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Review

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

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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 [3,16,17]. There have been studies linking LU/LC changes with natural disasters, Calder and Aylward [18] and Cui et al. [19] reported a significant increase in the worldwide annual river discharge of approximately 50% since 1900. Sauka [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 [14]. A study by Zhou et al. [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 [21,22].

An increase in population leads to new land developments, hence an increase in water demand and water users [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 [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 [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 [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 [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 [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 (see Appendix A) [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 [28,32,33], with an average rainfall of about 450 mm per annum, which is about 52% less than the world's average [30]. Mukheibir and Sparks [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 [34]. Shulze [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 [32].

Freshwater resources are classified into three sources, namely, surface water (77%), return flow (14%), and groundwater (9%) [36]. Water requirements are influenced by population, economic activities, mining, industries, irrigation, and afforestation. Kahinda and Boroto [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 [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]

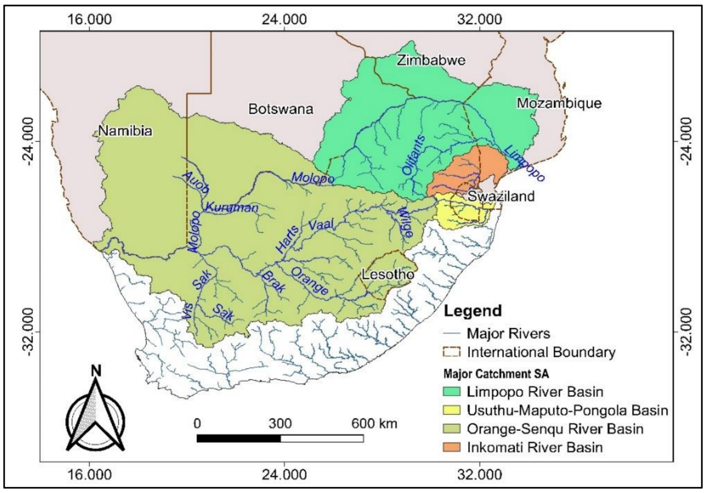


Figure 1. Shared basins, major rivers, and few dams in South Africa (Data from WR2012).

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.

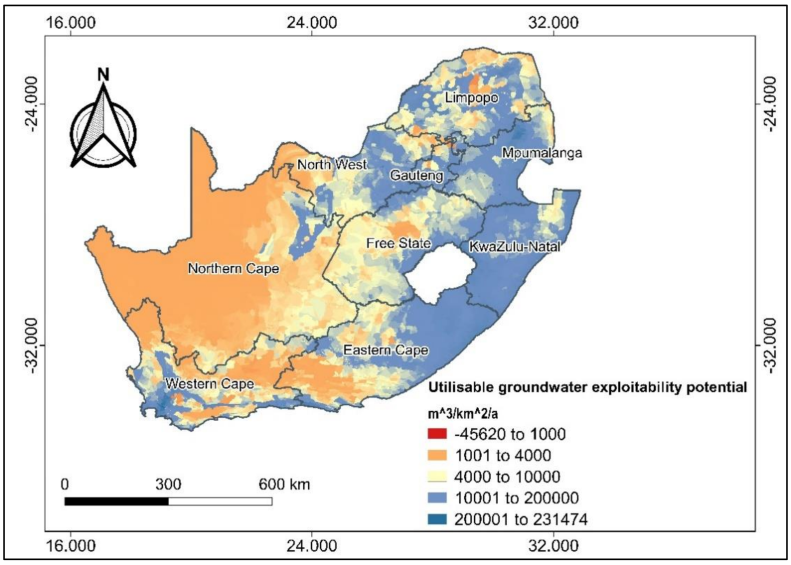


Figure 2. Exploitation potential for utilisable groundwater (Data from WR2012).

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.

Table 1. Internet databases.

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.

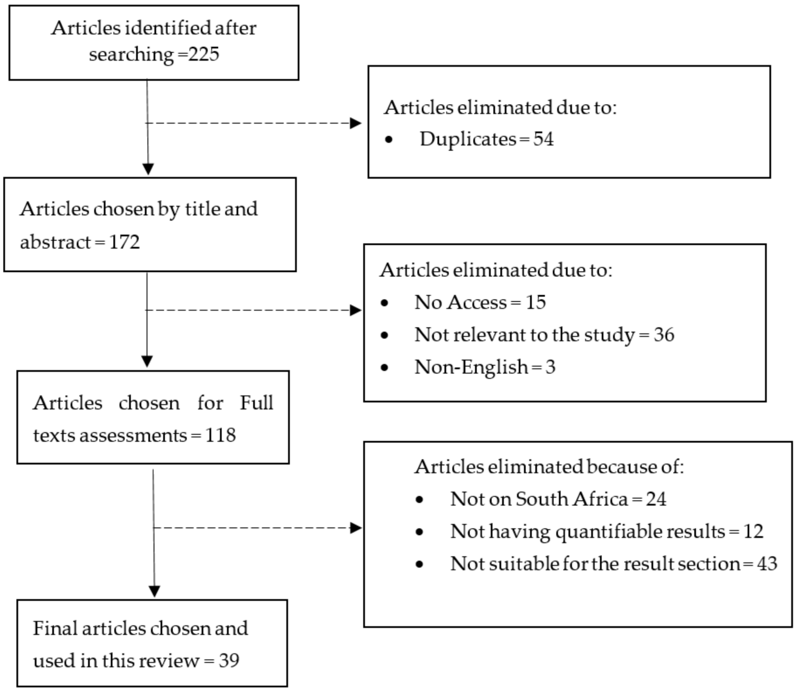


Figure 3. Article selection process.

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.

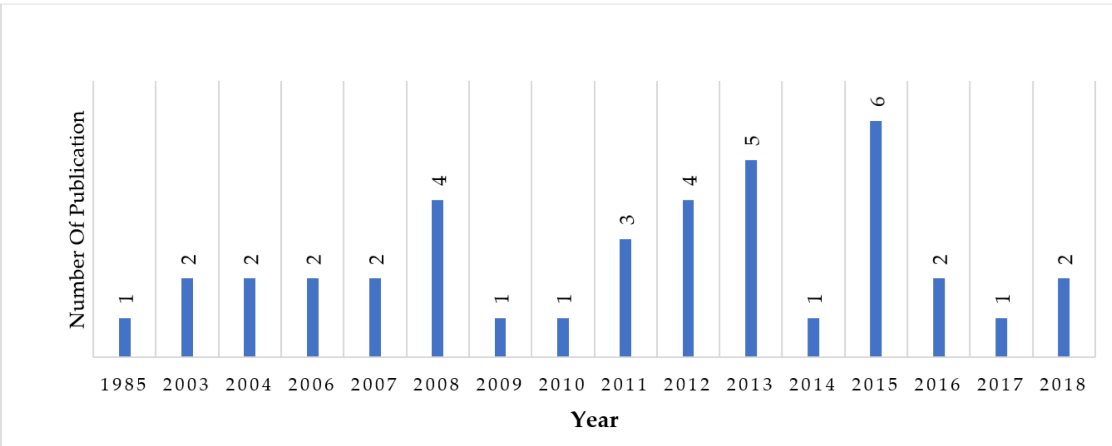


Figure 4. The yearly distribution of the articles used for extracting data.

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 m^3 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 m^3 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 m^3 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 m^3/a with average water demand management measures.

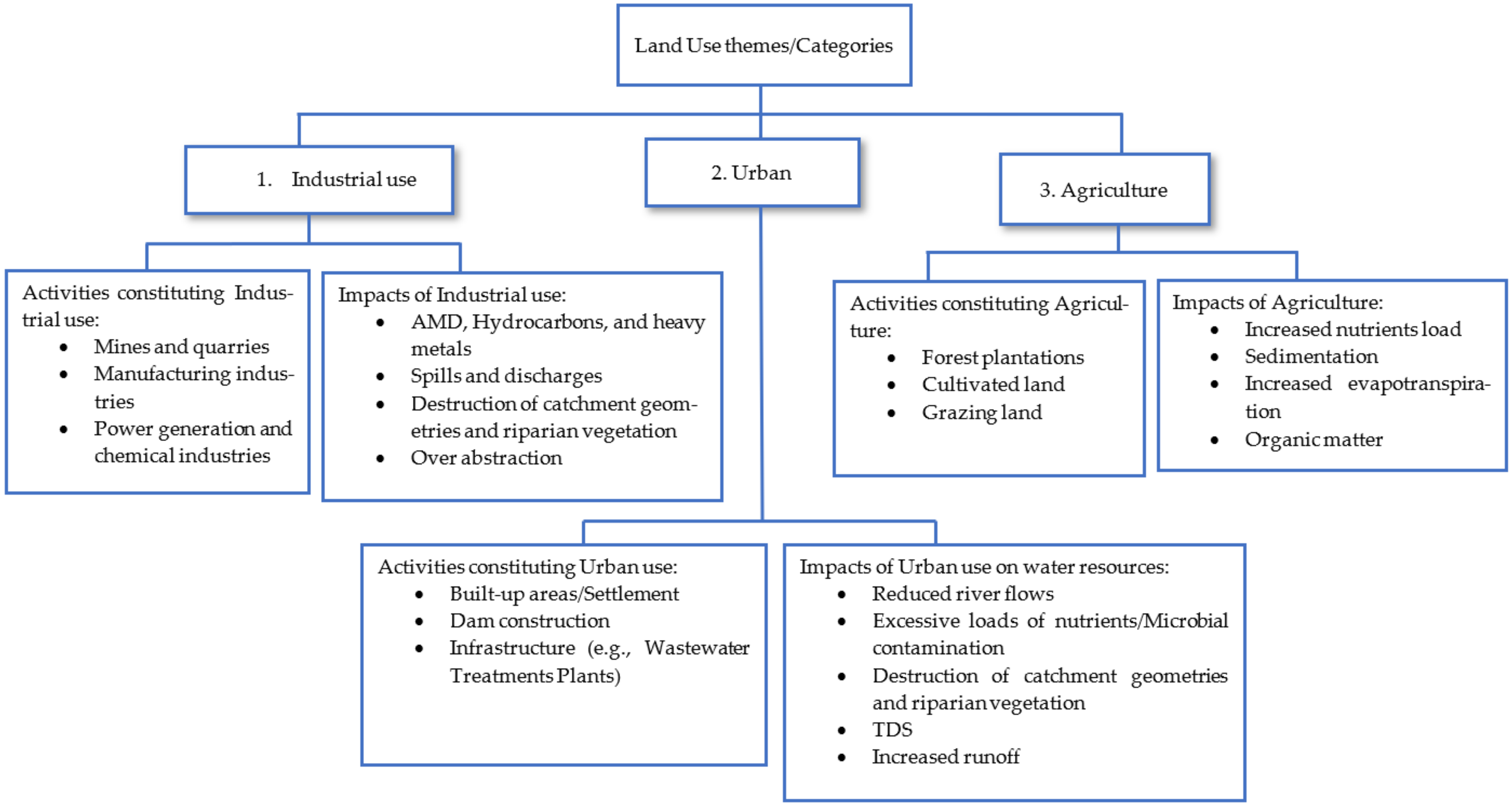


Figure 5. Thematic presentation of the extracted land use and respective impacts on water resources.

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.

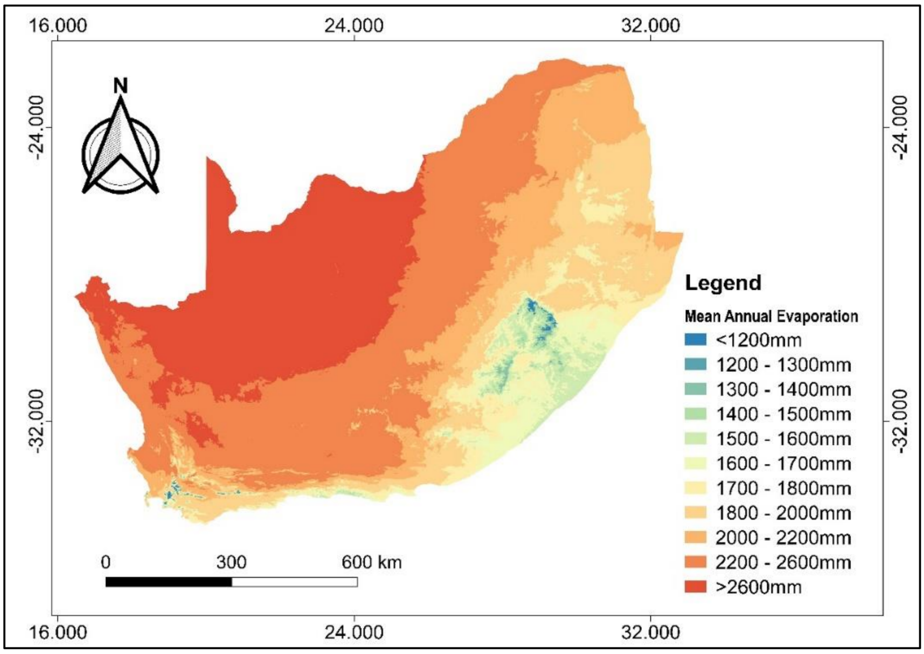


Figure 6. Overall evaporation in South Africa (Data Source: WRC, [72]).

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 chlorine, 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 socio-economic 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 quality and quantity.

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).

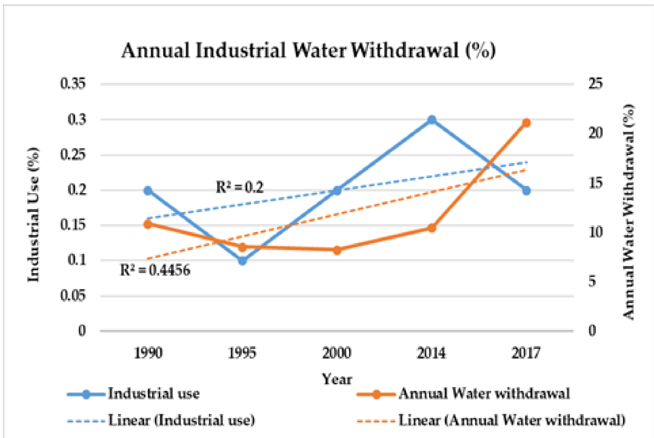
Table 2. Long term changes in the 3 major land use cover from 1990 to 2018.

Land-Cover Category	1990 (%) [94]	1994/1995 (%) [93,95]	2000 (%) [41]	2005 (%) [93]	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 use	**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**

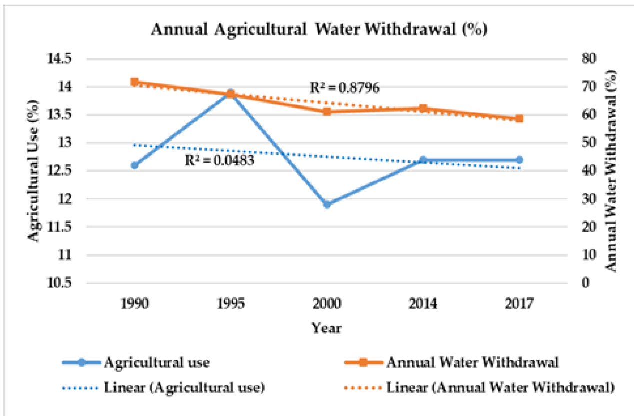
The bold indicates the total land use for each category which is the data used.

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.

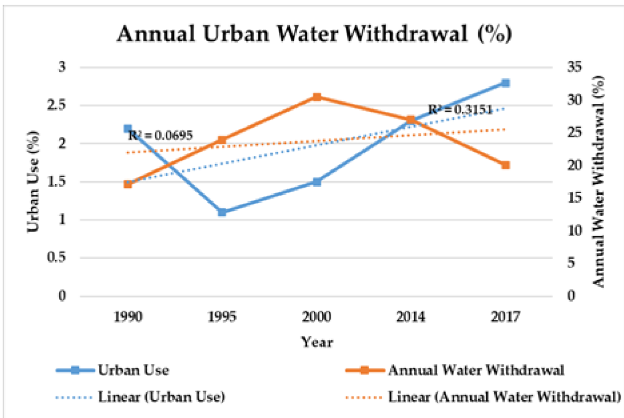
In terms of water requirements, Figure 7 further shows that agricultural activities consume more freshwater. Followed by urban/domestic cover, according to DWAF [42], this sector consumes about 27% of the country's water resources. As for industrial use, Figure 7 shows that Industrial cover consumes 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.



(**a**)



(**b**)



(**c**)

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]).

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.

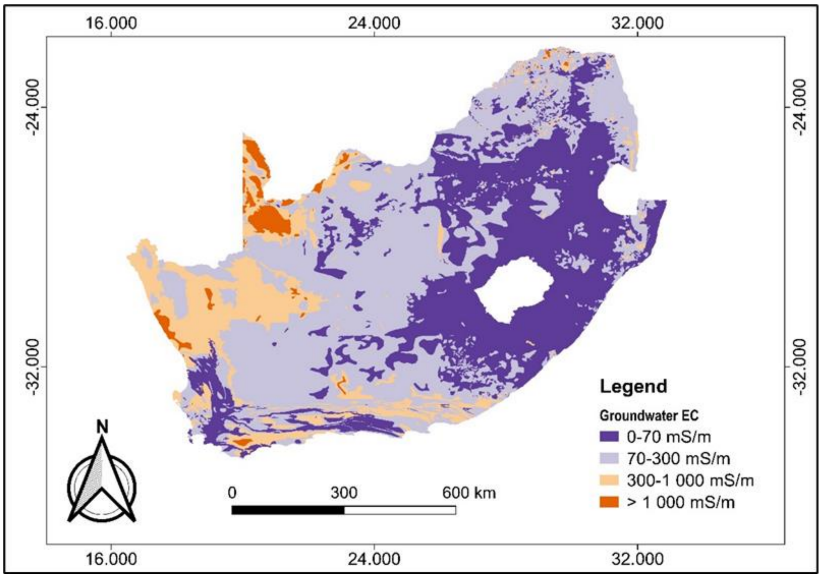


Figure 8. Groundwater quality in South Africa (Source: [WRC [72]]).

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].

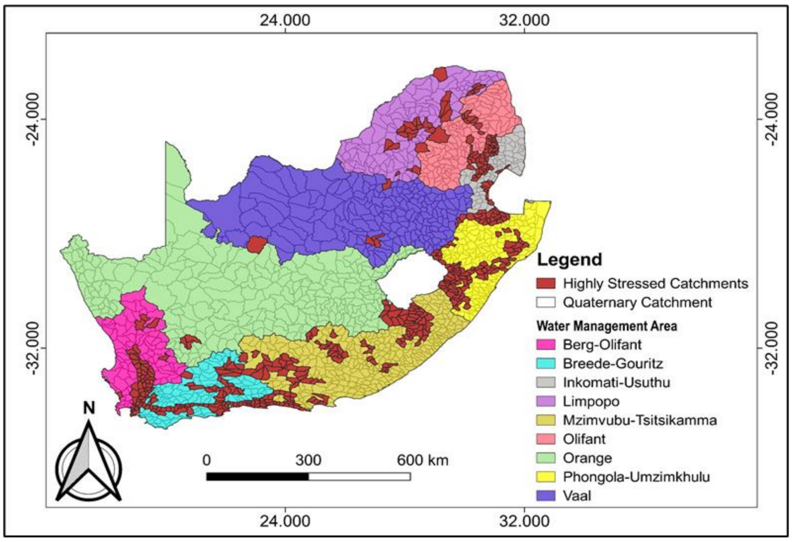


Figure 9. The country's most stressed catchments per WMA (Data source: [WRC [72]).

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 INHABITATS)	PRECIPITATION (MM/YR)	TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M^3/YR)	TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M^3/YR)
1.	Kuwait	1782	2595	4137	100	8	5
2.	Gaza Strip		1376		300	41	
3.	United Arab Emirates	8360	3051	9400	100	49	16
4.	Bahamas	1388	317	395	1300	63	1770
5.	Qatar	1161	619	2639	100	86	22
6.	Maldives	30	328	436	2000	91	69
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

Table A1. *Cont.*

	COUNTRY	TOTAL AREA (1000 HA)	POP 2005	POP 2017 (X 1000 INHABITATS)	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

Table A1. *Cont.*

	COUNTRY	TOTAL AREA (1000 HA)	POP 2005	POP 2017 (X 1000 INHABITATS)	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	1,441,131	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	

Table A1. *Cont.*

	COUNTRY	TOTAL AREA (1000 HA)	POP 2005	POP 2017 (X 1000 INHABITATS)	PRECIPITATION (MM/YR)	TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M^3/YR)	TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M^3/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'lvoire	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 INHABITATS)	PRECIPITATION (MM/YR)	TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M^3/YR)	TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M^3/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 Herzegoniva	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

Table A1. *Cont.*

COUNTRY	TOTAL AREA (1000 HA)	POP 2005	POP 2017 (X 1000 INHABITATS)	PRECIPITATION (MM/YR)	TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M^3/YR)	TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M^3/YR)
117. Angola	124,670	14,078	29,784	1000	10,510	4983
118. Hungary	9303	9831	9722	600	10,580	10,697
119. Viet Nam	33,123	82,481	95,541	1800	10,810	9254
120. Mozambique	78,638	19,182	29,669	1000	11,320	7317
121. Georgia	6970	5074	3912	1000	12,480	16,189
122. Indonesia	191,358	222,611	263,991	2700	12,750	7648
123. Ireland	7028	3999	4762	1100	13,000	10,920
124. Albania	2875	3194	2930	1000	13,060	10,307
125. Sao Tome And Principe	96	165	204	2200	13,210	10,671
126. Mongolia	156,412	2630	3076	200	13,230	11,313
127. Honduras	11,249	7099	9265	2000	13,510	9947
128. Latvia	6449	2286	1950	600	15,510	17,918
129. Slovenia	2068	1982	2080	1200	16,080	15,322
130. Cameroon	47,544	16,296	24,054	1600	17,520	11,769
131. Madagascar	58,730	17,901	25,571	1500	18,830	13,179
132. Sweden	44,743	8886	9911	600	19,580	17,556
133. Serbia And Monteneng	8836	10,519	8791		19,820	18,451
134. Guinea-Bissau	3613	1538	1861	1600	20,160	16,873
135. Myanmar	67,659	50,101	53,371	2100	20,870	21,885
136. Argentina	278,040	38,871	44,271	600	20,940	19,792
137. Finland	33,845	5215	5523	500	21,090	19,917
138. Brunei Darussala	577	366	429	2700	23,220	19,827
139. Malaysia	33,034	24,876	31,624	2900	23,320	18,341
140. 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 INHABITATS)	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

Table A1. *Cont.*

	COUNTRY	TOTAL AREA (1000 HA)	POP 2005	POP 2017 (X 1000 INHABITATS)	PRECIPITATION (MM/YR)	TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M^3/YR)	TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M^3/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	
178.	Saint Vincent	39	121	110	1600		910
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 INHABITATS)	PRECIPITATION (MM/YR)	TOTAL ANNUAL RENEWABLE WATER RESOURCES PER CAPITA 2005 (M^3/YR)	TOTAL RENEWABLE WATER RESOURCES PER CAPITA 2017 (M^3/YR)
189.	Samoa	284	180	196	3000		
190.	Seychelles	46	82	95	2000		
191.	Tonga	75	105	108	2000		
192.	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 Water 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

Table A2. *Cont.*

Author	Landuse	Aspect	Impact	Location
Saraiva Okello et al. [103]	Forestry, irrigated agriculture, urbanisation	Surface water quantity	Changes in streamflow	Inkomati River Catchmnet
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
Schulze et al. [67]		Groundwater quantity	Groundwater recharge	South Africa
van Dijk and van Vuuren [68]	Dam construction	Water quantity	Evaporation loss	South Africa
Schulze et al. [69]		Water quantity	Climate	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	State of Rivers	KwaZulu Natal
VDM [80]	WTTP		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, soild 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 Flouride	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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