SULPHATE DEPOSITION TO A SMALL UPLAND CATCHMENT AT SUIKERBOSRAND, SOUTH AFRICA

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Abstract. In 1992, a study was initiated by the Water Research Commission of South Africa, to investigate the relationship between atmospheric deposition and water quality in a small upland catchment. The selected catchment, which had a seasonal stream, was a pristine site at the Suikerbosrand Nature Reserve, which is 80 km south-east of Johannesburg. The catchment is 32.5 ha in extent and is characterised by having a quartz geology with sandy soils. Fifty-four percent of the catchment area is bare rock and the average soil depth is 15 cm. The climate is relatively arid when compared to other catchment studies in the northern hemisphere (Birkeness and Hubbard Brook) with long dry periods in the winter months and a low annual runoff (8.4 - 8.9% of mean annual precipitation). The measured inputs to the catchment included rainfall, rainwater chemistry, ambient SO_2 concentrations, rock runoff and bulk or particulate deposition. Outputs from the catchment included the measurement of runoff using a V-Notch weir and intensive sampling of a range of chemical water quality variables. During the wet summer months the dry deposition was estimated to be between 39 and 62% of the total atmospheric sulphate inputs into the catchment, whereas in the dry winter months this was estimated to be 90% of inputs. Over a complete annual cycle the net accumulation of sulphate on the catchment surface was estimated to be between 83 and 91% of inputs.

Key words: Water quality, Wet and dry sulphate (SO_4^{2-}) deposition, Gaseous deposition, Particulate deposition, Rock runoff, Stream flow, Suikerbosrand, South Africa.

1.Introduction

The Suikerbosrand study commenced in 1992 and forms part of a larger programme of the Water Research Commission of South Africa which aims to look at the salinisation of the Vaal Dam. The Vaal Dam is the most important source of water for the Gauteng Province, as it supplies more than nine million people with drinking water. It also supplies water for industry and agriculture.

One of the main purposes of this study was to examine the relationships between water quality and atmospheric deposition of sulphate (SO_4^{2-}) into a small, sensitive upland catchment. This included the measurement and estimation of both wet and dry deposition as well as water chemistry loads leaving the catchment.

The region is characterised by an annual mean precipitation of 700 mm per year, irregular rainfall patterns, dominated by summer thunder showers, long dry periods in the winter months when little or no rainfall occurs, and periodic drying out of the catchment between rainfall events.

There have been several well-documented calibrated catchment studies in the northern hemisphere such as Birkeness (Wright and Johannesen, 1980) and Hubbard Brook (Likens *et al.*, 1977), but to the author's knowledge this is the first study of its kind in the southern hemisphere.

Considerable industrial development has taken place in the region around the Suikerbosrand catchment and over one million tons of SO_2 are emitted into the atmosphere annually (Tyson *et al.*,1988).

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2. Materials and Methods

The criteria for selection of the study site included the following: the site should not be subjected to significant anthropogenic inputs other than atmospheric; it should be an upland catchment; and it should be less than 100 ha in extent. A suitable site was found at the Suikerbosrand Nature Reserve, located approximately 80 km south-east of Johannesburg in the Gauteng Province of South Africa. The catchment is 34.5 ha in extent, 1800 m above sea level, with a north-south axis of 700 m, an east-south axis of 500 m and a maximum elevation above the weir of 98 m.

The geology of the site is quartzite, which is an inert slow-weathering rock. Approximately 54% of the catchment was exposed rock with the remaining 46% consisting of grassland interspersed with areas of bare soil. The soils are characterised as loamy-sand with an average depth of 15 cm.

The rainfall over the two-year study period was measured using a tipping-bucket rain gauge (0.5 mm every 10 minutes). Wet deposition was collected for analysis using an automatic wet sampler and analyzed using ion-exchange chromatography.

The dry deposition component was estimated either directly by measuring ambient sulphur dioxide, whereby gaseous deposition was estimated using theoretical deposition velocities, or indirectly through the measurement of rock runoff and bulk sampling (particulate deposition).

Rock runoff was collected from five areas of exposed rock of between 0.54 and 0.74 m^2, which were demarcated using concrete strips. Each strip was sealed with an inert paint to prevent contamination. After each rainfall event, all wet and dry deposition was collected in polypropylene buckets. The net rock runoff was calculated by subtracting the wet deposition from the total rock runoff (Table 1).

Particulate deposition was measured using an inert bulk collector, which collected both wet and particulate deposition.

Ambient sulphur dioxide concentrations were measured using the peroxide method (Kemeny and Halliday, 1974). Measured volumes of air were drawn through a dilute solution of hydrogen peroxide where SO_2 was absorbed and oxidised to sulphuric acid. Test solutions were exposed for periods of either two or three days and the sulphate concentrations were determined using ion exchange chromatography. Theoretical deposition rates were calculated using deposition velocities for grassland of 0.3 and 1.3 $cm.sec.^{-1}$ (Shepherd, 1974). The lower rate (0.3 $cm.sec^{-1}$) was used for the dry winter months of Period B, where the vegetation was dormant, and the higher rate (1.3 $cm.sec^{-1}$) was used in Periods A and C when the grasses were actively growing.

The total dry deposition (Table 2) was calculated by multiplying the net rock runoff by 0.54 (area of catchment covered by exposed rock) and then adding this to the sum of the gaseous and net particulate deposition multiplied by 0.46 (area of catchment covered by grassland).

A V-notch weir was constructed on site, where the level of water was recorded and used to calculate stream flow in $m^3.sec^{-1}$. Event-related sampling of the water chemistry was undertaken using automatic water samplers. Water samples collected were analyzed using ion exchange chromatography and atomic absorption spectrophotometry. Output of sulphate from the catchment was calculated by multiplying the measured sulphate concentrations by the flow.

3. Results and Discussion

The study was undertaken between October 1992 and March 1994. This comprised two "wet" summer periods and one "dry" winter period. These periods are referred to as follows: Period A (October 1992 - March 1993) - wet summer, Period B (April 1993 - September 1993) - dry winter, and Period C (October 1993 - March 1994) - wet summer.

The total rainfall recorded for the three periods was 491.5 mm (Period A), 62.0 mm (Period B) and 843.5 mm (Period C). Interestingly, 70% more rain was recorded in Period C than in Period A, both of which covered the same months of the year; this reflects the annual variability of rainfall in the region. The monthly data are graphically represented in Figure 1.

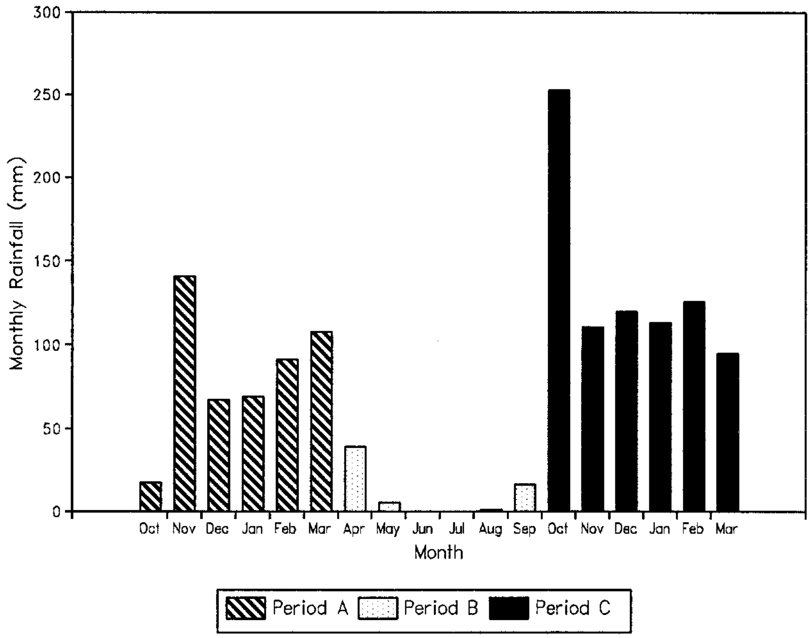

Figure 1:Monthly Rainfall at Suikerbosrand

The sulphate deposition measured from the wet sampler, the rock runoff plots, the particulate sampler and the calculated theoretical deposition using the atmospheric SO_2 data are shown in Table 1. The wet and total dry sulphate deposition rates are graphically represented in Figure 2.

The total wet deposition of sulphate (Table 1) was 11.8, 0.8 and 27.5 $kg.ha^{-1}$ for periods A, B and C respectively. The highest monthly sulphate deposition occurred during the months of highest rainfall.

The highest ambient levels of SO_2 were found in Period B (11.4 $\mu g.m^{-3}$) when there was little or no rainfall. The SO_2 levels were significantly lower in Period C

Table 1: Calculated(C) and Measured(M) Sulphate (SO_4^{2-}) Deposition Rates

Sulphate (SO_4^{2-}) Deposition in $kg.ha^{-1}$				
Period	Wet Deposition Rate (M)	Net Gaseous Deposition Rate (C)	Net Rock Runoff Deposition Rate (C)	Net Particulate Deposition Rate (C)
A (Oct 92 - Mar 93)	11.8	32.2	6.0	3.0
B (Apr 93 - Sep 93)	0.8	8.1	5.8	2.4
C (Oct 93 - Mar 94)	27.5	15.1	17.1	3.1

(4.9 $\mu g.m^{-3}$) which had 70% more rainfall than Period A (10.5 $\mu g.m^{-3}$.). Using deposition velocities of 1.3 (Periods A and C) and 0.3 $m.sec^{-1}$ (Period B), the estimated sulphate deposition loads were 32.2, 8.1 and 15.1 $kg.ha^{-1}$, respectively.

The rock runoff plots gave sulphate depositions of 6.0, 5.8 and 17.1 $kg.ha^{-1}$ for periods A, B and C respectively. The bulk samplers gave particulate depositions rates of 3.0, 2.4 and 3.1 $kg.ha^{-1}$.

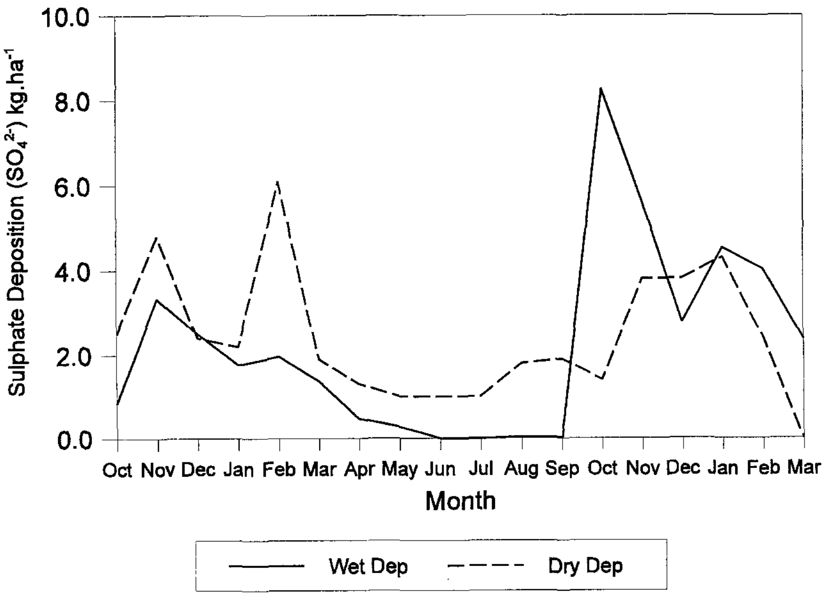

Figure 2: Wet and Total Dry Sulphate Deposition at Suikerbosrand

Table 2: Atmospheric Inputs and Outputs of Sulphate (SO_4^{2-}) for each sampling Period

Sampling Period	Total Wet Deposition ($kg.ha^{-1}$)	Total Dry Deposition ($kg.ha^{-1}$)	Total Catchment Output ($kg.ha^{-1}$)
Period A	11.8	19.4	2.8
Period B	0.8	7.5	0.0
Period C	27.5	17.6	7.6

It must be noted that the rock runoff plots measured the total dry deposition (gaseous and particulate) whereas the bulk sampler measured primarily particulate deposition. Gaseous deposition is affected by, amongst other things, the nature of the receiving surface, wetness and temperature. Little or no gaseous adsorption would be expected using the bulk sampler, where the collecting funnel was constructed of inert polypropylene.

During Periods A and C, the proportion of dry deposition in the total deposition (wet + dry) amounted to 62% and 39% respectively. Periods A and B were both wet summer periods. In Period B, when relatively little rainfall was recorded, the proportion of dry deposition to total deposition was 90%.

Over an annual cycle (Periods A and B and Periods B and C), the proportion of dry to total sulphate deposition was 68% and 46%, respectively.

The sulphate deposition velocities used in the calculation of gaseous deposition (0.3 and 1.3 $m.sec^{-1}$) were theoretical values and have not been calibrated in the field. A deviation in these velocities of 50% would lead to a variation of 24%, 28% and 8% in the three estimates of total sulphate deposition during Periods A,B and C.

During the eighteen month study period, stream flow was recorded at the weir on fourteen occasions (seven in Period A and seven in Period C). The stream at Suikerbosrand was seasonal, only flowing after significant rainfall events of greater than 20 mm. No flows were recorded during Period B. The total flows in Periods A and B were 13 354 m^3 and 24 335 m^3, respectively. No stream flow was recorded between the recorded rainfall-related flow events. Eight flow events corresponded to individual storm rainfall events. The remainder of the flows responded to periods of general and widespread rainfall in the region. The combined runoff over the study period amounted to 8.7% of the total rainfall.

This relatively low runoff is characteristic of the region where the mean daily evaporation rate is 8mm during the summer months when most of the rainfall occurs (DWAF, 1986).

The levels of both sulphate and nitrate were often highest at the onset of flow and lowest at times of peak flow. Hydrogen ion concentrations were highest at times of peaks in flow, being inversely proportional to the acid neutralising capacity.

Mean levels of sulphate concentrations in the outflow were consistently between 9 and 10 $mg.L^{-1}$. These are significantly higher than those recorded from other calibrated catchments in Norway, Sweden and North America where average sulphate concentrations of between 1.1 and 5.7 $mg.L^{-1}$ have been recorded (Hultberg, 1985). Similarly, mean levels of nitrate concentrations recorded at Suikerbosrand (2.5 $mg.L^{-1}$) were considerably higher than those measurements at other calibrated catchments (<0.5 $mg.L^{-1}$). The Suikerbosrand stream is however a seasonal stream with a relatively low mean annual runoff of between 8.4 and 8.9%. This contrasts with other northern hemisphere calibrated catchments which have mean annual runoff rates of 50% or higher.

Most of the sulphate deposited was not exported from the catchment. In period A, 9% of the total estimated inputs of sulphate was exported from the catchment, 0% in Period B (no flow) and 17% in Period C.

Acknowledgements

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