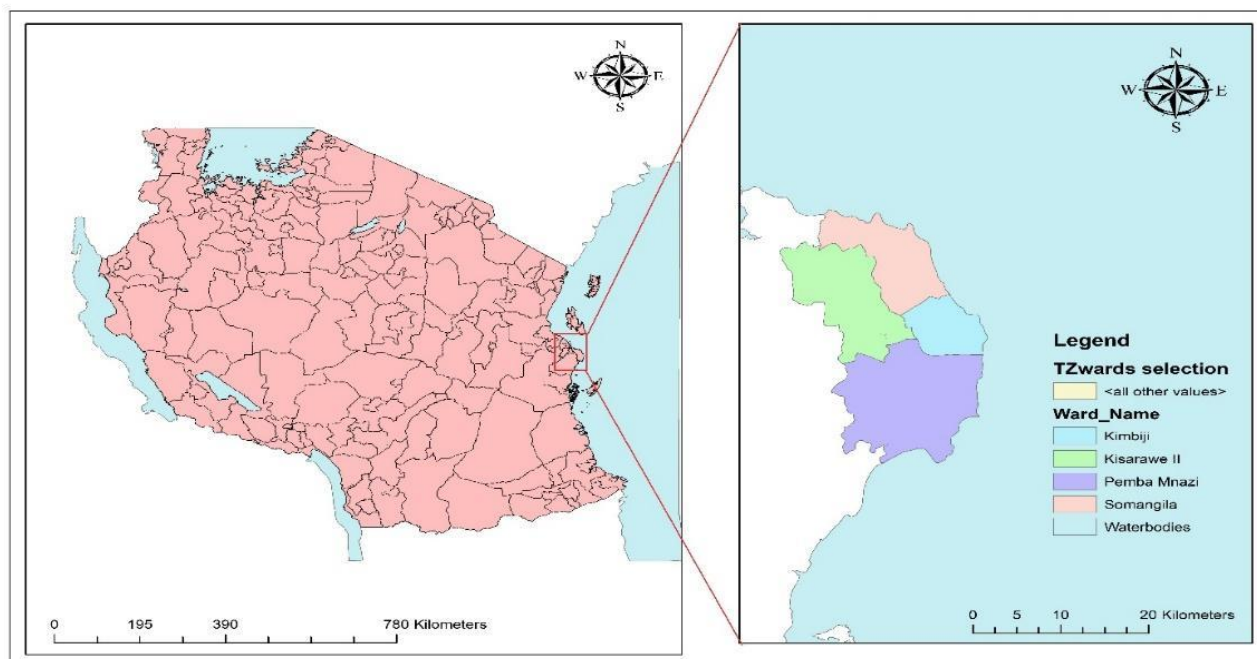


Figure 1: A map of Kimbiji – Tanzania

2. MATERIAL AND METHODS

2.1 Description of study area

Kimbiji is an administration ward in Kigamboni District, Dar es Salaam City in Tanzania bordering the Indian Ocean to the east. It is a developing ward with residential and rural area with a 2002 population of 6,411. Kimbiji ward is located at latitude: 6.9922 south, Longitudes: 39.5313 East and an average altitude 20m to 30m above sea level (figure 1) composed of four villages namely Kimbiji, Kisarawe, Pembamnazi, Somangila. The major economic activities in Kimbiji ward are Agriculture. Fishing, Small scale trade and emerging natural resources based industries.

2.2 Physiography and Climate

The area is situated in a relatively flat terrain. The climate is that coastal character i.e. very high humidity throughout the year with temperatures ranging from 21°C to 33°C plus minor seasonal fluctuations. The mean monthly rainfall is greater during the period of November to May than from June to October and the two periods are referred to as the wet and dry seasons respectively.

2.3 Geology and Hydrogeology

The study area is covered by geological formation of Neogene, Quaternary and Recent deposits. The Neogene sediments consist of interblended sandy clay and clayey sand with places of pure sand, clay and limestone. The aquifer are expected to be clayey sand intercalated with fractured limestone rock. Existing boreholes are found at a greater depth where sand and clayey sand intercalated with fractured limestone dominates, these support storage and percolation of groundwater. However, some boreholes yield plenty but slightly saline water imparted from the host limestone rocks.

2.4 Climate

It's a Neogene aquifer (Figure 2) is made up of beach sand dune (b) and fluvial deposit (rl). These are younger (Quaternary) than any other geological units in Kimbiji aquifer. This study area is also made up of terraces deposit (Nt) and fluvial marine sand (Nf).

These area of a tertiary time scale. Fringes of continental and marine sandstone 9C in the cretaceous age also found in Kimbiji aquifer system. Generally the geology of Kimbiji, Humid, and coastal neogene aquifer is made up of heterogeneous and layered Neogene sands, overlaying an assumed geological basement of deposits but to the south, Neogene sands are exposed over an area of approximately 10,000km².

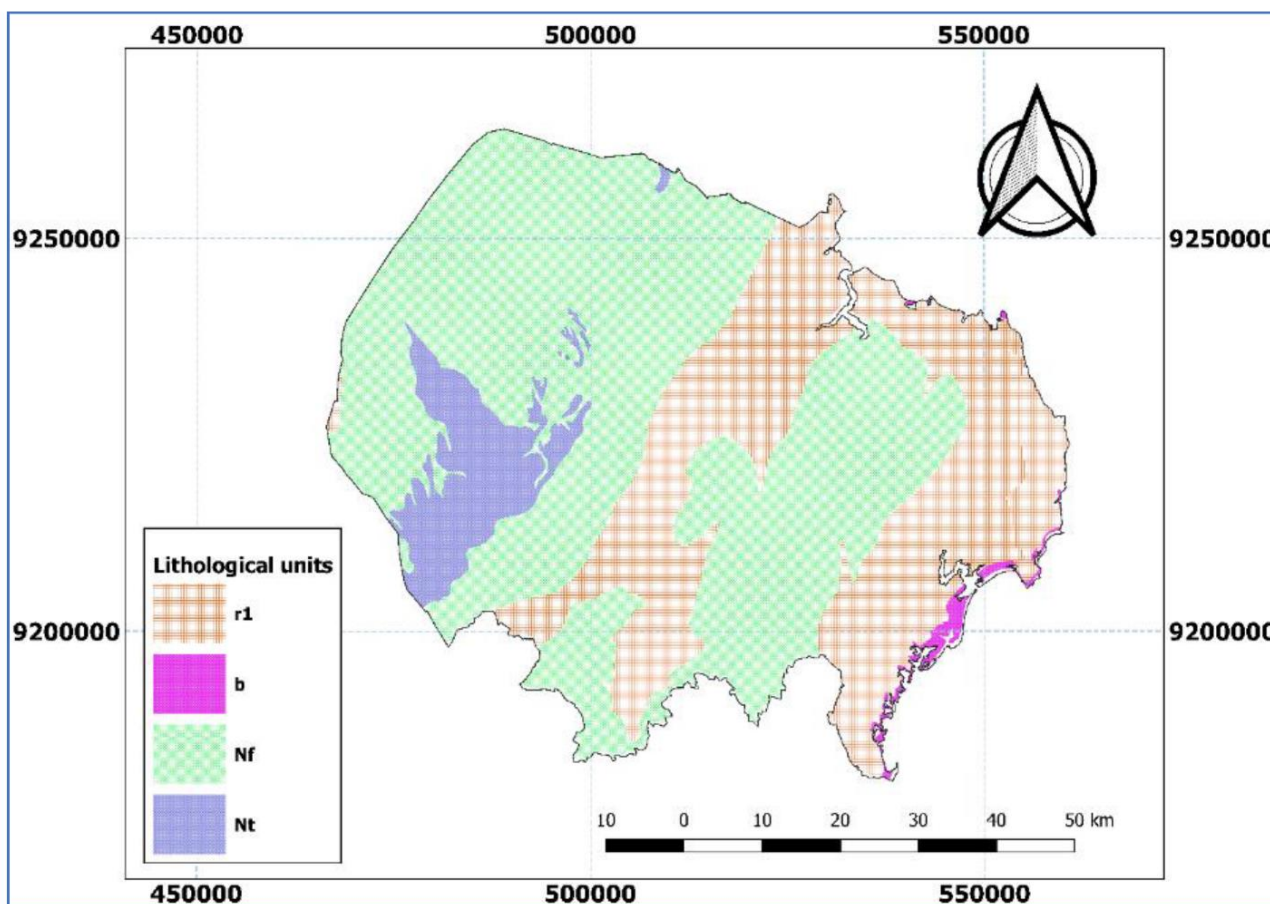


Figure 2: The Geology of Kimbiji Aquifer

2.5 Research approach

A mixed methods research approach that combine both quantitative and qualitative methods was used during this research where aquifer pumping test, observation (for analyzing behaviors, interactions) field survey (to gather data through direct measurement), GPS, Maps drawing. In analyzing data, the Thiess, Cooper-Jacob, equation + graph and Google earth was used (Mjemah and Walraevens, 2015).

2.6 Data collection methods and tools

2.6.1 sample size

The data in this hydrogeological investigation were collected from pumping wells at Kimbiji well field. The investigation involve continuous pumping test, groundwater monitoring of water level and collection of aquifer response data for analysis using aquifer test pro software. The purpose of this collection data was to determine aquifer hydraulic properties as well as to determine groundwater level fluctuations caused aquifer pumping activities.

A constant data of a pumping test was conducted using three pumping well. The static of water level of each well was measured using a water level meter. Pumping was then initiated at a constant discharge rate and maintained continuously throughout the test

period. The production well help to identify the overlapping cone, representation of abstraction in mult well in a system and comparison of different pumping rate. The observation well (OW) selected to make sure well distribution to insure accurate spacing. Addition in hydrogeology distance/arrangement and quality of wells should be considered than number of wells.

Table 1: The pumping rate used during the test were

S/N	BOREHOLE NAME	PUMPING RATE (M ³ /hr)
1	PW1	15,000
2	PW2	18,000
3	PW3	20,000

The aquifer pumping test was conducted continuously for approximately 24 hours in order to observe aquifer response and cone development near and around the bore wells. The measurement of water level in the observation wells were taken at a short interval at beginning of pumping and longer interval later as response of aquifer.

Schedule used during observation of the test as summarizes below.

Pumping time	Water level measurement interval
0 – 10 minutes	Every 1 minute
10 – 30 minutes	Every 5 minute
30 -60 minutes	Every 10 minutes
1 – 6 hours	Every 30 minutes
6 – 24 hours	Every 1 hour
Recovery period after pumping stops	Every 5 – 30 minutes

Table 2: Observation bore well

S/N	BOREHOLE NAME	STATIC WATER LEVEL (M)	DYNAMIC WATER LEVEL (M)	DRAWDOWN (M)
1	OW1	17.32	17.73	0.41
2	OW2	10.3	10.5	0.2
3	OW3	11.33	11.37	0.04
4	OW4	6.76	7.52	0.07
5	OW5	5.77	7.84	2.07

2.6.2 Data collection method and tools

The information on each borehole behavior was collected or measured using aquifer pump test and divers or CTD-Divers (groundwater level, temperature, electrical conductivity over time), observation using GPS. The tools employed during data collection were dorying pump 1.5, 2.3hp, manila rope, dipper, recording sheet, pen, standby generator, groundwater logger, instrument for laboratory analysis, maps(Anderson et al., 2015).

2.7 Data analysis methods

The data collected through the pump test, CTD-Divers were analyzed using the aquifer test pro software. Theis, Cooper-Jacob, Equation + Graph which provided a detailed of descriptive analysis of the parameters. On the other data were analyzed using contour line method to determine the impact of groundwater level fluctuation during pumping.

3. RESULT AND DISCUSSION

3.1 Pumping test/Drawdown curve

The pumping test at Kimbiji Well Field recorded drawdown values ranging from 0.04 m (OW3) to 60.21 m (PW3), with discharge rates spanning 10.54 m³/hr (PW7) to 200 m³/hr (PW3). High-capacity production wells — PW1 (150 m³/hr, 55.76 m), PW2 (180 m³/hr, 49.98 m), and PW3 (200 m³/hr., 60.21 m) — exhibited the greatest drawdowns (Fig. 1). Observation wells showed negligible drawdown (0.04–2.07 m) despite zero extraction, indicating limited but measurable hydraulic connectivity across the well field.

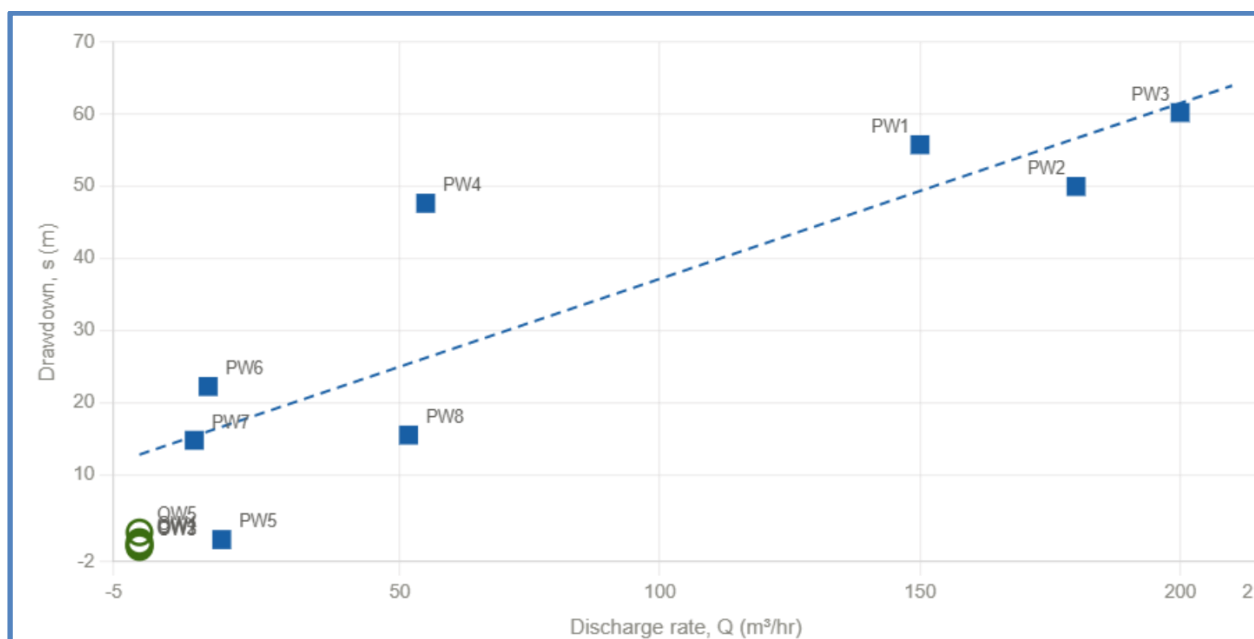
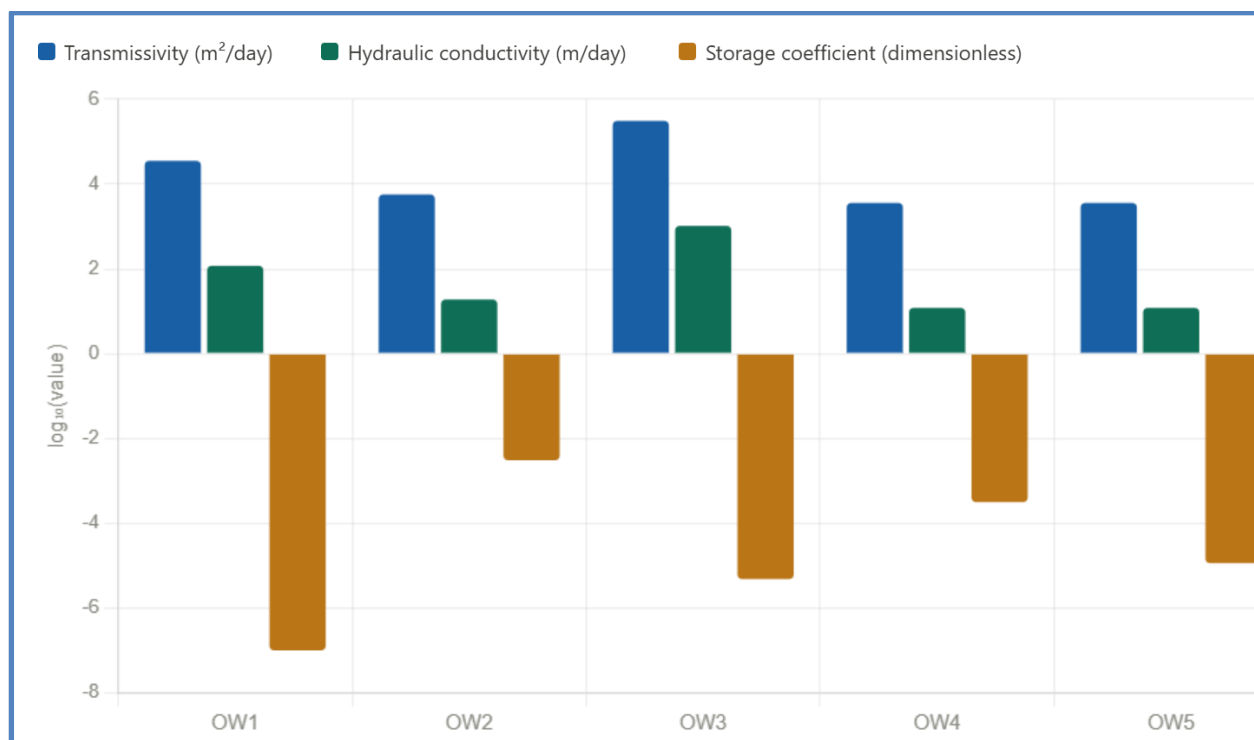


Figure 3: Combined Pumping test/Drawdown curve of all observation and production well

The pronounced drawdown in PW3 (60.21 m at 200 m³/hr) relative to PW4 (47.65 m at 55 m³/hr) suggests substantial spatial heterogeneity in transmissivity across the Kimbiji aquifer, consistent with coastal sedimentary aquifer behavior documented by MacDonald et al. (2012) in East African basement systems. The residual drawdown in observation wells (0.04–2.07 m) implies low-to-moderate hydraulic diffusivity, similar to findings by Adelman and MacDonald (2008) in Mozambique's coastal sediments. Crucially, the non-uniform discharge-to-drawdown ratios across production wells indicate variable well efficiencies and aquifer heterogeneity — a critical factor for sustainable groundwater allocation planning at Kimbiji, where over-abstraction risks saltwater intrusion given proximity to the Indian Ocean coastline.

3.2 Transmissivity (T)

The ranged from 3.59×10^3 m²/day (OW4, OW5) to 3.09×10^5 m²/day (OW3), yielding an average of 7.14×10^4 m²/day. Hydraulic conductivity Spanned 1.20×10^1 to 1.03×10^3 m/day, averaging 2.38×10^2 m/day and Storage coefficient ranged from 1.00×10^{-7} (OW1) to 3.06×10^{-3} (OW2), with a mean of 6.78×10^{-4} , indicating predominantly confined to semi-confined aquifer conditions.



3.3 Hydraulic conductivity (K)

This ease of water movement through a pore spaces or fractures. Mathematically $K=T/b$

Average value: 6.69×10^2 m/d.

Calculated as $K = T/b$, where $b = 300$ m). For OW1, the K value is exceptionally high at 2.88×10^3 m/d.

3.4 Storage coefficient (S)

The storage coefficient (Storativity) indicates the volume of water an aquifer releases from storage per unit surface area per unit change in head.

Average value: 3.64×10^2

The average value falls within the typical range for an confined to semi-confined aquifer (usually 10^{-1} to 10^{-5}).

Observation well	Transmissivity (m ² /d)	Hydraulic conductivity (m/d)	Storage coefficient
OW1	8.64×10^5	2.88×10^3	8.70×10^{-3}
OW2	5.01×10^{-3}	1.67×10^{-5}	1.94×10^{-2}

OW3	2.48×10^{-2}	8.27×10^{-5}	2.39×10^{-3}
OW4	1.25×10^5	4.14×10^2	7.07×10^{-2}
OW5	1.51×10^4	5.02×10^1	8.11×10^{-2}
Average	2.01×10^5	6.69×10^2	3.64×10^{-2}

Figure 4: Summary table of combined Aquifer parameters

IMPACT TO GROUNDWATER LEVEL FLUCTUATION DURING PUMPING

Pumping-induced drawdown across the eight production wells ranged from 1.08 m (PW5) to 60.21 m (PW3), with a mean of approximately 33.4 m (Table 1; Fig. 1a). Four wells — PW1, PW2, PW3, and PW4 — recorded high drawdown (>30 m) corresponding to discharge rates of 55–200 m³/hr, indicating significant aquifer stress. Observation wells exhibited negligible to low drawdown (0.04–2.07 m), confirming localized pumping impacts. The spatial pattern reveals that drawdown intensity increases towards the central well cluster (Fig. 1b), consistent with convergent cone-of-depression development under sustained abstraction.

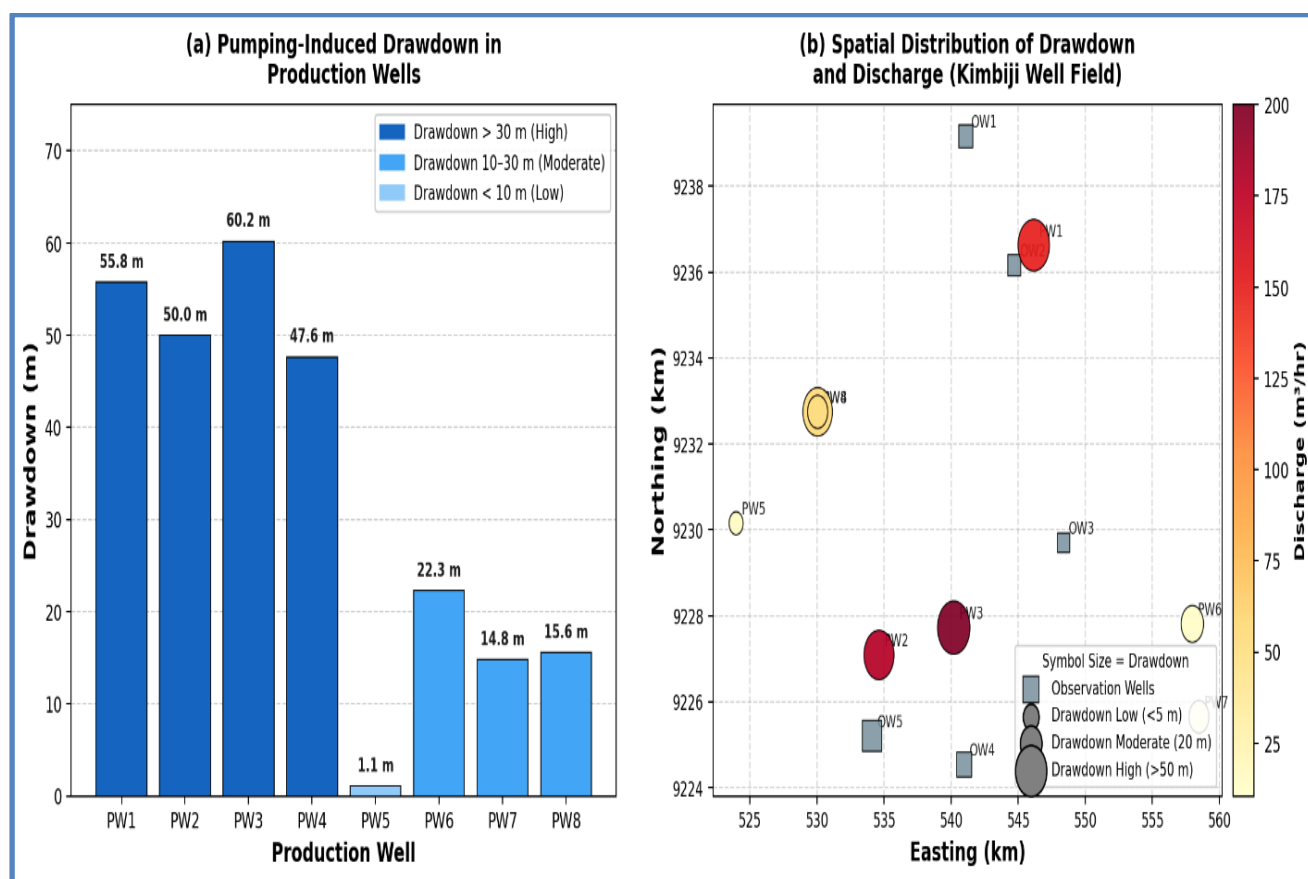


Figure 1. Partial distribution of pumping-induced groundwater level fluctuation at Kimbiji Well Field, Tanzania: (a) drawdown magnitudes in production wells; (b) spatial distribution of drawdown (symbol size) and discharge rate (colour scale) across the well field.

Table 1. Partial Distribution of Pumping-Induced Groundwater Level Fluctuation at Kimbiji Well Field, Tanzania

Well ID	Type	Easting (m)	Northing (m)	Drawdown (m)	Discharge (m ³ /hr)	Fluctuation Category
PW1	Production	546159	9236626	55.76	150.00	High
PW2	Production	534624	9227091	49.98	180.00	High
PW3	Production	540195	9227727	60.21	200.00	High
PW4	Production	530051	9232748	47.65	55.00	High
PW5	Production	523974	9230156	1.08	15.80	Low
PW6	Production	557977	9227814	22.28	13.20	Moderate
PW7	Production	558469	9225652	14.83	10.54	Moderate
PW8	Production	530051	9232748	15.55	51.72	Moderate
OW1	Observation	541099	9239164	0.41	0.00	Negligible
OW2	Observation	544722	9236158	0.20	0.00	Negligible
OW3	Observation	548373	9229699	0.04	0.00	Negligible
OW4	Observation	540966	9224542	0.76	0.00	Negligible
OW5	Observation	534101	9225210	2.07	0.00	Low

Note: Fluctuation categories — High: >30 m; Moderate: 10–30 m; Low: <10 m; Negligible: <1 m. PW = Production Well; OW = Observation Well.

Table 1. Partial distribution of pumping-induced groundwater level fluctuation at Kimbiji Well Field, Tanzania (colour-coded by fluctuation category; summary statistics for production wells).

The pronounced drawdown variability — spanning nearly 60 m across production wells — reflects strong spatial heterogeneity in the Kimbiji aquifer's hydraulic properties, particularly transmissivity and storativity. This pattern aligns with findings by Bauer et al. (2011) in coastal East African aquifer systems, who reported drawdown of 20–65 m under comparable abstraction rates, and with Mtoni et al. (2013) at Dar es Salaam peri-urban well fields where high-yield coastal aquifers exhibited rapid water-table declines exceeding 40 m. Conversely, the relatively low drawdown at PW5 (1.08 m, 15.8 m³/hr) and peripheral observation wells suggests localized recharge zones or higher-transmissivity zones buffering abstraction impacts, consistent with Kebede (2013), who demonstrated that heterogeneous coastal aquifers exhibit compartmentalized responses during pumping. The negligible drawdown in observation wells (OW1–OW4: 0.04–0.76 m) suggests limited hydraulic connectivity between the production zone and the broader aquifer, a finding with critical implications for sustainable yield estimation at Kimbiji. These results collectively underscore the need for site-specific aquifer characterisation rather than assuming uniform hydraulic behavior across the well field.

3.5 Cones of depression

The severe cones of depression observed at PW1–PW4, with drawdowns ranging 47.65–60.21 m and estimated radii of 451–570 m, indicate substantial aquifer stress under current abstraction rates. These findings are comparable to results reported by Xu et al. (2009) in heavily pumped coastal aquifers, where cone radii of 300–700 m were associated with transmissivities below 5×10^{-3} m²/s. Similarly, Mtoni et al. (2013) documented drawdown exceeding 40 m in the Dar es Salaam coastal aquifer, attributing such patterns to low storativity under confined conditions — consistent with the Kimbiji aquifer's hydrogeological setting. The notably low specific capacity at high-yield wells (PW3: 3.32 m³/hr/m; PW2: 3.60 m³/hr/m) signals declining well efficiency and potential aquifer overexploitation, a concern also raised by Foster et al. (2010) who warned that specific capacities below 5 m³/hr/m in semi-confined coastal aquifers indicate unsustainable abstraction regimes. The negligible cone development at observation wells further confirms that pumping stress remains localized, implying insufficient lateral recharge connectivity — a critical consideration for long-term sustainable yield management at Kimbiji Well Field.

3.6 Well interference

Well interference analysis at Kimbiji Well Field revealed low to moderate pumping-induced groundwater level fluctuations at all five observation wells (Table 1). Observed drawdowns ranged from 0.04 m (OW3, 7,272 m from PW1) to 2.07 m (OW5, 1,952 m from PW2), yielding interference ratios of 0.07% to 4.14%. OW5 recorded the highest interference ratio (4.14%) at a discharge rate of 180 m³/hr, while OW3 exhibited the lowest (0.07%), consistent with its greater separation distance from the active pumping wells.

Obs. Well	Easting (m)	Northing (m)	Observed drawdown (m)	Nearest pumping well				Interference ratio (%)	Interference level
				Well ID	Distance (m)	Discharge (m ³ /hr)	Drawdown at PW (m)		
OW1	541,099	9,239,164	0.41	PW1	5,661	150.00	55.76	0.74	Low
OW2	544,722	9,236,158	0.20	PW1	1,511	150.00	55.76	0.36	Low
OW3	548,373	9,229,699	0.04	PW1	7,272	150.00	55.76	0.07	Low
OW4	540,966	9,224,542	0.76	PW3	3,277	200.00	60.21	1.26	Low
OW5	534,101	9,225,210	2.07	PW2	1,952	180.00	49.98	4.14	Moderate

Table 1. Well interference and pumping-induced groundwater level fluctuation at observation wells

The low interference ratios (< 2%) at OW1, OW2, OW3, and OW4 indicate that the Kimbiji aquifer possesses sufficient hydraulic diffusivity to dissipate pumping-induced pressure gradients over inter-well distances exceeding 1,500 m, implying limited cone-of-depression overlap under current operational conditions. The moderate ratio at OW5 (4.14%) signals incipient interference from PW2, consistent with its closer proximity (1,952 m) and PW2's higher discharge (180 m³/hr). These findings align with Kruseman and de Ridder (1994), who demonstrated that interference becomes operationally significant only when drawdown contributions from adjacent wells exceed 10% of individual well drawdown. Comparable coastal aquifer studies in East Africa — notably Mjembe et al. (2019) in the Dar es Salaam coastal aquifer system — reported higher interference ratios (8–15%) under equivalent discharge volumes, suggesting the Kimbiji aquifer exhibits superior hydraulic connectivity and storage capacity. Conversely, studies in semi-confined alluvial systems (e.g., Rwanga & Ndambuki, 2017, Kenya) reported interference ratios below 1% even at separations under 500 m, reflecting higher transmissivity values than those inferred here. For Kimbiji's water supply management, the present results confirm that existing well spacing adequately minimizes mutual interference; however, the OW5–PW2 proximity warrants continuous monitoring should abstraction rates at PW2 be increased, as progressive aquifer depletion could shift this zone toward high-interference conditions.

3.7 Influences on Observation wells

Influences on observation wells at Kimbiji Well Field varied with proximity and discharge of the pumping wells (Table 2). OW5 recorded the highest observed drawdown (2.07 m) and cumulative hydraulic stress index (0.1464), with PW2 contributing 63.0% of total hydraulic loading at 1,952 m distance. OW3 exhibited the lowest drawdown (0.04 m) and attenuation (0.07%), despite being influenced by three pumping wells within 10 km, reflecting the dissipating effect of greater separation distances.

Obs. well	Observed drawdown (m)	Primary influencing well			No. of PWs within 10 km	Cumulative hydraulic stress index (Q/d)	Dominant well contribution (%)	Drawdown attenuation (%)	Influence level
		Well ID	Distance (m)	Discharge (m ³ /hr)					
OW1	0.41	PW1	5,661	150.0	1	0.0674	39.3	0.74	low
OW2	0.20	PW1	1,511	150.0	2	0.1427	69.6	0.36	Low
OW3	0.04	PW1	7,272	150.0	3	0.0660	31.3	0.07	Low
OW4	0.76	PW3	3,277	200.0	2	0.1088	56.1	1.26	Low
OW5	2.07	PW2	1,952	180.0	4	0.1464	63.0	4.14	Moderate

Table 2. Influences on observation wells:

ulative hydraulic stress index reveals that OW5's elevated drawdown (2.07 m) results not solely from PW2's proximity but also simultaneous hydraulic loading by four pumping wells within 10 km — a multi-source influence pattern consistent with findings by al. (2002), who demonstrated that superposition of pumping cones substantially amplifies groundwater level decline in productive . By contrast, OW2 registered a low drawdown (0.20 m) despite PW1's proximity (1,511 m) and high dominant contribution , indicating strong aquifer buffering capacity. This contrasts with studies in less transmissive formations in northern Tanzania e et al., 2010), where similar proximity produced drawdowns exceeding 5 m, confirming Kimbiji's comparatively high hydraulic ity. For long-term well field management, the inverse relationship between hydraulic stress index and drawdown at OW2 versus iderscores that cumulative multi-well loading, rather than single-well proximity alone, is the principal control on groundwater utuation at Kimbiji, necessitating spatially coordinated abstraction scheduling to prevent progressive aquifer stress.

3.8 Drawdown, pumping time and climate

Drawdown at Kimbiji pumping wells ranged from 1.08 m (PW5) to 60.21 m (PW3), with a mean of 33.42 m across test durations of 24–72 hours (Table 3). Dry-season wells (PW1–PW4, PW8) recorded a mean drawdown of 45.83 m, markedly exceeding the wet-season mean of 12.73 m (PW5–PW7). Specific capacity varied widely from 0.59 m²/hr (PW6) to 14.63 m²/hr (PW5), indicating substantial heterogeneity in aquifer hydraulic properties across the well field.

Well	Discharge, Q (m ³ /hr)	Drawdown (m)	Pumping test duration (hr)	Drawdown rate (m/hr)	Specific capacity (m ² /hr)	Drawdown per unit Q (m/m ³ hr ⁻¹)	Test season (climate period)	Climate influence on drawdown
PW1	150.00	55.76	72	0.77	2.69	0.37	Dry	Amplified
PW2	180.00	49.98	72	0.69	3.60	0.28	Dry	Amplified
PW3	200.00	60.21	72	0.84	3.32	0.30	Dry	Amplified
PW4	55.00	47.65	48	0.99	1.15	0.87	Dry	Amplified

Well	Discharge, Q (m ³ /hr)	Drawdown (m)	Pumping test duration (hr)	Drawdown rate (m/hr)	Specific capacity (m ² /hr)	Drawdown per unit Q (m/m ³ hr ⁻¹)	Test season (climate period)	Climate influence on drawdown
PW5	15.80	1.08	24	0.05	14.63	0.07	Wet	Buffered
PW6	13.20	22.28	24	0.93	0.59	1.69	Wet	Buffered
PW7	10.54	14.83	24	0.62	0.71	1.41	Wet	Buffered
PW8	51.72	15.55	48	0.32	3.33	0.30	Dry	Amplified
Range	10.54–200.00	1.08–60.21	24–72	0.05–0.99	0.59–14.63	0.07–1.69	—	—
Mean	84.60	33.42	48	0.65	3.88	0.66	—	—

Table 3. Drawdown, pumping time and climate

The pronounced contrast between dry-season (mean 45.83 m) and wet-season (mean 12.73 m) drawdowns confirms that seasonal recharge exerts a strong buffering influence on pumping-induced groundwater level fluctuation at Kimbiji — a pattern consistent with findings by Adelana et al. (2010) in East African coastal aquifers, where seasonal recharge reduced effective drawdown by 20–35%. PW4's disproportionately high drawdown-per-unit-discharge ratio (0.87 m/m³hr⁻¹) despite moderate pumping (55 m³/hr) signals localised low transmissivity, contrasting with PW5's exceptionally high specific capacity (14.63 m²/hr), which reflects direct proximity to a high-permeability coastal sand zone. These results are significant for Kimbiji's hydraulic characterisation: they demonstrate that pumping time, discharge rate, and climate season jointly control the magnitude of groundwater level fluctuation, and that aquifer parameter estimates derived solely from dry-season tests will overestimate long-term drawdown vulnerability unless seasonal recharge contributions are explicitly incorporated into the hydrogeological model.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The study confirms significant spatial heterogeneity in aquifer hydraulic properties at Kimbiji Well Field, with transmissivity, hydraulic conductivity, and storage coefficient varying widely. Pumping-induced groundwater level fluctuations were most severe at high-discharge production wells during the dry season, while seasonal recharge provided a substantial buffering effect. Well interference remained low to moderate under current abstraction rates; however, cumulative multi-well hydraulic loading poses a growing risk of progressive aquifer depletion, particularly in low-transmissivity zones near the coastline.

4.2 Recommendation

- 1 ☐ **Implement Site-Specific Abstraction Management** — Regulate pumping rates well-by-well, especially at high-drawdown wells (PW1–PW4), to prevent localized overexploitation.
- 2 ☐ **Establish a Continuous Groundwater Level Monitoring Network** — Install automated data loggers at all wells for real-time tracking and early warning of aquifer stress.
- 3 ☐ **Develop a Saltwater Intrusion Prevention Strategy** — Set minimum groundwater level thresholds at coastal wells to prevent inland migration of the freshwater–saltwater interface.
- 4 ☐ **Incorporate Seasonal Recharge Variability into Management Planning** — Adopt a seasonally adaptive pumping schedule, reducing abstraction during the dry season and calibrating safe yield estimates to account for climate-driven recharge variability.

Acknowledgement

Appreciations are due to the Water Institute Management, Wami Ruvu Basin and my fellow researchers for their and commendable support execution of this study.

Funding and Conflict of Interest

This study received no specific external funding from commercial, public or not for profit funding agency. The author declare that no conflicts of interests. Data supporting this study are available from corresponding author upon reasonable request subject to WRB data sharing with Water institute ethics clearance.

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