Impact of Land Management on Water Resources, a South African Context

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Abstract: Globally, the changes exerted on the land cover have shown greater impacts on the quality and quantity of water resources and thus affecting catchment’s hydrological response (i.e., runoff, evapotranspiration, infiltration, amongst others). South Africa is a water-scarce country faced with domestic water supply challenges. A systematic review was conducted on the overview impacts of land use/land cover changes on water resources. Despite the country’s best efforts in ensuring the protection and sustainable use of water resources, the review indicated that water quality has been compromised in most parts of the country thus affecting water availability. The increase in water demand with development presents the need for better integrated strategic approaches and a change in behaviour towards water resource and land management. Thus, the review suggested a few possible solutions that will promote sustainable development, while protecting and preserving the integrity of South African water resources.

Keywords: hydrological response; land cover/land use; land management; water quality; water resources; water resource management

1. Introduction

Demographic, economic, and technological trends have led to the modification of the natural environment throughout the world. Cosgrove et al. [1] reported that humans have become the primary drivers of environmental modifications that have significant impacts on the temporal distribution of precipitation in catchments and timing of runoff. These changes coupled with landscape changes due to increased food demand, energy production, and urbanisation, have compromised the quantity and quality of freshwater resources [1–3]. Economic development, human settlement patterns, and population distribution are linked to water sources, therefore increasing the vulnerability of freshwater resources as development progresses [4]. Soko and Gyedu-Ababio [5] mentioned that environmental pollution started with the emergence of towns and built-up areas in the 19th century. The interaction of hydrological systems with land use and weather patterns (rainfall, temperature) has a “cause and effect” relationship [6,7]. Studies have linked population growth with changes in Land use/ Land cover (LU/LC) and estimated modification of about 39 to 50% around the world [8–11].

The impact of land management is highly visible on water resources since catchment hydrology is sensitive to land use dynamic changes [4,12,13]. Some studies have described the likely impacts of LU/LC changes on streamflow, sediment yield, and on the availability and quality of water for both ecosystem and human use [3,14]. Issaka and Ashraf [15] further stated that this has also given rise to other environmental problems such as soil erosion and sedimentation. Due to the direct link between LU/LC and the hydrological response, Kumar et al. [3] emphasised the need to urgently integrate water resources management and land management. Sustainable management of the earth’s surface includes sustainable management of the land. Kumar et al. [3] further indicated that these processes also play a significant role in the surface and groundwater budget.
Different LU/LC factors responsible for the modification of runoff, evapotranspiration, sediment transport, and groundwater recharge may sometimes lead to land degradation \cite{3,16,17}. There have been studies linking LU/LC changes with natural disasters, Calder and Aylward \cite{18} and Cui et al. \cite{19} reported a significant increase in the worldwide annual river discharge of approximately 50% since 1900. Sauka \cite{4} linked deforestation with the erosion of riverbeds and decreased infiltration thereby promoting runoff. The expansion of agriculture, urbanisation, deforestation, and daily human activities can temporally and spatially change river flow path \cite{14}. A study by Zhou et al. \cite{20} reported an increase in surface runoff and a reduction in baseflow in Yangtze River Delta region. Converting forests to grazing lands and agricultural land has resulted in reduced soil infiltration and reduced groundwater recharge in Amazon’s lowlands and Kenya’s rift Valley, respectively \cite{21,22}.

An increase in population leads to new land developments, hence an increase in water demand and water users \cite{23}. LU/LC changes need to be sustainable to maintain water quantity and water quality and thus sustaining water availability. Water plays a major role in the ecological and socio-economic wellbeing of a country. It has been noted by WWF-SA \cite{24} that South Africa is still facing challenges when it comes to domestic water supply and water service delivery. Some of the noted major contributing factors were inadequate water resource availability to meet the demand, underdeveloped infrastructure for water storage, abstraction, distribution and treatment \cite{25}. It has also been highlighted that some people in developing countries still turn to open rivers for basic water supply while some opt for groundwater resources \cite{26,27}. For this reason, there is a need to ensure that land development is not at the cost of the integrity of water resources. Since LU/LC interacts with water at different scales and times \cite{6,28}, this article aims to provide a holistic overview of the impact it has on water resources in South Africa, both quality and quantity included. The review presents the theoretical background of South Africa’s land and water resources management. It further collates, analyses and discusses the impacts of LU/LC on water resources and finally recommends possible mitigation approaches and/or strategies.

1.1. Theoretical Background

1.1.1. Overview of South Africa’s Water Resources

Water availability and water resources management are the key aspects of environmental and socio-economic systems \cite{29,30}. South Africa has been declared water-stressed with highly seasonal and variable rainfall, water availability was estimated to be about 1100 m$^3$/person/annum in 2005, and in 2017 it was estimated to be about 905 m$^3$/person/annum \cite{29–31}. It was mentioned to be the 29th driest country out of the 193 driest countries in 2005 (Appendix A) and ranked 30th driest country in the world \cite{28,32,33}, with an average rainfall of about 450 mm per annum, which is about 52% less than the world’s average \cite{30}. Mukheibir and Sparks \cite{29} reported that only a small part of the country receives rainfall amount of more than 750 mm per annum, mostly in the south-eastern coastlines while the western part is arid to semi-arid. Furthermore, about 65% of the country receives less than 500 mm of rainfall per year. Climate and River regimes display inter-annual and intra-annual variability in both timescales and streamflow is reported to be very low for most of the year \cite{34}. Shulze \cite{35} indicated that South Africa has a low conversion of rainfall to runoff. Approximately 9% of the rainfall in wetter regions of the country makes its way to the river in a form of runoff and is considered the lowest in the world \cite{32}.

Freshwater resources are classified into three sources, namely, surface water (77%), return flow (14%), and groundwater (9%) \cite{36}. Water requirements are influenced by population, economic activities, mining, industries, irrigation, and afforestation. Kahinda and Boroto \cite{36} reported that South Africa mostly use surface water resources to meet urban, industrial and irrigation needs. Figure 1 presents some of the major rivers and dams in South Africa \cite{37–40}. It was reported that surface water resources are highly developed with approximately 320 major dams with a supply capacity exceeding 1 million m$^3$ and more than 500 state-owned dams storing an estimated amount of 37 million m$^3$. 
of water [29,36]. McCarthy [40] indicated that so far, the most important river is the Vaal River as it supplies water to the heart of the economy and some of the important mining districts in this country, such as Welkom and Sishen. The biggest indicated dam is the Gariep Dam with a storage capacity of approximately 5.5 million m$^3$ [36].

Groundwater plays a significant role in rural water supplies [30]. Department of Environmental Affairs and Tourism (DEAT) [41] indicated 6 major aquifers in South Africa, namely, the Dolomites, Table Mountain Group Sandstones, coastal sand deposits, basement granites, Karoo dolerites, and alluvium found along the perennial rivers. According to Kahinda and Boroto [36], the quantity and quality of groundwater are highly influenced by the geological structure, soil conditions, rainfall patterns, and anthropogenic activities in the recharge zone. Major groundwater aquifers in South Africa cannot be utilised due to high salinity in some parts of the country [30]. In this view, groundwater resources are more exploitable in the eastern and north-eastern parts of the country and the Western Cape (Figure 2). The useable groundwater exploitation varies between 10,000 to 16,000 million m$^3$ in normal rainy years while during drought periods, the potential is estimated to be between 7000 to 7500 million m$^3$ [42,43]. As summarised by DEAT [41], about 9500 million m$^3$ out of the 12,871 million m$^3$ total requirements of water are abstracted from surface water resources while the remaining amount is supplied by groundwater and return flows.
1.1.2. Water Resource Management in South Africa

Water resource management implies the planning of water use in such a way that it remains sustainable in terms of the hydrological cycle and water availability [44]. Water management involves both quality and quantity. South Africa’s water policies and legislations are based on the principles of the Integrated Water Resources Management (IWRM) approach [45]. The IWRM approach integrates the management of land, environment and water to ensure sustainability of water resources [45,46]. Sustainable water use is realised when the rate of resource withdrawal, consumption, or depletion does not exceed the rate of replenishment. The approach also promotes the need to balance the protection of water resource with the need to use water for socio-economic development [45].

The main driving forces to South Africa’s freshwater environment [4,33,47] include:

- The natural conditions (soil and rock type, landforms, and topology), ecosystem, the combined impacts of climatic changes affecting the availability of run-off.
- Population increase and the need for economic development leading to increased water demand and increased pollution of available water resources.
- Water resource management policies governing relevant authorities in managing water resources.

The National Water Act (NWA) of 1998 and the Water Service Act (WSA) of 1997 offer a holistic legal framework for the governance of water resources with emphasis on the management of the entire catchment and optimal use of freshwater without negatively affecting the aquatic ecosystem [30,44,48]. Under the National Water Act, the National Water Resource Strategy (NWRS) and the Catchment management strategy were implemented to provide information on water resources and to facilitate and promote the efficient use, management, development, protection, and control of water resources. The first NWRS was established in 2004 which served as the blueprint for the management, protection, development, conservation, and control of South African Water Resources [49]. The second NWRS was published in 2013 and it builds on the first NWRS and continue to ensure the management of national water resources towards achieving the growth, development and socio-economic priorities in an equitable manner for the next 5 to 10 years [45]. Through the NWRS, the Catchment Management Strategies were established, and they go as far as creating the framework for water allocation to both existing and potential users while considering the factors affecting the management, proper use, and development of water resources. The National Groundwater Strategy was developed later in 2010 to increase the knowledge and use of groundwater and therefore, ensuring sustainable management of groundwater resources [30].

There are two major water resource protection strategies developed under the NWA and NWRS, namely, Resource-directed Measures and Source-directed Controls. Resource-directed Measures deal with the quality of water resources as they reflect the overall health or condition of the resource and they also measure the ecological status [50]. Resource quality refers to the quality and quantity of water, character, and condition of the in-stream and riparian habitats. They set objectives for the required level of protection of each resource. The objectives ensure that each aspect of the Reserve is not damaged beyond repair. The source-directed controls, control water use activities, the sources of impact, include tools such as standards, incentives, and situation-specific conditions ensuring that the protection objectives are achieved [50]. According to the White Paper on National Water Policy [51], actions that affect resource quality can be controlled by changing the ways of water-and land-users.

1.1.3. Land Use and Land Management in South Africa

Land cover is defined as the biophysical or vesical cover (i.e., vegetation or crop) that can be detected by remote sensing [6], while [52,53] defined land use as an arrangement or activities undertaken by humans in land cover to produce, modify or maintain the land. Unlike land cover, land use cannot be mapped easily, its data can be obtained indirectly from the agricultural census and determined through socio-economic market
forces [53]. South Africa covers an area of approximately between 121.9–34 million ha, and of this, over 80% (100 million ha) is used for agriculture [54,55]; with about 3% owned by smallholders or irrigation schemes. In 1990, 12.3% of the land was classified as degraded. Ngcofe et al. [54] assessed land cover changes between 2013/14 and 2017/18 and on comparison with the 2000 landcover changes, there was a decrease in natural woodland of 9.29%, and bare and degraded areas increased by approximately 6.09% [55]. There is a need to optimise the use of land in South Africa to ensure livelihood support and improve environmental conditions.

Land Use Management (LUM) is part of a land governance system that establishes the framework to regulate access to land, land rights, land use, and land development [56]. This can be viewed as part of land management, which is a much broader concept that considers the policies and regulations that govern and regulate land. Access to land is one of the most socially and politically sensitive issues in South Africa and requires an integrated and holistic programme to achieve its sustainability [56,57]. Historically, the LUM system was used in the service of racial and spatial segregation [58]. Charlton [56] further explained that this was adapted from the British town planning activities which were initially developed to respond to the impact of the industrial revolution and promote the health and safety of urban residents only. Currently, LUM has been experiencing a shift in policy from the “restrictive, control-oriented approach to a more comprehensive, facilitative approach” [57]. Some of the laws and policies shaping current land management include the 1995 Development Facilitation Act 67, 2001 White Paper on Spatial Planning and Land Use Management, 1998 National Environmental Management Act (NEMA) 107, and legislations such as IDPs, strategic plans, and zoning schemes [56,57,59].

2. Methodology

This article is a literature review of the impact of land management on water resources. The search methodology was adapted from Feil et al. [60]. The aim is to collate, analyse and discuss pertinent information sitting in different publications and governmental reports to provide a holistic overview of the impact of LU/LC on water resources in South Africa and how they have been managed, both in terms of quality and quantity, and infer/suggest other appropriate management strategies and/or approaches. The review made use of previous articles and secondary data. The article selection process is further explained in the ensuing section. The selected articles were further analysed and organised according to their years of publication. Secondary data was used to depict the long-term impacts of LU/LC on water resources (see Table 1). The study used freshwater withdrawal data covering a period of 27 years (1990–2017) and the changes were compared with the corresponding land use cover.

| Database          | Data Retrieved                              | Date Accessed      |
|-------------------|---------------------------------------------|--------------------|
| WR2012            | Spatial data (shapefiles)                   | 15 July 2020       |
| FAO-AQUASTATS     | South African freshwater withdrawal data    | 15 July 2020, revised 5 December 2020 |
| FAO               | Global total water renewable data           | 15 July 2020       |

2.1. Article Selection

Articles were selected systematically, the process for selection is depicted in Figure 3. The string of keywords used to search for the articles were “Water resource Management in South Africa”, “the effects of land use/land cover on water quantity”, “the effects of land use/land cover on water quality”, “the effects of land use/land cover on water quantity in South Africa”, “the effects of land use/land cover on water quality in South Africa”, “Land use management in South Africa”, “surface water and groundwater resource management in South Africa”. The strings of keywords were typed on the Google search bar and Google Scholar. Only publications published in English were considered.
Figure 3. Article selection process.

A total of 118 publications were chosen and reviewed to populate the full paper. From the 118 publications, 55 were publications covering the impact of land use on water resources and presenting the state of water resources in South Africa, however, only 39 publications were selected for analysis based on quantifiable information.

2.2. Data Extraction

In order to provide a more holistic overview, this review included governmental reports. Figure 4 and Appendix B presents information on the chosen publications. Appendix B presents the data extracted from each article and the location in which the study was conducted, the appendix further indicated the aspect of the study in which the publication focused. The appendix also indicates the type of land use and the impacts. About 19 publications covered the whole country, while the remaining covered certain catchments, Catchment Management Areas (CMAs) or Water Management Areas (WMAs) and provinces (see Appendix B). The results section narrates the impact of LU/LC on surface and groundwater quality and quantity as covered by the selected publications.

Figure 4. The yearly distribution of the articles used for extracting data.
3. Results

After data selection and extraction (see Appendix B), the data was analysed using thematic analysis. Thematic analysis is useful in summarising key features of a large data set, it assists in producing a clear and organised final report [61]. The data was then organised into three major land use themes, namely, urban, industrial and agricultural use as shown in Figure 5. The three major themes form the foundation of the discussion.

3.1. Water Quantity

In South Africa, about one-third of the precipitation becomes runoff, and two-thirds is evaporated, transpires, or infiltrates, as further indicated by Muller et al. [32], approximately 66% of the Mean Annual Runoff (MAR) in the country is found in the rivers. From the total MAR of 49,040 million m³ p.a., total requirements make up only 20% while 8% is lost through evaporation from storage and conveyance along rivers, and 6% is lost through land use [32,41]. Mukheibir and Sparks [29] indicated that only about 5400 million m³ of water is obtained in the groundwater sources per year.

3.1.1. Runoff and Infiltration

Schulze [35] stated that runoff patterns reflect rainfall and soil characteristics. Drainage, vegetation, land use, and soil types have impacts on the amount of runoff generated in a catchment. Schulze [35] indicated that the production of the forest is a major concern because it consumes more water than the natural vegetation, therefore they were declared “stream flow activity”. Forest plantations were calculated to have used an additional of 922 million m³ of water which was estimated to be 1.8% of South Africa’s MAR [35]. A rapid development of irrigation farming resulted in large-scale deforestation in the Crocodile River rising from the Witwatersrand, Johannesburg and only the riverbanks remained vastly covered with invasive syringa trees and reeds [62]. Parsons [63] mentioned alien plants to be another major concern in catchments, it was indicated that streamflow in South Africa was reduced by 10% due to this vegetation. The latter author further stated that alien plant removal in Limpopo and North-west Provinces resulted in a 20 m rise in the water table over a period of 30 years. DWA [64] also reported that invasive alien plants were found to be one of the factors that affected runoff in Crocodile and Sabie River Catchments under the Inkomati-Usuthu WMA. A reduction in streamflow was reported in the latter catchments due to exotic plantations such as Pine, Eucalyptus, and wattles [64]. In addition, activities such as irrigation, domestic water use, and mining were reported to have reduced streamflow in the Olifants River in Mpumalanga, thus negatively affecting the aquatic ecosystem of this river [10]. Construction of dams, weirs, and diversion of rivers contributed to the alteration of hydrological patterns in catchments. Dabrowski et al. [6] reported a decrease in flow volumes in the uMngeni river due to small dam constructions. The Crocodile River (West) is the largest and most important river in the previous Marico Water Management Area, currently called the Limpopo WMA. It is also one of the major rivers influenced by human activities in South Africa. The river has limited surface and groundwater resources, most of the water resources in this catchment are for urban and industrial purposes. The natural flow of many tributaries has been highly altered due to a large quantity of return flow [29,65]. Basson and Rossow [65] indicated that urban return flow has compromised 30% of the Crocodile River (West) water availability and estimated that by 2030, the total urban flow will be 486 million m³/a with average water demand management measures.
Figure 5. Thematic presentation of the extracted land use and respective impacts on water resources.
Groundwater provides an important source of water supply in rural and semi-arid places, especially during drought [66]. However, these sources are at risk of being depleted [67]. DEAT [41] indicated that over-abstraction of groundwater resources is a problem in most parts of South Africa. Stevens and van Koppen [30] reported a long-term decrease in aquifer saturation level in some places in the Limpopo region, namely, the Limpopo, Luvuvhu, and Letaba (currently known as Limpopo WMA) and the Olifants CMA currently called the Olifant WMA. It was further indicated that towards the west of the Limpopo province, the groundwater level decreased from 0.2 to 5 m p.a. More cases of over-abstraction of groundwater were reported in places such as North-west and Witwatersrand [29,30]. Land use/land cover changes have an impact on the infiltration process consequently affecting the groundwater recharge [66,67]. Parsons [62] indicated cases where runoff volumes had been altered and decreased groundwater recharge, while in some cases, leaking pipes and water tanks have created new sources of recharge. After observing an increase of 8% in groundwater recharge for a period of 21 years, Albhaisi [66] confirmed and concluded that the clearing of non-native hill slope vegetation can increase groundwater recharge in the upper Berg catchments.

3.1.2. Evaporation/Evapotranspiration

Evaporation is the process whereby water transforms from liquid to vapour. Figure 6 shows mean annual evaporation over South Africa. van Dijk and van Vuuren [68] indicated that evaporation loss from reservoirs is greater in South Africa and it is above 1400 mm/year for most parts of the country. Evapotranspiration (ET) varies with vegetation type, climate, soil properties, and landscape. Schulze [69] and Jovanovic et al. [70] indicated that an increase in land use will worsen human-induced global warming and add to the already existing environmental problems such as increased temperatures and potential evapotranspiration (PET). A combination of rainfall of shorter duration, more intense, and increased ET is expected to lead to groundwater depletion [6,33]. Steven and Van Koppen [30] demonstrated a study for 2011/12 where evaporation was discovered to have increased over a broad area of South Africa, it affected Lower Orange and Lower Vaal WMA and some parts of Limpopo Province. By replacing pine forest with native vegetation upstream of a dam in Berg River, DWAF [71] hypothesised that groundwater recharge will increase while evapotranspiration decreases.

![Figure 6. Overall evaporation in South Africa (Data Source: WRC, [72]).](image-url)
3.2. Water Quality

Water quality refers to the microbial, toxicological, and radioactivity (which is physio-chemical, biological, and eutrophication) status of water against a set of standards used to ensure that water is safe for human consumption and the environment [73,74]. Water can become unusable due to several reasons, simple urban expansion and changes in agricultural practice can often have detrimental impacts on water quality [32]. Water quality problems in South Africa include salinity which can occur naturally or can be due to activities such as agriculture and mining and low oxygen levels arising from elevated levels of organic matter. Humans can tolerate a moderate salinity of less than 1000 mg/L. DWS [75] further indicated water-borne diseases such as diarrhoea or cholera due to microbial contamination, and toxicants arising from pesticides as some of the impacts of poor water quality. Water quality parameters or indicators include eutrophication, suspended solids, hydrocarbons from petrochemicals, acidification due to low pH, littering, herbicides, and pesticides [33]. Schulze [35] stated that poor water quality in South Africa has resulted in major health concerns, ecosystems threats and exacerbated the issue of water security in this country, thus placing the country’s water resources under a lot of pressure. Muller et al. [32] indicated that, once water quality is compromised, it can be a challenge and expensive to reverse the changes, especially for groundwater sources.

There are programmes the government has put in place to monitor water quality and protect water resources, namely, the River Health Program (RHP), the development of water resource classification, and wastewater risk management plans such as the Green Drop [75]. The RHP was established to assess the quality of river systems, ensure a better understanding of these systems and indicate the extent of human use impact [5,41]. The function of the Green Drop certification is to reduce pollution to the environment due to municipal wastewater treatment works and identify priority ecosystems for conservation and programmes that monitor and manage the river health system [75].

3.2.1. Surface Water Quality

The lack of proper sanitation in rural areas and unmanaged sanitation services in urban areas have negative impacts on water resources [33]. Mema [76] stated that population growth has put a lot of pressure on wastewater treatment plants (WWTP), thus affecting the effectiveness of these plants in treating water. Edokpayi et al. [77] found that the WWTP at Thohoyandou is inefficient in its treatment of wastewater due to overloading from increased population and socio-economic activities. It was reported that sewerage system failures have led to toxic cyanobacteria identified in all the WMAs in the country [32,78]. According to DWAF [79], of all the WSAs in the country, only 46% reported that they monitor the volume of discharge of their waterworks. Most South African WWTPs obtained low green drop scores, for example, the Makhado and Musina WWTPs in Limpopo Province and the Kingstonvale and Kabokweni WWTPs in Mpumalanga [64,80].

Other quality problems as mentioned by Dabrowski et al. [6] were overgrazing and misusing the land, which resulted in increased sediment load in river systems, which negatively affects water flows and degrades the ecosystem. Manufacturing and mining companies also continue to have significant impacts on water quality, studies indicated that water quality was deteriorating in the Crocodile River due to agricultural run-offs, industrial and sewage effluent, and mining seepage from the Kaap River tributary [5,71]. Compromised water quality was further reported in the upper Olifants River in Mpumalanga due to agricultural activities and industrial works [81,82]. The “cocktail” of pollution on the upper Olifants catchments resulted in compromised ecological and human health concerns downstream of the catchment with Loskop dam being the most affected [83]. Van der Laan et al. [73] indicated high levels of salinity, chloride, and phosphate especially in winter, and high levels of magnesium in summer in the middle reaches of the Olifants catchment. The Upper Vaal WMA, currently known as the Vaal WMA, is highly developed and impacted upon by human activities [84], Nel and Driver [37] reported elevated levels
of Total Dissolved Solids (TDS). Return flows and urban wash-off have resulted in high eutrophication which led to poor quality of the Hartbeespoort and Roodeplaat Dams [30].

3.2.2. Groundwater Quality

Groundwater quality varies from place to place. Groundwater is very vulnerable to pollution especially in highly populated areas; and locations with concentrated economic activities [37]. In Lower Orange WMA, currently known as the Orange WMA, groundwater quality was reported to be deteriorating at an alarming rate in boreholes due to salinity changes from 1996 to 2012 that led to increased electrical conductivity from 220 mS/m to approximately 435 mS/m. McCarthy [40] indicated that acid mine drainage (AMD) is one of the major water quality challenges due to mining activities. The water seeping from abandoned mine dumps, open pits, and mine shafts is highly acidic. The most affected catchments include the gold mines in the Western Basin (Krugersdorp area), Central basin (Roodepoort to Boksburg area), and Eastern basin (Brakpan, Springs, and Nigel areas of the Witwatersrand) [37]. Pit latrines have been associated with chemical and microbial contamination of groundwater [85,86]. Holland [87] highlighted numerous water supply boreholes in villages sited next to pit latrines to have been affected by microbial contamination. In some areas of Sabie River catchment, pit latrines were found to be the cause of poor groundwater quality [88]. While the disposal of paper mill effluents in Ngodwana, Mpumalanga were the main reason for the decrease in water quality, especially in the Elands River [88]. High levels of chloride, fluoride, nitrates, calcium and magnesium were highlighted as major groundwater quality problems within South Africa [45,87,89–92]. Odiyo and Makungo [91] indicated fluoride concentrations of 5.1, 5.6 and 1.7 mg/L in all the sampled boreholes in Siloam Village and these are higher than the 1 mg/l indicated as acceptable for domestic use by the DWAF.

4. Discussions and Suggestions

Water plays a significant role, not only in sustaining lives but also in the socioeconomic wellbeing of a country [32]. Nel and Driver [37] reported that most of South Africa’s rivers are classified as upper or lower foothill rivers and extensive cultivation takes place in the fertile floodplains. Water resources go beyond domestic purposes and agriculture and play an important role in the removal and purification of wastes, navigation, ecotourism and recreational opportunities through the maintenance of habitats [51]. While water is renewable, it cannot be substituted, it is a finite resource. Mukheibir and Sparks [34] emphasised that, water is an integral part of the ecosystem, a natural resource of social and economic good whose quantity and quality determine the nature of its application. The results from the collected studies indicated that industrial, agricultural and urban use had the most impact on water resources, both in terms of quantity and quality.

4.1. Water Quantity

According to DEAT [41], the country was covered by almost 10.46% cultivation, 1.51% urban land use and 1.41 forestry by 2002. Land cover assessment from 1995-2005 shows that forest plantation, urban and mining increased by 1.1% collectively, and Schoeman et al. [93] showed a decline in cultivated land from 12.4% to 11.9% (see Table 2).

| Land-Cover Category | 1990 (%) [94] | 1994/1995 (%) [93,95] | 2000 (%) [41] | 2005 (%) [95] | 2013/14 (%) [95] | 2017/18 (%) [96] |
|---------------------|--------------|----------------------|--------------|--------------|----------------|-----------------|
| Cultivated areas    | 11.1         | 12.4                 | 10.5         | 11.9         | 11.2           | 11.0            |
| Forest plantations  | 1.5          | 1.5                  | 1.4          | 1.6          | 1.5            | 1.7             |
| Total Agriculture   | 12.6         | 13.9                 | 11.9         | 13.5         | 12.7           | 12.7            |
| Mines               | 0.2          | 0.1                  | 0.2          | 0.2          | 0.3            | 0.2             |
| Urban areas         | 2.2          | 1.1                  | 1.5          | 2            | 2.3            | 2.8             |
| Total Land use      | 15           | 15.1                 | 13.6         | 15.7         | 15.3           | 15.7            |

The bold indicates the total land use for each category which is the data used.
Furthermore, Figure 7 presents the annual abstraction of freshwater by the above-mentioned land uses. Freshwater abstraction for industrial use for 1995 coincides with the decrease in land use cover but generally, there is an increasing trend in both industrial use and water withdrawal. Both agricultural use and freshwater withdrawals show a long-term decreasing trend from 1990 to 2017, which is the opposite of agricultural use. However, it should be noted that agriculture remains the highest water user, as it has been reported that approximately 62% of South Africa’s water resources are reserved for agricultural purposes [30]. For urban use, freshwater withdrawal was high in most of the years when urban use was low. However, the latter also showed long-term increasing trends in water withdrawal and urban growth from 1990 to 2017, and water withdrawal depicted a steady increasing trend compared to the land use at self.

In terms of water requirements, Figure 7 further shows that agricultural activities consume more freshwater. Followed by urban/domestic cover, according to DWAF [42], this sector consumes about 27% of the country’s water resources. As for industrial use, Figure 7 shows that Industrial cover consumes the least amount of water out of the three land uses, though, it shows a growing trend. It should also be noted that 2014–2016 was a drought year in South Africa [97], thus the decreasing trend in some of the land use cover, especially the ones that are highly dependent on water, such as agriculture.

![Figure 7. Long-term freshwater withdrawal by major land-users from 1990 to 2014, (a) Annual freshwater withdrawal for industrial use; (b) Annual freshwater withdrawal for agricultural use; (c) Annual freshwater withdrawal for urban use (Data source: FAO-Aquastat, World bank [98]).](image-url)
4.2. Water Quality

As shown by precious articles, the above-mentioned LU/LCs also have impacts on the quality of water resources through the alteration of hydrological responses such as runoff, evaporation, and infiltration as already covered in the previous section. The results from previous publications indicated sediment load, salinity, excessive nutrients, high concentrations of metals, and high levels of chloride and fluoride as some of the major water quality problems. Figure 8 shows the general electrical conductivity (EC) of groundwater in the entire country. According to DWAF [99], the minimum required standards for EC are between 70–150 mS/m and the target range is 0–70 mS/m. Conrad [100] added that EC above 370 mS/m is considered poor and completely unacceptable. High amounts of EC were observed in most parts of the country (Figure 8), however, it should be noted that groundwater naturally contains small amounts of dissolved gases and TDS, therefore, it is hardly pure.

![Figure 8. Groundwater quality in South Africa (Source: [WRC [72]])](image)

The North-western part of the country reported low-quality conditions resulting from low annual recharge [32,37], as depicted in Figure 8, High levels of EC are observed in the western part of the country. Comparing Figures 6 and 8, the high levels of EC correspond with the areas having the highest evaporation rates. It was mentioned that high recharge rate promotes high groundwater quality by diluting the water, as such, climate change could have adverse impacts on groundwater recharge due to its variability with rainfall in South Africa [100].

Figure 9 shows the most stressed quaternary catchments in WMAs, out of the 9 WMAs, most of the stressed catchments are within 6 WMAs, namely Breede-Gouritz, Berg-Olifant, Mzimvubu-Tshitsikama, Phongola-Umzikhulu, Inkomati-usuthu, Olifant and Limpopo WMA. Through the River Health Programme, a few rivers have already been assessed, among these, is the Berg River, Vaal River, Orange River, Umgeni River, Luvuvhu River, Sabie River, Sand River, and Olifants Rivers [41]. The assessed rivers were all in fair to good conditions in the upper tributaries while the lower reaches had fair to poor conditions, especially those catchments in highly urbanised areas such as Gauteng [41,101]. According to Driver et al. [90], 57% of the country’s river types are under threat, 25% were found to be in critical danger, 19% are endangered and 13% vulnerable. The Crocodile River, Inkomati River basin, and the Vaal River were some of the rivers found to be water-stressed due to increasing demand from different water users, namely, emerging farmers and domestic use [4,102,103].
4.3. Possible Solutions for the Major Users

Despite the strategies already in place to limit negative impacts on water resources and promote sustainable use, the mentioned water users continue to have visible impacts on water resources, especially surface resources [32,33,53,97]. Some of the outstanding challenges from the first NWRS in 2004, namely, Water conservation and water demand management (WCWDM), decentralising water resource management, lack of technical skills, backlog of infrastructures, stronger regulation of water resources continue to have visible impacts on water resources. The socio-economic and ecological significance of water has already been stressed to some extent by previous studies [73,104]. Thus, there is need to change the way water is currently being managed to ensure water availability for future generations [23].

4.3.1. Low-Cost Technologies

In 2009, it was indicated that the country treats about 54% of its municipal wastewater and the existing infrastructure requires extensive investment [97]. Poor maintenance of existing WWTPs is due to lack of expenditure and human capacity especially in poorer, rural, and peri-urban areas, thus worsening water quality and limiting the government’s ability to provide basic water services [26,86]. For this reason, the government should invest more in low-cost technologies, the introduction of WSP to rural and poor-urban areas can minimise the disposal of poorly treated waste in water resources [26]. Low energy treatment technologies such as sedimentation, anaerobic treatment, filtration, and construction of artificial wetlands and the recovery of sewage sludge as compost or energy as suggested by Cullis et al. [105] have the potential to stabilise sludge thus decreasing the risk of contamination. As part of low cost and safe technology, indigenous plants have been used in many contemporary studies for the purification of water and to improve its quality [106,107]. Particularly in rural environments with no reticulated water supply and relies on run-of-river abstractions or groundwater [106]. For example, scientifically, it has been discovered that the *dicerocaryum eriocarpum* plant has the potential to reduce suspended matter and heavy metals through coagulation and biosorption [108,109]. Edokpayi et al. [77] showed that mucilaginous leaves of *dicerocaryum eriocarpum* plant can also be used to improve the efficiency of removal of Lead (II) ion and improve on quality of wastewater from stabilisation ponds before discharge into the river.

Furthermore, water users such as industries and mining should ensure that their wastewater is treated before being disposed back to water sources to minimise the costs of purifying it. According to Edokpayi et al. [26], pollutants such as heavy metals, nutrients, radionuclides, pharmaceutical, and personal care not only reduce water supply but can...
increase the cost of purification. Other alternative sources of water such as rainwater harvesting should be encouraged for urban, rural settlement, industrial, and agricultural use to reduce the withdrawal of freshwater resources. Masindi and Duncker [25] noted that the amount of rainfall to be collected is not usually the limit of rainwater harvesting but rather is the size of the storage that sustainably supply water throughout a period of little or no rainfall. Ndiritu et al. [110] has shown rainwater harvesting as a reliable source of water supply to rural communities, particularly when combined with other sources of water supply.

4.3.2. Amendments of Policies and Programs

Africa is projected to be the fastest urbanisation region during 2020–2050 [111], therefore programmes and policies should be in alignment with the current social and environmental issues. Most programmes and strategies such as the demand mitigation strategy implemented by DWS are not effective as water demand continues to increase (see Figure 7) [112]. For example, the Water Conservation and Water Demand Management (WCWDM) pricing strategy is by far the most important element in ensuring stability in the water sector [97]. However, owing to the country’s apartheid history and the structural inequalities, precautions need to be taken when pricing water.

Land reform policies should be integrated with water management legislations to achieve a holistic approach towards water management and planning. Molobele and Sinah [28] argued that the management of water in the catchment should be guided by the existing water resources in that basin. Land planning and land development should be built around the existing water resources, with more focus on water demand than water supply. According to Donnenfeld et al. [97], a great number of proposed solutions are oriented towards increasing the levels of surface water resources through large infrastructure projects and new dams.

There should be guidelines specifically for each water user or use. “Policy instruments that are effective and efficient solutions to water quality problems must consider the pollution impact based on the pollution and the context characteristics” [105]. Understanding the risk that is associated with the land-use activity is important in supporting investments that are oriented towards the management of water resources. Van der Merwe-Botha [113] indicated the importance of valuing water not only as an available resource, but also as an increasingly scarce resource, for that reason, costs should be inclusive of downstream quality impacts. The Green drop is a good initiative to monitor and regulate the efficiency of WWTPs, therefore frequent monitoring should be encouraged, and the report should be updated more regularly. As reported in a study by Edokpayi et al. [26], the frequent monitoring program is recommended to most WWTPs. The strict implementation of buffer zones should also be stressed, according to Norris [114], buffer zones are very effective against filtering pollutants from runoff water and can improve the quality of water sources to some extent. Mayer et al. [115] noted that protecting existing buffer zones is less costly than creating new ones and restoring degraded one, however, the necessity of restoring degraded buffers has been emphasised in protecting the quality of a catchment.

4.3.3. Public Participation and Capacity Building at All Levels

One of the major challenges contributing to the failure of most WWTPs is the lack of human capacity, especially in rural areas. In this view, better planning, and investments towards improving the capacity of responsible personnel is encouraged, especially in poor rural areas. Muller et al. [32] pointed the need to improve the capacity of local government to ensure water supply and water efficiency and prevent pollution. The public should be informed on the issues of water resources despite their background and their level of education, this will encourage public participation in the management of water resources. In South Africa, the policy and legal frameworks for community consultation, involvement and participation are clearly spelt out in the constitution [116]. However, despite the attention public participation has received, Kahinda and Boroto [36] indicated that the country
is yet to have in place a “comprehensive and functional approach to public engagement at all level of water management area”. In this view, better communication platforms that will allow communities to ask questions should be encouraged for both officials and community members, especially in the poorest parts of the country. The importance of transparency in building public trust was noted in a study by Rodda et al. [31]. Muller et al. [32] also indicated the need to have effective institutional arrangements when it comes to developing and managing water resource infrastructure. Land development proposals must include proposed strategies for water resource planning, and it must be approved by all relevant departments. For example, with regards to groundwater, DWA [45] stated that land use planners must take the necessary steps to guarantee that groundwater resources as well as their recharge mechanism are sustainable and well protected.

5. Conclusions

Land management continues to have adverse impacts on the quality and quantity of water resources. Land use activities such as urban use, industrial use and agriculture use are the key drivers affecting catchment and groundwater hydrology in South Africa [4,117,118]. As water quality problems continue to spike due to the disposal of untreated water into the rivers from acid drainage, industrial effluent, urban/settlements wastewater drainages and agricultural runoff; more lives are put in danger, especially in poor communities whose livelihoods are dependent on those water sources [26]. Although the country has several programs for improved supply, management and protection of water resources [23], current water challenges such as resource constraints, financial instability, political impacts, environmental degradation and inequalities between water users inhibit the effectiveness of those programs and policies in managing and protecting water resources [33]. Considering that South Africa is still developing, water use can be expected to increase, as depicted in Figure 7, thus, exacerbating the impacts of LU/LC on water resources. This coupled with the variability of rainfall and increasing temperatures, makes the country’s water resources vulnerable and sensitive to changes in land cover and climate. Henceforth, a review and/or effective implementation of legislation and an introduction of low cost and safe water treatment technologies at the community level or point of use are some of the solutions recommended in this study. In addition, alternative sources that increase access to water such as rainwater harvesting, and strict implementation of the buffer zones are recommended. From the White Paper on National Water Policy [51], it was stated that “Planning must be based on the water catchment rather than political borders since each activity taking place on the land has some effect on water resources”. A new strict approach that accounts for LU/LC and climate change is needed to ensure the management, sustainable use, and protection of water resources.

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Appendix A. List of the Driest Countries [98,119].

Table A1. Water availability per country.

| COUNTRY                     | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 (X 1000 INHABITANTS) | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M³/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M³/YR) |
|-----------------------------|----------------------|----------|--------------------------------|-----------------------|---------------------------------------------------------------|---------------------------------------------------------|
| 1. Kuwait                   | 1782                 | 2595     | 4137                           | 100                   | 8                                                             | 5                                                       |
| 2. Gaza Strip               | 1376                 | 3051     | 9400                           | 100                   | 49                                                            | 16                                                      |
| 3. United Arab Emirates     | 8360                 | 317      | 395                            | 1300                  | 63                                                            | 1770                                                    |
| 4. Bahamas                  | 30                   | 328      | 436                            | 2000                  | 91                                                            | 69                                                      |
| 5. Qatar                    | 1161                 | 619      | 2639                           | 100                   | 86                                                            | 22                                                      |
| 6. Maldives                 | 30                   | 317      | 395                            | 1300                  | 63                                                            | 1770                                                    |
| 7. Saudi Arabia             | 214,969              | 24,919   | 32,938                         | 100                   | 96                                                            | 73                                                      |
| 8. Libyan Arab Jamahiriya   | 175,954              | 5659     | 6375                           | 100                   | 106                                                           | 109,8                                                   |
| 9. Malta                    | 32                   | 396      | 431                            | 400                   | 130                                                           | 117                                                     |
| 10. Singapore               | 72                   | 4315     | 5709                           | 2500                  | 139                                                           | 105                                                     |
| 11. Bahrain                 | 78                   | 739      | 1493                           | 100                   | 157                                                           | 78                                                      |
| 12. Jordan                  | 8932                 | 5614     | 9702                           | 100                   | 160                                                           | 97                                                      |
| 13. Yemen                   | 52,797               | 20,733   | 28,250                         | 200                   | 198                                                           | 74                                                      |
| 14. Israel                  | 2207                 | 6560     | 8322                           | 400                   | 250                                                           | 214                                                     |
| 15. Barbados                | 43                   | 271      | 286                            | 2100                  | 296                                                           | 280                                                     |
| 16. Oman                    | 30,950               | 2935     | 4636                           | 100                   | 340                                                           | 302                                                     |
| 17. Djibouti                | 2320                 | 712      | 957                            | 200                   | 420                                                           | 314                                                     |
| 18. Algeria                 | 238,174              | 32,339   | 41,318                         | 100                   | 440                                                           | 282                                                     |
| 19. Tunisia                 | 16,361               | 9937     | 11,532                         | 300                   | 460                                                           | 400                                                     |
| 20. Saint Kitts And Nevis   | 26                   | 42       | 55                             | 2100                  | 560                                                           | 434                                                     |
| 21. Rwanda                  | 2634                 | 8481     | 12,208                         | 1200                  | 610                                                           | 1089                                                    |
| 22. Cabo Verde              | 403                  | 473      | 546                            | 400                   | 630                                                           | 549                                                     |
| COUNTRY               | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 (X 1000 INHABITANTS) | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M$^3$/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M$^3$/YR) |
|----------------------|----------------------|----------|--------------------------------|-----------------------|-----------------------------------------------------------------|----------------------------------------------------------|
| 23. Antigua And Barbuda | 44                   | 73       | 102                            | 2400                  | 710                                                             | 510                                                      |
| 24. Egypt             | 100,145              | 73,390   | 97,552                         | 100                   | 790                                                             | 589                                                      |
| 25. Kenya             | 58,037               | 32,420   | 49,700                         | 700                   | 930                                                             | 618                                                      |
| 26. Burkina Faso      | 27,422               | 13,393   | 19,193                         | 700                   | 930                                                             | 703                                                      |
| 27. Morocco           | 44,655               | 31,064   | 35,740                         | 300                   | 930                                                             | 811                                                      |
| 28. Cyprus            | 925                  | 808      | 1180                           | 500                   | 970                                                             | 661                                                      |
| 29. South Africa      | 121,909              | 45,214   | 56,717                         | 500                   | 1110                                                           | 905                                                      |
| 30. Denmark           | 4292                 | 5375     | 5734                           | 700                   | 1120                                                           | 1046                                                     |
| 31. Lebanon           | 1045                 | 3708     | 6082                           | 700                   | 1190                                                           | 740                                                      |
| 32. Czech Rep         | 7887                 | 10,226   | 10,618                         | 700                   | 1290                                                           | 1238                                                     |
| 33. Somalia           | 63,766               | 10,312   | 14,743                         | 300                   | 1380                                                           | 997                                                      |
| 34. Malawi            | 11,848               | 12,337   | 18,622                         | 1200                  | 1400                                                           | 928                                                      |
| 35. Pakistan          | 79,610               | 157,315  | 197,016                        | 300                   | 1420                                                           | 1253                                                     |
| 36. Syrian Arab Rep.  | 18,518               | 18,223   | 18,270                         | 300                   | 1440                                                           | 920                                                      |
| 37. Korea, Rep.       | 10,034               | 47,951   | 50,982                         | 1100                  | 1450                                                           | 1367                                                     |
| 38. Eritrea           | 11,760               | 4297     | 5069                           | 400                   | 1470                                                           | 1443                                                     |
| 39. Comoros           | 186                  | 790      | 814                            | 1800                  | 1520                                                           | 1474                                                     |
| 40. Zimbabwe          | 39,076               | 12,932   | 16,530                         | 700                   | 1550                                                           | 1210                                                     |
| 41. Poland            | 31,268               | 38,551   | 38,171                         | 600                   | 1600                                                           | 1585                                                     |
| 42. Haiti             | 2775                 | 8437     | 10,981                         | 1400                  | 1660                                                           | 1278                                                     |
| 43. Ethiopia          | 110,430              | 72,420   | 104,957                        | 800                   | 1680                                                           | 1162                                                     |
| 44. Lesotho           | 3036                 | 1800     | 2233                           | 800                   | 1680                                                           | 1353                                                     |
| 45. India             | 328,726              | 1,081,229| 1,339,180                      | 1100                  | 1750                                                           | 1427                                                     |
| 46. Belgium           | 3053                 | 10,340   | 11,429                         | 800                   | 1770                                                           | 1601                                                     |
| COUNTRY                      | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 (X 1000 INHABITANTS) | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M^3/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M^3/YR) |
|-----------------------------|----------------------|----------|-------------------------------|-----------------------|----------------------------------------------------------------|--------------------------------------------------|
| 47. Puerto Rico             | 887                  | 3898     | 3663                          | 2100                  | 1820                                                            | 1938                                              |
| 48. Germany                 | 35,758               | 82,526   | 82,114                        | 700                   | 1870                                                            | 1875                                              |
| 49. Sudan                   | 64,433               | 34,333   | 12,576                        | 400                   | 1880                                                            | 3936                                              |
| 50. Uzbekistan              | 44,740               | 26,479   | 31,911                        | 200                   | 1900                                                            | 1531                                              |
| 51. Iran, Islamic Rep.      | 174,515              | 69,788   | 81,163                        | 200                   | 1970                                                            | 1688                                              |
| 52. China                   | 960,001              | 1,320,892| 1,411,131                     | 600                   | 2140                                                            | 1971                                              |
| 53. Burundi                 | 2783                 | 7068     | 10,864                        | 1200                  | 2190                                                            | 1154                                              |
| 54. Mauritius               | 204                  | 1233     | 1265                          | 2000                  | 2230                                                            | 2175                                              |
| 55. Nigeria                 | 92,377               | 127,117  | 190,886                       | 1200                  | 2250                                                            | 1499                                              |
| 56. Dominican Republic      | 4867                 | 8872     | 10,767                        | 1400                  | 2370                                                            | 2183                                              |
| 57. Tanzania                | 94,730               | 37,671   | 57,310                        | 1100                  | 2420                                                            | 1680                                              |
| 58. United Kingdom          | 24,361               | 59,648   | 66,182                        | 1200                  | 2460                                                            | 2221                                              |
| 59. Uganda                  | 24,155               | 26,699   | 42,863                        | 1200                  | 2470                                                            | 1402                                              |
| 60. Ghana                   | 23,854               | 21,377   | 28,834                        | 1200                  | 2490                                                            | 1949                                              |
| 61. Tajikistan              | 14,138               | 6,298    | 8,921                         | 500                   | 2540                                                            | 2456                                              |
| 62. Sri Lanka               | 6561                 | 19,218   | 20,877                        | 1700                  | 2600                                                            | 2529                                              |
| 63. Niger                   | 126,700              | 12,415   | 21,447                        | 200                   | 2710                                                            | 1585                                              |
| 64. Spain                   | 50,594               | 41,128   | 46,354                        | 600                   | 2710                                                            | 2405                                              |
| 65. Bulgaria                | 11,100               | 7829     | 7085                          | 600                   | 2720                                                            | 3006                                              |
| 66. Moldova, Rep.           | 3385                 | 4263     | 4051                          | 600                   | 2730                                                            | 3029                                              |
| 67. Ukraine                 | 60,355               | 48,151   | 44,223                        | 600                   | 2900                                                            | 3964                                              |
| 68. Iraq                    | 43,505               | 25,856   | 38,275                        | 200                   | 2920                                                            | 2348                                              |
| 69. Togo                    | 5679                 | 5017     | 7798                          | 1200                  | 2930                                                            | 1885                                              |
| 70. China, Taiwan Prov.     | 22,894               |          |                                | 2400                  | 2930                                                            |                                                  |
| COUNTRY                                      | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 (X 1000 INHABITANTS) | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M³/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M³/YR) |
|----------------------------------------------|----------------------|----------|-------------------------------|------------------------|----------------------------------------------------------------|----------------------------------------------------------------|
| 71. Trinidad And Tobago                      | 513                  | 1307     | 1369                          | 1800                   | 2940                                                           | 2805                                                           |
| 72. Turkey                                   | 78,535               | 72,320   | 80,745                        | 600                    | 2950                                                           | 2621                                                           |
| 73. Macedonia, Fr Yugoslav Rep.              | 2571                 | 2066     | 2083                          | 600                    | 3100                                                           | 3072                                                           |
| 74. Italy                                    | 30,134               | 57,346   | 59,360                        | 800                    | 3340                                                           | 3223                                                           |
| 75. Japan                                    | 37,797               | 127,800  | 127,484                       | 1700                   | 3360                                                           | 3373                                                           |
| 76. France                                   | 54,909               | 60,434   | 64,980                        | 900                    | 3370                                                           | 3247                                                           |
| 77. Cuba                                     | 10,988               | 11,328   | 11,485                        | 1300                   | 3370                                                           | 3319                                                           |
| 78. Korea, Dem. People's Rep.                | 12,054               | 22,776   | 25,491                        | 1400                   | 3390                                                           | 3027                                                           |
| 79. Armenia                                  | 2974                 | 3052     | 2930                          | 600                    | 3450                                                           | 2652                                                           |
| 80. Jamaica                                  | 1099                 | 2676     | 2890                          | 2100                   | 3510                                                           | 3744                                                           |
| 81. Azerbaijan                               | 8660                 | 8447     | 9829                          | 400                    | 3580                                                           | 3529                                                           |
| 82. Senegal                                  | 19,671               | 10,339   | 15,851                        | 700                    | 3810                                                           | 2459                                                           |
| 83. El Salvador                              | 2104                 | 6614     | 6378                          | 1700                   | 3810                                                           | 4119                                                           |
| 84. Benin                                    | 11,476               | 6918     | 11,176                        | 1000                   | 3820                                                           | 2361                                                           |
| 85. Mauritania                               | 103,070              | 2980     | 4420                          | 100                    | 3830                                                           | 2579                                                           |
| 86. Kyrgyzstan                               | 19,995               | 5208     | 6045                          | 400                    | 3950                                                           | 3907                                                           |
| 87. Eswatini                                 | 1736                 | 1083     | 1367                          | 800                    | 4160                                                           | 3299                                                           |
| 88. Mexico                                   | 196,438              | 104,931  | 129,163                       | 800                    | 4360                                                           | 3576                                                           |
| 89. Côte D'Ivoire                            | 32,246               | 16,897   | 24,295                        | 1300                   | 4790                                                           | 3463                                                           |
| 90. Chad                                     | 128,400              | 8854     | 14,900                        | 300                    | 4860                                                           | 3067                                                           |
| 91. Turkmenistan                             | 48,810               | 4940     | 5758                          | 200                    | 5000                                                           | 4302                                                           |
| 92. Gambia                                   | 1130                 | 1462     | 2101                          | 800                    | 5470                                                           | 3808                                                           |
Table A1. Cont.

| COUNTRY                      | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 X 1000 INHABITANTS | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M³/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M³/YR) |
|------------------------------|----------------------|----------|-----------------------------|-----------------------|----------------------------------------------------------------|------------------------------------------------------|
| 93. Netherlands              | 4154                 | 16,227   | 17,036                      | 800                   | 5610                                                           | 5342                                                 |
| 94. Philippines              | 30,000               | 81,408   | 104,918                     | 2300                  | 5880                                                           | 4565                                                 |
| 95. Belarus                  | 20,760               | 9852     | 9468                        | 600                   | 5890                                                           | 6115                                                 |
| 96. Thailand                 | 51,312               | 63,465   | 69,038                      | 1600                  | 6460                                                           | 6353                                                 |
| 97. Reunion                  | 767                  |          | 2100                        |                       | 6520                                                           |                                                      |
| 98. Luxemburg                | 259                  | 459      | 584                         | 900                   | 6750                                                           | 5998                                                 |
| 99. Greece                   | 13,196               | 10,977   | 11,160                      | 700                   | 6760                                                           | 6129                                                 |
| 100. Botswana                | 58,173               | 1795     | 2292                        | 400                   | 6820                                                           | 5340                                                 |
| 101. Portugal                | 9223                 | 10,072   | 10,330                      | 900                   | 6820                                                           | 7493                                                 |
| 102. Kazakhstan              | 272,490              | 15,403   | 18,204                      | 200                   | 7120                                                           | 5955                                                 |
| 103. Lithuania               | 6529                 | 3422     | 2890                        | 700                   | 7280                                                           | 8478                                                 |
| 104. Mali                    | 124,019              | 13,409   | 18,542                      | 300                   | 7460                                                           | 6472                                                 |
| 105. Switzerland             | 4129                 | 7164     | 8476                        | 1500                  | 7470                                                           | 6312                                                 |
| 106. Bangladesh              | 14,763               | 149,664  | 164,670                     | 2700                  | 8090                                                           | 7451                                                 |
| 107. Nepal                   | 14,718               | 25,725   | 29,305                      | 1300                  | 8170                                                           | 7173                                                 |
| 108. Guatemala               | 10,889               | 12,661   | 16,914                      | 2700                  | 8790                                                           | 7562                                                 |
| 109. Namibia                 | 82,429               | 2011     | 2534                        | 300                   | 8810                                                           | 15,750                                               |
| 110. Bosnia And Herzegovina  | 5121                 | 4186     | 3507                        | 1000                  | 8960                                                           | 10,693                                               |
| 111. Slovakia                | 4903                 | 5407     | 5448                        | 800                   | 9270                                                           | 9196                                                 |
| 112. Romania                 | 2384                 | 22,280   | 19,679                      | 600                   | 9510                                                           | 10,773                                               |
| 113. Austria                 | 8388                 | 8120     | 8735                        | 1100                  | 9570                                                           | 8895                                                 |
| 114. Zambia                  | 75,261               | 10,924   | 17,094                      | 1000                  | 9630                                                           | 6131                                                 |
| 115. Estonia                 | 4534                 | 1308     | 1310                        | 600                   | 9790                                                           | 9779                                                 |
| 116. United State Of America | 983,151              | 297,043  | 324,459                     | 700                   | 10,270                                                          | 9459                                                 |
| COUNTRY               | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 (X 1000 INHABITANTS) | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M³/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M³/YR) |
|-----------------------|----------------------|----------|-------------------------------|-----------------------|---------------------------------------------------------------|----------------------------------------------------------|
| Angola                | 124,670              | 14,078   | 29,784                        | 1000                  | 10,510                                                        | 4983                                                     |
| Hungary               | 9303                 | 9831     | 9722                          | 600                   | 10,580                                                        | 10,697                                                   |
| Viet Nam              | 33,123               | 82,481   | 95,541                        | 1800                  | 10,810                                                        | 9254                                                     |
| Mozambique            | 78,638               | 19,182   | 29,669                        | 1000                  | 10,940                                                        | 11,320                                                   |
| Viet Nam              | 6970                 | 5074     | 3912                          | 1000                  | 9254                                                         | 12,480                                                   |
| Indonesia             | 191,358              | 222,611  | 263,991                       | 750                   | 12,750                                                        | 16,189                                                   |
| Ireland               | 7028                 | 3999     | 4762                          | 1100                  | 13,000                                                        | 10,920                                                   |
| Albania               | 2875                 | 3194     | 2930                          | 1000                  | 13,060                                                        | 10,307                                                   |
| Sao Tome And Principe | 96                   | 165      | 204                           | 2200                  | 13,210                                                        | 10,671                                                   |
| Mongolia              | 156,412              | 2630     | 3076                          | 200                   | 13,230                                                        | 11,313                                                   |
| Honduras              | 11,249               | 7099     | 9265                          | 2000                  | 13,510                                                        | 9947                                                     |
| Latvia                | 6449                 | 2286     | 1950                          | 600                   | 15,510                                                        | 17,918                                                   |
| Slovenia              | 2068                 | 1982     | 2080                          | 1200                  | 16,080                                                        | 15,322                                                   |
| Cameroon              | 47,544               | 16,296   | 24,054                        | 1600                  | 17,520                                                        | 11,769                                                   |
| Madagascar            | 58,730               | 17,901   | 25,571                        | 1500                  | 18,830                                                        | 13,179                                                   |
| Sweden                | 44,743               | 8886     | 9911                          | 600                   | 19,580                                                        | 17,556                                                   |
| Serbia And Montenegro | 8836                 | 10,519   | 8791                          |                       | 19,820                                                        | 18,451                                                   |
| Guinea-Bissau         | 3613                 | 1538     | 1861                          | 1600                  | 20,160                                                        | 16,873                                                   |
| Myanmar               | 67,659               | 50,101   | 53,371                        | 2100                  | 20,870                                                        | 21,885                                                   |
| Argentina             | 278,040              | 38,871   | 44,271                        | 600                   | 20,940                                                        | 19,792                                                   |
| Finland               | 33,845               | 5215     | 5523                          | 500                   | 21,090                                                        | 19,917                                                   |
| Brunei Darussala      | 577                  | 366      | 429                           | 2700                  | 23,220                                                        | 19,827                                                   |
| Malaysia              | 33,034               | 24,876   | 31,624                        | 2900                  | 23,320                                                        | 18,341                                                   |
| Congo, Dem Rep.       | 234,486              | 54,417   | 81,340                        | 1500                  | 23,580                                                        | 3027                                                     |
Table A1. Cont.

| COUNTRY             | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 (X 1000 INHABITANTS) | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M$^{3}$/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M$^{3}$/YR) |
|---------------------|----------------------|----------|-------------------------------|-----------------------|-------------------------------------------------------------------|-----------------------------------------------------------------|
| 141. Croatia        | 5659                 | 4416     | 4189                          | 1100                  | 23,890                                                           | 25,185                                                          |
| 142. Australia      | 774,122              | 19,913   | 24,450                        | 500                   | 24,710                                                           | 20,123                                                          |
| 143. Guinea         | 24,586               | 8620     | 12,717                        | 1700                  | 26,220                                                           | 17,771                                                          |
| 144. Costa Rica     | 5110                 | 4250     | 4906                          | 2900                  | 26,450                                                           | 23,033                                                          |
| 145. Sierra Leone   | 7230                 | 5168     | 7557                          | 2500                  | 30,960                                                           | 21,172                                                          |
| 146. Russian Federation | 1,709,825           | 142,397  | 143,990                       | 500                   | 31,650                                                           | 31,426                                                          |
| 147. Ecuador        | 25,637               | 13,192   | 16,625                        | 2100                  | 32,170                                                           | 26,611                                                          |
| 148. Cambodia       | 18,104               | 14,482   | 16,005                        | 1900                  | 32,880                                                           | 29,747                                                          |
| 149. Fiji           | 1827                 | 847      | 906                           | 2600                  | 33,710                                                           | 31,530                                                          |
| 150. Nicaragua      | 13,037               | 5597     | 6218                          | 2400                  | 35,140                                                           | 26,455                                                          |
| 151. Central Africa Rep. | 62,298              | 3912     | 4659                          | 1300                  | 36,910                                                           | 30,264                                                          |
| 152. Uruguay        | 17,622               | 3439     | 3457                          | 1300                  | 40,420                                                           | 49,812                                                          |
| 153. Bhutan         | 3839                 | 2325     | 808                           | 1700                  | 40,860                                                           | 96,582                                                          |
| 154. Brazil         | 851,577              | 180,654  | 209,288                       | 1800                  | 45,570                                                           | 41,316                                                          |
| 155. Panama         | 7542                 | 3177     | 4099                          | 2700                  | 46,580                                                           | 33,984                                                          |
| 156. Venezuela,     | 91,205               | 26,170   | 31,977                        | 1900                  | 47,120                                                           | 41,436                                                          |
| 157. Colombia       | 114,175              | 44,914   | 49,066                        | 2600                  | 47,470                                                           | 48,098                                                          |
| 158. Equatorial Guinea | 2805              | 507      | 1268                          | 2200                  | 51,280                                                           | 20,505                                                          |
| 159. Paraguay       | 40,675               | 6018     | 6811                          | 1100                  | 55,830                                                           | 1835                                                            |
| 160. Lao Peoples Dem. Rep. | 23,680         | 5787     | 6858                          | 1800                  | 57,640                                                           | 48,629                                                          |
| 161. Chile          | 75,670               | 15,996   | 18,055                        | 700                   | 57,640                                                           | 51,127                                                          |
| 162. Liberia        | 11,137               | 3487     | 4732                          | 2400                  | 66,530                                                           | 49,028                                                          |
| 163. Bolivia        | 109,858              | 8973     | 11,052                        | 1100                  | 69,380                                                           | 51,936                                                          |
| 164. Peru           | 128,522              | 27,567   | 32,165                        | 1500                  | 69,390                                                           | 58,449                                                          |
| COUNTRY          | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 (X 1000 INHABITANTS) | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M³/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M³/YR) |
|------------------|----------------------|----------|-------------------------------|-----------------------|---------------------------------------------------------------|---------------------------------------------------|
| 165. Belize      | 2297                 | 261      | 375                           | 2200                  | 71,090                                                        | 57,993                                           |
| 166. New Zealand | 26,771               | 3904     | 4706                          | 1700                  | 83,760                                                        | 69,486                                           |
| 167. Norway      | 62,522               | 4552     | 5305                          | 1100                  | 83,920                                                        | 74,081                                           |
| 168. Solomon Islands | 2890              | 491      | 611                           | 3000                  | 91,040                                                        | 73,123                                           |
| 169. Canada      | 998,467              | 31,744   | 36,624                        | 500                   | 91,420                                                        | 79,238                                           |
| 170. Gabon       | 26,767               | 1351     | 2025                          | 1800                  | 121,390                                                       | 81,975                                           |
| 171. Papua New Guinea | 46,284           | 5836     | 8251                          | 3100                  | 137,250                                                       | 97,079                                           |
| 172. Congo       | 34,200               | 3818     | 5261                          | 1600                  | 217,920                                                       | 158,145                                           |
| 173. Suriname    | 16,382               | 439      | 563                           | 2300                  | 277,900                                                       | 175,719                                           |
| 174. Guyana      | 21,497               | 767      | 778                           | 2400                  | 314,210                                                       | 348,374                                           |
| 175. Iceland     | 10,300               | 292      | 335                           | 1000                  | 582,190                                                       | 507,463                                           |
| 176. French Guiana | 182                |          | 2900                          |                       | 736,260                                                       |                                                  |
| 177. Greenland   | 57                   |          | 600                           |                       | 10,578,950                                                    | 910                                              |
| 178. Saint Vincent | 39                 | 121      | 110                           | 1600                  |                                                               |                                                  |
| 179. Saint Lucia  | 62                   | 150      | 179                           | 2300                  |                                                               | 1678                                             |
| 180. Grenada     | 34                   | 80       | 108                           | 1500                  |                                                               | 1855                                             |
| 181. Dominica    | 75                   | 79       | 74                            | 3400                  |                                                               | 2706                                             |
| 182. Aruba       | 101                  |          |                               |                       |                                                               |                                                  |
| 183. Bermuda     | 82                   |          |                               |                       |                                                               | 1500                                             |
| 184. French Polynesia | 248                |          |                               |                       |                                                               |                                                  |
| 185. Guadeloupe  | 443                  |          |                               |                       |                                                               | 200                                              |
| 186. Martinique  | 395                  |          |                               |                       |                                                               | 2600                                             |
| 187. New Caledonia | 233                |          |                               |                       |                                                               | 1500                                             |
| 188. Saint Helena | 5                    |          |                               |                       |                                                               | 800                                              |
Table A1. Cont.

| COUNTRY   | TOTAL AREA (1000 HA) | POP 2005 | POP 2017 (X 1000 INHABITANTS) | PRECIPITATION (MM/YR) | TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M^3/YR) | TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M^3/YR) |
|-----------|----------------------|----------|-------------------------------|-----------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| Samoa     | 284                  | 180      | 196                           | 3000                  |                                                               |                                                               |
| Seychelles| 46                   | 82       | 95                            | 2000                  |                                                               |                                                               |
| Tonga     | 75                   | 105      | 108                           | 2000                  |                                                               |                                                               |
| West Bank | 2386                 |          |                               | 1                     |                                                               |                                                               |

* The highlighted indicates South Africa’s ranking.
Appendix B. The Geographical Location Covered by the Publications.

Table A2. Publications used to generate results.

| Author                        | Landuse                                                                 | Aspect                        | Impact                                                                                                                                      | Location                                                                 |
|-------------------------------|-------------------------------------------------------------------------|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Dabrowski et al. [6]          | Agricultural activities, WWTP, industries, mining, river damming       | Surface Water quality and quality | Excess nutrients and E. coli. load, eutrophication, sedimentation, reduced streamflow, destruction of riparian zone | Upper Umngeni River Catchment (KZN) and Upper Olifant River (Mpumalanga) |
| Soko and Gyedu-Ababio [5]     | Industrial effluent, Sewage discharge, Farming, domestic runoff        | Surface Water Quality         | Increased nutrients, high concentration of Chloride, high salinity and TDS                                                                | Crocodile River Catchment, Mpumalanga                                  |
| Gyamfi et al. [10]            | Urban and agriculture expansion                                         | Water quantity                | Increased evapotranspiration, Increased runoff                                                                                               | Olifant River Basin                                                    |
| Mukheibir and Sparks [29]     | Water resource management                                              | Water quantity                | Driving forces for water future                                                                                                              | South Africa                                                            |
| Stevens and van Koppen [30]   | Mining, Agriculture, urbanisation                                      | Surface and groundwater quality and quantity | AMD, Abstraction, reduced infiltration, increased runoff                                                                                   | South Africa                                                            |
| Muller et al. [32]            | Urbanisation, agriculture, industrial use and Mining                   | Water quality                 | Water pollution                                                                                                                              | South Africa                                                            |
| Hornby et al. [33]            | Drought and Water demand from different water sectors                  | Water quantity                | Decreased dam storages, streamflow and groundwater storage                                                                                 | Msinga, KwaZulu-Natal                                                  |
| Schulze [35]                  | Forestry, Industrial and mining, Agriculture, invasive alien plants, urban expansion | Water quantity and water quality | Enhanced deep percolation, runoff losses, sewage and industrial effluent, sedimentation                                                   | South Africa                                                            |
| Nel and Driver [37]           | Agricultural and mining expansion                                      | Water quantity                | Modification of river length                                                                                                                | South Africa                                                            |
| Oberholster and Ashton [43]   | Spray irrigation practices, Sewage effluent                            | Surface Water quality         | Eutrophication                                                                                                                             | South Africa                                                            |
| McCarthy [40]                 | Mining                                                                  | Water quality                 | AMD                                                                                                                                       | South Africa with special focus on Olifants and Vaal River Catchments  |
| DEAT [41]                     | Urbanisation, irrigation, industries, WWTP                             | Surface and groundwater quality and water quantity | Over-abstraction, changes in timing of flow, low flows, chemical waste, excessive nutrients, increased salinity | South Africa                                                            |
| Namugizea et al. [47]         | Built-up areas, Cultivated areas                                       | Surface water quality         | Increased concentration of nutrients, increased sediment-related variables                                                                    | Umngeni River Catchment                                                |
| Albhaisi et al. [66]          | Forest plantation                                                      | Groundwater quantity          | Decrease in groundwater recharge,                                                                                                           | Berg Catchment, Western Cape                                           |
| Driver et al. [90]            | Land use                                                                | Water quality                 | River health                                                                                                                               | South Africa                                                            |
| Author                          | Landuse                                                                 | Aspect                                      | Impact                                      | Location                                      |
|--------------------------------|------------------------------------------------------------------------|---------------------------------------------|---------------------------------------------|-----------------------------------------------|
| Saraiva Okello et al. [103]    | Forestry, irrigated agriculture, urbanisation                         | Surface water quantity                      | Changes in streamflow                       | Inkomati River Catchment                      |
| Hobbs et al. [62]              | Groundwater quality                                                   |                                             |                                             | Crocodile River Catchment                     |
| Parsons [63]                   | Invasive plants                                                       | Groundwater resources                       | Reduced flow                               | South Africa                                 |
| Basson and Rossouw [65]        | Urban use, industrial, mining                                         | Water quality and water quantity            | Reduced return flow, water pollution        | Crocodile River Catchment west               |
| Schulz et al. [67]             | Groundwater quantity                                                  |                                             |                                             | South Africa                                 |
| van Dijk and van Vuuren [68]   | Dam construction                                                      | Water quantity                             | Evaporation loss                           | South Africa                                 |
| Schulze et al. [69]            | Water quantity                                                        |                                             |                                             | South Africa                                 |
| Jovanovic et al. [70]          | Land use                                                               | Water quantity                             | Evapotranspiration                         | South Africa                                 |
| Van Der Laan et al. [73]       | Sugarcane                                                             | Water quality                              | EC, pH, Inorganic matter, Phosphate         | South Africa                                 |
| Mema [76]                      | WWTP                                                                   | Water quality                              | Sewage discharge                           | South Africa                                 |
| DWS [75]                       | WWTP and agriculture                                                  | Water quality and water quantity            | Microbial contamination                    | South Africa                                 |
| Edokpayi et al. [77]           | WWTP                                                                   | Water quality                              | Sewage effluent                            | Limpopo Province                             |
| Ground-Truth [78]              | Water quality                                                         |                                             |                                             | KwaZulu Natal                                |
| VDM [80]                       | WTP                                                                    | Sewage discharge                           |                                             | Limpopo Province                             |
| DWA [64]                       | WWTP                                                                   | Water quantity and water quality            | Sewage discharge                           | Mpumalanga                                   |
| Hart et al. [81]               | Agricultural activities                                               | Water quality                              | Phosphorus                                  |                                             |
| Dabrowski and de Klerk [83]    | WWTW and mining activities                                            | Water quality                              | Sewage effluent, Excessive nutrients, High concentration of ortho-phosphate, nitrogen, TDS, AMD | Upper Olifant River Catchments               |
| Graham and Matthew [86]        | Pit Latrines                                                          | Groundwater Quality                        | High levels of contaminates                 | Global                                       |
| Holland [87]                   | Pit latrines                                                          | Groundwater quality                        | Contamination                              | Limpopo Province                             |
| Mbombela SoER [88]             | Agricultural and industrial activities, pit toilets, solid waste dumping | Surface and groundwater quality            | Sewage effluent, organic pollution, sedimentation, invasive alien plants | Mpumalanga                                   |
| Vinger et al. [89]             | Pit laterine                                                          | Groundwater quality                        | High levels of fluoride                     | South Africa                                 |
| Odiyo and Makungo [91]         | Groundwater Quality                                                   |                                             | High levels of Fluoride                    | Siloam, Limpopo                              |
| Odiyo and Makungo [92]         | Groundwater quality                                                   |                                             | High concentrations of fluoride and nitrates, microbial concentrations from Pit latrines | Siloam, Limpopo                              |
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