HISTORICAL LAND USE CHANGE AND ITS INFLUENCE ON STREAM ECOSYSTEMS AND WATER QUALITY

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The southern Cape region, Western Cape, South Africa, is of ecological importance with the lower Wilderness Lake systems being a designated Ramsar site. Agriculture is the main land use in the study catchment and water user with a steady increase in population growth. As the demand for water increases the availability and quality is affected. Land cover was assessed to determine catchment changes that impacts river ecosystems and water quality.

1 INTRODUCTION

Geomorphic processes have become important in river management as they can be used to understand the physical processes involved in transport and storage of sediment-bound pollutants in water resources. It is, however, essential for sustainable river management that process and response of riverine ecosystems are understood before any restoration or mitigation measures can be implemented. Looking at the past is an effective way to gain such an understanding both in terms of water quality and fluvial response. The southern coast of South Africa balances between natural areas, urban population and tourism as well as agriculture placing increasing demands and impacting on quantity and quality of available water resources. It is an area sensitive to climate change of which the effects are already evident with water shortages during low rainfall periods and damage to infrastructure during floods and sea storm surges [3]. This present day situation can be placed into perspective by looking at how the catchment evolved over time. This study hypothesizes that there is a link between land uses, development and the deterioration of water quality in two important freshwater supply resources.

2 STUDY AREA

The Gouritz Water Management Area (WMA) is situated along the southern coast of South Africa almost entirely within the Western Cape Province. It extends from the coast inland and the topography is characterized by flat open plains of the Great and Little Karoo (arid zone). The arid zone is fed by the Olifants River with mountain streams rising in the Swartberg Mountains to the north, the central Kammanassie Mountains and the coastal Outeniqua Mountains in the south. The Coastal Belt rivers drain from the Langeberg and Outeniqua Mountains. The other numerous short reach coastal rivers drain an area of 7 437 km^2 with the total area of the WMA being 53 139 km^2 [1]. The study area is limited to the Coastal sub-WMA, which includes the Touws River and estuary, the three lakes, Rondevlei, Langvlei and Eilandvlei (all recognized Ramsar sites) with their rivers. Ramsar sites are wetlands that are of international importance and are designated according to the Convention based on their significance to conserve global biological diversity and sustain human livelihoods by maintaining ecosystem goods, services and processes [7]. Signatories to the Ramsar Convention commit to the wise use of the wetlands, to ensure effective management and to cooperate internationally should such wetlands cross between boundaries [7]. The rainfall is orographically influenced where the mountains separate the moist coastal regions from the arid inland Little Karoo [2]. The annual rainfall ranges between 900 to 1400 mm in the upper catchments and decreasing away from the mountains [5].

3 METHODS

Land cover history for the catchments was assessed using the national land cover data sets for South Africa derived from satellite imagery. Imagery was obtained between the years 2000 to 2014. Differences between the land cover occurred with the categories mapped as more detail was included in later years. The categories were standardised to include: natural forests, vegetation (grassland, thickets, shrubland fynbos, indigenous forests), cultivated lands (irrigated pastures, and orchards), urban areas (residential, smallholdings, informal), waterbodies (dams, natural lakes), wetlands and plantations. Water quality and flow data were obtained from gauging stations on two mainstem rivers in the study catchment from the Department of Water and Sanitation for the period 2000 to 2014. The flow and water quality were statistically analysed using the non-parametric Spearmans rank correlation (rs) test and the seasonal Mann-Kendall trend test using XLSTAT version 2015 Addinsoft.

4 RESULTS AND DISCUSSION

Figure 1 shows the land changes between 2000 and 2014 for the study catchment, including the Wilderness Lake area to the coast, which occurs in the protected Garden Route National Park. The two main rivers, Touws and Duiwe, are impacted by land use in different ways. The Touws River is largely natural with the exception of commercial plantations in the upper catchment while the lower reaches of both rivers occur in a protected area. Agriculture and urban land uses are the main water users with agriculture being the highest water user [4]. Most agricultural activities occur in the Duiwe River catchment, showing substantial increase in area over time. Urban built-up areas also expanded with time along the coast as well as informal and low cost housing settlements in the upper Touws River catchment.

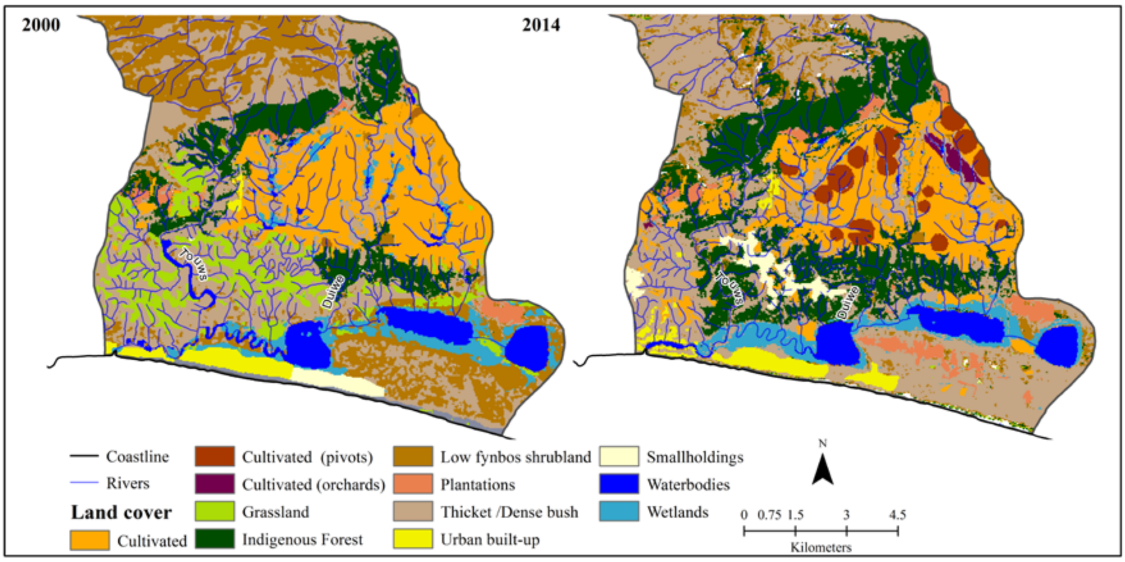

Figure 1. Land cover changes in the study catchment (2000-2014)

As agriculture intensified storage dams and smallholdings increased. In later years cultivation is also seen occurring on the floodplain around the lakes, although not on a commercial scale. The irrigation techniques of farmers changed as numerous center pivot systems are seen in 2014. Some diversification is seen in agriculture in 2014 in the form of irrigated orchards. As a result of agriculture water quality in the Duiwe River has deteriorated more than that of the Touws River as presented in Table 1.

Table 1. Summary statistics for water quality and flow data for the Touws and Duiwe Rivers (2000-2014)

Parameter	Unit	Max	Min	Mean	Median	Standard deviation
Touws River						
River flow	m^3/s	0.59	0.03	1.14	0.42	2.11
Electrical Conductivity (EC)	mS/m	25.97	12.04	17.50	17.60	2.14
Calcium Ca^{2+}	mg/ℓ	5.79	0.50	2.15	2.02	0.90
Chloride Cl^-	mg/ℓ	51.53	13.14	40.81	41.87	6.53
Fluoride F^-	mg/ℓ	0.59	0.03	0.11	0.10	0.09
Potassium K^+	mg/ℓ	2.83	0.06	1.01	0.66	0.71
Magnesium Mg^{2+}	mg/ℓ	6.49	0.75	2.91	2.90	0.96
Sodium Na^+	mg/ℓ	47.64	12.68	20.74	21.40	4.26
Ammonium NH_4^+(N)	mg/ℓ	0.84	0.015	0.04	0.025	0.098
Nitrite Nitrate NO_2^- NO_3^- (N)	mg/ℓ	0.25	0.01	0.04	0.03	0.03
Phosphate PO_4 (P)	mg/ℓ	0.28	0.01	0.02	0.02	0.04

Parameter	Unit	Max	Min	Mean	Median	Standard deviation
pH		8.24	4.26	5.75	5.65	0.85
Duiwe River						
River flow	m^3/s	0.336	0.00	0.06	0.02	0.08
Electrical Conductivity (EC)	mS/m	783.75	39.3	140.86	127.70	77.48
Calcium Ca^{2+}	mg/ℓ	64.22	7.31	27.60	26.68	12.18
Chloride Cl^-	mg/ℓ	783.87	93.11	348.08	300.61	155.89
Fluoride F^-	mg/ℓ	0.61	0.03	0.21	0.19	0.08
Potassium K^+	mg/ℓ	24.60	1.15	11.16	11.22	4.31
Magnesium Mg^{2+}	mg/ℓ	67.95	6.98	25.21	23.77	11.89
Sodium Na^+	mg/ℓ	397.28	52.14	188.28	178.89	80.83
Ammonium NH_4^+(N)	mg/ℓ	0.40	0.02	0.05	0.03	0.06
Nitrite Nitrate NO_2^- NO_3^- (N)	mg/ℓ	3.63	0.01	0.19	0.06	0.38
Phosphate PO_4 (P)	mg/ℓ	0.42	0.004	0.04	0.03	0.05
pH		8.16	6.68	7.51	7.52	0.28

The flow regime of the Duiwe River was altered due to abstraction for mostly agricultural but also domestic use where the Duiwe River runs dry at times. A decreasing trend for flow in the Duiwe River was observed over the time period assessed (Tau = -0.108; p = <0.0001). The Touws River showed no statistically significant trend for flow data over the time period assessed (Tau = -0.015; p = 0.82).

Table 2. Summary of the seasonal Mann-Kendall trend analysis (2000-2014). Results of the Spearman rank correlation (rs) between river flow and each parameter are included for the Touws and Duiwe River stations

Parameter	Unit	Spearmans r_s	Trend	Kendall's Tau
Touws				
Total Alkalinity	mg/ℓ	-0.164	-	-0.283**
Calcium Ca^{2+}	mg/ℓ	-0.111***	-	-0.042
Chloride Cl^-	mg/ℓ	-0.364***	+	0.256***
Electrical conductivity (EC)	mS/m	-0.445***	+	0.161*
Fluoride F^-	mg/ℓ	-0.072	-	-0.063
Potassium K^+	mg/ℓ	0.442	+	0.464***
Sodium Na^+	mg/ℓ	-0.289***	-	-0.268**
Magnesium Mg^{2+}	mg/ℓ	-0.273*	0	0.065
pH		-0.421***	0	-0.092
Phosphate PO_4	mg/ℓ	0.063	-	-0.354***
Nitrite and nitrate NO_2^- and NO_3^- (N)	mg/ℓ	0.03	0	0.118
Ammonium NH_4^+(N)	mg/ℓ	0.223	+	0.276*
Sulphate SO_4^{2-}	mg/ℓ	0.200*	-	-0.439***
Silica Si	mg/ℓ	-0.008	0	0.054
Duiwe				
Total Alkalinity	mg/ℓ	-0.670***	+	0.215**
Calcium Ca^{2+}	mg/ℓ	-0.653***	+	0.144*
Chloride Cl^-	mg/ℓ	-0.658***	0	0.096
Electrical conductivity (EC)	mS/m	-0.670***	+	0.152*
Fluoride F^-	mg/ℓ	-0.131**	+	0.245**
Potassium K^+	mg/ℓ	-0.616***	+	0.137*
Sodium Na^+	mg/ℓ	-0.665***	+	0.189*
Magnesium Mg^{2+}	mg/ℓ	-0.695***	+	0.126*
pH		-0.376***	+	0.141*
Phosphate PO_4	mg/ℓ	0.493***	-	-0.177*
Nitrite and nitrate NO_2^- and NO_3^- (N)	mg/ℓ	0.241***	-	-0.294***
Ammonium NH_4^+(N)	mg/ℓ	-0.160*	+	0.216**
Sulphate SO_4^{2-}	mg/ℓ	-0.108***	0	-0.096
Silica Si	mg/ℓ	0.553	0	0.089

(+), upward trend; (-), downward trend; (0), no significant trend * Significance: *** < 0.0001; ** < 0.001; * < 0.05

The EC and most solutes of both rivers are significantly negatively correlated to river flows so that as river flow increases the concentrations decrease due to the effects of dilution, although concentrations are still at higher levels in the Duiwe River than the Touws River (Table 1, 2) as a result of anthropogenic activities. Phosphate and nitrogen showed a significant positive correlation to river flow for both rivers with the exception of NH_4^+(N) in the Duiwe River. As the river flows increased so did the concentrations of phosphate and nitrogen in both river systems implying that overland flows may be responsible for the transport of nutrients to rivers with increased rainfall events. The qualities of water in both rivers were found to be closely linked to rainfall run-off patterns and land use. Trends for nitrogen (NO_2^- and NO_3^-) (Tau = -0.294) and phosphates (Tau = -0.177) are decreasing in the Duiwe River catchment, which may be related to changes in improved upstream agricultural land management. Nitrogen (NH_4^+) in the largely natural Touws River showed an increasing trend most likely due to urban related run-off further upstream in the catchment (Table 2).

The changed flow regime of the Duiwe River negatively impacts the downstream lake system, which it feeds, by reducing flushing and thereby affecting the estuary mouth dynamics. The lakes as a result have reduced connection to the sea and water quality in the lakes deteriorates due to poor quality river inflow from the Duiwe River [6]. At times after flooding events in the upstream catchment high levels of nutrients (nitrogen and phosphorus) were recorded in the lakes fed by rivers. Although chlorophyll concentrations were not included in the water quality analysis of the rivers due to erratic and insufficient sampling, Russell *et al*. [6] showed that increased nutrients in the lakes were accompanied by increases in chlorophyll concentrations in the water column. Events such as these triggered algal growth spurts in the lakes, however it was short-lived as the floodplain and semi-aquatic vegetation were efficient in reducing nutrients in the lake system [6].

The results showed that water quality is linked to land use. Inefficient land use management of upstream catchments therefore has implications for the ecology of the lake system and for future water supply to the urban population. The coastal area is a popular holiday resort town with both permanent residences and holiday homes. The influx of tourists over peak season times creates an increasing demand on already limited water resources with water restrictions often implemented. Predictions of a warming climate will place further stress on water security for all water users including the ecological reserve. Investment in ecological infrastructure such as riparian buffer zones, which are known to provide mitigation to water resources from land based activities, is recommended. Any upland wetland areas should also be maintained as both these mitigation measures for water quality improvement should be considered in any future land development.

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