Linking Groundwater Protection and Wastewater Reuse in West Omdurman, Sudan: A Framework for Urban Water Resources Management

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Abstract: ***West Omdurman, a rapidly growing part of Khartoum State, relies heavily on groundwater from the upper Nubian aquifer for domestic and agricultural supply. At the same time, most wastewater is generated and disposed of via on-site sanitation systems, with only a small fraction reaching centralised treatment plants. This situation leads to two interrelated challenges: increasing pressure on groundwater resources and progressive deterioration of groundwater quality. The study examines groundwater vulnerability and wastewater management in West Omdurman, Sudan, where increasing demand and inadequate sanitation threaten the Nubian aquifer. Drawing from hydrochemical, microbiological, and geophysical data, the research outlines an integrated water resources framework that links aquifer protection with advanced wastewater reuse. By proposing a phased, zone-based implementation strategy for wastewater treatment, the study suggests that reclaimed water could reduce irrigation pressure on groundwater, improve water quality, and foster sustainable urban water use. The findings underscore the importance of coordinated planning and investment in sanitation infrastructure. The analysis suggests that introducing properly designed wastewater treatment and reuse in West Omdurman could reduce groundwater abstraction for irrigation, lower contaminant loads reaching the aquifer and contribute to more balanced use of surface water, groundwater and reclaimed water. The paper proposes a phased strategy that starts with priority zones and averages existing municipal and environmental management institutions in Khartoum State.***

Keywords: groundwater contamination, wastewater reuse, Nubian aquifer, urban water management, West Omdurman.

1. Introduction

1.1 Background

In arid and semi-arid regions such as central Sudan, water resources management must address both quantity and quality constraints.

Khartoum State is located at the confluence of the White and Blue Nile, yet surface water alone cannot meet the demands of its rapidly growing population, industries and agricultural activities. Groundwater from the Nubian aquifer system has therefore become a core component of water supply. At the same time, wastewater generation has increased sharply, while treatment capacity has not kept pace.

In West Omdurman, most households and small businesses rely on septic tanks and pits, and only a limited share of wastewater reaches the existing treatment plants at Soba and Khartoum North. The combination of intensive groundwater use and inadequate wastewater handling poses a serious risk for the long-term sustainability of the aquifer and for public health. This paper builds on the hydrochemical and microbiological investigation of the upper Nubian aquifer in West Omdurman and explores how wastewater treatment and reuse can be integrated into a broader strategy for urban water resources management.

This study aims to develop a region-specific framework for integrating groundwater protection with wastewater reuse to address water scarcity and contamination challenges in West Omdurman.

1.2 Statement of Problem

Khartoum State is located at the confluence of the White and Blue Nile. Therefore, it is important to know the impact of groundwater and surface water quality, how this impact can change daily life, and how to reduce water pollution in a city. The River Nile water quality and groundwater quality is affected by this seasonal variation and groundwater contamination. Today, with the advancement of science and technology, the population, industries, agricultural activities, and urban developments have grown up along the river banks in Khartoum state. Domestic sewage, factories effluents, and agricultural waste can lead to deterioration of River Nile water quality as well as underground water. Groundwater contamination inventory is an indispensable part of any comprehensive groundwater protection strategy. Before appropriate protection measures can be designed and implemented, groundwater contamination and its sources must be identified and assessed, and their impacts on groundwater quality determined. An inventory of the number, type, and intensity of potentially contaminating activities and of the extent of existing contamination of groundwater can serve a twofold purpose for groundwater protection:

- It provides government officials, planners, and managers with an understanding of the potential for groundwater contamination needed for successful management programs.
- It provides basic data that can be used for the design of the type and location of various controls and of monitoring programs.

The fundamental principle of sanitation should be practiced in every locality as far as possible. Authorities all over the world are increasingly realizing a need for providing and maintaining the urban environment clean and healthy which essentially is a traditional function of local government. However, There is always the problem of the generation of 15 16 some undesirable matter. It should be removed as soon as possible to some place where it may not affect the health of the community. Therefore, this research will analyze and discuss the problem of groundwater contamination and how to realize and treat the sewage needs well in the study area.

1.3 Objectives

The overall objective of the study is to provide a comprehensive and up-to-date overview of all existing groundwater wells in the survey area. Moreover, the well inventory is the source of much of the hydro-geological data to be used within the scope of the Inventory of contamination Studies of Water Resources of West Omdurman and Overlying Aquifers. and to phase out reliance on septic tanks and boreholes in Sudan by using Sewage network and wastewater treatment plant and reused treated water for irrigation. However, the specific objectives of this study are the following:

a) To check the accessibility and suitability of wells for the execution of groundwater sampling.
b) To check the performance of all the existing hydro-meteorological installations and water level recorders in the study area.
c) To survey the current situation in terms of water quality with regard to domestic, agricultural land use and corresponding water use within the study area.
d) To investigate geophysical parameters and stratigraphic boundaries of the sedimentary formation and overlying strata in the study.
e) To describe the hydrochemical composition of the groundwater underlying the study area and to assess its contamination or NOT and quality with respect to domestic, agricultural, and industrial usage. the detailed objectives of the groundwater quality study are:
    - Determination, description, and explanation of lateral and vertical variations of major ion concentrations in the occurring aquifers, o Investigation of time-related changes of major ion concentrations, o Calculation of saturation indices with respect to selected minerals for the assessment of corrosion and encrustation hazards.
    - Determination of trace element concentrations and "fingerprints" in the different aquifers.
    - Determination of detrimental effects of agriculture-related chemicals on the groundwater.
    - Assessment of the water quality with regard to domestic, agricultural, and industrial usage.
f) Microbiological analysis of water (groundwater and wastewater) samples.

The study is significant as it provides a model for integrating sanitation planning with groundwater protection in arid regions, where unchecked urban expansion and inadequate wastewater infrastructure risk compromising critical aquifer systems.

2. Water Use and Sanitation in West Omdurman

Groundwater abstraction in the study area is dominated by production wells operated by the Khartoum State Water Corporation and by numerous private wells for domestic and irrigation use. Seventy production wells lie within a corridor 1–22 km west of the White Nile, and many additional wells are located on farms and in local communities. Groundwater is used directly for drinking water supply, for small-scale irrigation of vegetables and trees and for livestock.

Sanitation infrastructure lags behind this development. On-site sanitation systems are widespread, and in many cases effluents infiltrate directly into the subsurface without any intermediate treatment or control. The two centralised treatment facilities in Khartoum State – waste stabilisation ponds at Soba and an activated sludge/Sequencing Batch Reactor plant in Khartoum North – do not provide coverage for West Omdurman. Their performance is constrained by overloading, variable influent quality and limited enforcement of industrial pre-treatment.

As a result, untreated or poorly treated wastewater contributes to groundwater contamination in the West Omdurman area, as evidenced by elevated nitrate and microbiological indicators in some wells.

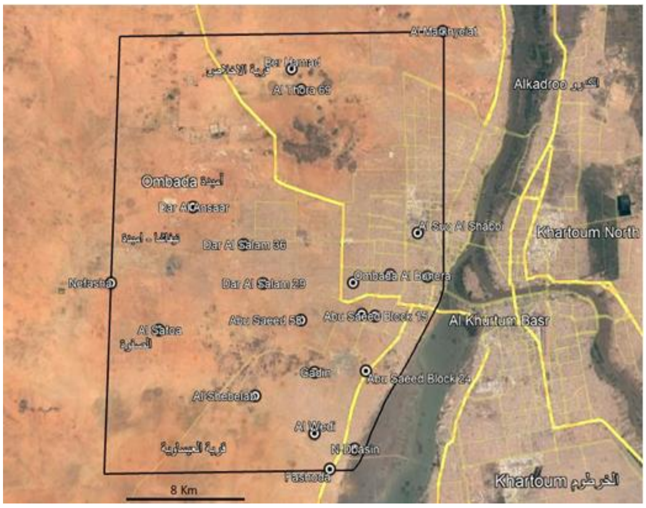

Figure 2.1: Location map of the study area and main groundwater abstraction corridor in West Omdurman (adapted from Ahmed, 2022)

Paper ID: SR251201052720 DOI: https://dx.doi.org/10.21275/SR251201052720

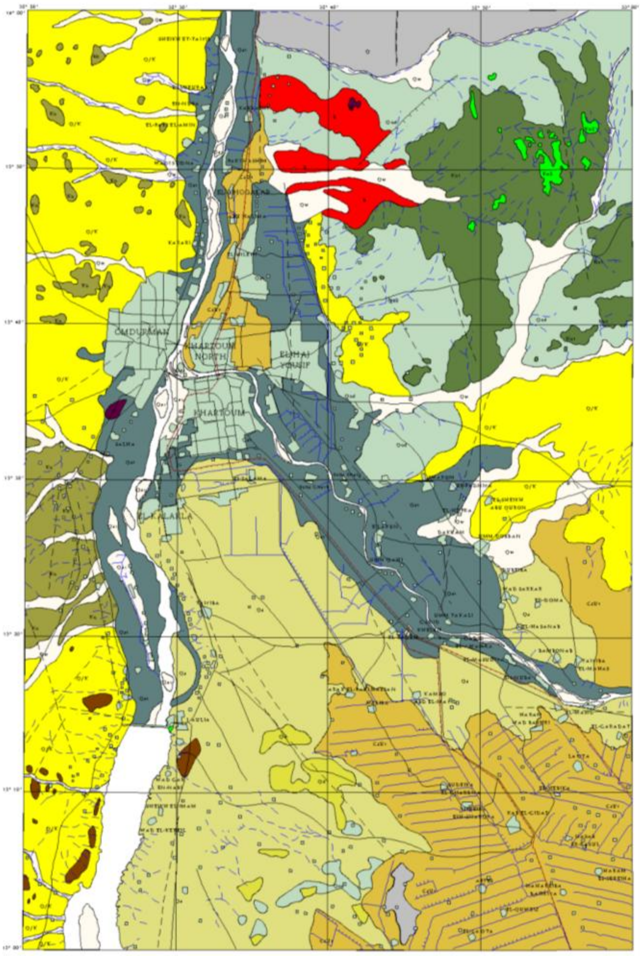

Figure 2.2: Geological and hydrogeological setting of the study area (modified after GRAS, 2004).

Table 2.1: Summary of main well fields and groundwater abstraction characteristics in West Omdurman (after Ahmed, 2022).

X: EASTING	Y: NORTHING	Well Name	Total Depth (m)	Casing Depth (m)	casing diameter (mm)	Q (m3/h)	SWL (m)
435917.51	1721151.00	Gadin	228.6	225.5	219.0	91	61.1
437062.25	1714745.40	Fashoda	227.1	222.5	219.0	60	50.2
438772.11	1716037.18	Dbasin Bidege	289.5	280.4	355.6	273	11.8
424853.00	1724159.00	Al Safoa	271.3	268.2	273.0	182	70.2
444953.00	1744636.00	Al Markhyeiat	160.0	158.5	219.0	60	43.4
440140.00	1724858.00	Abu Saeed 15	262.1	249.9	273.0	150	56.5
439199.00	1724986.00	Abu Saeed 19	224.0	216.4	273.0	150	50.6
439527.00	1721187.00	Abu Saeed 24	190.5	182.9	219.0	60	21.2
434663.00	1740614.00	Al Thora 69	182.9	176.8	219.0	60	57.3
431761.00	1719647.00	Al-Shebelab	225.5	219.4	219.0	41	28.8
435961.00	1717107.00	Al Wedi	219.4	213.3	219.0	41	43.1
432158.00	1727191.00	Dar Al Salam 29	310.9	298.7	355.6*273	364	67.0
430734.00	1729869.00	Dar Al Salam 36	286.5	280.4	273.0	91	82.1
438567.00	1727143.00	Ombada Al Buhera	251.4	249.9	219.0	50	49.9
421327.00	1727395.00	Nefasha	280.4	268.2	219.0	273	73.8
434906.25	1724663.35	Abu Saeed 58	190.5	181.3	219.0	59	48.6
443850.00	1727475.00	Banat	265.2	260.6	355.6*273	273	17.4
427022.61	1732508.83	Dar Al Ansaar	310.9	298.7	355.6*273	364	67.0
433936.00	1742096.00	Ber Hamad	190.5	187.4	219.0	60	50.6
441197.50	1727642.12	Ombada 14	243.8	210.3	219.0	45	47.8
443157.00	1730469.00	Al Suq Al Shabbi	265.2	260.6	219.0	273	17.4

3. Methodology

The integrated framework presented here is based on three elements:

- Characterization of groundwater quality and vulnerability using hydrochemical, microbiological and geophysical data.
- Definition of a baseline scenario in which wastewater continues to be managed mainly through on-site systems with no advanced treatment in the study area.
- Definition of alternative scenarios in which centralised or semi-centralised wastewater treatment plants are introduced, designed to produce effluent suitable for irrigation, thus partly substituting groundwater abstraction.

The analysis aims at a coherent qualitative and semi quantitative comparison of these scenarios in terms of pressures on the aquifer, environmental risks and opportunities for reuse.

Table 3.1: Overview of groundwater-quality datasets used for the integrated groundwater and reuse assessment (after Ahmed, 2022)

Name	Ph [-]	T[°C]	EC [µS/cm]	TDS [mg/l]	T.Alk. [mg/l]	TH [mg/l]I	PO43- [mg/l]	Cl- ([mg/l]	F- [mg/l]	SO42- [mg/l]	NH4+ [mg/l]	NO2- [mg/l]	NO3- [mg/l]	Fe2+ [mg/l]	Ca2+ [mg/l]	Mg2+ [mg/l]	Na+ [mg/l]	K+ [mg/l]
Gadin	7.1	28	593.00	391.00	200.00	116.00	0.60	28.00	1.20	13.00	0.50	0.02	2.40	3.00	24.00	13.44	60.00	9.90
Fashoda	7.4	30	814.55	488.71	302.00	186.00	0.21	23.00	0.43	31.00			7.20	0.08	30.40	26.40	78.96	13.84
Dbasin Bidege	7.5	29	806.50	443.50	238.00	132.00	0.14	50.00	0.48	64.10	0.42	0.32	5.72	0.03	28.80	14.40	117.68	3.30
Al Safoa	6.9		497.00	347.60	219.60	204.00		56.00	0.51		0.28	0.02	7.92		45.60	21.87	48.89	
Al Markhyeiat	7.7	27	573.00	343.80	235.00	200.00		25.00	0.38	29.90		0.02	5.28	0.01	44.80	21.12	44.88	5.34
Abu Saeed 15	7.4	31	1346.00	740.00	220.00	310.00	0.57	156.00	0.43	86.00	0.57	0.06	2.80	0.02	67.20	34.08	104.40	7.30
Abu Saeed 19	7.4	31	732.00	439.00	246.00	176.00	0.28	38.00	0.15	28.00	0.25	0.01	1.70	0.04	35.20	21.12	64.80	6.50
Abu Saeed 24	7.6	30	1464.00	805.17	284.00	340.00	0.32	196.00	0.62	116.00	0.63	0.24	3.00	0.04	57.60	47.04	149.12	6.68
Al Thora 69	7.0	29	576.00	386.00	239.00	176.00	0.40	11.00	0.29	12.00	0.03	0.04	3.80	0.01	42.40	16.80	39.20	5.80
Al-Shebelab	7.6	24	1831.00	1007.00	270.00	224.00		160.00	0.72	140.00	0.05	0.17	2.00		48.00	24.96	216.00	12.40
Al Wedi	7.4		733.00	513.10	402.47	173.60		50.41	0.75	77.50	0.46	0.01	4.40		44.40		166.87	
Dar Al Salam 29	7.8	28	873.00	480.00	218.00	202.00	0.54	72.00	0.72	47.00	0.44	0.07	1.90	0.07	38.40	25.44	73.50	5.70
Ombada Al Buhera	7.3	31	510.00	250.00	190.00	140.00		60.00			0.04			0.29	32.00			
Nefasha	7.3	25	776.30	426.90	210.00	180.00		50.00	1.00	41.00	0.11	0.03	7.30	0.09	30.00	24.00	70.00	5.30
Abu Saeed 58	7.3	27	1445.40	794.00	276.00	296.00	0.03	170.00	0.47	121.20	0.20	0.01	5.72	0.01	65.60	31.68	155.52	13.46
Banat	7.2	25	590.00	354.00	230.00	168.00	0.12	18.00	0.28	17.00	0.31	0.07	1.80	0.17	36.00	18.72	49.00	7.50
Dar Al Ansaar	7.8	28	873.00	480.00	218.00	202.00	0.54	72.00	0.72	47.00	0.44	0.07	1.90	0.07	38.40	25.44	73.50	5.70
Ber Hamad	7.2		498.00	348.00	207.00	106.00		22.70	0.90	30.00	0.33	0.01	4.80		24.00	11.30	48.00	5.00
Ombada 14	8.3		460.00	322.00	286.60	138.00		18.46	0.75	33.00	0.00	0.02	0.44		24.80	18.46	27.30	
Al Suq Al Shabbi	7.9	29	282.00	155.00	66.00	84.00	0.21	32.00	0.17	10.00	0.09	0.03	3.60	0.10	18.40	9.12	16.20	1.00
max	8.3	31	1831.00	1007.00	402.47	340.00	0.60	196.00	1.20	140.00	0.63	0.32	7.92	3.00	67.20	47.04	216.00	13.84
min	6.9	24	282.00	155.00	66.00	84.00	0.03	11.00	0.15	10.00	0.00	0.01	0.44	0.01	18.40	9.12	16.20	1.00
avg	7.5	28	813.69	475.74	237.88	187.68	0.33	65.43	0.58	52.43	0.29	0.07	3.88	0.27	38.80	22.52	84.41	7.17

4. Results and Analysis

This chapter is organized into four main sections:

- Publication trends and research topics.
- Technological distribution and sectoral analysis.
- Machine learning and optimization algorithm performance.
- Economic, environmental, and social indicators.

4.1 Groundwater Quality Constraints

The groundwater quality assessment shows that, while large parts of the upper Nubian aquifer still provide usable water, specific zones exhibit significant contamination by nitrate and faecal indicators. These zones are typically associated with dense settlement, shallow groundwater and permeable surface deposits. In such areas, unregulated abstraction for domestic use is risky without treatment, and further intensification of on-site sanitation will aggravate the problem.

From a water resources perspective, this means that the aquifer cannot be considered an unlimited, uniformly safe source. Instead, groundwater availability is constrained by both quantity and quality, and some wells may need to be reserved for lower-risk uses or improved by treatment.

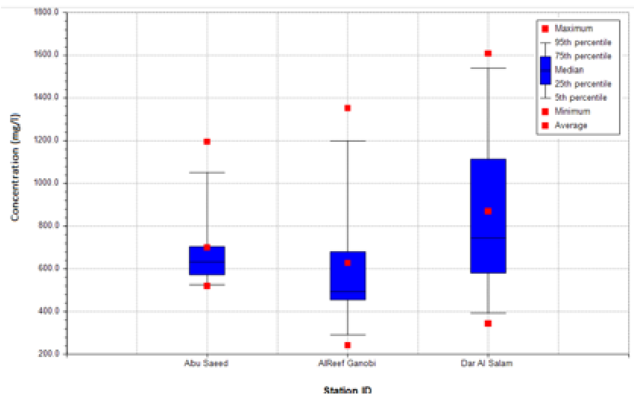

Figure 4.1: Box-whisker plots of selected hydrochemical parameters in groundwater of West Omdurman.

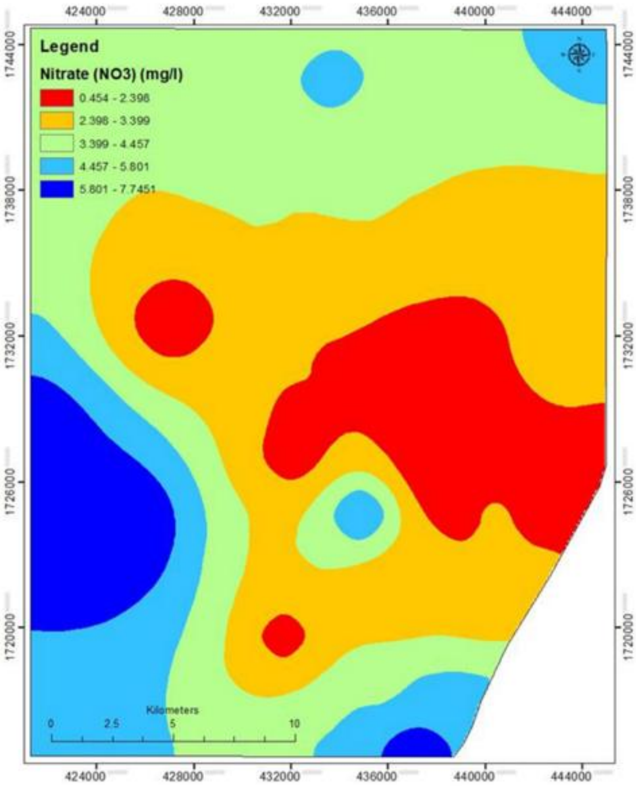

Figure 4.2: Spatial distribution of nitrate concentrations in groundwater, illustrating contamination hotspots.

4.2 Role of treated wastewater in the water balance

The thesis includes the design of an advanced wastewater treatment plant for West Omdurman, based on combinations of biological treatment, sand filtration, membrane bioreactors and disinfection. Depending on design assumptions, such a plant could treat a significant share of the wastewater generated in the area and produce substantial volumes of effluent suitable for irrigation.

If this reclaimed water is used to replace part of the groundwater currently abstracted for irrigation, the net abstraction from the upper Nubian aquifer can be reduced. This would help stabilise groundwater levels and limit the spread of contamination, while providing a reliable water source for agriculture and green spaces.

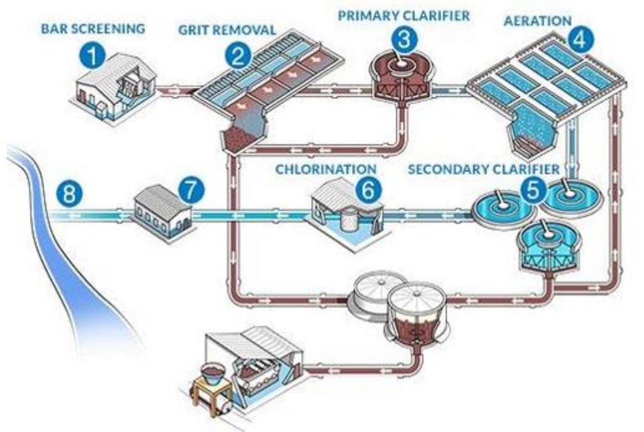

Figure 4.3: Conceptual process train for advanced wastewater treatment and reuse in West Omdurman (adapted from Ahmed, 2022).

4.3 Integrated management implications

The comparison between the baseline and reuse-oriented scenarios suggests that managing groundwater and wastewater as separate sectors is no longer adequate. Instead, water resources planning in West Omdurman should treat groundwater and reclaimed wastewater as complementary resources, allocate high-quality groundwater preferentially to domestic supply and supply irrigation partly from treated effluent where quality standards are met. Groundwater quality data should guide the location and design of new sanitation and treatment infrastructure.

5. Conclusions and Recommendations

The research underscores that groundwater quality in West Omdurman is increasingly compromised by on-site sanitation and unregulated abstraction. The introduction of wastewater reuse schemes, supported by data-driven infrastructure planning, offers a viable path toward sustainable water management. By aligning groundwater allocation with quality assessments and reusing treated wastewater for irrigation, authorities can mitigate aquifer depletion and health risks. This integrated model holds promise for replication in similarly challenged urban settings across Sudan and beyond.

Key recommendations include:
- Developing an advanced wastewater treatment and reuse project for West Omdurman as a priority component of the regional water strategy.
- Linking decisions on well siting, pumping rates and reuse areas explicitly to groundwater quality monitoring results.
- Strengthening institutional coordination between water supply, sanitation and environmental authorities.

This integrated approach is applicable not only to West Omdurman but also to other urban areas in Sudan and the wider region that face similar challenges.

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