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SPATIAL VARIATION IN WATER QUALITY AT SELECTED WEIRS IN THE VAAL AND HARTS RIVER SYSTEMS

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ABSTRACT

The spatial variation of several chemical constituents were studied at selected weirs in the Vaal and Harts rivers. Using the coefficient of variation as an index of the variation, significant variation was found in samples taken across the rivers. The coefficients of variation were the largest for NO_3 and PO_4 and the lowest for Cl, EC and Na. The difference in variation between NO_3 and PO_4 as compared to Cl, EC and Na can probably be related to different causative factors. The use of alternative sampling procedures to that being practised are suggested.

INTRODUCTION

Representative sampling is one of the basic premises of any water quality monitoring program. If sampling is not carefully planned and executed then no matter how much effort is spent on accurate analysis, data manipulation and reporting of results, the end result will be inherently weak. A dominant aspect of sampling is the cost and effort associated with it. An important goal therefore should be, the conduct of sampling in such a way that it will lead to results that bear some reasonable relationship to the time, effort and money spent (Haney and Schmidt, 1958).

A sample is an estimator of the water quality of a specific reach of a river at a given instant in time. The confidence attached to a single sample as an estimator of the water quality at a given instant in time is therefore amongst other factors, a function of the spatial variation in water quality. Spatial variation can be sub-divided into longitudinal, vertical and lateral variation (Oguss and Erlebach, 1976).

The authors' purpose of sampling is to estimate the quality of the water flowing over a weir downstream in a river. The only reason for taking samples at a weir is because flow readings can be taken at the same time. Flow readings are important for load calculations. In the context of our sampling objective, as defined above, evaluation of only lateral variation is required. For other sampling objectives spatial variation in all three directions would probably have to be investigated for example when the quality of the body of water lying behind a weir is important for drinking purposes.

As part of a project to evaluate the different aspects of grab sampling, the results of a study on spatial variation in water quality across a river at selected weirs in the Vaal and Harts river systems are reported in this paper.

METHOD

Samples were taken at different positions laterally across a river on or immediately upstream of a weir. The sampling positions included points where water was actually flowing over a weir as well as stagnant water on the sides where samples can be taken without undue effort.

The samples were treated according to standard procedures used at the Hydrological Research Institute ie: complete filling of sample bottles and storage in a cool dark place until they were analysed. All samples were analysed in the laboratory according to the methods currently employed by the Hydrological Research Institute within a maximum of 14 days after sampling. The samples were analysed for the following constituents: EC, pH, Ca, Mg, Na, K, TAL, SO_4 , Cl, PO_4 , NO_3 and F.

In situ measurements of electrical conductivity were taken at all the weirs included in this study to evaluate the temporal variation of water quality at fixed points.

RESULTS

Variation with time:

Sampling at exactly the same instant in time at the different points across a river was not possible. Consequently the temporal variation

will be part of the variation as determined in this study. To estimate the magnitude of the contribution of temporal variation to the variation measured in this study, electrical conductivity was measured continuously for 15 minute intervals at some of the different sampling points across a river. In none of the cases were any variation in electrical conductivity observed. With reference to these results it is assumed that the contribution of time variation to the measured variation is insignificant.

Spatial variation:

The averages (\bar{x}) for each constituents calculated from the different samples across a river at the specific weirs are listed in table 1 together with estimates of the standard deviations (s) according to Snedecor (1956) and the coefficients of variation (CV).

The assumptions made in this study must be appreciated. The total variation measured, presumably excludes time variation at the time of sampling but includes, besides spatial variation, the following:

- (1) Variation caused by changes taking place in the samples from the time of sampling up to analysis, commonly referred to as ageing.
- (2) Variation inherent in the analytical methods.

According to the authors' experience the inherent variation in the chemical analysis (2) expressed as coefficients of variation are less than one percent and definitely much less than the average coefficients of variation reported for the different constituents. The influence of ageing (1) on the total variation measured is impossible to evaluate from the results obtained in this study.

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TABLE 1 : AVERAGES, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION FOR THE DIFFERENT CONSTITUENTS AS MEASURED ACROSS A RIVER AT THE DIFFERENT WEIRS

Weir No	CONSTITUENTS											
	pH			EC			Ca			Mg		
	\bar{x}	s	CV	\bar{x}	s	CV	\bar{x}	s	CV	\bar{x}	s	CV
C2M18	7,17	1,97	27,48	621	15,95	2,57	46,35	2,92	6,29	23,45	1,68	7,18
C2M61	6,73	0,27	4,01	616	14,18	2,30	47,90	0,18	0,37	27,50	2,66	9,67
C6M03	7,27	0,29	3,98	478	23,05	4,73	41,20	13,47	32,69	17,60	0,71	4,03
C2M65	7,41	0,33	4,39	628	190,30	30,32	51,93	16,08	30,96	25,87	7,09	27,41
C2M67	7,67	0,30	3,94	1 923	69,99	3,64	28,35	0,27	0,95	32,30	2,30	7,13
C4M04	7,59	0,09	1,17	590	4,43	0,75	36,85	0,62	1,68	19,70	0,53	2,69
C2M66	6,67	0,18	2,75	503	36,09	7,16	39,30	6,86	17,44	17,10	1,54	8,89
C9M09	6,93	0,56	8,02	384	15,96	4,16	27,53	1,42	5,15	14,97	0,53	3,55
C3M13	7,76	0,47	6,06	581	14,18	2,44	32,35	6,11	18,90	26,70	0,17	0,66
C3M07	6,95	0,06	0,86	950	3,55	0,37	45,87	1,12	2,44	40,00	0,00	0,00
C3M03	6,99	0,06	0,86	632	1,77	0,28	30,45	1,86	6,11	22,20	2,13	9,58
C9W01	6,77	0,58	8,6	344	7,29	2,12	27,25	0,97	3,57	12,90	0,39	3,01
C9W02	6,51	0,19	2,77	337	7,09	2,10	25,50	0,89	3,49	12,50	0,89	7,09
Average			6,24			5,25			10,84			7,58

Weir No.	CONSTITUENTS											
	Na			K			Cl			SO ₄		
	\bar{x}	s	CV	\bar{x}	s	CV	\bar{x}	s	CV	\bar{x}	s	CV
C2M18	38,00	1,77	4,66	7,00	0,53	7,59	36,50	0,89	2,43	161,00	1,77	1,10
C2M61	33,50	0,89	2,64	5,35	0,44	8,28	29,50	0,89	3,00	134,00	5,32	3,97
C6M03	35,07	0,89	2,53	5,93	0,53	8,97	26,50	0,59	2,23	43,00	1,77	4,12
C2M65	50,00	23,64	47,28	3,47	0,65	18,73	24,17	3,84	15,89	6,17	4,15	67,29
C2M67	353,50	11,52	3,26	11,58	0,31	2,68	255,50	4,43	1,73	44,50	2,66	5,97
C4M04	52,50	0,00	0,00	5,68	0,13	2,34	81,00	0,00	0,00	43,50	0,00	0,00
C2M66	37,83	0,89	2,34	4,87	0,18	3,64	29,00	4,14	14,27	12,63	0,77	6,08
C9M09	25,07	1,24	4,95	4,77	0,65	13,63	18,50	0,59	3,19	43,83	1,18	2,70
C3M13	52,10	0,71	1,36	6,30	0,18	2,81	54,50	0,00	0,00	46,00	0,00	0,00
C3M07	92,33	1,18	1,28	7,23	0,53	7,36	112,83	3,25	2,88	84,00	0,59	0,70
C3M03	66,75	2,22	3,32	7,35	0,62	8,40	64,00	1,78	2,77	19,00	2,67	14,50
C9W01	22,73	0,63	2,77	4,48	0,49	10,86	16,20	0,78	4,80	35,95	2,28	6,35
C9W02	21,25	0,44	2,08	4,45	0,09	1,99	14,75	0,44	2,98	39,00	0,00	0,00
Average			8,11			6,54			4,68			9,40

Weir No.	CONSTITUENTS											
	TAL			NO ₃			PO ₄			F		
	\bar{x}	s	CV	\bar{x}	s	CV	\bar{x}	s	CV	\bar{x}	s	CV
C2M18	89,00	23,04	25,88	3,63	5,98	164,97	0,21	0,19	92,82	0,63	0,06	9,92
C2M61	160,00	0,00	0,00	2,40	3,72	155,02	0,13	0,04	35,44	0,44	0,03	6,82
C6M03	194,00	24,82	12,79	3,30	2,72	82,38	0,23	0,06	25,70	0,36	0,00	0,00
C2M65	333,67	160,75	48,18	7,17	2,66	37,09	0,04	0,02	44,33	0,43	0,06	13,95
C2M67	683,00	30,12	4,41	3,65	3,28	89,81	0,03	0,00	0,00	0,78	0,02	2,27
C4M04	152,50	6,20	4,06	4,75	1,33	28,00	0,20	0,09	44,30	0,36	0,12	31,99
C2M66	163,00	18,32	11,24	7,40	3,43	46,32	0,26	0,39	152,30	0,51	0,09	18,54
C9M09	122,33	18,32	14,98	3,20	3,49	108,97	0,08	0,03	36,94	0,32	0,01	3,69
C3M13	214,50	4,43	2,07	5,75	1,33	23,11	0,05	0,02	35,44	0,32	0,01	2,81
C3M07	253,67	30,73	12,11	2,27	3,37	148,62	0,14	0,19	135,08	0,46	0,04	8,99
C3M03	215,50	4,43	2,06	1,80	3,01	167,36	0,24	0,28	118,00	0,39	0,11	27,26
C9W01	102,25	22,84	22,34	2,93	3,30	112,98	0,05	0,01	29,16	0,27	0,01	3,67
C9W02	82,50	6,20	7,52	2,30	1,77	77,04	0,06	0,02	29,53	0,28	0,01	3,22
Average			13,97			103,47			65,24			11,04

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The authors' view is, considering that the samples were all identically treated up to the time of analysis, that variation caused by different rates of ageing is primarily caused by the original differences between sampling points and accordingly this variation is treated as spatial variation.

It is noted that the coefficients of variation for some of the constituents are consistently high whereas for others they are generally low. The coefficients of variation for the different constituents were statistically compared utilizing the Friedman nonparametric method of analysis of variance (Siegel, 1956). The results of the Friedman test are summarized in table 2. Rank totals, X^2_r -value (Friedman test statistic) and least significant differences, calculated according to Reinach (1966) are presented. Rank totals not significantly different from each other are underlined.

TABLE 2 : RANK TOTALS, X^2_r -VALUE AND LEAST SIGNIFICANT DIFFERENCE (LSD) FOR COEFFICIENTS OF VARIATION

Constituents:	NO ₃	PO ₄	TAL	K	F	Ca	Mg	pH	SO ₄	Na	EC	Cl
Rank totals :	148	133	103	85,5	84,5	83	79	74	63,5	55	54	51,5

$$X^2_r = 60,36 \quad (\text{Significant at the 1\% level})$$

$$\text{LSD} = 43,42 \quad (\text{Calculated for the 5\% level})$$

DISCUSSION

As shown in table 2 the coefficients of variation for NO₃ and PO₄

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ranks much higher than the rest, whereas Cl, EC and Na are on the lower end of the scale.

This fits in well with the usual assumptions that Cl and Na are conservative constituents relative to NO_3 and PO_4 .

The magnitude of the average coefficient of variation for NO_3 and PO_4 , 103% and 65% respectively, causes concern in view of the importance of these constituents in dam enrichment studies. From this study it seems virtually impossible to make any accurate and reliable calculations of nutrient loads from the results obtained from single grab samples in the river systems considered. The surprisingly high coefficients of variation for NO_3 and PO_4 were never suspected by the authors prior to the results obtained by this investigation, emphasizing the fact that assumptions as to spatial variation across rivers must be tested before general acceptance as far as sampling is concerned.

At all the weirs investigated, the biggest differences occurred between stagnant and running water. It is obvious that a single grab sample of the running water will be more representative, than a sample of the stagnant water, of the quality of the water in the river downstream of the weir. The problem however is that at some weirs it is difficult and often dangerous to take a sample of the running water. In the past it was assumed that in these cases the difference in water quality between stagnant and flowing water is insignificant and a sample was taken from the stagnant water. As this study shows, this type of assumptions must be critically examined. Some or other procedure to obtain representative samples, at least as far as NO_3 and PO_4 is concerned, will have to be applied in future studies of these river systems.

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An interesting aspect of this study is that the significant difference observed between the average coefficients of variation for NO_3 and PO_4 as compared to the rest of the constituents suggests that the primary causes of the variation are completely different for the two groups of constituents. Variation in NO_3 and PO_4 are probably caused by the activity of living organisms whereas for the rest of the constituents the primary causes of variation are the usual physical and chemical factors characteristic of the natural environment.

CONCLUSIONS

1. The spatial variation, expressed as coefficients of variation for some constituents e.g. NO_3 and PO_4 across a river are unexpectedly high.
2. The constituents measured in this study can probably be divided into two groups. (1) Those with high coefficients of variation e.g. NO_3 and PO_4 and (2) those with low coefficients of variation e.g. Cl, EC and Na. The primary causes of variation in the first group are probably biological as apposed to physical/chemical in the second group.
3. It is doubtful whether a single grab sample, even if it is obtained at frequent intervals, could be used for accurate and reliable calculations of nutrient loads considering the very wide spatial variation in NO_3 and PO_4 .
4. It is recommended that alternative methods of sampling be applied in future studies of the Vaal and Harts river systems with the object of overcoming the problem of spatial variation. Sampling at places below weirs where the water is thoroughly mixed appears

to be the most practical alternative, provided that the flow figures obtained at the weirs would still be applicable for load calculations.

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