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Revisiting Rietspruit: Land Cover Change and Water Quality in South Africa

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Abstract--South Africa's societal transformation and rapidly expanding population has led to the spread of both "informal settlements" that are largely devoid of adequate sanitation and water infrastructure, as well as more formal and serviced settlements. This study continues 1993 research that used remote sensing to explore how urban development was affecting water quality in a catchment southwest of Johannesburg over a period of 19 years. Recent satellite imagery was used to extrapolate land cover classes identified in the original study, measure their spatial extent, and compare the findings to current water quality data. Results confirm that urban expansion is still occurring at a tremendous rate with unacceptably high levels of specific contaminants impacting water quality conditions.

I. INTRODUCTION

One of the more daunting challenges facing the recently democratized country of South Africa concerns the provision of water and sanitation to its citizens. Millions of South Africa's people lack access to adequate sanitation and water, and a rapidly expanding population has led to the spread of settlements, many of which seemingly arise overnight, virtually devoid of basic infrastructure such as electricity, sewage, or water. The consequences of such unmanaged growth can be significant in a country largely reliant on an uncertain supply of surface water to fulfill the needs of its industry, agriculture, and citizenry.

This study builds upon the results of a joint project undertaken in the early 1990s by the Department of Water Affairs and Forestry (DWAF), Rand Water (RW), and the Council for Scientific and Industrial Research. The purpose of the initial study was to examine the influence of urban development on water quality conditions by studying the growth of informal settlements in the Rietspruit catchment, a subcatchment of the Vaal River catchment. Covering the years 1972-1991, the researchers performed a detailed analysis of change in water quality data collected from five water quality monitoring points, and change in settlement growth using aerial photography and satellite images. Results indicated that deterioration of water quality conditions in the area was largely a byproduct of growth in informal settlements. The researchers advised that remotely sensed data continue to be used to detect and monitor residential development in the Vaal Barrage catchment, asserting that "... identification of the position, size and nature of informal settlements in relation to hydrologically significant factors would . . . provide invaluable information of the impact of informal developments . . ." on the watershed (Howman et al. 1993).

The immediate goals of the present study are to: 1) perform visual image analysis and land cover classification using 1998 Thematic Mapper imagery, 2) measure the land class' spatial extent, deriving growth figures, 3) update the water quality data gathered during the initial study, and 4) perform a comparative analysis of the updated water quality and land cover data.

II. POPULATION GROWTH, NONPOINT WATER POLLUTION, WATER QUALITY, AND HEALTH

According to Saff (1996, p. 235), approximately 7.7 million people (about 19%) of South Africa's population live in "squatter camps and informal settlements." Many who reside in informal settlements do so because of proximity to water, employment and transport routes. These informal settlements contribute to "nonpoint source water pollution" or, " . . . broad and diffuse pollution resulting from land runoff, precipitation, atmospheric deposition, drainage, and seepage" (Chandler 1994 in Henderson et al. 1998). Urban, residential and agricultural land uses are major sources of nonpoint source pollution, and contribute to degradation in water quality (Henderson et al. 1998). To assess pollutant loads in water, chemical and biological water constituents are monitored to ascertain the suitability of water for domestic, industrial, recreational and other uses.

Consumption of poor quality water is not only damaging to human health but also to a nation's economy via lost productivity and cost of medical treatment. Identifying "... the environmental and social contexts that are likely to create disease environments . . ." is vital in a developing country such as South Africa, since widespread disease can threaten a social system's dynamic equilibrium through negative psychological, behavioural, economic and political effects (Lewis and Mayer 1988). Consequently, it is "... critically important to understand which areas are at risk and . . . prepare maps showing areas of differential risk . . ." (Luscombe and Hassan 1992). To control nonpoint source water pollution through land management techniques that modify or change present land use activities, one must know the current size and spatial distribution of land use classes and population (Henderson et al. 1998; Lo 1987), critical information with which to measure future change (Lindgren 1985).

III. BACKGROUND--THE STUDY AREA, WATER QUALITY VARIABLES AND IMAGE ANALYSIS

A. The Study Area

Located approximately 25 kilometres southwest of Johannesburg, the Rietspruit catchment empties into Loch Vaal and the Vaal Barrage, is approximately 39 km wide by 46 km long, and covers an area of approximately 1120 km^2 (Fig. 1). The catchment is an appropriate study site because it is relatively small with known water treatment and sewage works, industrial point sources, expanding formal and informal settlements, areas of spray irrigation using treated effluent, and pastures, all of which contribute to nonpoint contamination of water courses.

B. Water Quality Variables

The original study incorporated data from five water monitoring sites. However, in the current research only one site was used. RV1 (Fig. 1) monitors a part of the catchment where the greatest growth in formal and informal residential expansion has been experienced. This site, therefore, provides data on waterborne constituents that mainly reflect the influence of urban expansion.

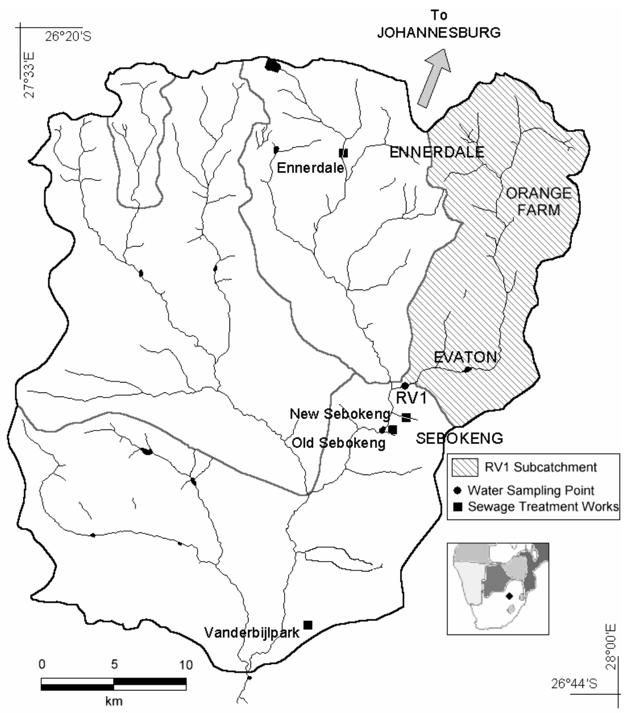

Fig. 1. Location of study area.

In this study, a subset of a wide range of water quality variables is used to represent water quality. Electrical conductivity (EC) provides an overview of the gross salinity of a water source but not much insight into chemical water quality. Phosphate (PO_4) is considered an indicator that undesirable effluents may be entering a watercourse. Nitrate (NO_3) is an important constituent of fertilizer. Ammonia (NH_3) is commonly found in both sewage effluent and fertilizer, and can rapidly oxidize to NO_3. Faecal coliforms (FC) are indicators of faecal pollution. (Note: for part of the data record, only *Escherichia coli (E.coli)* data exist.)

Because the original study's objective was to identify correlations between water quality indicators and urbanisation, emphasis was placed on detecting concentration changes in the water quality data record and presenting the information in the form of time-series graphs (Fig. 2).

C. Image Analysis and Land Cover Classification

A major use for satellite imagery is land use/land cover classification, and in South Africa imagery has been successfully used to determine land classes (see Howman et al. 1993). In concert with imagery-derived land classes, multi-date change detection techniques can be used to identify and measure urban growth and direction, quantify growth rate, estimate where future growth will occur, and theorize how growth will impact the environment (Estes and Simonett 1980). In this study, multi-date analysis focussed on the Sebokeng-Evaton-Orange Farm portion of the Rietspruit catchment because it is experiencing the greatest residential growth.

Originally, satellite images from three dates (1972-11-21, 1982-11-16, and 1991-04-07) were geometrically registered to each other, visually examined and classified by DWAF. Land use was divided into: formal and informal housing, mining, industry, open land, agriculture, and agricultural smallholdings. Classifications derived from the higher spatial resolution 1991 Thematic Mapper imagery were overlaid on the 1972 and 1982 Multispectral Scanner images to guide their classification. Because it was difficult to distinguish specific land cover types (e.g. formal and informal residential areas), panchromatic aerial photographs were used to verify results obtained from the 1991 satellite imagery. Analysis of 1998-04-26 TM imagery was performed by Southwest Texas State University's (SWT) Department of Geography using a visual classification method and the 1991 land use coverages provided by DWAF as a guide. When the 1998 classification was complete, hard copies of the classifications were field checked, where possible, by DWAF and RW scientists.

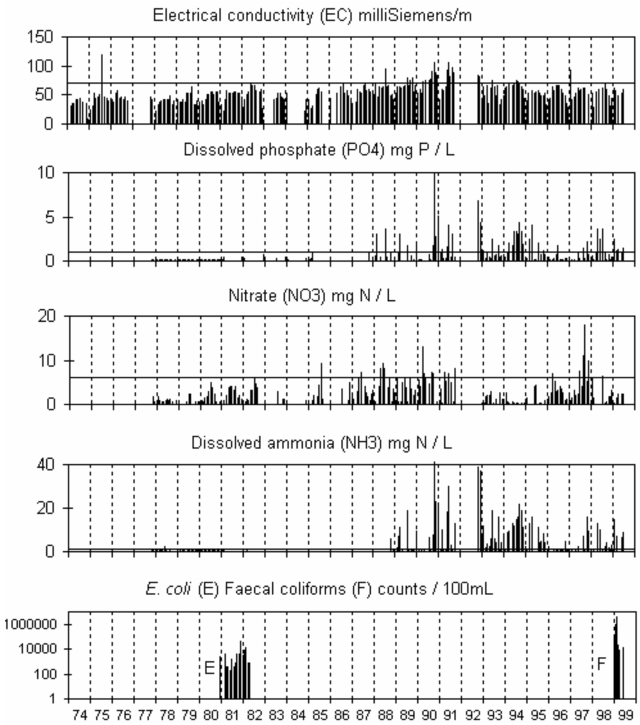

Fig. 2. Time-series graphs of water quality at RV1: Horizontal lines are water quality guidelines.

IV. FINDINGS

A. *Water Quality*

During the 1970s and 1980s, the salinity at RV1 gradually increased, and by the early 1990s it frequently exceeded the 70 mS/m guideline for domestic use (Fig. 2). Since 1991, it has stayed within the 70 mS/m guideline. Sodium and chloride (not shown) followed this trend but never exceeded their 100 mg/L guidelines. Phosphorus and nitrogen show completely different trends. Phosphate concentrations remained below the effluent limit of 1 mgP/L until the mid 1980s but often reached or exceeded this level since then. Nitrogen in nitrate has occasionally exceeded the 6 mgN/L guideline, for example in 1997, but in the form of ammonia it has increased from the low concentrations before 1990 to values that consistently exceed the guideline of 1 mgN/L.

These high nutrient concentrations suggest that raw effluent of some kind is entering the Rietspruit upstream of the monitoring point, and the faecal coliform counts support this assumption (Fig. 2). Microbiological results are only available from two specific studies in 1981 and 1999, and for different indicator organisms, but in both cases the counts often exceed not only drinking water standards but also the safe limits for recreational use. Any activities involving direct contact with the water, such as bathing, religious rites and washing of clothes (not to mention consumption) would

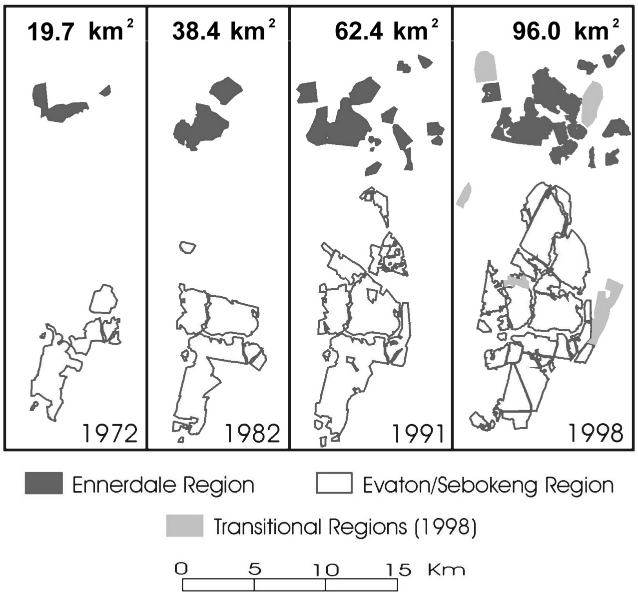

Fig. 3. Increase in residential area in the eastern part of the Rietspruit catchment.

expose the user to serious risk of infection.

B. *Land Cover*

The extent of urban land cover in the eastern part of the study area, for the four time periods examined, is illustrated in Fig. 3. Since 1991, there has been a significant increase in the extent of settlements. Indeed, the urban/residential area's average growth rate of 1.87 square kilometres per year between 1972-1982, which nearly doubled in the following nine years (1982-1991) to 2.67, almost doubled again in the most recent seven years (1991-1998) to 4.79 square km/year. Given that Silberbauer and Moolman (1993) estimate that ". . . in 1991, about 40% of the urban land cover in the Rietspruit catchment consisted of informal housing . . ." the implications of such growth vis-a-vis water quality are substantial. In field investigations undertaken in 1999, however, it was apparent that the most significant change has been in the extensive development of formal, low cost housing developments.

VI. CONCLUSIONS AND RECOMMENDATIONS

Multiple views of satellite imagery over a 25-year period provide an unusual historical perspective of settlement growth in a rapidly changing catchment in South Africa. Almost as rapid as the country's social and economic transformation is the exponential increase in formal and informal development and the potential associated deterioration in water quality conditions. The need to identify potentially hazardous situations is essential to enable water resource managers to take the steps necessary to protect both human health and the environment. Currently, the effective implementation of a National Microbiological Monitoring programme in South Africa depends on knowing where such conditions prevail in order to initiate regular monitoring of resources at risk.

While visual classification of imagery has been the preferred tool in this study, efforts to automate the classification of urban growth from satellite imagery as a surrogate for time-consuming visual classification are ongoing. Clearly, however, satellite imagery can help ameliorate one of the key problems facing land use managers in any developing country — the lack of resources to collect, analyse, and disseminate information. This study confirms that satellite imagery, in association with carefully collected water quality indicators from a limited number of sites, provides valuable information for land use managers charged with maintaining the public's health and safety.

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