Research Article

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Land use pollution potential of water sources along the southern coast of South Africa

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Abstract: Since the 1990's, the groundwater quality along the southern coast of the Western Cape Province of South Africa has been affected by increasing land use activities. Groundwater resources have become increasingly important in terms of providing good quality water. Polluted coastal groundwater as a source of submarine groundwater discharge also affects the quality of coastal water. For this study, land use activities causing groundwater pollution and areas at particular risk were identified. An assessment approach linking land use/land cover, groundwater and submarine groundwater discharge on a meso-scale was developed and the methods applied to two study regions along the southern coastal area. Dryland and irrigated crop cultivation, and urbanized areas are subject to a “high” and “very high” risk of groundwater nitrogen pollution. Application of fertilizer must be revised to ensure minimal effects on groundwater. Practice of agricultural activities at locations which are not suited to the environment's physical conditions must be reconsidered. Informal urban development may contribute to groundwater nitrogen pollution due to poor waste water disposal. Groundwater monitoring in areas at risk of nitrogen pollution is recommended. Land use activities in the submarine groundwater discharge contribution areas was not found to have major effects on coastal water.

Keywords: land use/land cover, nitrogen, groundwater, DRASTIC, submarine groundwater discharge

1 Introduction

Population growth and increasing land use activities place greater pressure on ecosystems to deliver good quality water for human use and to support healthy habitats. The supply of water is generated by terrestrial ecosystems and therefore the quality is influenced by land use/land cover (LULC) [1-2]. Increasing global demand for good quality freshwater has shifted the focus on groundwater resources, which over recent years have experienced increasing pressure from human populations. Groundwater is vulnerable to anthropogenic pollutants such as pesticides, fertilizers, heavy metals, nutrients, organic compounds and microbes resulting from land use activities [3-7].

Mapping of groundwater resources is a useful tool to ensure long-term protection of potential groundwater pollution [8]. It delivers spatial overviews of groundwater vulnerability in data scarce regions [9]. Various groundwater assessments to identify areas at risk of groundwater pollution from land use activities have been conducted [10-17]. Agricultural activities, such as intense fertilizer application, greatly affect groundwater resources [10, 12-13, 15]. Point source pollution from wastewater discharge in urban areas also contributes to groundwater pollution [15, 18]. In addition, polluted coastal groundwater as a potential source of submarine groundwater discharge (SGD) may affect the quality of coastal marine and estuarine water essential to sustain healthy aquatic habitats [1-2]. The pollution risk of coastal water from land use activities by means of SGD has been addressed by several authors [19-22]. However, these studies applied measurements and analyses along shorelines which are cost-intensive.

In South Africa, groundwater has become an increasingly important source of freshwater for local scale irrigation and domestic use [23]. A greater emphasis

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on protecting groundwater resources has become evident in the Western Cape Province (WCP), which experienced significant population influx after the political change in 1994 [24]. People mainly settled along the southern coastal region, causing increased urban development and land use activities. Dryland cultivation, irrigated cultivation of vegetables, wine grapes and orchards are major land use activities covering extensive areas of this coastal region [25]. The southern coastal region has also been experiencing water shortages due to prolonged drought events, thereby increasing the importance of protecting the region's groundwater [26]. National scale groundwater vulnerability assessments for South Africa have been conducted [14, 27]. The vulnerability map presented by [14] indicated that the southern coast of the WCP is vulnerable to groundwater pollution. Although local scale studies, i.e. focusing on smaller basins of groundwater, exist for this region, no meso-scale assessment of nitrogen pollution of groundwater covering extensive land areas has been conducted so far. In addition, there is no spatial assessment approach identifying areas where polluted groundwater may contribute towards SGD. Filling the gaps in our knowledge regarding the relationship between LULC, groundwater and SGD will assist management authorities and stakeholders to give important land use recommendations and to outline management strategies.

The objective of this study is to identify land use activities causing groundwater nitrogen pollution and to determine hotspot areas of potentially polluted groundwater by nitrogen in a data scarce region. Furthermore, SGD contribution areas (SGD-CA's) contributing to coastal marine and estuarine nitrogen pollution will be described. This will be achieved by linking LULC, groundwater and SGD on a meso-scale and applying this approach to two study regions representing a variety of LULC types along the southern coast of the WCP, South Africa. The DRASTIC approach and linear summations of the DRASTIC index with diffuse nitrogen surplus in the rooting zone (DNS), and consecutively nitrogen concentration in the deep percolation (NC) were applied for the groundwater assessments. An approach was developed to delineate SGD contribution areas (SGD-CA's) and the groundwater contribution potential of such areas.

The remainder of the paper is organized in four parts: Section 2 introduces the DRASTIC approach and the linear summation of the DRASTIC approach with nitrogen related LULC parameters. The steps used to identify high-risk land use activities contributing to groundwater pollution are described and a simplified approach to identify SGD-CA's

located in hotspot areas is presented. Section 3 presents the groundwater assessment results and the relevant SGD-CA's. In section 4, the results are discussed in light of other findings. Section 5 provides recommendations to assist with groundwater and coastal management of the study regions and globally.

2 Methods

2.1 Study regions

The assessment approach was applied to two study regions along the southern coast of the WCP, South Africa. These were described as the western and the eastern regions. The western region extends along the coastline from Cape Point (34°21'S; 18°28'E) to 22 km east of Struis Bay (34°48'S; 20°03'E). It extends approximately 50 km inland and includes regions of the Cape Flats, Cape Winelands District, and the Overberg District, covering a land surface area of 643,542 ha. The eastern region extends along the coastline, 15 km west of Mossel Bay (34°11'S; 22°8'E) to 12 km east of Knysna (34°04'S; 23°03'E). It is located in the Eden District, extending a maximum of 38 km inland and covering a land surface area of 285,735 ha (Figure 1a). The study regions are characterized by a Mediterranean climate of hot and dry summer seasons, rainy winter seasons, and mild to warm autumn and spring seasons. A mean annual precipitation gradient exists along the southern coastal regions extending eastwards. The highest mean annual precipitation in the coastal and mountainous regions is 1,000 – 1,200 mm, while the lowest mean annual precipitation is measured along coastal areas and for the inland at 200 – 400 mm [28].

The study regions were selected based on their physical conditions with regards to SGD and the diversity of LULC evident for both regions. The 2000 National Land Cover data [29], incorporating the 2013 map of Agricultural Commodities in the WCP [30] were used to represent the LULC for each study region (Figure 1b, c). The natural vegetation of the western region includes "Fynbos", with percentage coverage of 52.7%, while the eastern region includes Fynbos, and indigenous forests/woodlands covering 43.3% and 12.6% respectively. The Fynbos biome is rich in biodiversity and is recognized as one of the floral kingdoms of the world [31]. Dryland crop cultivation is the most important land use activity, covering 25.9% of the western region and 17.1% of the eastern region. The eastern region has high forest plantation coverage of 15.4%, compared to 2.2% coverage in the western region. Irrigated agricultural activities are

practiced less extensively in both study regions. Informal urban development is present in both study regions, although it is most prevalent in the western part of the western region. Other LULC present in both study regions include natural grazing and grassland, bare rock and soil, water bodies and wetlands.

2.2 Groundwater assessments: DRASTIC approach / linear summation with LULC parameters

In order to describe the potential effects of land use activities on groundwater quality, an assessment of

Figure 1a. Location of the study regions along the southern coast, Western Cape Province, South Africa [45]. **b.** Land use/land cover of the western region. **c.** Land use/land cover of the eastern region.

the groundwater and related formation processes was needed. The DRASTIC approach is a widely used approach used to assess the groundwater vulnerability of an area. It does not replace site-specific assessments, but rather aggregates relevant data in a spatially explicit manner, based on the environment's physical conditions [32]. The following hydrogeological settings, forming the acronym DRASTIC, are included in the approach: Depth to water table (D); Net recharge (R); Aquifer media (A); Soil media (S); Topography (T); Impact of the vadose zone (I); Hydraulic conductivity (C). The selection of parameters used for the DRASTIC approach can be reviewed in [32]. Details of the data sources used for the hydrogeological settings for this study are given in Table 1.

The DRASTIC approach may be used to incorporate LULC parameters. This is beneficial to assess the groundwater pollution risk from land use activities and to identify hotspot areas of potentially polluted groundwater. Linear summations of the DRASTIC index with a LULC parameter have been applied in several studies. For these studies LULC classes were rated according to their nitrogen pollution risk of groundwater. Ratings have been done using expert knowledge [10], surface nitrogen loads [13, 17], or referring to literature [11-12, 14-15]. This study used nitrogen related LULC parameters not considered before in the DRASTIC index. Firstly, the addition of diffuse nitrogen surplus (DNS) in the rooting zone was a more accurate LULC parameter to describe the groundwater nitrogen pollution risk from land use

activities. Secondly, we assessed and mapped hotspot areas of potentially polluted groundwater by nitrogen by successively integrating nitrogen concentration (NC) in the deep percolation as a second LULC parameter.

A flowchart of the methods used to create the groundwater vulnerability, groundwater nitrogen pollution risk and hotspot maps using ArcGIS version 10.1 software [33] are given in Figure 2.

For the groundwater vulnerability assessment, the following specified equation was used, where a high DRASTIC index indicates high groundwater vulnerability [32]:

Equation 1:

DRASTIC index (henceforth referred to as the D index) = $D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w$ (r = rating and w = weight)

The weight of each parameter describes the relative effect on groundwater vulnerability. It includes values from 1 to 5, with 5 being the most significant and 1 the least significant. Rating of each parameter describes the relative importance of each range or class in terms of groundwater vulnerability. The values range between 1 and 10, with 10 being the most significant and 1 the least significant. The weights and rates allocated to each of the DRASTIC index parameters were mainly based on [32]. The classes and rates for the aquifer media and impact of vadose zone

Table 1. Data sources for the hydrogeological settings of the DRASTIC approach.

Data type	Detail of data	Additional detail	Output layer
Digital elevation models	Stellenbosch University Digital Elevation Model (SUDEM)	Ground surface (m.a.s.l.) –	Depth to groundwater
Borehole data	[45] National Groundwater Archive (data acquired 2014) [46]	depth to groundwater (m) = groundwater table (m.a.s.l.)	(m)
Net groundwater recharge	Weihenstephan-Triesdorf University of Applied Science (HSWT, data acquired 2016)	Inverse distance weighting WebGIS based model applying STOFFBILANZ [34]	Net groundwater recharge (mm/a)
Geological maps	Helmholtz Centre for Environmental Research (UFZ unpublished material, data acquired 2015)	Modified after the Council for Geoscience 1990, 1993, 1997	Aquifer media
Soil maps	Harmonized World Soil Database [47]	-	Soil media
Digital elevation models	SUDEM [45]	-	Topography (slope [%])
Hydrogeological maps	1:500,000 hydrogeological map of South Africa [36-37]	-	Impact of vadose zone
Geological maps	Helmholtz Centre for Environmental Research (UFZ unpublished material, data acquired 2015)	Modified after the Council for Geoscience 1990, 1993, 1997 Values assigned to post-processed lithologies	Hydraulic conductivity (m/s)

parameters were taken from [27] as these are adapted for South African settings.

For the groundwater nitrogen pollution risk assessment, DNS was added to the DRASTIC index. The simulation of DNS using the STOFFBILANZ model is based on a mass balance approach of nitrogen input and nitrogen output [34]. To describe the relative effects of LULC on groundwater nitrogen pollution risk, the DNS parameter was allocated the highest weight of 5. The following specified equation was used, where a high D+DNS index indicates high groundwater nitrogen pollution risk:

Equation 2:

$D+DNS \text{ index} = \text{DRASTIC index} + \text{DNS}_i \text{DNS}_w$ ($r = \text{rating}$ and $w = \text{weight}$)

Hotspot areas of potentially polluted groundwater by nitrogen were assessed by adding the nitrogen concentration in deep percolation (NC) to the D+DNS index. NC contributes mostly to groundwater nitrogen concentrations, and therefore the NC parameter was allocated the highest weight of 5. The rates for each of the NC parameter ranges were assigned based on the Water Research Commission's 1998 South African guideline values for nitrogen levels in drinking water [35]. Based on the guidelines, nitrogen levels in drinking water were divided into five ranges according to the potential effects on human health. These were presented on a scale from negligible health effects to increasing acute health risks in babies. The following equation was used, where a high D+DNS+NC index indicates potential hotspot areas:

Figure 2. Flowchart of the DRASTIC approach including a linear summation with LULC parameters.

Equation 3:

$$D+DNS+NC \text{ index} = \text{DRASTIC index} + DNS_r DNS_w + NC_r NC_w$$

(r = rating and w = weight)

The weight and rates allocated to the DRASTIC, DNS and NC parameters are given in Table 2. The DNS and NC maps were provided by HSWT [34]. The index values for each of the approaches were classified, on a scale of very low to very high in equal percentile intervals; very low (0–20th), low (20–40th), medium (40–60th), high (60–80th), and very high (80–100th).

To determine the potential extent of groundwater nitrogen pollution due to land use activities, two steps were followed:

- 1) High-risk land use activities were identified. For the purpose of this study, high risk land use activities were defined as activities covering land areas with DNS values greater than 30 kg/ha/yr.
- 2) Percentage LULC coverage in “high” and “very high” (henceforth referred to as “H+VH”) groundwater nitrogen pollution risk areas were calculated for each study region.

Table 2. Weights and rates of the DRASTIC parameters including diffuse nitrogen surplus in the rooting zone and nitrogen concentration in deep percolation.

Parameter	Weight	Classes/Ranges	Rates
Depth to groundwater (m)	5	<5	10
		5–10	7
		15–30	3
		>30	1
Net groundwater recharge (mm/a)	4	>100	9
		50–100	8
		10–50	6
		5–10	3
Aquifer media	3	<5	1
		Intergranular	8
		Fractured	6
		Fractured & Intergranular	3
Soil media	2	Loamy sand	7
		Sandy loam	6
		Sandy clay loam & Loam	5
		Clay loam	3
Topography (slope [%])	1	0–2	10
		2–6	9
		6–12	5
		12–18	3
Impact of vadose zone	5	>18	1
		Sandveld Group, Bredasdorp Groups	10
		Table Mountain Group, Witteberg Group, Cape Granite Suite	6
		Malmesbury Group, Bokkeveld Group	4
Hydraulic conductivity (m/s)	3	>10 ⁻⁴	8
		10 ⁻⁴ –10 ⁻⁵	6
		10 ⁻⁵ –10 ⁻⁶	4
		10 ⁻⁶ –10 ⁻⁷	2
Diffuse nitrogen surplus (kg/ha/yr)	5	<10 ⁻⁸	1
		0–10	2
		10–20	4
		20–30	6
Nitrogen concentration in the deep percolation (mg/l)	5	30–40	8
		>40	10
		<6	2
		6–10	4
		10–20	6
		20–40	8
		>40	10

High-risk land use activities located in H+VH groundwater nitrogen pollution risk areas are very likely to have a negative impact on the groundwater resources. LULC not identified as high-risk but located in H+VH groundwater nitrogen pollution risk areas, would indicate that the physical conditions of the environment rather than the land use activity itself makes the groundwater vulnerable to pollution.

2.3 Identification of submarine groundwater discharge contribution areas

Polluted coastal groundwater from hotspot areas which contributes to SGD is a good measure of the extent to which coastal marine and estuarine water is subjected to nitrogen pollution from land use activities. With limited available data, a simplified approach delineating SGD-CA's was developed. The coastal intergranular aquifers of the study regions are predominantly sandy sediments. Therefore, the assumption is that surface catchments located in the coastal intergranular areas represent subsurface catchments. Based on this assumption sandy aquifer areas were delineated from the 1:500,000 hydrogeological maps [36-37]. The sandy aquifer areas which do not have river outlets contribute to SGD, and were identified as SGD-CA's. SGD-CA's located in hotspot areas are likely to result in groundwater with increased nitrogen concentrations reaching marine and estuarine environments. This is particularly relevant for SGD-CA's which have a high groundwater contribution potential, i.e. high nitrogen flux. Deep percolation was simulated using STOFFBILANZ [34] and the maps were used to distinguish areas with high and low groundwater contribution potential to SGD. For the scope of this study, SGD-CA's with deep percolation rates greater than 50 mm a⁻¹ were considered as areas with a high groundwater contribution to SGD.

3 Results

The analysis showed that high-risk land use activities include dryland crop cultivation, irrigated crop cultivation and the irrigated production of wine grapes. Dryland crop cultivation covers 88% of land areas with DNS values greater than 30 kg/ha/yr, followed by irrigated crop cultivation and irrigated wine grapes, covering 6% of such land areas respectively.

In both of the study regions, dryland crop cultivation and irrigated crop cultivation are present in the H+VH

groundwater nitrogen pollution risk areas. These land use activities therefore do contribute to potential groundwater pollution.

3.1 Groundwater assessments: DRASTIC approach / linear summation with LULC parameters

The groundwater vulnerability, groundwater pollution risk, and hotspot maps for the western region are shown in Figure 3a, b, c.

The Cape Flats, located to the west of the study region, showed extensive H+VH groundwater vulnerability (Figure 3a) and H+VH groundwater nitrogen pollution risk (Figure 3b). This area is considered to be a hotspot area (Figure 3c). Irrigated crop cultivation covered 10% of the H+VH groundwater nitrogen pollution risk areas, with this area of overlap being concentrated in the Cape Flats.

The area towards the inland, east of the Cape Flats showed “medium” and “high” (henceforth referred to as “M+H”) groundwater vulnerability (Figure 3a) and groundwater nitrogen pollution risk (Figure 3b). There is extensive irrigated production of wine grapes in this area.

The area east of Struis Bay represents M+H groundwater vulnerability (Figure 3a) and H+VH groundwater pollution risk (Figure 3b). This area is considered to be a hotspot area (Figure 3c). Dryland crop cultivation had the highest coverage, covering 27% of H+VH groundwater pollution risk areas, mainly in the area east of Struis Bay.

Other LULC present in H+VH groundwater nitrogen pollution risk areas were mainly found in areas of the Cape Flats. These included the natural vegetation (Fynbos) (16%), urbanization (14%) and informal settlements (11%).

The groundwater vulnerability, groundwater pollution risk, and hotspot maps for the eastern region are shown in Figure 4a, b, c.

The area between Wilderness and Knysna showed H+VH groundwater vulnerability (Figure 4a) and H+VH groundwater nitrogen pollution risk (Figure 4b), and is the primary hotspot area of the eastern region (Figure 4c). The area is characterized by Fynbos and forest plantations. The latter LULC showed high coverage in H+VH groundwater pollution risk areas predominantly within this coastal area (Fynbos with 38% coverage and forest plantations with 16% coverage).

Extensive areas of the eastern region showed “medium” groundwater vulnerability (Figure 4a), but have “high” groundwater nitrogen pollution risk (Figure 4b). In these areas, dryland crop cultivation has the

Figure 3. Groundwater assessment maps of the western region. a. Groundwater vulnerability map applying the DRASTIC index. b. Groundwater pollution risk map applying the D+DNS index. c. Hotspot map applying the D+DNS+NC index.

Figure 4. Groundwater assessment maps of the eastern region. a. Groundwater vulnerability map applying the DRASTIC index. b. Groundwater pollution risk map applying the D+DNS index. c. Hotspot map applying the D+DNS+NC index.

highest coverage (24% of H+VH groundwater pollution risk areas), followed by irrigated crop cultivation with a coverage of 5%.

3.2 Identified of submarine groundwater discharge contribution areas

The SGD-CA's located in hotspot areas for the study regions are shown in Figure 5.

The SGD-CA of the western region is located in the Cape Flats (Figure 5a). It is characterized by urbanization, mainly informal settlements, and irrigated cultivation of vegetables. This SGD-CA has a high groundwater contribution potential.

The SGD-CA of the eastern region is located in the area between Wilderness and Knysna (Figure 5b). Natural land cover is mainly present in this area.

4 Discussion

Our findings indicate that agriculture is an important potential contributor to groundwater nitrogen pollution. This corresponds with findings from other groundwater assessment studies conducted for various regions across the globe. These findings showed that agricultural activities, particularly from fertilizer application, were major contributors [10, 12-13, 15]. It was also found that agricultural nitrogen loading is higher than domestic nitrogen loading [13, 17]. The “very high” groundwater pollution risk area in the Cape Flats (Figure 3b), identified as a hotspot area (Figure 3c), might be influenced by the irrigated crop cultivation of intense multiple cropping of vegetables. The Fertilizer Association of South Africa states that the average rate of nitrogen fertilizer used for irrigated cultivation of vegetables is as high as 170 kg/ha [38]. The nitrogen surplus rate for the cultivation of

Figure 5. Submarine groundwater discharge contribution areas located in hotspot areas. a. Submarine groundwater discharge contribution area of the western region. b. Submarine groundwater discharge contribution area of the eastern region.

vegetables in this area is found to be high [34]. However, the Cape Flats has a high percolation rate which results in lower nitrogen concentrations reaching the groundwater. This suggests that nitrogen loads generated in such areas may be higher [34].

There was no irrigated production of wine grapes in the H+VH groundwater nitrogen pollution risk areas. The production of wine grapes in the western region is concentrated in an area east of the Cape Flats, which represents M+H groundwater vulnerability (Figure 3a) and groundwater nitrogen pollution risk (Figure 3b). Findings showed that the nitrogen surplus of irrigated wine grapes is high [34]. However, the nitrogen concentration in total runoff simulated for this area is low [34]. It may be concluded that the production of wine grapes in this area is adapted to the physical conditions regulating diffused nitrogen inputs.

The area east of Struis Bay shows an increase from M+H groundwater vulnerability (Figure 3a) to H+VH groundwater pollution risk (Figure 3b). This suggests that the dryland crop cultivation practiced within the area does influence the groundwater resources. The average rate of nitrogen fertilizer applied for dryland crops is 27 kg/ha [38]. Even at such low nitrogen fertilizer rates, the low percolation rates may contribute to increasing nitrogen concentrations reaching the groundwater [34], which supports the finding that this is a hotspot area (Figure 3c). The dryland crop cultivation practiced in this area does not seem well adapted to the physical conditions of the landscape.

Our findings indicate that urban development is not a high-risk activity as simulation of the diffused nitrogen surplus parameter for this study considers point source waste water to flow directly into river systems [34]. This suggests that the environment's physical conditions are an important contributor to the H+VH groundwater nitrogen pollution risk in the Cape Flats (Figure 3b). Groundwater assessment studies also indicate that domestic sources do not greatly influence groundwater resources [13, 17]. However, findings show that groundwater in the vicinity of point source pollution is subject to groundwater pollution [16, 18]. A large proportion of urban development in the Cape Flats is informal. Waste water disposal from informal settlements covering the flat sandy plains might contribute to high nitrogen concentrations and other organic and microbial contaminants reaching the groundwater [39]. Gaining information on waste water disposal from informal settlements is a major challenge, particularly due to a variety of political and social aspects [40].

The area between Wilderness and Knysna represents H+VH groundwater nitrogen pollution risk (Figure 4b).

The land cover of this area is mainly natural ecosystems. Therefore it may be concluded that the groundwater is subjected to a high pollution potential due to the environments' physical conditions. The area was found to be a hotspot (Figure 4c), indicating that the groundwater is very susceptible to nitrogen pollution. The natural land cover must remain pristine and the area must remain part of the Wilderness National Park and the Goukamma Nature Reserve managed by South African National Parks under the 2009 Garden Route National Park management plan [41].

The SGD-CA located in the Cape Flats (Figure 5a) is characterized by urbanization, principally informal settlements, and irrigated cultivation of vegetables. This SGD-CA has a high groundwater contribution potential which could contribute to nitrogen pollution of the coastal environment, particularly from groundwater originating from irrigated agricultural activities. However, the offshore coastal marine environment of the southern Western Cape region is dynamic [42] and discharged nutrients should disperse rapidly. Groundwater from the SGD-CA located between Wilderness and Knysna (Figure 5b) mainly originates from natural land cover and should be of good quality minimizing nitrogen pollution of the coastal water. Long term data did not indicate a drastic decline in the water quality of the Swartvlei and Knysna estuaries [43-44].

Rating of selected DNS and NC classes as LULC parameters is an improved approach compared to rating LULC using expert knowledge or based on assumptions. This is supported by the finding that the nitrogen concentration in the deep percolation simulated for this study corresponds well to nitrate and nitrite hotspots in groundwater based on an interpolation of borehole sampling conducted for South Africa [34]. Although our approach gives a good overview of the potential groundwater nitrogen pollution from land use activities, it does have limitations. The limited data available for our study regions is challenging. The limited number and uneven distribution of boreholes to determine the depth to water table parameter caused irregularities in the data which may have contributed to less optimal results. Another limitation of our study was the insufficient information to simulate the nitrogen budgets using the STOFFBILANZ model [34]. Thus, no validation of the nitrogen budgets was possible, which implies that it is important to regard the DNS and NC results as potentials [34]. Also, due to a lack of sufficient information, no differentiation was made between formal and informal urban settlements for the simulation of the nitrogen budgets [34].

5 Conclusion

The objective of this study was to identify land use activities causing groundwater nitrogen pollution and to determine hotspot areas of potentially polluted groundwater by nitrogen in a data scarce region. Also, SGD-CA's contributing to coastal marine and estuarine nitrogen pollution was described. This was achieved by linking LULC, groundwater and SGD on a meso-scale to two study regions along the southern coast of the WCP, South Africa. From the findings, the groundwater assessment approaches and delineation of the SGD-CA's were successfully carried out. Groundwater assessment approaches are the first step in gaining a critical understanding of how LULC relate to the environment and to identify priority areas requiring well defined management strategies. Although data are limited, the assessment approach provides relevant results for our study regions and may be applied to other regions of interest. This is supported by various studies highlighting that the addition of LULC to the DRASTIC approach delivers a good spatial overview of areas at increased risk of groundwater nitrogen pollution. Simulated nitrogen budgets might not be available for most regions. In such cases, rating of LULC classes based on nitrogen loading is plausible. Findings from this study and other research indicate that agricultural activities are a major contributor of diffuse nitrogen groundwater pollution. With increasing pressure placed on the Cape Flats aquifer, it is important for land managers to not only improve management strategies for the small-scale irrigated cultivated area, but also for upstream agricultural activities beyond the boundaries of this study region. It is important that the land owners revise and monitor excessive use of fertilizer. Land rehabilitation of the area east of Struis Bay is most likely not viable for the land owners. Revision of fertilizer application in this area is also recommended. Globally, it is important that the intensity of agricultural activities must be reviewed. In regions with sufficient resources, in situ monitoring of groundwater is recommended. Agricultural activities may not always be adequately adapted to the physical conditions of the environment. It is important that the intensity of these activities is adjusted to their foreseen environment. For this study, urban development was not found to be high-risk. However, other research has shown groundwater pollution in areas of waste water treatment. Diffuse groundwater pollution from poor waste water disposal might be of concern for informal urban developments such as the Cape Flats. The groundwater of areas known to have poor waste water disposal, particularly areas where physical conditions

contribute to infiltration, must be monitored and waste management strategies improved. It is recommended that waste water disposal in the Cape Flats is addressed by the government. Prevention of groundwater pollution is more viable than remediation, highlighting the importance that natural ecosystems must remain pristine in areas of high groundwater vulnerability. This study is the first known attempt to delineate areas contributing to SGD in order to assess the effects that land use activities might have on coastal water. Measurements and analysis of coastal water to identify areas of SGD are cost intensive. Instead, delineation of SGD-CA's can be done using hydrogeological maps. Land use activities in SGD-CA's, which might contribute to coastal pollution, must also be managed accordingly. Coastal water monitoring remains important due to pollution contribution from stream, rivers and waste water discharge. Water quality monitoring of the Swartvlei and Knysna estuaries is recommended.

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