Using groundwater quality index and concentration duration curves for classification and protection of groundwater resources, South Africa

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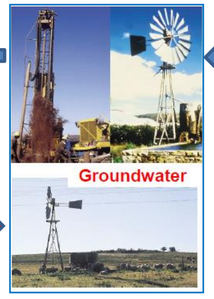
ABSTRACT

Water quality assessment for water resource protection and management is key towards sustainable provision of potable water supply and in meeting sustainable development goals (SDGs) linked to clean water and sanitation. The spatial and temporal aspects of groundwater quality in the Nseleni catchment, South Africa (SA) was investigated, its suitability for domestic use was considered, and required protection measures were established. Using a hybrid approach methodology based on multiple water quality resource assessment techniques such as groundwater quality index (GQI) and concentration duration curves (CDCs), 72 groundwater samples collected from 1994 to 2017 were analysed for physico-chemical (Na+, Ca2+, Mg2+, Cl-, SO42-, NO3-, F-, EC, pH) parameters. Approximately, 33.3% of groundwater samples in the Nseleni catchment were found suitable for drinking when compared to South African water quality guidelines. The use of a hybrid approach method showed that overall groundwater quality in the study catchment was classified as excellent for domestic water use when groundwater quality index was calculated to be 39.11. Groundwater quality reserve limits for groundwater resources protection were determined for the nine water quality parameters using CDCs. The study concluded that using groundwater quality index and concentration duration curves, it was feasible to classify groundwater resources for improved groundwater quality of reserve determination in the South African context. The study recommends the application of the hybrid method in various catchments of similar characteristics to the studied catchment for setting groundwater quality limits that would contribute towards achieving the goal of groundwater resources protection in other catchments.

BACKGROUND

Sustainable Development Goal 6:

Clean Water and Sanitation



Policy Intervention

- Localized Site Specific Assessment
- Regional Scale Assessment

Challenges:

- Farming Chemicals
- Poor Waste Management
- Mining Operations
- Landfills and Waste Disposal

Assessment Tools

- Water Quality Guidelines best suitable for site specific assessment
- Suffer subjectivity at Regional Scale
- Challenge with Spatial Variability
- Water Quality Guidelines linked to User Requirements (Not linked to the Conditions of the Resource)

Fig. 1: Groundwater use and exploration

Table 1. Hybrid Approach for assessing and setting of Groundwater Resource Quality Limits

Technique	Application	Suitability
Water Quality Guidelines (WRC, 1998)	Site Specific Assessment	√
Groundwater Quality Index (GQI)	Regional Scale Assessment	√
Concentration Duration Curves (CDC)	Resource Based Quality Limits	?

MAIN OBJECTIVE OF THE STUDY

To establish suitability of the Hybrid Approach methodology in assessing groundwater quality and setting of groundwater quality reserve limits for groundwater resources protection

SPECIFIC OBJECTIVES OF THE STUDY

- To undertake site-specific groundwater quality assessment using South African Water Quality Guidelines (WRC, 1998; SANS:241, 2015);
- To to evaluate and classify groundwater quality for the entire study area using techniques of Water Quality Index (WQI); and
- To quantify and determine groundwater quality reserve limits for individually selected water quality parameters using Concentration Duration Curves (CDC) techniques.

STUDY AREA CHARACTERISTICS

- Study Area Size estimated at 485 km²Groundwater Recharge estimated at 36,35 Mm³/a
- Receives 1038,5mm of Mean Annual Precipitation (MAP)
- Integranular Aquifers Cover major part of the study area [Borehole yields of 0,5 to 2,0/s]
- Fractured Aquifers cover minor portion of the study area [Borehole yields of 0,1 to 0,5L/s]
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STUDY AREA LOCATION AND METHODOLOGICAL APPROACH

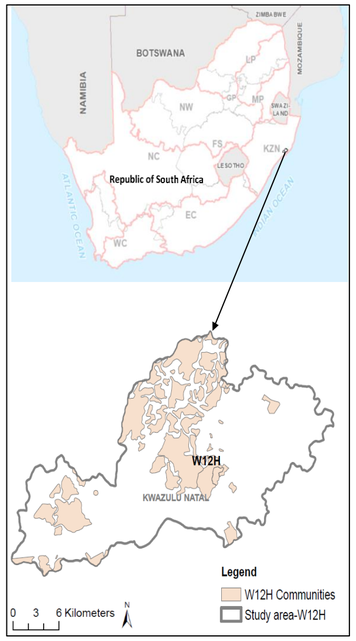

Fig. 2: Location of the study area

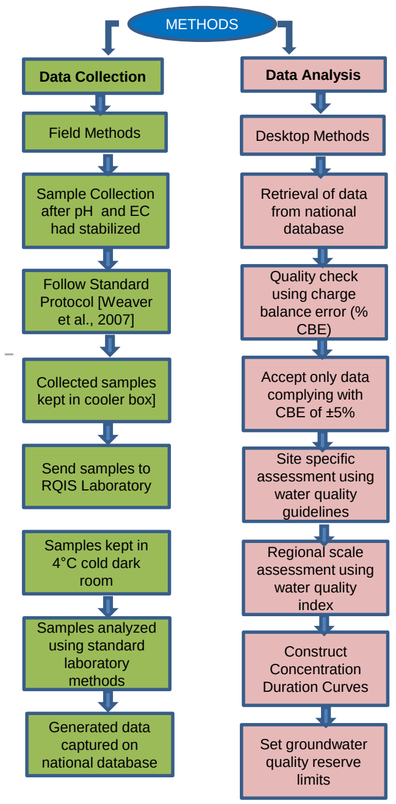

Fig. 3: Methodological Approach

RESULTS AND DISCUSSION

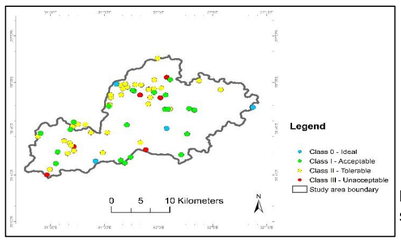

Fig. 4: Regional scale assessment [Groundwater Quality Index]

Fig. 2: Specific site assessment for drinking water suitability

WQ parameter	Standard limit *(Si)*	Weight *(wi)*	Relative weight *(Wi)*	Parameter concentration (Ci)	Quality rating scale *(qi)*	Sub-index *(SIi)*	GQI
pH	7.35	2	0.063	8.12	110.48	6.960	*39.11*
EC	170	2	0.063	108.00	63.53	4.002	
Ca	150	3	0.094	37.65	25.10	2.359	
Mg	100	3	0.094	15.05	15.05	1.415	
Na	200	3	0.094	175.25	87.63	8.237	
Cl	300	4	0.125	200.05	66.68	8.335	
SO4	250	4	0.125	28.25	11.30	1.413	
NO_3	11	5	0.156	2.74	24.91	3.886	
F	1.5	4	0.125	0.30	20.00	2.500	

RESULTS AND DISCUSSION

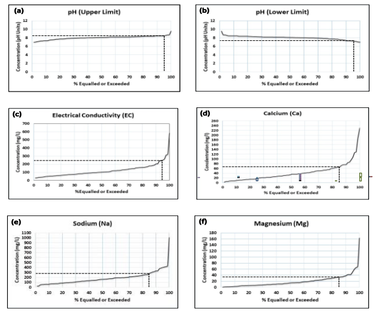

Fig. 3a-f Concentration duration curve used to establish groundwater reserve **a)** upper limit for pH, **b)** lower limit for pH, **c)** electrical conductivity, **d)** calcium, **e)** sodium, and **f)** magnesium

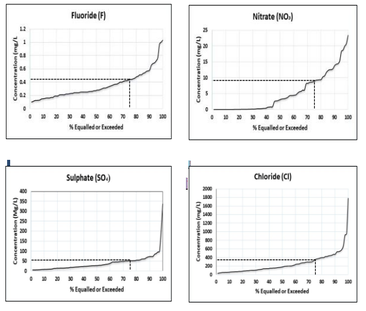

Fig. 3a-d Concentration duration curve used to establish groundwater reserve limit for **a)** Fluoride, **b)** Nitrate, **c**) Sulphate, and **d)** Chloride

Table 2. Summary of groundwater quality reserve limits established for the study area

WQ parameter	Recommended reserve limits	Required compliance per period (%)	Key note
pH (upper limit)	8.2	95%	The parameters are considered as a general indicator of water quality in domestic water use
pH (lower limit)	7.5	95%	
Electrical conductivity (EC)	250 ms m^{-1}	95%	
Calcium (Ca)	70 mg L^{-1}	85%	The parameters may commonly be present at concentrations of aesthetic or economic concern in domestic water use
Magnesium (Mg)	35 mg L^{-1}	85%	
Sodium (Na)	280 mg L^{-1}	85%	
Chloride (Cl)	350 mg L^{-1}	75%	The parameters are commonly present at concentrations which may lead to health problems in domestic water use
Sulphate (SO_4)	50 mg L^{-1}	75%	
Nitrate (NO_3)	8 mg L^{-1}	75%	
Fluoride (F)	0.42 mg L^{-1}	75%	

RESULTS AND DISCUSSION

In this paper, a novel hybrid methodology that considers use of water quality standards, groundwater quality index (GQI), and concentration duration curves (CDC) concept is proposed to analyse, evaluate, and recommend target levels of groundwater quality protection. The study shows that the concentrations of the water quality parameters for the majority of groundwater sites assessed in the study area do not fall within the target limits stipulated in the South African water quality guidelines. Such findings suggest that groundwater in the study area is impacted in terms of water quality. However, when the GQI was established for the catchment, the assessment showed that the overall groundwater quality in the study area is excellent for drinking purpose which translates to water that is ideal for domestic use. When the concept of CDC analysis was applied to set groundwater quality reserve limits for selected water quality parameters, the baseline conditions linked to groundwater quality management in the study area were successfully established. Such revelation implies that the CDC analysis technique is suitable for use in groundwater resources management and protection activities.

CONCLUSSION

The study concluded that the hybrid methodology which incorporates complementary strategies for comprehensive water quality assessment at catchment scale provides a better groundwater resources assessment and management approach. The approach is therefore recommended for use in other settings to improve groundwater resources protection practices, especially in areas where groundwater quality for domestic water supply remains a challenge.

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