

Groundwater resource quality objectives determination

Training manual



March 31, 2023

Contents

[**Chapter 1: Historical background and purpose: RQOs** 2](#_Toc130472477)

[**Chapter 2: Existing methods and steps for RQOs** 2](#_Toc130472478)

[**Chapter 3: New methods and steps for RQOs** 2](#_Toc130472479)

[**Chapter 4: Step-by-step practical guide with a case study** 2](#_Toc130472480)

[**Chapter 5: Glossary of terms and abbreviations** 2](#_Toc130472481)

# **Chapter 1: Historical background and purpose: RQOs**

## **1.1 Overview**

This training manual focuses on the determination of groundwater resource quality objectives. It is divided into 5 chapters. Chapter 1 focuses on historical background and the purpose of undertaking groundwater resources quality objectives determination study. The overview, context, purpose, requirements, application, implications, alignment with water related regulations, and water institutions mandated for RQOs implementation are all discussed under this chapter. Chapter 2 outlines current methodology followed for undertaking groundwater resources quality objectives. Under this sub-section methods, equations, advantages, and disadvantages are provided. Furthermore, this chapter provides a reflection on the steps applied currently, and in this context process, advantages, and disadvantage associated with the application of the existing steps are reflected upon. Chapter 3 outlines the proposed methodology and steps for undertaking groundwater resources quality objectives determination study. Chapter 4 provides a practical guide on the application of the proposed methodology and associated steps using two case studies, which have been included to demonstrate applicability of the proposed approach for undertaking and reporting on the outcomes of the GRQOs assessment. Chapter 5 provides for the glossary of terms and abbreviations used in this training manual.

## **1.2 Context**

The Department of Water and Sanitation (DWS) is required determine the class and resource quality objectives of all or part of those water resources considered to be significant. Once each major water resource is classified, national government through the Minister needs to determine how the water resource will be protected and used. This is called determining the resource quality objectives. RQOs are used to put a classification and Reserve into practice by specifying conditions that will ensure that the class is not compromised and that the Reserve can be met. RQOs should spell out the principles upon which licensing conditions are based. In general terms, RQOs establish clear goals relating to the quantity and quality of a water resource. They provide goals and objectives that frame the

vision for sustainable use of a water resource, and hence form the basis for catchment decision-making and management. Typical characteristics of RQOs include the following:

• They set limits that are simple and measurable.

• They set the limits of acceptable impact.

• They may be numeric or descriptive.

This training manual focuses only on the aspects of groundwater resources quality objectives that was improved in the methodology, which is the quality components. The current GRDM methodology followed for quantity component, protection zones abstraction rates were all deemed adequate, and improvements were not necessary.

## **1.3 Purpose**

The purpose of this training manual is to provide guide on the methodology and steps to be applied and followed when the quality component of the groundwater resource quality objectives is determined in order to implement groundwater resources protection for sustainable use.

1.4 Requirements

1.5 Application

1.6 Implication

1.7 Alignment with water related regulations.

\* WUL Conditions/SDC

\* Rehabilitation Initiatives

1.8 Water institutions mandated: RQOs

\* DWS Regional Offices

\* Catchment Management Agencies

\*\*\*\*Municipalities not involved [challenge needs redress]

# **Chapter 2: Existing methods and steps for RQOs [GRDM, 2012]**

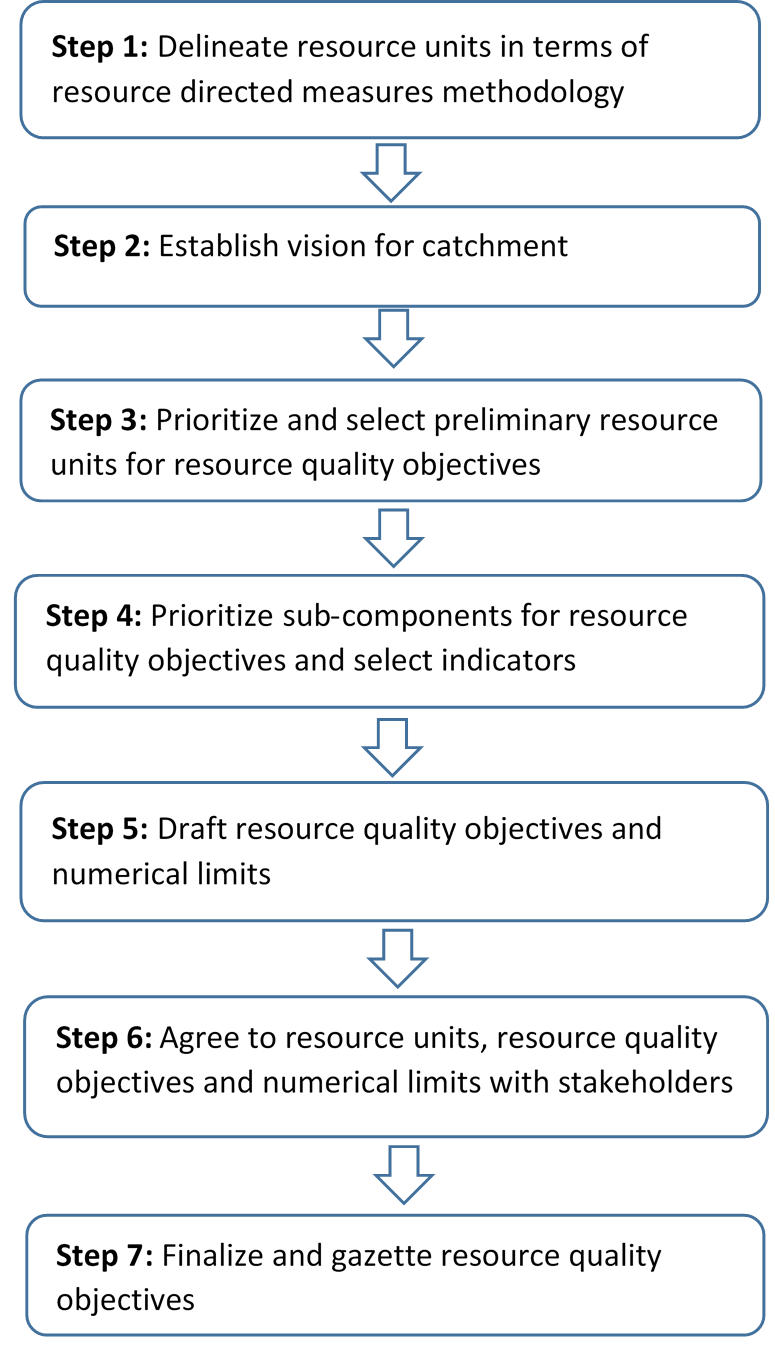
2.1 Methodology: Methods, equations, advantages, and disadvantages

2.2 Steps: process,  advantages, and disadvantage

\* Mainly focuses on quantity and protection zones aspects, quality limited (using two different values for EC-irrigation & domestic) (ie the focus should be protecting the environment, therefore we need the condition for the environment

\* Steps for determination of groundwater quality component of RQOs not specified

\* As a results limits from the South African Water Quality Guidelines are used/adopted [as default value]



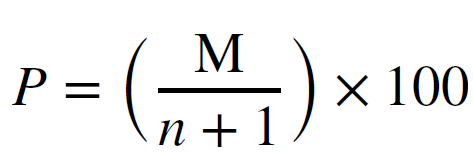
# **Chapter 3: New methods and steps for RQOs**

## **3.1 Methodology: Methods, equations, advantages, and disadvantages**

The South African National Standard for drinking water (SANS 241:2015) and other South African Water Quality Guidelines (SAWQG) for various water users are available and extensively used in the county to ensure that their requirements in terms of water quality are met. Importantly, when setting RQOs, a balance must be sought between the need to protect and sustain water on the other hand, and the need to develop and use them on the other. But due to lack of a prescribed procedure for setting numerical limits for quality component of groundwater RQOs practitioners often rely on the water quality guidelines, subsequently using their limits as numerical limits for groundwater RQOs. Numerical limits prescribed in the water quality guidelines are the same nationally, and do not reflect on the spatial variability of catchments, they are a requirement for a specific water use such as domestic, industrial, aquatic ecosystem, and they are not a requirement for the environment which is the focus for resource protection.

Although groundwater contamination may result from anthropogenic sources, however natural geogenic sources through hydro‐geochemical processes may be responsible for controlling groundwater quality in various aquifers (Lalumbe et al., 2022). Therefore, it is critical that when RQOs for groundwater quality are set, reference or background/prevailing conditions within a particular area under investigation are taken into consideration. RQOs can not be set at a level more stringent than background conditions of a particular groundwater resource, otherwise, such RQO would be impractical to implement. In order to redress the challenge, a methodology that applies a technique of Concentration Duration Curves (CDCs) construction for groundwater quality parameters is presented.

CDC a is a graphical illustration of the percentage of time (duration) a concentration level of a particular groundwater quality parameter is met and sustained in the study area, and such illustration uses time-series data from a catchment, which is analysed based on temporal variation (Nzama et al., 2021). CDC for each water quality parameter is generated using the recorded historic groundwater quality data, and the equal or below or no exceedance probability for each concentration of water quality parameter considered is determined using the formula in Eq. (1)

 (1)

where ***P*** = the probability that a concentration will be equalled or exceeded (% of time); ***M*** = assigned a rank number; ***n*** = the total number of data set recorded on each water quality parameter for a record period of interest.

The CDC is constructed by plotting the calculated ***P*** values on the X-axis (% equalled or exceeded) and corresponding concentration values on the Y-axis (mg L-1), and mS m-1 in case of electrical conductivity.

Two disadvantages associated with the use of this methodology are evident:

* The method requires extensive data to establish trends which is not always available in some catchments.
* The method is labour intensive as the CDCs must be determined for each water quality parameter, but this can be minimized through prioritization of water quality parameters.

Some of the advantages associated with the use of this methodology are as follows:

* The method relies on the use of data collected from the catchment instead of relying on limits from the water quality guidelines. This implies that the method considers prevailing environmental conditions which differ from one catchment to another (spatial variability consideration).
* It gives stakeholders powers to decide on the level of protection (numerical limits) which conforms with requirements for RDM processes. Numerical limits are derived from the data and not extracted from the water quality guidelines.
* It further enables stakeholders such as local communities, NGOs, private sector to play a significant role in groundwater resources protection in terms of data provision, thus improving groundwater governance and decentralized decision making (polycentric governance).

The outcomes of the graphical illustration of the percentage of time (duration) a concentration level of a particular groundwater quality parameter, allows for the establishment of numerical limits which is linked to *step 5* of the RQOs determination procedure. When setting numerical limits from the constructed CDC, it is critical to note that the lower the concentration level set, the lower the percentage of time (duration) a concentration level of a particular groundwater quality parameter is met, and vice versa. The established numerical limits from the CDCs are then presented to the stakeholders with full explanation of their implications for stakeholders to agree on the final outcomes (limits), and this activity is linked to step 6 of RQOs determination process.

**Table 1:** Water quality parameters and their associated human health impacts as per WRC (1998)

|  |  |
| --- | --- |
| **Parameters** | **Consideration as per Implications** |
| pH | The parameter is considered as a general indicator of water quality in domestic water use. |
| Electrical Conductivity as EC | The parameter is considered as a general indicator of water quality in domestic water use. |
| Calcium as Ca | The parameter may commonly be present at concentration of aesthetic or economic concern in domestic water use. |
| Magnesium as Mg | The parameter may commonly be present at concentration of aesthetic or economic concern in domestic water use. |
| Sodium as Na | The parameter may commonly be present at concentration of aesthetic or economic concern in domestic water use. |
| Chloride as Cl | The parameter is commonly present at a concentration which may lead to health problems in domestic water use. |
| Sulphate as SO4 | The parameter is commonly present at a concentration which may lead to health problems in domestic water use |
| Nitrate as NOx-N | The parameter is commonly present at a concentration which may lead to health problems in domestic water use. |
| Fluoride as F | The parameter is commonly present at a concentration which may lead to health problems in domestic water use |

When groundwater is mainly used for drinking purposes in the study area, it is important to take note of the individual water quality parameter impacts on human health (Table 1) as provided in the South African water quality guideline (WRC,1998). The guideline considers electrical conductivity and pH as general indicators of water quality for domestic water use. Therefore, these parameters are deemed to require less stringent conditions for compliance, and thus can be assigned *less stringent target level* of management corresponding to a 95% compliance over a period of interest. Calcium, magnesium, and sodium may commonly be present at concentrations of aesthetic or economic concern in domestic water use. Thus, these parameters can be assigned *stringent target levels* of management corresponding to at least 85% compliance over a period of interest. Furthermore, the guidelines consider chloride, sulphate, nitrate, and fluoride as parameters that are commonly present at concentrations that may lead to health problems in domestic water use. Therefore, these water quality parameters can be assigned *higher stringent target levels* of management requiring at least 75% compliance over a period of interest. In cases where dominant groundwater use is for industrial or agriculture, stakeholders can decide and agree on the numerical limit taking into consideration the need to support agricultural and industrial activities for socio-economic sustainability.

## **3.2 Steps: process, advantages, and disadvantage**

The steps are followed when numerical limits for groundwater quality component of RQOs are establishment are outlined below:

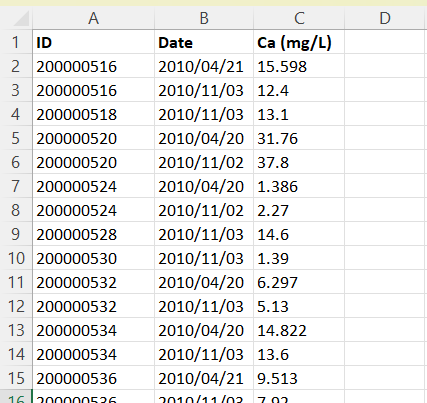
***Step 1:* Acquisition and gathering of data records**

* *Before beginning CDC, obtain groundwater quality data from groundwater monitoring sites (boreholes) for a given study area and time frame.*
* *Sources of data maybe National databases or from private organizations, and water users*

***Step 2:* Capturing of data records**

After locating the relevant data for creating the concentration compliance probability curve, the water quality data for the period of record are entered into a Microsoft Excel © (Excel) spreadsheet as follows:

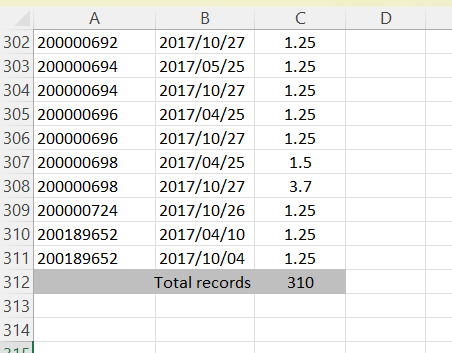
* Transfer or input the groundwater quality data into Excel.
* Create three columns (Point ID, Date, and Concentration, and organize the data accordingly (Figure xx ).



**Figure xx:** Example of initial organization of groundwater quality data

***Step 3:*** **Determine the number of records**

* Compute the total number of data sets in the period of record (Fig xx)**.**

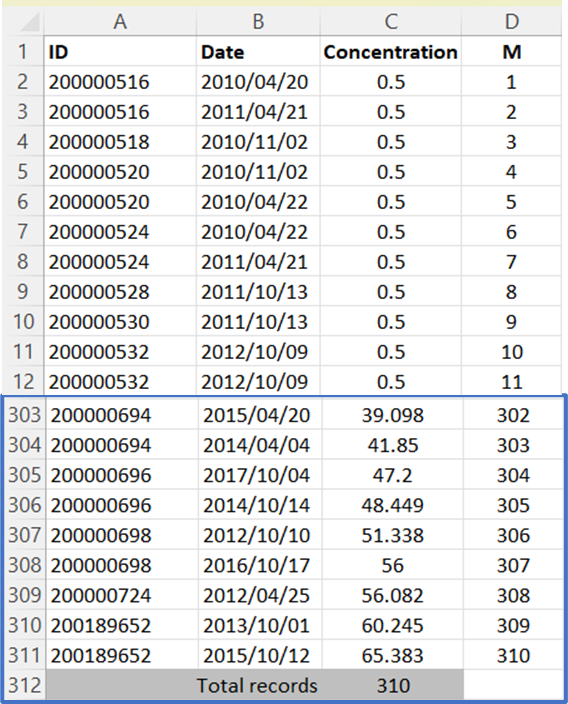
****

**Figure xx.** Example of calculation of data sets covered in the period of

record using groundwater quality data.

***Step 4:*** **Sorting of the data according to magnitude and assigning of ranks**

* Highlight all the data (excluding column headers) and select the “sort” command to rank data by concentration (mg/l), from smallest to largest.
* Create a new column and assign concentration value a rank (M), starting with 1 for the smallest concentration value. Use the Excel auto-fill feature to generate a list of rank numbers down to the last concentration row (Figure xx).



**Figure xx.** Example of sorting and ranking in Excel using concentration data.

***Step 5:*** **Computing of compliance probability (P)**

* Compute *compliance probability* (P) for concentration in each line of data by using the formula provided below.
* Create a new column and input the formula in the first cell (Figure xx). Make sure to select the appropriate cells called for by the formula (M = rank #, n = total records calculated) and use “$” symbols to lock the formulas’ reference (absolute reference) to the total records cell.
* Apply the formula to all concentrations and calculate all the compliance probabilities by copying the formula down the column to the last ranked concentration row. (You can copy the formula by hovering the mouse over the lower right corner of the formula’s cell until a black cross-hair appears, then drag down the column.)

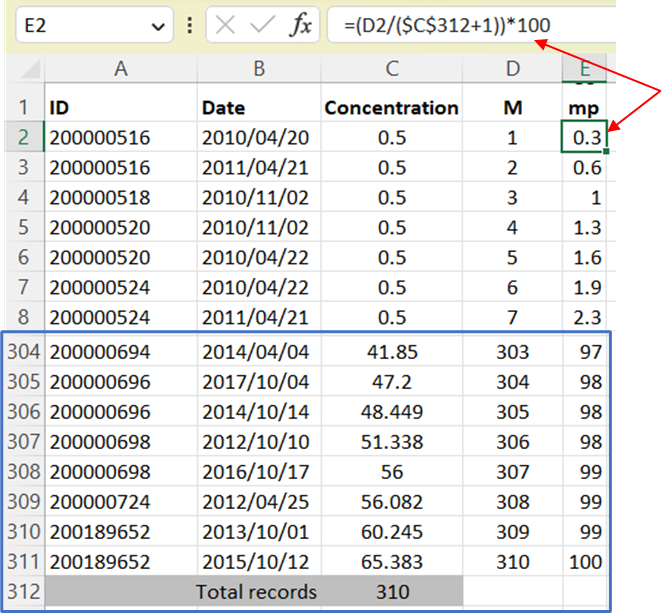
**P = [ M / (n + 1) ] x 100% (2)**

**P** = the probability that a given concentration will be equalled or below or not exceeded (% of time)

**M** = assigned rank number

**n** = the total number of days for period of record

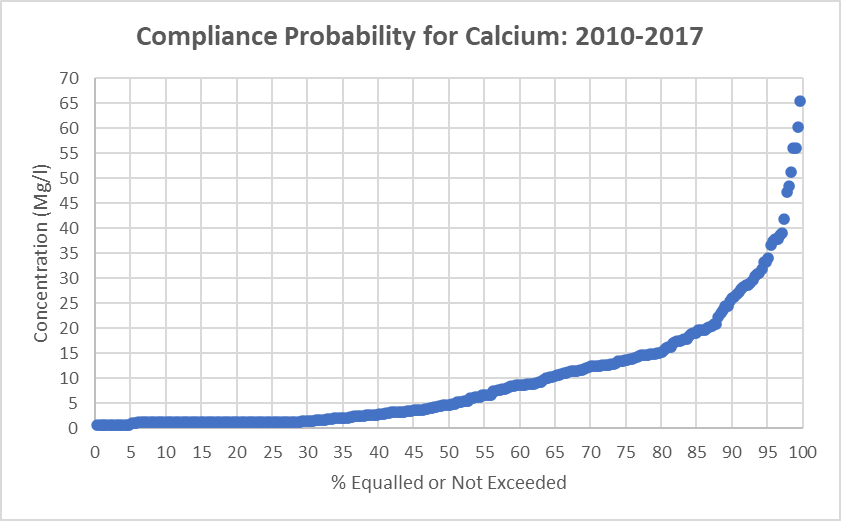
The Excel formula, as shown in Figure 5 is =(F3/($E$21917+1))\*100.



**Figure xx.** Example of display showing the calculation for compliance probabilities using groundwater quality data.

***Step 6:*** **Creating the Annual concentration compliance Graph**

* Plot the compliance probability values calculated in Step 5 against associated concentrations.
* In Excel, highlight the data to be graphed (in the Figure xx example, columns C and E), then select the “scatter plot” graph option.
* Place compliance probability values on the x-axis and concentrations on the y-axis.
* The graph should look like Figure xx:



**Figure xx.** Example of concentration compliance probability curve for Calcium

# **Chapter 4: Step-by-step practical guide with a case study (Upper Berg)**

## **4.1 Methodology: Methods, equations, graphs, advantages, and disadvantages**

***Less stringent target level* of management corresponding to a 95% compliance over a period of interest.**

**Figure xx.** Concentration compliance probability curve for pH upper limit

**Figure xx.** Concentration compliance probability curve for pH lower limit

**Figure xx.** Concentration compliance probability curve for electrical conductivity

Electrical conductivity and pH are regarded as general indicators of water quality in domestic water use by the South African water quality guideline (WRC 1998). As a result, these parameters were given a far more liberal target level of management requiring a length of time of 95% compliance, as they were assessed to not require strict conditions for compliance. The bassline limit for the EC, pH upper limit and lower limit in upper Berg River catchment are: 42 mS/m, 8.4 and 6.0 respectively.

***Stringent target levels* of management corresponding to at least 85% compliance over a period of interest.**

**Figure xx.** concentration compliance probability curve for Calcium

**Figure xx.** concentration compliance probability curve for magnesium

**Figure xx.** concentration compliance probability curve for sodium

In domestic water use, calcium, magnesium, and sodium may frequently be present at levels that raise aesthetic or economical concerns. As a result, these requirements have more stricter goal levels of management and call for at least 85% compliance over time. The RQO limits for calcium, magnesium, and sodium were set as follows: 25.3, 4.9 and 26.2 mg/l respectively.

***Higher stringent target levels* of management requiring at least 75% compliance over a period of interest.**

**Figure xx.** Concentration compliance probability curve for chloride

**Figure xx.** Concentration compliance probability curve for sulphate

**Figure xx.** Concentration compliance probability curve for fluoride

Furthermore, the guidelines (WRC [1998](https://link.springer.com/article/10.1007/s40899-021-00503-1#ref-CR40)) consider chloride, sulphate, nitrate, and fluoride as parameters that are commonly present at concentrations that may lead to health problems in domestic water use. Therefore, these water quality parameters were assigned much more stringent levels of management requiring at least 75% compliance over a period. The RQO limits for chloride, sulphate, and fluoride were set as follows: 29.7, 9.3 and 0.7 mg/l respectively.

## **4.2 Steps: Process, advantages, and disadvantage**

# **Chapter 5: Step-by-step practical guide with a case study (Heuningnes)**

***Less stringent target level* of management corresponding to a 95% compliance over a period of interest.**

**Figure xx.** Concentration compliance probability curve for Electrical Conductivity

**Figure xx.** Concentration compliance probability curve for pH upper limit

**Figure xx.** Concentration compliance probability curve for pH lower limit

Electrical conductivity and pH are regarded as general indicators of water quality in domestic water use by the South African water quality guideline (WRC 1998). As a result, these parameters were given a far more liberal target level of management requiring a length of time of 95% compliance, as they were assessed to not require strict conditions for compliance. The bassline limit for the EC, pH upper limit and lower limit in Heuningnes catchment are: 4938 mS/m, 8.4 and 5.8 respectively.

***Stringent target levels* of management corresponding to at least 85% compliance over a period of interest.**

**Figure xx.** Concentration compliance probability curve for calcium

**Figure xx.** Concentration compliance probability curve for magnesium

**Figure xx.** Concentration compliance probability curve for sodium

In domestic water use, calcium, magnesium, and sodium may frequently be present at levels that raise aesthetic or economical concerns. As a result, these requirements have more stricter goal levels of management and call for at least 85% compliance over time. The RQO limits for calcium, magnesium, and sodium were set as follows: 197.6, 304.5 and 5887.8 mg/l respectively.

***Higher stringent target levels* of management requiring at least 75% compliance over a period of interest.**

**Figure xx.** Concentration compliance probability curve for chloride

**Figure xx.** Concentration compliance probability curve for sulphate

**Figure xx.** Concentration compliance probability curve for flouride

Furthermore, the guidelines (WRC [1998](https://link.springer.com/article/10.1007/s40899-021-00503-1#ref-CR40)) consider chloride, sulphate, nitrate, and fluoride as parameters that are commonly present at concentrations that may lead to health problems in domestic water use. Therefore, these water quality parameters were assigned much more stringent levels of management requiring at least 75% compliance over a period. The RQO limits for chloride, sulphate, and fluoride were set as follows: 2040, 103 and 0.14 mg/l respectively.

## **5.1 Methodology: Methods, equations, graphs, advantages, and disadvantages**

## **452 Steps: Process, advantages, and disadvantage**

* Terms
* Abbreviations

**Cited Literature**

Lalumbe, L., Oberholster, P.J., & Kanyerere T. (2022). Feasibility Assessment of the Application of Groundwater Remediation Techniques in Rural Areas: A Case Study of Rural Areas in the Soutpansberg Region, Limpopo Province, South Africa. <https://doi.org/10.3390/w14152365>

Nzama, S.M., Kanyerere, T.O.B., & Mapoma, H.W.T. (2021). Using groundwater quality index and concentration duration curves for classification and protection of groundwater resources: relevance of groundwater quality of reserve determination, South Africa. <https://doi.org/10.1007/s40899-021-00503-1>.