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Effects of Oil Production on Groundwater Levels in Lokichar Basin, Turkana County, Kenya

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Abstract

Increased groundwater abstraction may lead to decline in water levels. This study investigated the effects of oil production on groundwater levels in Lokichar basin in Turkana County, Kenya. The specific objectives were to: 1) establish changes in groundwater demand and 2) determine borehole water levels in the study area. Water levels for two boreholes within the study area were recorded between 12th August and 11th September 2020. The Kenya Ministry of Water and Irrigation Design Manual guidelines were adopted in estimating the groundwater demand in the study area. The study showed that groundwater demand in Lokichar basin increased from 1,846,001.55 l/d in 2009 to 4,951,043.44 l/d in 2019, a growth in groundwater demand of 168%. In addition, the groundwater demand was projected to increase to 145,235,374.23 l/d when full commercialization of the oil fields begins, representing 2,833% water demand increase between 2019 and 2022. It was observed that 58% of the overall groundwater demand was utilized for oil production in 2019 and this was expected to increase to 99% in 2022. The study showed that the average daily groundwater levels remained constant with Chinese 1 and Nawoyatira boreholes registering average daily water level of 18.12 m and 19.5 m respectively. However, there were major changes in hourly groundwater levels with the highest levels being recorded in the morning and the lowest levels being recorded at noon (2:00 pm). The level declined from 8:00 am when pumping commenced up to 2:00 pm after which the levels would start rising again. The decline in water levels worsened upon the incorporation of the oil production water demand into the abstraction, with levels at Chinese 1 reducing to a low of 74 m and Nawoyatira reducing to a low of 61 m. Therefore, the study concluded that increased groundwater abstraction led to borehole water level decline.

Subject Areas

Water Demand

Keywords

Energy Production, Groundwater Demand, Fracking, Groundwater Abstraction

1. Introduction

The demand for water globally has been increasing at an approximate rate of 1% per annum fueled by growth in population, economic growth as well as changes in the patterns of consumption [1]. It is expected that the global water demand will continue growing significantly over the next thirty years and is expected to reach 6000 km^3 per year by 2050 [2]. Out of the overall global water demand, energy production accounts for the second largest water consumer with agricultural production (irrigation water) accounting for the largest water demand. Water demand for energy production is expected to continue rising over the next two decades [3]. Energy production water demand is mostly required in oil and gas production which had a consumption of 30 billion gallons per day by the year 2015. Water is required in oil and gas production to flood declining conventional and offshore wells, well drilling, injecting to fracture underground shale or to steam reservoirs for oil sands extraction. These processes require millions of gallons of water [3]. It is estimated that in stripper oil operations, approximately nine barrels (equivalent to 1431 litres) of water is injected into the oil reservoirs to extract one barrel of oil [4]. With such large volumes of water being required to produce oil and gas, it is evident that water resources in areas where oil production is taking place are under immense water stress especially if the existing water sources are limited. A study on hydraulic fracturing from major shale producing areas in the United States showed that between the year 2011 and 2016, the water use per well increased by 770% [5]. The study recommended that further studies be undertaken to assess any changes in groundwater table due to increased water use in areas where oil and gas production was taking place. In June 2011, France effected a national ban on fracking due to the high water consumption required to frack a single shale well [6]. While effecting the ban France's Environment Minister cited the effects of over abstraction of groundwater resources posing major risks to the water table.

[7] carried out a study on the effects of hydraulic fracturing in South Africa concentrating on arid area of Karoo. The study found out that there has been increased conflict over water resources between the local residents and oil producing companies due to reallocation of water from people to oil production. According to the study, each well required approximately 15 million litres of water which led to reduced water supply to the residents. Kenya has got only 640 m^3 of renewable fresh water per capita and thus is classified as a water scarce

country [8]. Approximately 41% of the Kenyan population depends on unimproved sources of water that include rivers, ponds and shallow wells [9]. The areas mostly affected by lack of water in Kenya are the urban slums and rural areas especially the arid and semi-arid areas. With such scarcity of water resources, it is important that all the available water be utilized optimally. Turkana County is an arid area that largely depends on groundwater for operations. The water is mostly obtained from boreholes that are mostly located on the banks of the Laggers. Except for Lake Turkana and Turkwel river, naturally occurring surface water bodies are negligible due to the high evaporation rates [10]. Turkana County experiences both physical and economic water scarcity. This is brought about by lack of water infrastructure, low rainfall amounts and occasional droughts [10].

Oil production in the study area commenced in August 2018 under the Early Oil Pilot Scheme (EOPS). By June 2020, 1,460,000 barrels of oil had been produced, translating to 13,140,000 barrels of water (2,089,260,000 litres) utilized over that period. Water required during EOPS was obtained from boreholes drilled within the basin. Residents on the basin rely on groundwater for their various water needs. Commencement of oil production therefore, resulted to competition for groundwater resources in the basin, an area already experiencing acute water shortage. Oil production targets of 100,000 barrels daily translating to 143,100,000 litres of water utilization/generation daily is expected this year. This will lead to over-abstraction of groundwater which will result to decline in groundwater levels. Protection of the available groundwater resources in Turkana is therefore, key for sustainable development. Thus, this study aimed at investigating the effects of oil production on groundwater levels in Lokichar basin, Turkana County, Kenya with an aim of protecting local residents from lack of water resulting from over abstraction through recommending appropriate water use, management and conservation measures.

2. Materials and Methods

2.1. Study Area

The study was conducted in Lokichar basin, Turkana South Sub-County, Turkana County, Kenya. The basin lies between the Lokapei Lokichar Road to the west, Kapenguria Lodwar road to the North and Lokichar Loperot road to the south. The Basin is located between Easting 790,000 m and 820,000 m and Northing 240,000 m and 270,000 m. The study focused on boreholes in the vicinity of Lokichar town and those that were drilled by Tullow Oil Company during the Early Oil Pilot Scheme project. The boreholes were drilled along the Laggers. According to the [11] and [12], Turkana County had a population of 855,399 and 926,976 in 2009 and 2019 population census respectively. Turkana South had a population of 226,379 and 153,736 over the same period. The reduction in population for Turkana South was due to changes in the delimitation which resulted in Lokori and Lomelo divisions being moved out of Turkana

South to Turkana East. Lokichar location had a population of 23,452 and 27,036 persons in 2009 and 2019 population census respectively. Lokichar basin hosts the Twiga, Ngamia and Amosing oil fields which were the identified oil production areas in Kenya and where the Early Oil Pilot Scheme took place. **Figure 1** shows the map of the study area.

Lokichar basin is classified as an arid and semi-arid area and is characterized by warm and hot climate. The temperatures range between 20˚C and 41˚C with a mean of 30.5˚C [10]. The rainfall pattern and distribution are unpredictable and unreliable both in time and in space. The area receives an annual average rainfall of 121 mm with two rainfall seasons, the long rains occurring between April and July (commonly referred to as Akiporo) and the short rains occurring between October and November. The driest periods in the area are January, February and September [10]. The rainfalls are brief and accompanied with violent storms thus resulting in flush floods. The surface runoff and potential evaporation rates are extremely high.

The geology in the study area largely comprises Tertiary and Quaternary sediments and volcanic rocks. The basin was formed by rifting of basement rocks and is now partially infilled with superficial (drift) deposits. In certain sections of the study area the Precambrian basement rocks are exposed at the surface and comprise of intensely folded gneisses and migmatites while in other sections the Precambrian basement rocks are overlain by Tertiary Turkana Grits, Tertiary sedimentary deposits and a Tertiary volcanic succession [14]. The superficial geology that underlies Lokichar basin is mapped as Alluvium. The alluvial material comprises Plio-Holocene unconsolidated alluvial fan material that has in places been redistributed by ephemeral stream, and fluvial sediments. The main soil types comprise of Eutric and Calcaric regsols [14]. The topographical features consist of plateaus, low lying plains with isolated hill ranges, minor scarps, foot slopes, footbridges and seasonal rivers [15].

The two main sources of water in Lokichar basin are surface water and groundwater sources. Lokichar basin has numerous seasonal rivers called Laggers. The Lagger riverbeds are usually filled up with a thick layer of sand. When it rains, the surface runoff flows on the Laggers with part of the surface runoff percolating into the thick layer of sand occupying the Lagger riverbed and thus act as major medium for groundwater recharge. The flow on the Laggers is however ephemeral lasting for less than a week after the rains stop. Water can be accessed immediately after the rains along the Laggers by hand scooping the sand to create small water pans. Water can be accessed on the laggers for less than a week after rainfall cessation as the pans dry up. The limitation of this water sources is that the water stored under the river is only available for a short period after the rains have stopped. Due to high rate of evaporation within the basin, this water evaporates in less than a week and can therefore not be relied upon. Residents of Lokichar basin rely on groundwater to meet their daily needs. The boreholes within the basin have been drilled along the Laggers. This helps to recharge the aquifers when rains occur.

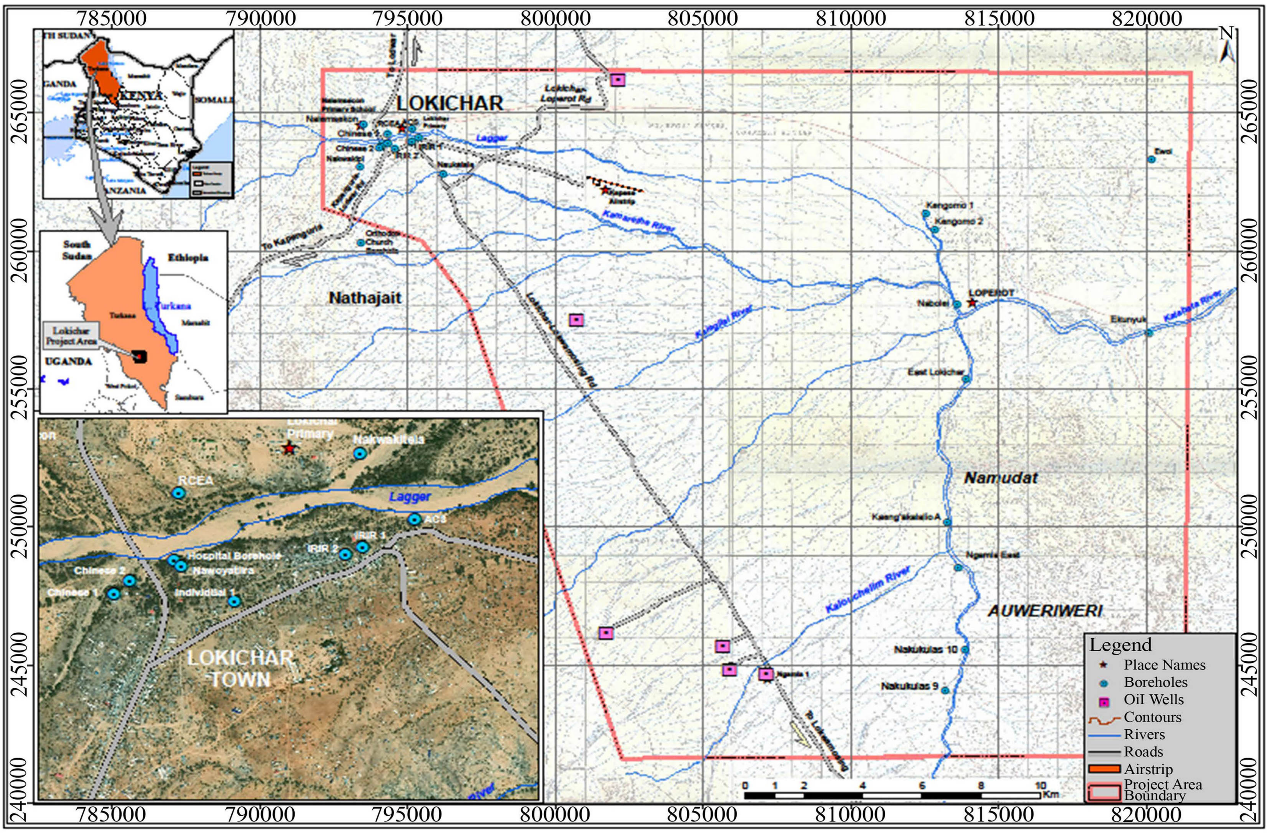

Figure 1. Map of lokichar basin. Source: [13].

2.2. Methods

2.2.1. Primary Data Collection

Data of the existing institutions, administrative offices, number of staff in the administrative offices, hospitals and number of hospital beds, shops, bars and schools in Lokichar basin were first identified and recorded in February 2020. The record was later validated during the months of August and September 2020. The number of individual connections and the main water sources were also identified in February by the help of Lokichar Water & Sanitation Company Limited (LOKIWASCO). The main water consumers in the study area were also identified by the help of LOKIWASCO.

2.2.2. Secondary Data Collection

Data on human and livestock population in Lokichar basin was obtained from the Kenya National Bureau of Statistics. The calculation of water demands was determined using the conversion factor given by the Kenya Ministry of Water and Irrigation design manual [16] as shown in **Table 1**. Data on oil production (under the Early Oil Pilot Scheme and planned full commercialization) was also obtained.

2.2.3. Groundwater Level Measurement

Hourly groundwater levels on two selected boreholes were recorded for a period

Table 1. Guidelines on estimation of water demand. Source: Kenya ministry of water and irrigation design manual (2005).

CONSUMER	UNIT	RURAL AREAS			URBAN AREAS		
		High Potential	Medium Potential	Low Potential	High Class Housing	Medium Class Housing	Low Class Housing
People with individual connections	l/head/day	60	50	40	250	150	75
People without connections	l/head/day	20	15	10	-	-	20
Livestock Unit	l/head/day		50			-	
Boarding Schools	l/head/day				50		
Day Schools with WC without DW	l/head/day				25 5		
Hospitals Regional District Other	l/bed/day	 400 200 100		}		+20 l per outpatient per day (minimum 5000 l/day)	
Dispensary and Health Centre	l/day				5000		
Hotels High Class Medium Class Low Class	l/bed/day				 600 300 50		
Administrative Offices	l/head/day				25		
Bars	l/day				500		
Shops	l/day				100		
Unspecified Industry	l/ha/day					20,000	
Coffee Pulping Factories	l/kg coffee				25 (when re-circulation of water is used)		

of 30 days as from 12th August 2020 to 11th September 2020. The recording of borehole water levels was carried out using a dipper and a Solinst Levelogger model 3601 - LTC M200. A Solinst Baralogger model 3001 LT F5/M1.5 was used to record the barometric pressure fluctuations. The choice of the borehole where levels were recorded was guided by the borehole area of service. Water levels for the borehole serving the largest area/demand within Lokichar urban area, and one borehole within its area of influence were recorded for purposes of establishing existing trends.

2.2.4. Data Analysis

Changes in ground water demand were analyzed by determining the groundwater demand for the year 2009 (before commencement of oil production) and 2019 (after commencement of oil production). A projection was carried out for groundwater demand for the year 2022. Groundwater demand was determined by focusing on all water demand sectors in Lokichar basin including domestic water demand, livestock water demand, institutional water demand, commercial water demand and industrial water demand (oil production water demand). The Kenya Ministry of Water and Irrigation Design Manual [16] guidelines were adopted in computing the various sectorial water demands. The computed water demands were further analysed in MS-Excel to establish the trends from 2009 to 2022. The borehole water levels were analyzed in MS-Excel, ARCGIS, and AutoCAD Civil 3D. Descriptive statistics were used to show changes in borehole water levels during the study period. The changes in borehole water levels were related to groundwater abstraction (demands) over the various periods to show the effect of increased groundwater abstraction to borehole water levels.

3. Results and Discussion

3.1. Groundwater Demand in Lokichar Basin

3.1.1. Domestic Water Demand in Lokichar Basin

An analysis of the 2009 and 2019 Kenya population census revealed that household population in Lokichar basin grew at a rate of 1.53% over a period of 10 years (0.153% annual growth rate). The national growth rate over the same period was 2.3%. The estimated domestic water demand in Lokichar basin for year 2009, 2019 and 2022 was found to be 1,011,954 litres per day, 1,166,603 litres per day and 1,195,768 litres per day respectively as shown in **Table 2**.

Domestic water demand increased by 15% between the year 2009 to 2019 (1.5% per annum) and is expected to increase by 2.5% between 2019 and 2022. The low growth in domestic water demand in Lokichar basin compared to the national growth rate was due to a low population growth rate experienced and low number of consumer water connections in the area. The trend in domestic water demand in the study area from 2009 to 2022 was as shown in **Figure 2**.

Table 2. Domestic water demand in Lokichar basin.

No.	Item	Demand Category	Population			Water Demand (l/day)		
			Year 2009	Year 2019	Year 2022	Year 2009	Year 2019	Year 2022
1	Urban - With Individual Connections	Low Class Housing	10,553	12,166	12,470	791,505	912,465	935,277
2	Urban - Without Individual Connections	Low Class Housing	3518	4055	4157	70,356	81,108	83,136
3	Rural - With Individual Connections	Low Potential	1876	2163	2217	75,046	86,515	88,678
4	Rural - Without Individual Connections	Low Potential	7505	8652	8868	75,046	86,515	88,678
	Total Domestic Water Demand (l/day)					1,011,954	1,166,603	1,195,768

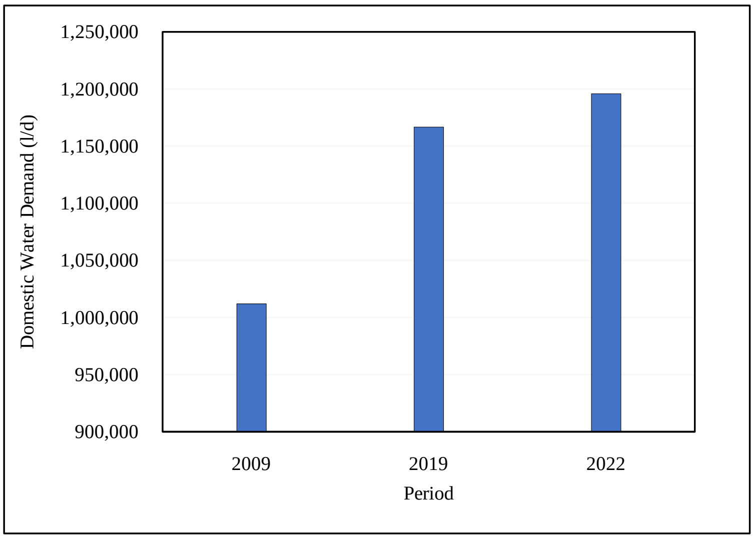

Figure 2. Trend in domestic water demand from 2009 to 2022.

3.1.2. Domestic Water Demand in Lokichar Basin

Due to the extreme temperatures and low rainfall experienced in the study area, the livestock reared are goats, sheep, and camels. Analysis of 2009 and 2019 livestock data showed that the number of livestock in Lokichar basin increased at an average rate of 0.3% per annum. The estimated livestock water demand in Lokichar basin for year 2009, 2019 and 2022 gave 373,273 litres per day, 382,308 litres per day and 384,192 litres per day respectively as shown in Table 3. In addition, the trend in livestock water demand in the study area from 2009 to 2022 was found to be as shown in Figure 3.

3.1.3. Institutional Water Demand in Lokichar Basin

The estimated institutional water demand in Lokichar basin for the years 2009, 2019 and 2022 assuming that no additional institutions will be established in the area between the year 2020 and 2022 were 449,780 litres per day, 522,006 litres per day and 535,194 litres per day respectively as shown in Table 4. The trend in institutional water demand in the study area from 2009 to 2022 was as shown in Figure 4.

3.1.4. Commercial Water Demand in Lokichar Basin

Shops and bars were the contributing factors to commercial water demand in Lokichar basin. The estimated commercial water demand in Lokichar basin for year 2009, 2019 and 2022 were 11,000 litres per day, 19,500 litres per day and 21,700 litres per day respectively as shown in Table 5.

Commercial water demand was found to be increasing significantly in Lokichar basin between the year 2009 and 2019 and was projected to continue increasing to year 2022. Between the year 2009 and 2019, commercial water demand in the study area increased by 77% and was further expected to increase by 10% from 2019 to 2022. The high increase in commercial water demand was found to be propagated by the increased number of shops and bars in the area to cater for Tullow oil workers. Figure 5 shows the trend in commercial water demand in the study area from 2009 to 2022.

Table 3. Livestock water demand in lokichar basin.

No.	Item	Livestock Units (LU)	Number of Livestock			Water Demand (l/day)		
			Year 2009	Year 2019	Year 2022	Year 2009	Year 2019	Year 2022
1	Sheep	15 Sheep = 1 LU	20,517	21,036	21,142	68,390	70,120	70,473
2	Goats	15 Goats = 1 LU	53,695	55,504	55,783	178,983	185,013	185,943
3	Camels	2 Camels = 1 LU	5036	5087	5111	125,900	127,175	127,775
	Total Livestock Water Demand (l/day)					373,273	382,308	384,192

Table 4. Institutional water demand in lokichar basin.

1. Education Water Demand								
No.	Item	Demand Category	Population			Water Demand (l/day)		
			2009	2019	2022	2009	2019	2022
1	Urban	Low Class Housing	14,071	16,227	16,627	316,598	365,108	374,108
2	Rural	Low Potential	9381	10,814	11,085	112,572	129,768	133,020
2. Health Water Demand								
No.	Item		Population			Water Demand (l/day)		
			2009	2019	2022	2009	2019	2022
1	Rural and Urban (Entire Sub-County)		226,379	292,262	303,952	18,110	23,381	24,316
3. Administration Water Demand								
No.	Item		Number of Staff			Water Demand (l/day)		
			2009	2019	2022	2009	2019	2022
1	Turkana South Sub-County Offices		100	150	150	2500	3750	3750
	Total Institutional Water Demand (l/day)					449,780	522,006	535,194

Table 5. Commercial water demand in lokichar basin.

No.	Item	Number of Shops & Bars			Water Demand (l/day)		
		2009	2019	2022	2009	2019	2022
1	Shops	60	120	132	6000	12,000	13,200
2	Bars	10	15	17	5000	7500	8500
	Total Commercial Water Demand (l/day)				11,000	19,500	21,700

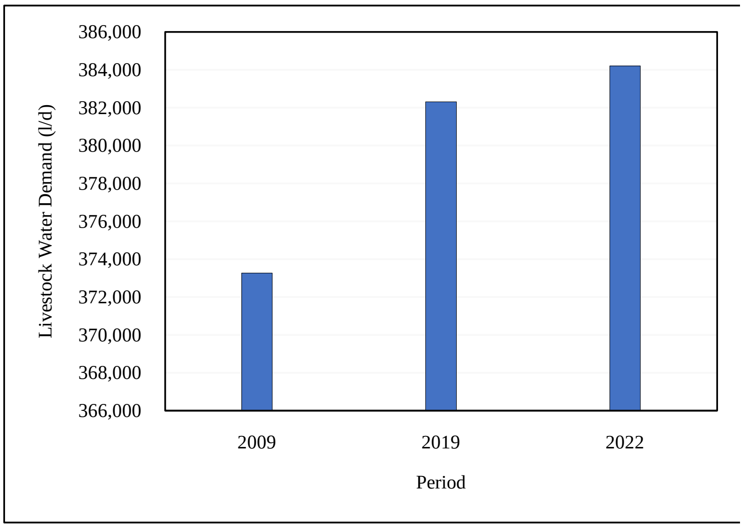

Figure 3. Trend in livestock water demand from 2009 to 2022.

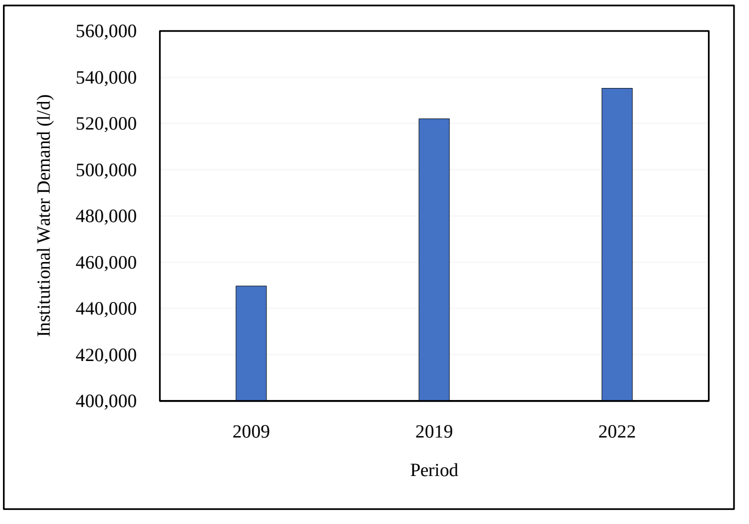

Figure 4. Trend in institutional water demand from 2009 to 2022.

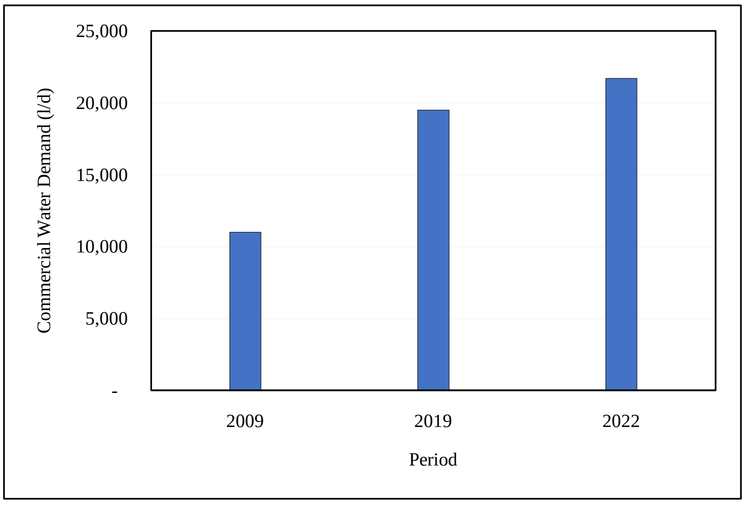

Figure 5. Trend in commercial water demand from 2009 to 2022.

3.1.5. Industrial/Oil Production Water Demand in Lokichar Basin

The estimated industrial water demand in Lokichar basin for the years 2019 and 2022 were 2,862,000 litres per day and 143,100,000 litres per day respectively as shown in **Table 6**.

There were no major industries in Lokichar basin in 2009 and thus no industrial water demand was registered. However, in 2019 after the commencement of oil production, industrial water demand rose from 0 to 2,862,000 litres per day (**Table 6**). This was more than the water demand from all other sectors combined. A projection of the industrial water demand for the year 2022 showed that the demand will increase to 143,100,000 litres per day representing 4900% growth rate (99% of all the water required in the study area). This implied that 99% of the water generated in the study area will be directed to oil production with other sectors left to share the remaining 1%. The trend in industrial water demand in the study area from 2009 to 2022 was as shown in **Figure 6**.

3.1.6. Overall Groundwater Demand in Lokichar Basin

The sectorial groundwater demands for the periods 2009, 2019 and 2022 as shown in **Figure 7** clearly indicated that by the year 2022, industrial water demand will by a large extent supersede all other sectors. This would result to inaccessibility of water by some sectors which may end up causing conflicts between residents and oil producing companies.

A comparison of industrial water demand and a summation of water demands from all the other sectors was carried out to establish the magnitude of the change in demands caused by the commencement of oil production. A plot of industrial water demand and a combination of other demands showed that all other demands being surpassed by the industrial demand by 2022 as shown in **Figure 8**.

Between year 2009 and 2019, there was an increase of 168% in the overall groundwater demand. It was projected that between 2019 and 2022, the overall groundwater demand would increase by 2833% as shown in **Figure 9**.

3.2. Groundwater Levels

Hourly and Daily Borehole Water Levels

Analysis of the hourly borehole water levels for Chinese 1 and Nawoyatira borehole shows that the water levels were usually high during morning and evening hours and lowest between 1:00 pm and 3:00 pm During the study period the lowest water level for Chinese 1 borehole was recorded on 5th September 2020 at 2:00 pm at depth of 29.0 m while the highest water level was recorded on 15th August 2020 at 7:00 am at a depth of 3.5 m. In the case of Nawoyatira borehole, the lowest water level was recorded on 29th August 2020 at 3:00 pm at a depth of 26.60 m while the highest water level was recorded on 13th August 2020 at 8:00 am at a depth of 3.84 m as shown in **Figure 10**. The average daily water level for Chinese 1 borehole was 18.12 m while that for Nawoyatira was 19.5 m as shown in **Figure 11**.

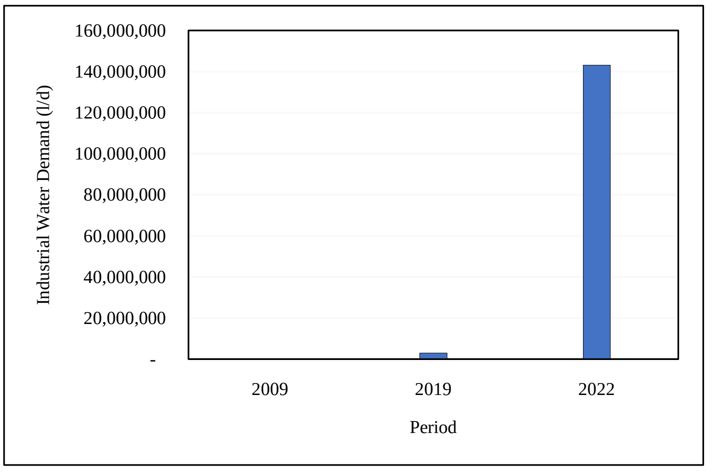

Figure 6. Trend in industrial water demand from 2009 to 2022.

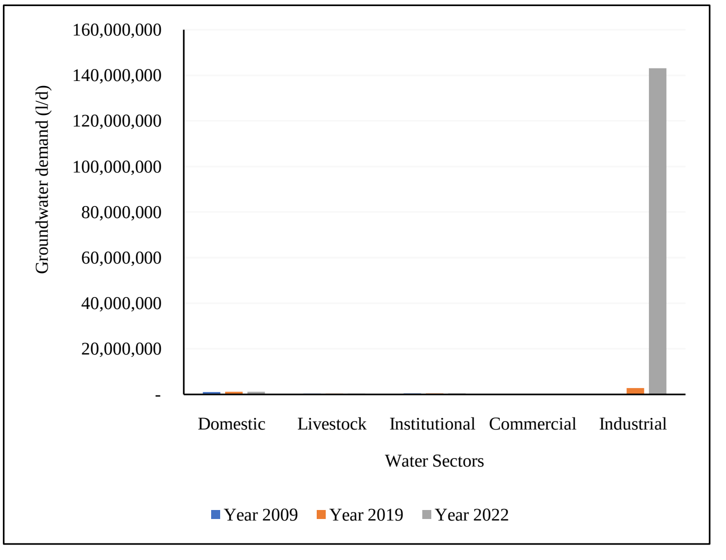

Figure 7. Comparison of sectorial water demand.

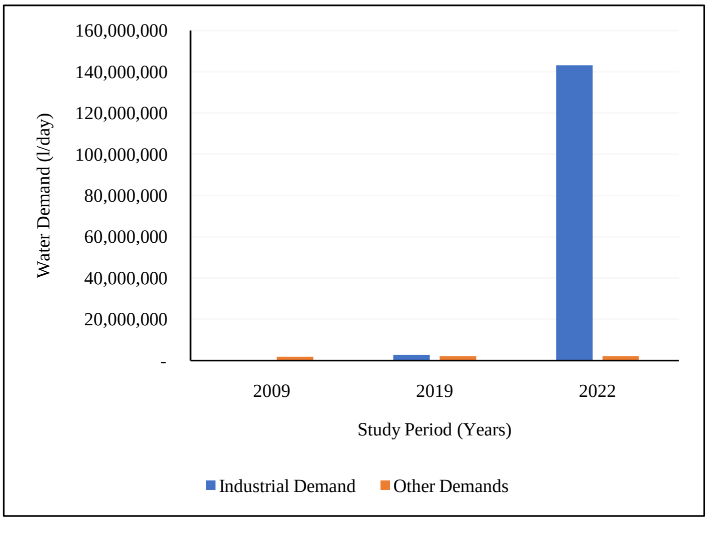

Figure 8. Industrial demand vis-a-vis a summation of other demands.

Table 6. Industrial water demand in lokichar basin.

No.	Item	Barrels of Oil produced per day			Water Demand (l/day)		
		2009	2019	2022	2009	2019	2022
1	Oil Production	0	2000	100,000	0	2,862,000	143,100,000
	Total Industrial Water Demand (l/day)				0	2,862,000	143,100,000

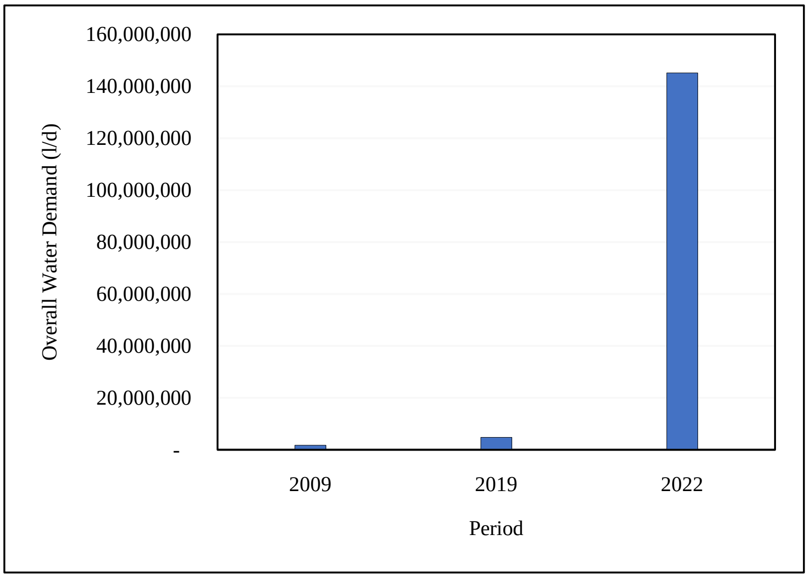

Figure 9. Trend in overall water demand in lokichar basin.

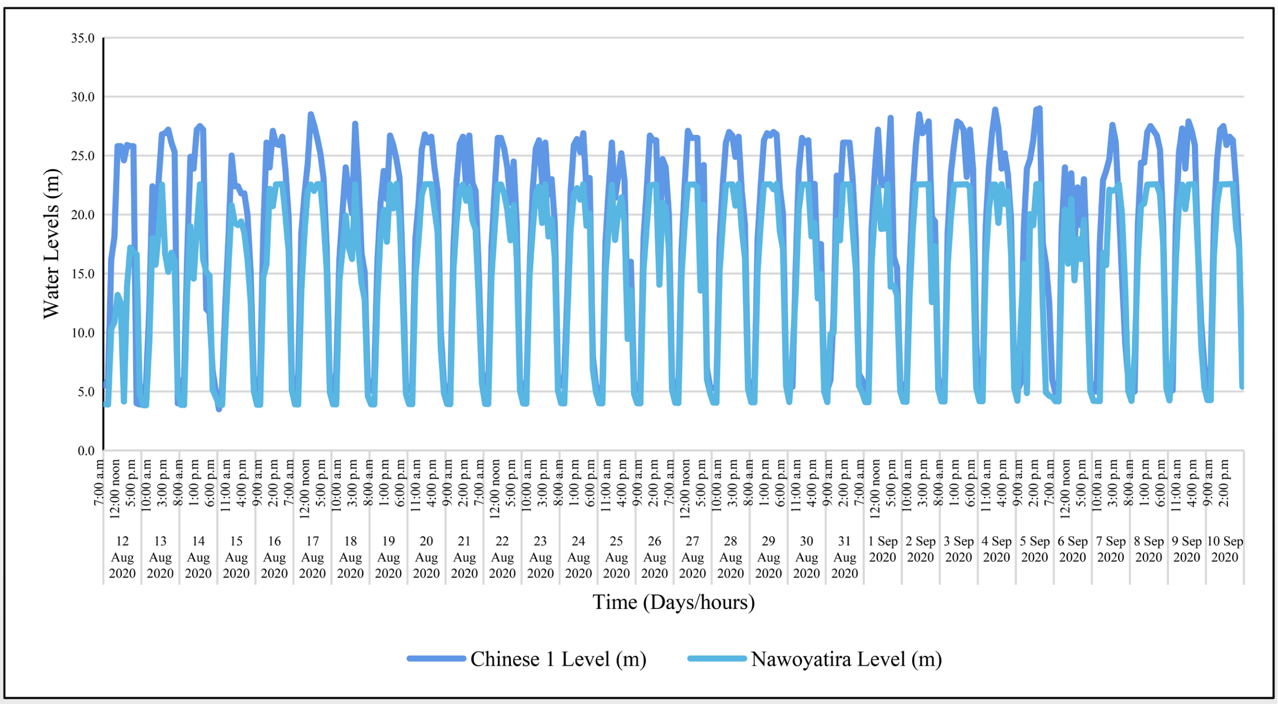

Figure 10. Trend in water levels for Chinese 1 and nawoyatira boreholes.

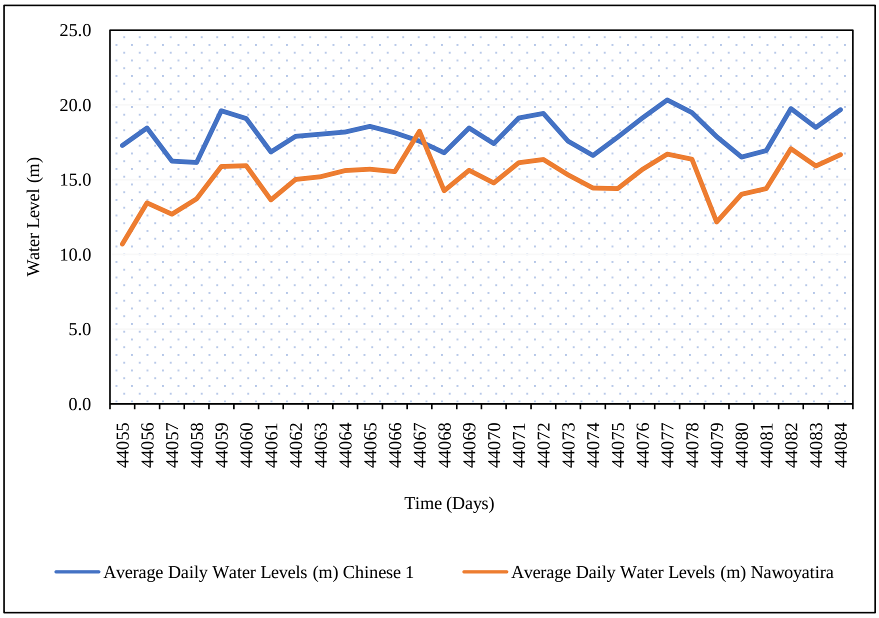

Figure 11. Average daily borehole water levels.

4. Conclusions

The study results showed a significant increase in groundwater demand in Lokichar Basin between year 2009 and year 2022. Between year 2009 and 2019, there was an increase of 168% in the overall groundwater demand in Lokichar Basin. Groundwater demand is further expected to increase by 2833% by the year 2022. The increase in groundwater demand has been exacerbated by the commencement of oil production in the study. In 2019, oil production water demand accounted for 58% of the overall water demand in the study area. 99% of the overall water demand in the study area will be utilized in oil production in the year 2022.

The study results further showed that daily groundwater levels in the basin remained constant over the study period. This could have been brought about by the suspension of oil production at the time of field data collection after successful completion of the Early Oil Pilot Scheme. Analysis of hourly groundwater level fluctuations showed that when water pumping commences in the morning, groundwater decline commences up to around 2 pm, which implies that the abstraction was higher than the rate of recharge. The reduction in pumping from around 2 pm, resulted in groundwater levels rise implying that the recharge at this time was higher than groundwater abstraction. Oil production was found to majorly contribute to the decline in water levels to as low as 74 m for Chinese 1 and 61 m for Nawoyatira boreholes respectively. In conclusion, increased groundwater abstraction was found to lead to borehole water level decline. The incorporation of oil production water demand exacerbated the decline in the water levels. Therefore, the study highly recommends that an alternative source of water be identified during full commercialization of the oil fields to avoid overreliance on groundwater for oil production. In addition, Turkana

County government should enact policies aimed at protecting the Laggers which are the main agents of groundwater recharge by imposing a ban on sand harvesting.

Acknowledgements

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Data Availability Statement

All relevant data are included in the paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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