

# Surface and Groundwater Quality in South African Area—Analysis of the Most Critical Pollutants for Drinking Purposes <sup>†</sup>

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**Abstract:** According to a recent report by World Health Organization, the countries which still have limited access to water for drinking purposes are mainly those in the Sub-Saharan region. (Potential) water sources for drinking needs may contain different contaminants. In this context, the current study consists in an overview of the quality of surface water and groundwater in the Republic of South Africa (RSA) and Mozambique (MZ) and provides the variability ranges of the concentrations of the main pollutants in the two countries. Chemical and physical characteristics and concentrations of macropollutants, inorganic compounds (metals) and selected microorganisms were collected for surface water and groundwater and compared with the standards for drinking water set in the two countries. It was found that in surface water, microorganisms were always at very high concentrations. In addition, nickel (in RSA) and boron and chlorine (in MZ) were the most critical compounds. It emerged that in groundwater, arsenic, lead and chlorine (in RSA) and boron, sodium and chlorine (in MZ) were the main critical pollutants. Adequate treatments in the construction of new drinking water plants in rural areas should be selected on the basis of these most critical compounds and their observed variability over time.

**Keywords:** drinking water; groundwater quality; rural area; Sub-Saharan region; surface water quality

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## 1. Introduction

According to the recent World Health Organization (WHO) report, the countries which still have limited access to water for drinking purposes are mainly those in the Sub-Saharan region [1].

In cases of small rural communities, it may be very expensive to guarantee (including investment and operational and maintenance costs) safe water by means of decentralized small water works. Pollution of source water may be due to many causes, among them a continuous release of untreated wastewater (generated within the rural communities), land runoff and acid mine drainage.

This paper deals with the quality of surface and groundwater in rural areas in the Republic of South Africa (RSA) and Mozambique (MZ) and its variability along the year (mainly due to temperature variations, rainfall and consequent land runoff) in case of their withdrawal for drinking purposes. In order to evaluate how polluted these waters may be (expected), water quality standards for potable use adopted in RSA and MZ are provided.

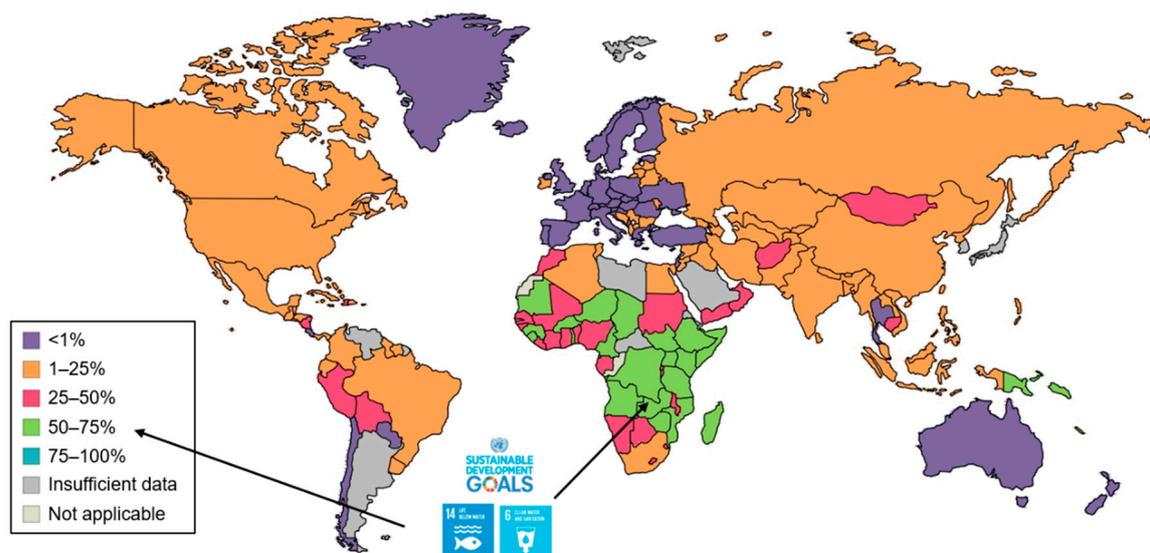
The aims of this study are (i) to identify the most critical pollutants in surface and groundwater and relate them to their potential origin; and (ii) to show the importance of the need of interventions both in sanitation and potabilization fields. The first type of interventions will improve the quality of

surface water bodies and groundwater, considered potential sources for drinking purposes for small communities in rural and peri-urban areas.

## 2. The Area under Study

The area under study refers to the RSA and MZ ( $1.2 \times 10^6 \text{ km}^2$  and  $8.0 \times 10^5 \text{ km}^2$ , respectively). In RSA, the current resident population is around 58.8 million of persons. According to statistical data referring to the last formal 2018 census, 80.1% are living in formal settlements, 13.1% in traditional settlements and 5% in informal housing (corresponding to 2,940,000 people) [2,3]. In Mozambique, the population, in 2017, was around 28 million of inhabitants [4], and 69% was living in rural areas [5].

The access to (safe) drinking water is limited in some regions of RSA and in most of MZ (Figure 1).



**Figure 1.** Percentage of rural population using surface water for drinking water or unimproved or limited drinking water. Focus on Sub-Saharan region. (Adapted from [6]).

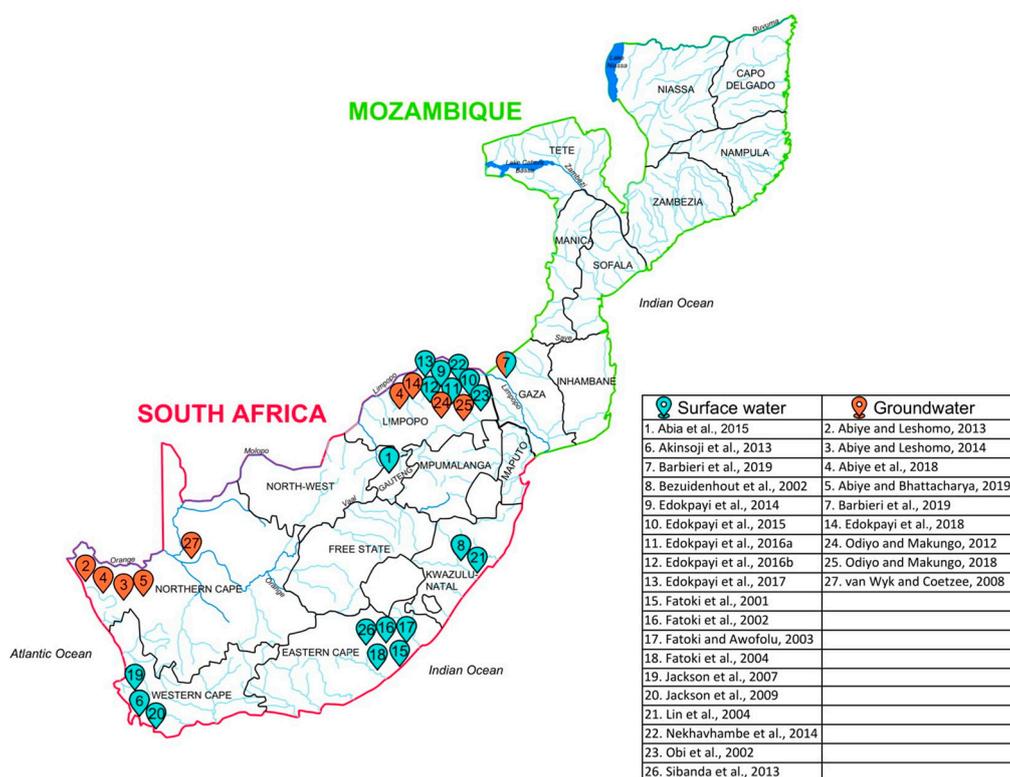
In particular, in Mozambique, the percentage of the rural population using limited or unimproved surface water for drinking water is 60%, and the remaining 40% uses an improved surface water. Safely managed water in these rural areas is not currently reported. In South Africa, the percentages are 19% and 81%, respectively.

According to the local South African regulation, the basic water services are defined in South Africa as 25 L/d per person [7] and according to the UNDP report, in Mozambique less than 10 L/d per person [8]. In these countries, the treatment of rural wastewater is generally absent or scarce. This practice leads to a deterioration of the quality of the local surface water and, due to percolation/infiltration, also of the groundwater. In addition, animal farms are not safely managed from an environmental viewpoint, and generally, zotechnical effluents are directly released into surface water bodies or directly spread on the soil [9].

### 2.1. Investigations Included in This Overview—Collected Parameters

The study collects quality data of surface water and groundwater in RSA and MZ from the literature. The selected parameters include macropollutants, inorganic chemicals and microorganisms in addition to physical parameters of the water. Their variability ranges are commented on and discussed in order to evaluate which should be the main problems in case the water is withdrawn for drinking purposes.

The map in Figure 2 reports the indicative place where the investigations included in this study were carried out, with the corresponding reference.



**Figure 2.** Indicative location map of the studied papers with the corresponding references.

### 2.2. National Standards for Potable Use in South Africa and Mozambique

Table 1 reports the limits for the selected pollutants according to the Mozambique regulation (DM-180/2004 [10]) and South African law (SANS-241-1:2015 [11]). These values will be compared with the measured concentrations found in the two water sources (surface water and groundwater) in the area under study.

**Table 1.** Drinking water quality standards  $S_i$  set by Mozambique and South Africa.

Contaminant	Unit	$S_i$ Mozambique (DM-180/2004 [10])	$S_i$ South Africa (SANS-241-1:2015 [11])
Aluminium	µg/L	200	≤300
Ammonia	µg/L	1500	≤1500
Arsenic	µg/L	10	≤10
Barium	µg/L	700	≤700
Boron	µg/L	300	≤2400
Cadmium	µg/L	3	≤3
Calcium	mg/L	50	
Chloride	mg/L	250	≤300
Chlorine	µg/L	200–500 (residual)	≤5000 (free)
Chromium (total)	µg/L	50	≤50
Conductivity	mS/m	5–200	≤170 (25 °C)
Copper	µg/L	1000	≤2000
Fluoride	µg/L	1500	≤1500
Iron	µg/L	300 (total)	≤2000 (chronic health) ≤300 (aesthetic)
Lead	µg/L	10	≤10
Magnesium	mg/L	50	
Manganese	µg/L	100	≤400 (chronic health)

Contaminant	Unit	$S_i$ Mozambique (DM-180/2004 [10])	$S_i$ South Africa (SANS-241-1:2015 [11])
			≤100 (aesthetic)
Mercury	µg/L	1	≤6
Molybdenum	µg/L	70	
Nickel	µg/L	20	≤70
Nitrate	mg N/L	50	≤11
Nitrate+Nitrite	mg N/L		≤1
Nitrite	µg N/L	3000	≤900
pH (25 °C)		6.5–8.5	5–9.7
Phosphorus	µg/L	100	
PAHs total	µg/L	0.1	
Sodium	mg/L	200	≤200
Sulphate	mg/L	250	≤500 (acute health)
Total dissolved solids	mg/L	1000	≤250 (aesthetic)
Turbidity	NTU	5	≤1200 (aesthetic)
Uranium	µg/L		≤1 (operation)
Zinc	µg/L	3000	≤5 (aesthetic)
<i>Escherichia coli</i> ( <i>E.coli</i> )	n/100 mL		≤30
Fecal coliforms	n/100 mL	0-10 or absent	≤5000
Heterotrophic plate count (HPC)	n/1 mL		Not detected
Total coliforms	n/100 mL	Absent	Not detected
			≤1000
			≤10

On the basis of the comparison, the selected parameters will be divided into six groups according to the criteria defined in Table 2 called Variability Range-Standards criteria.

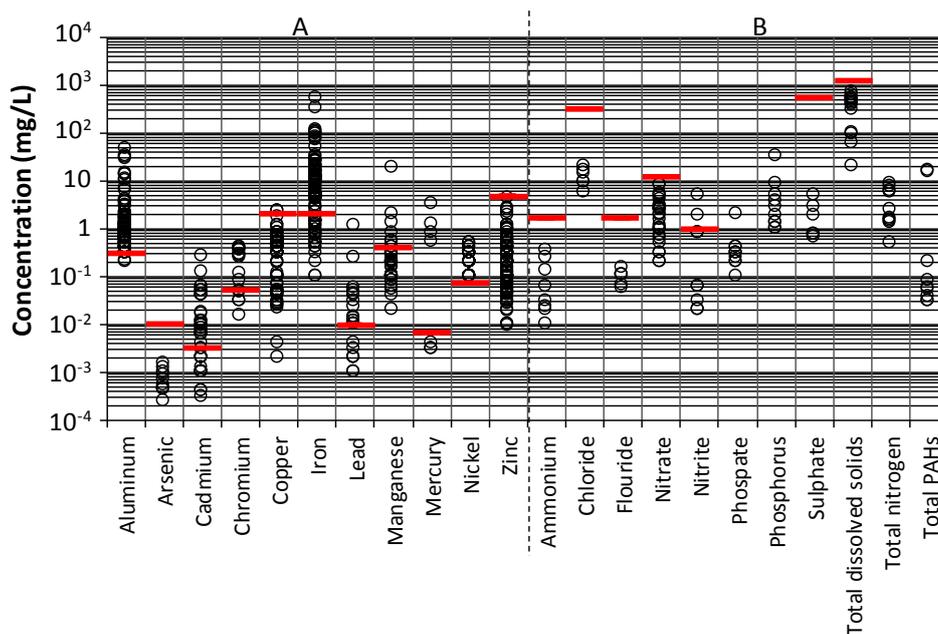
**Table 2.** Criteria defining the level of pollution due to the concentrations  $c_i$  of the compounds included in the review.

Group	Variability Range-Standards Criteria	Pollution Level
1	Maximum measured concentrations of the pollutant $c_{i,max} < \text{standard } S_i$	
2	75th percentile $< S_i \leq$ 100th percentile of the collected values of concentrations	
3	50th percentile $< S_i \leq$ 75th percentile of the collected values of concentrations	
4	25th percentile $< S_i \leq$ 50th percentile of the collected values of concentrations	
5	$S_i \leq$ 25th percentile of the collected values of concentrations	
6	Minimum measured concentrations $c_{i,min} > S_i$	

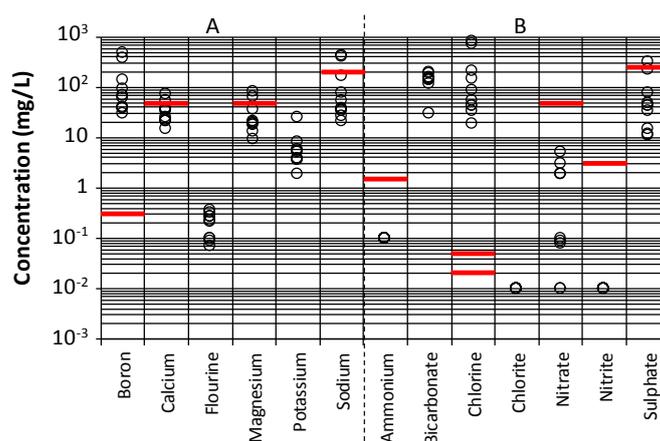
### 3. Results

#### 3.1. Surface Water Quality and Observed Variability of Concentrations

Figures 3 and 4 refer to concentrations of chemical and physical parameters measured in surface water in RSA and MZ, grouped according to the classes of inorganic chemicals (A) and macropollutants (including PAHs) (B). In addition, the values of the corresponding standard maximum concentrations, set by the national law for drinking water, are reported (red dash) in order to show how far the quality of the water which could be withdrawn for drinking purposes is from the corresponding standard.



**Figure 3.** Observed concentrations (circle) of inorganic compounds (A) and macropollutants (B) in surface water in the reviewed studies referring to the Republic of South Africa (RSA) and the corresponding limits (red dashes) set by SANS-241 for drinking water. Data from [12–25].



**Figure 4.** Observed concentrations (circles) of inorganic compounds (A) and macropollutants (B) in surface water in the reviewed studies referring to Mozambique and the corresponding limits (red dashes) set by the national in force law (red line) for drinking water. Data from [26].

It is interesting to observe that in Figure 3, most data refer to inorganic chemicals, such as some common heavy metals. This is strictly related to the fact that in RSA, mine activities represent one of the most important economic activities for the country, and different investigations were carried out to monitor their occurrence in surface water receiving mine drainage during mine exercise. Only a few data are available for Mozambique (see Figure 4), and all of them refer to a recent investigation [26].

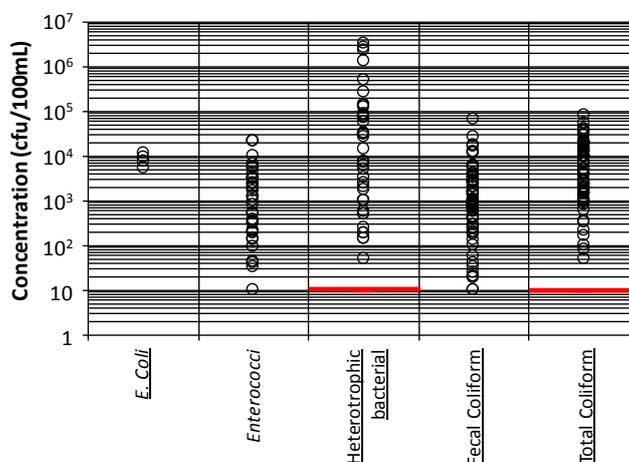
The analysis of the observed ranges of concentration for the different pollutants and the corresponding legal standard leads to the classification of the compounds of Table 3.

**Table 3.** Classification of the compounds occurring in surface water, according to the criteria “Variability Range-Standard” (Table 2) applied to specific RSA and MZ regulations for drinking water (Table 1).

Group	South Africa	Mozambique	Pollution Level
$C_{i,max} < S_i$	Arsenic, zinc, ammonium, chloride, fluoride, nitrate, sulphate, TDS	Ammonium, nitrite, nitrate	😊
75th perc. $< S_i \leq$ 100th perc.	Copper, manganese, nitrite	Calcium, magnesium, sodium, sulphate	😐
50th perc. $< S_i \leq$ 75° perc.	Mercury	--	😐 😐
25th perc. $< S_i \leq$ 50° perc.	Cadmium, chromium, lead, manganese	--	😞
$S_i \leq$ 25th perc.	Aluminium, iron	--	😞 😞
$C_{i,min} > S_i$	Nickel	Boron, chlorine	😞 😞 😞
Comparison not possible	Phosphate, phosphorus, total nitrogen, PAHs	Fluorine, potassium, bicarbonate, chlorite	

It emerges that in RSA, nickel, and in MZ, boron and chlorine, are the selected parameters whose concentrations always exceed the corresponding standards for drinking water set by the local regulations (Table 1).

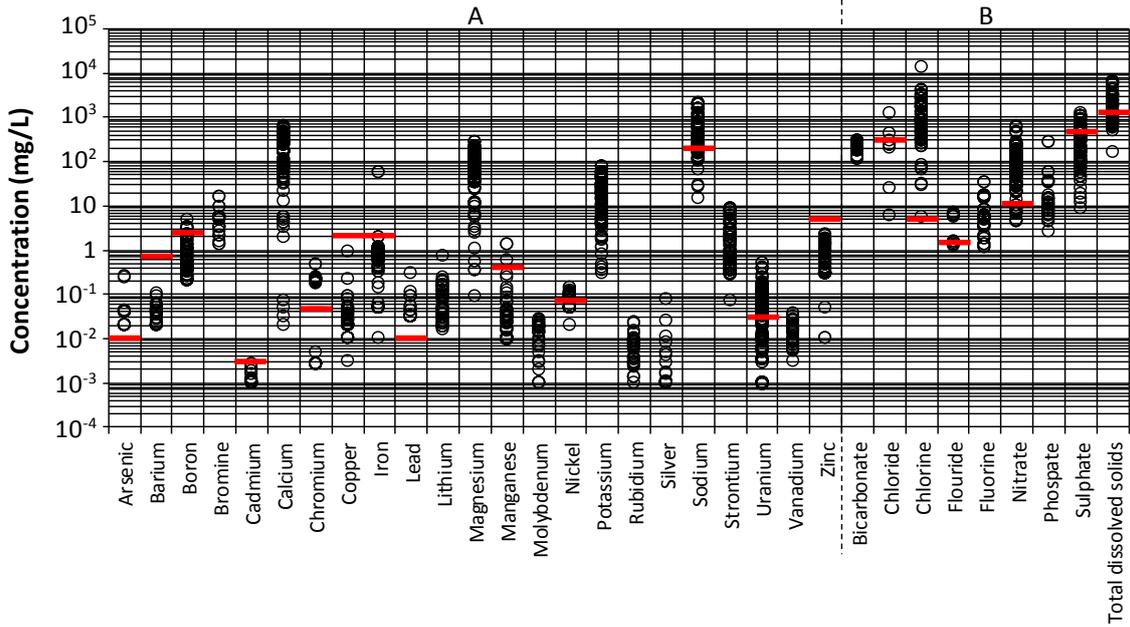
As to microorganisms, surface water contains high concentrations of all the investigated species. This consideration is not surprising as surface water bodies may receive land runoff from areas characterized by the presence of grazing animals and where manure may be applied, as well as untreated rural and zootechnic wastewater, which contribute in terms of microorganisms [27].



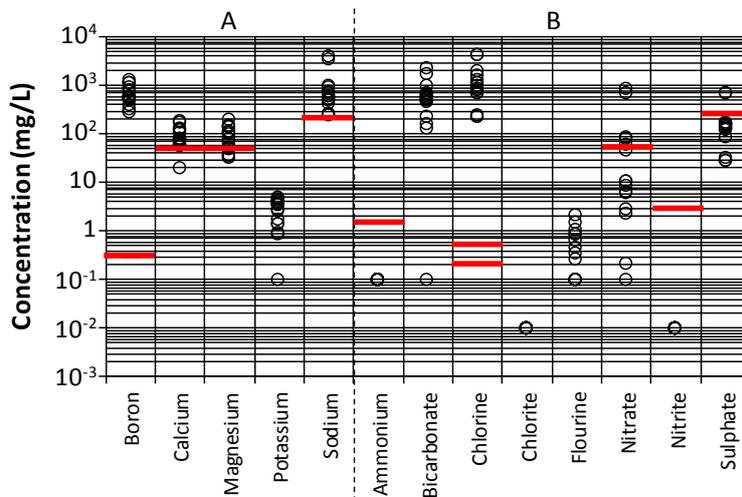
**Figure 5.** Observed concentrations of microorganisms (circles) in surface water in the reviewed studies referring to South Africa and the corresponding limits set by SANS-241 (red dashes) for drinking water. On the x axis, the underlined names refer to indicator bacteria, and those not underlined refer to pathogen bacteria. Data from [14,19,24,28–31].

### 3.2. Groundwater Quality and Observed Variability of Concentrations of Selected Parameters

A higher number of compounds were investigated in groundwater in RSA with respect to surface water, and also, in this case, most data refer to inorganic chemicals (Figures 6 and 7). On the basis of the collected data, it emerges that in RSA, only for barium, cadmium, copper and zinc, measured concentrations are always below the corresponding standard limits for drinking purposes. For arsenic, lead and chlorine the collected, values of concentrations always exceed the corresponding drinking standard. In MZ, on the basis of the limited number of collected data, it is possible to observe that measured concentrations are higher than the drinking standards, with the exception of nitrites.



**Figure 6.** Observed concentrations (circles) inorganic compounds (A) and macropollutants (B) in groundwater in the reviewed studies referring to South Africa and the corresponding limits (red dashes) set by SANS-241 (red line) for drinking water. Data from [32–39].



**Figure 7.** Observed concentrations of inorganic compounds (A) and macropollutants (B) (circle) in groundwater in the reviewed studies referring to Mozambique and the corresponding limits set by the local law (red line) for drinking water. Data from [26].

Table 4 groups the compounds according to the criteria Variability Range-Standard defined above (Table 2).

A comparison between Tables 3 and 4 shows that for Mozambique, boron and chlorine were also critical for surface water; for South Africa, nickel was the most critical one for surface water body.

**Table 4.** Classification of the compounds occurring in groundwater, according to the criteria “Variability Range-Standard” applied to specific South Africa and Mozambique regulations for drinking water (see Table 1).

Group	South Africa	Mozambique	Pollution Level
$C_{i,max} < S_i$	Barium, cadmium, copper, zinc	Nitrite, ammonium	😊
75th perc. $< S_i \leq$ 100° perc.	Boron, iron, manganese, chloride, sulphate	Sulphate	😐
50th perc. $< S_i \leq$ 75th perc.	Nickel, fluoride, TDS	Nitrate	😞 😞
25th perc. $< S_i \leq$ 50th perc.	Chromium, uranium	Magnesium	😞
$S_i \leq$ 25th perc.	Sodium, nitrate	Calcium	😞 😞
$C_{i,min} > S_i$	Arsenic, lead, chlorine	Boron, sodium, chlorine	😞 😞 😞
Comparison not possible	Bromine, calcium, lithium, magnesium, molybdenum, potassium, rubidium, silver, strontium, vanadium, bicarbonate, fluorine, phosphate	Potassium bicarbonate, chlorite, fluorine	

Microorganisms may be present in groundwater due to percolation/infiltration of untreated wastewater. This is the case reported by [9] for the groundwater below 37 dairy farms in the central Free State, in South Africa: *Escherichia coli* was occasionally found up to  $2.4 \times 10^4$  CFU/100 mL, and its mean value in the monitoring campaign was equal to 84.5 CFU/100 mL in 2009 and 3.9 CFU/100 mL in 2013.

#### 4. Discussion and Conclusions

The occurrence of the inorganic compounds (Cd, Hg, Pb, Al, As, Cr, Cu, Ni, Zn, Sn) in surface water was associated with the use of fertilizers and biocides in agriculture [23]. Specific investigations in different periods remarked on this correspondence.

Metal enrichment of groundwater may be due to geochemical processes involving oxidation reactions, leaching, evaporation and other interactions between host rocks and water. In addition, infiltration and percolation of acidic mine drainage may cause increment of the concentration of specific metals.

A recent study by [26] remarked that in the Limpopo National Park, Gaza Province, in the south of Mozambique, only 13.3% of the groundwater was suitable for drinking purposes, and the remaining was brackish and undrinkable due to high content of chloride and sodium naturally present. As for surface waters, it was found that 80% was suitable for drinking water.

The high content of As in groundwater was correlated to natural origins (release from minerals and host rocks), but also to the discharge of industrial activities (As used in glass manufacturing, steel melting process and as a wood preservative) and to agricultural activities (due to the use of pesticides as remarked above) [35].

Surface water quality may rapidly deteriorate due to anthropic pressures (for instance, untreated as well as accidental releases, land runoff) as well as natural ones (among them, heavy rain events, flooding).

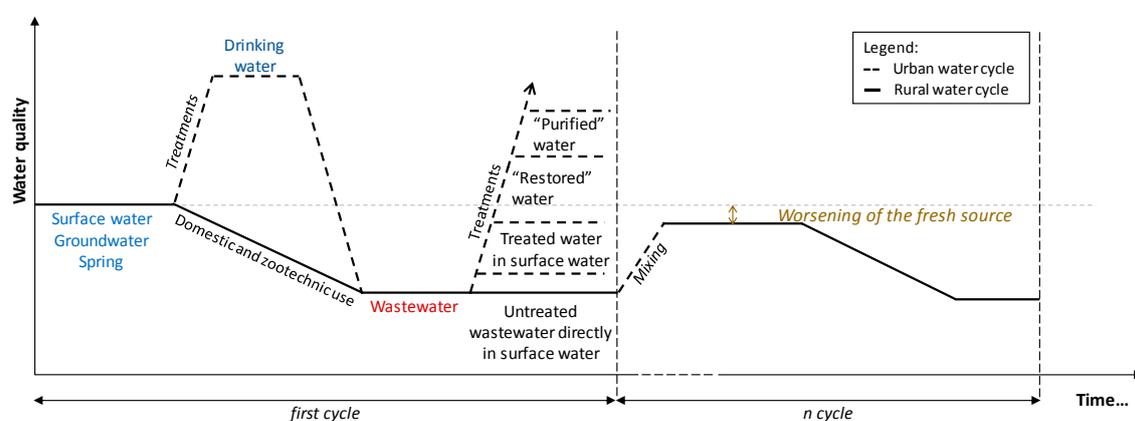
In those areas where domestic wastewater is not properly treated before its release in the aquatic environment, surface water quality is destined to get worse (Figure 8). In this context, a waterworks could have some difficulties in coping with the changes of feeding water and in guaranteeing safe water, adequate for drinking purposes if the influent water may rapidly change and become more polluted over time.

A waterworks is designed on the basis of a well-defined (expected) quality of the influent water. This may change, but any design parameter may vary within a defined variability range. It is important to underline that the waterworks consists of a multibarrier system able to remove different

pollutants in the different treatment steps (mainly raw materials, turbidity, colloidal substances, inorganic compounds, microorganisms). It should work, and if well managed, it should guarantee a continuous exercise and the respect of the legal requirements for a long time. Specific treatments could be added after waterworks construction if a revision of the local regulation leads to the definition of new standards for some pollutants (of emerging concern, or introduced for the first time in the specific regulation).

With regard to the rural areas under study, it emerges that the quality of surface and groundwater could get worse over time due to untreated releases by anthropic activities (the level of treatment of existing wastewater treatment plants is characterized by moderate or limited progress, and zootechnic effluents are released untreated in most cases).

In order to guarantee that the construction of the waterworks will produce safe water for a long time in areas where the access to drinking water is still modest as those under study, it is necessary that other actions could be planned and completed. These actions refer to the whole rural water cycle (Figure 8). In particular, interventions would refer to (domestic, zootechnic and industrial) wastewater management and treatment in order to guarantee that the quality level of the fresh source remains constant over time.



**Figure 8.** The water quality versus time in case inadequate treatments are present for wastewater produced by anthropic activities. The dashed lines refer to the case in which a treatment is present and properly works. The graph reports two “cycles” (first and n°) occurring in two periods in the same place where no treatments are present for wastewater.

**Author Contributions:** P.V. conceived and designed the study; V.G. collected data and processed them; P.V. and V.G. wrote the paper. All authors have read and agreed to the published version of the manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

### Abbreviations

The following abbreviations are used in this manuscript:

- WHO World Health Organization
- RSA Republic of South Africa
- MZ Mozambique

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