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Coliforms as a measure of sewage contamination of the River Zambezi

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The effect of releasing untreated sewage from Victoria Falls Town into the Zambezi river was determined by bacteriological examination of water samples collected upstream of Victoria Falls and for 22 km downstream. Most probable numbers of faecal coliforms and *Escherichia coli* were estimated. Water upstream of the falls, on the Zimbabwe side of the river, contained between seven and 130 *E. coli* per 100 ml. This section of the river was free from major sources of faecal pollution. Below the falls, but before the Victoria Falls Town sewage outfall, numbers of *E. coli* were between $1{\cdot}8 \times 10^2$ and $1{\cdot}4 \times 10^4$/100 ml, indicating the existence of a sewage discharge other than that from Victoria Falls Town. The river was also highly polluted from the Victoria Falls Town sewage outfall to a point 18·6 km downstream. The highest *E. coli* count was $3{\cdot}3 \times 10^4$/100 ml and declined slowly to $1{\cdot}4 \times 10^3$/100 ml 18·6 km downstream of the outfall.

Wastewater collected from cities and towns must ultimately be returned to receiving waters or to the land. Disposal of wastewater by dilution in larger bodies of water, such as lakes, rivers, estuaries, or oceans, is the most common method (Tchobanoglous 1979). In most industrialized countries secondary treatment of sewage is considered to be essential before discharge to a water course. In cases where the dilution is thought to be large, however, wastewater or sewage may be discharged into the receiving water after only primary treatment.

Among the organisms that are found in wastewater, pathogens pose the greatest threat to public health; especially when the receiving water is used for domestic, recreational or agricultural purposes (Tchobanoglous 1979). This is because, before treatment, waste water containing sewage will contain the complete spectrum of pathogenic micro-organisms excreted by the local human population serviced. This will include viruses (Slote 1976; Larkin 1982; Strauch 1983; Krikelis *et al.* 1985), bacteria (Simpson 1982), and parasites (Hayes 1977).

The particular organisms that must be removed from wastewater and the extent to which their numbers are controlled to protect the environment can be determined only on an individual basis. The local conditions and needs must be examined and assessed in the light of scientific knowledge and government controls and regulations. In Zimbabwe, the Water (Effluent and Waste Water Standard) Regulations (Anon. 1977; 1982a) prescribe standards for the quality of effluents and wastewaters discharged to receiving water. These regulations do not specify, however, the microbiological content of effluent or wastewater in terms of faecal indicators.

Victoria Falls Town was granted exemption from these regulations in 1971 and hence raw sewage is discharged into the Zambezi River. The exemption was granted in view of the small size of the population and dilution of the sewage (1 : 33 000) on entry to the River Zambezi at times of low flow (15×10^6 cubic metres per day). At the time, sewage treatment to the standard required by the Regulations was beyond the financial resources of the town. The local authority also claimed that much larger volumes of raw sewage were discharged into the

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river by Livingstone Town and that it was this discharge, rather than that of Victoria Falls Town, that was the main factor determining the quality of the Zambezi River.

Full examination of a river water quality embodies four lines of investigation: topographical, chemical, biological, and bacteriological; each is essential and yields information not otherwise obtainable. Bacteriological examination is the most sensitive means of detecting faecal and, therefore, potentially dangerous pollution (Anon. 1982b). Simple and frequent tests for commensal gastro-intestinal bacteria are used to indicate the degree of faecal contamination. Coliforms, especially *Escherichia coli* are used because they are easy to isolate and characterize and large numbers occur in faeces of man and warm-blooded animals and hence in sewage. The presence of faecal indicator organisms in a sample of water indicates that intestinal pathogens could also be present and that the water supply may pose a risk to health (Anon. 1982b).

The aim of this study was to measure faecal coliforms, and in particular *E. coli*, in three sections of the Zambezi River: upstream of Victoria Falls; below the falls and above the Victoria Falls Town sewage outfall; and downstream of this for 18·6 km. In this way the impact of sewage discharges from Livingstone as well as that caused by the Victoria Falls Town discharge could be observed.

Materials and Methods

THE RIVER AND RELATED SAMPLE SITES

The Zambezi River forms the boundary between Zimbabwe and Zambia. The map, Fig. 1, shows the sample points on the river and the position of the two towns; Victoria Falls Town,

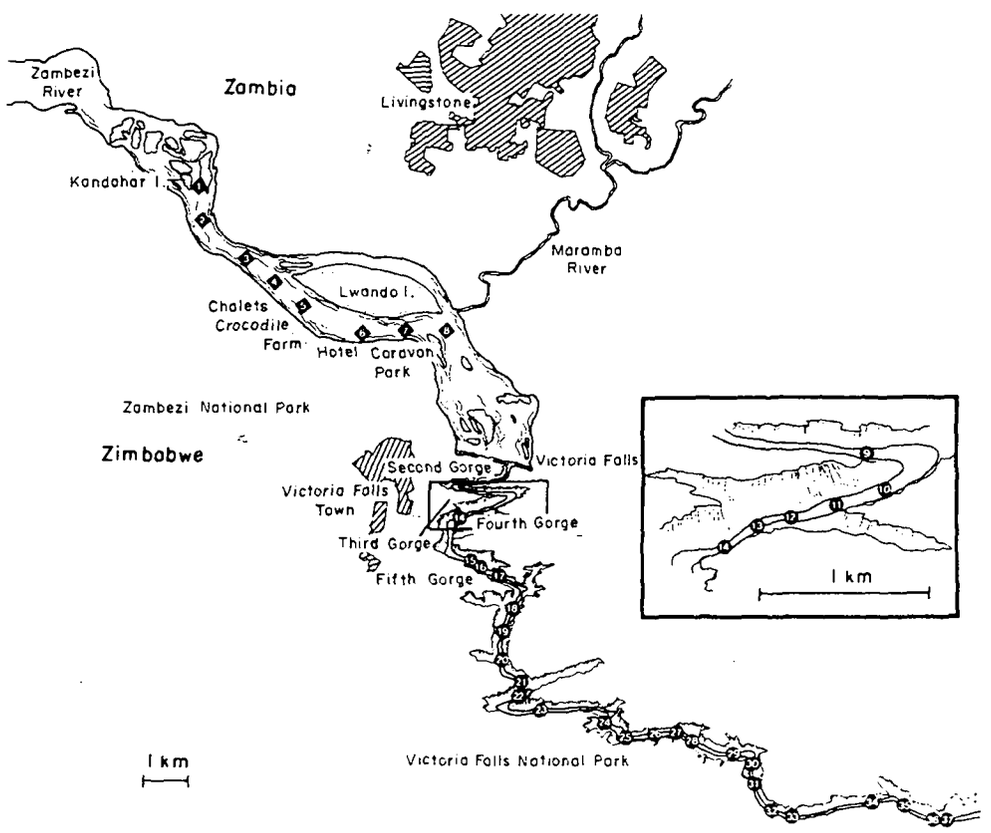

Fig. 1. Map of the section of the Zambezi River studied showing sampling sites. ●, ◆, sampling sites; ▨, towns.

on the Zimbabwean side and Livingstone, on the Zambian side, which was believed to be discharging raw sewage or effluent into the river.

The sewage from Victoria Falls Town is collected through pipes and discharged near to the Fourth Gorge (sampling site 13, Fig. 1). The primary treatment consists only of screening through coarse 80 mm screens.

Livingstone is larger than Victoria Falls Town and is believed to produce a larger volume of sewage. It is outside the jurisdiction of the Zimbabwean Department of Water Resources and Development so information about where it discharges its sewage is based on local opinion but it is thought to be upstream of the Victoria Falls or at the Third Gorge (Fig. 1).

Upstream of the falls the river is wide and navigable. Below the falls, the gorge is approximately 0·5 km deep with cliff-like sides and is inaccessible to wildlife. Although access is difficult there is a footpath down the Fourth Gorge to the point of discharge of Victoria Falls Town sewage (site 13, Fig. 1). Raft trips occur from approximately 150 m downstream of the sewage outfall to about 18·6 km down the river.

Sites 1–8 were selected as representative of the river above the Victoria Falls. Sources of contamination are few; two flush toilets at Kandahar Island discharge directly into the river (opposite site 1); a game park, with access to the river bank, but with no settlements (opposite sites 2 and 3); and settlements which include chalets, a hotel and a caravan park on the river bank (opposite sites 4, 5 and 6). There are no settlements opposite sites 7 and 8.

Sites 9–12 below the falls represent the part of the river which could be affected by Livingstone discharges upstream of the Victoria Falls outfall. Site 13 was in the plume of Victoria Falls Town discharge. Sites 14–37 were downstream of Victoria Falls Town sewage outfall. This section of the river has 14 major rapids and the water, therefore, is very turbulent and well aerated.

SAMPLING TECHNIQUES

Samples were taken on 14 October 1986 and 9 December 1986. Midstream samples from sites 1–8 were collected only on 9 December 1986 from a motorboat. River bank samples were collected from sites 9–13 on both occasions as midstream sampling was not practicable. Samples of sites 14 to 37 were collected from a raft, in between rapids. The midstream sites were not necessarily identical on each occasion because of the logistic problems of sampling from a raft.

Water samples were collected in sterile amber glass bottles of 250 ml capacity, from 30 cm below the water surface, against the water flow, avoiding still water and low flow areas (Anon. 1982b). Samples were transported in insulated cooler bags and examined within 14 h of collection.

BACTERIOLOGICAL EXAMINATION

Samples were tested by the most probable number (MPN) method (Anon. 1982b). Five 10 ml amounts of water were added to equal volumes of double strength MacConkey broth (Oxoid); five 1 ml samples of the water sample were added to 5 ml volumes of single strength MacConkey broth; and five 1 ml volumes of a 1 in 10 dilution of the water sample in quarter strength Ringer solution (Oxoid), were added to 5 ml volumes of single strength MacConkey broth.

Because high counts were obtained from downstream samples on 14 October 1986 (>1800 per 100 ml) the second samples on 9 December 1986 were diluted to 1:1000 in quarter-strength Ringer solution before they were examined. The samples collected upstream of the falls were not diluted.

Tubes showing acid and gas after incubation at 37°C for 24 h were regarded as presumptive coliform positive and each subcultured into Brilliant Green Lactose Bile Broth (BGLBB) (Oxoid). These were incubated at 44°C for 24 h. Gas production was considered to confirm the presence of faecal coliforms (Anon. 1982b). The remaining tubes were reincubated for a further 24 h and any more which showed acid and gas formation were subcultured into BGLBB.

In addition to BGLBB, a tube of tryptone water was inoculated and incubated at 44°C for 24 h and tested for indole by Kovac's method. Suitable control strains were tested at the same time.

Indole formation together with gas production from lactose at 44°C was used as confirmation of *E. coli* (Anon. 1982b).

The presumptive MPN counts of coliforms, faecal coliforms and of *E. coli* in 100 ml of water

Table 1. The most probable number of presumptive coliform organisms, faecal coliforms and *Escherichia coli* upstream of the Victoria Falls

Site number* 9/12/86	MPN count/100 ml	
	Presumptive coliform organisms	Confirmed *E. coli*†
1	540	70
2	240	79
3	79	49
4	130	130
5	350	49
6	540	27
7	280	8
8	540	7

* Sites are numbered as in Fig. 1.
† Faecal coliform counts were equal to *E. coli* counts at all sites.

sample were estimated from published tables (Anon. 1982b).

Results

In most samples the *E. coli* counts were equal to the faecal coliform counts. When differences occurred, these are shown in Tables 1, 2 and 3.

Table 1 shows the results from sample points upstream of the Victoria Falls. Between sites 1 and 6, the counts of *E. coli* increased from 70/100 ml at site 1 to 130/100 ml at site 4 and then declined to 27/100 ml at site 6. At sites 7 and 8, nearest to the falls, *E. coli* was only just detectable. These findings are compatible with the minor and intermittent sources of faecal matter. There was some evidence that the settlement and hotel contributed localized contamination of the river near to site 4 (Table 1).

Table 2 shows the results of samples taken below the Victoria Falls but above the point of the Victoria Falls Town discharge. Counts of *E. coli* were high: $1{\cdot}8 \times 10^2$ to $1{\cdot}4 \times 10^4$/100 ml. The absence of faecal coliforms and *E. coli* at site 11 on 9 December 1986 was undoubtedly due to too high a dilution (1 : 1000) of the sample before it was tested.

Table 3 shows the counts obtained between the Victoria Falls Town outfall and a point 18·6 km downstream. Again the *E. coli* counts were high, $1{\cdot}4 \times 10^3$ to $3{\cdot}3 \times 10^4$/100 ml. These findings indicate gross pollution of the river by sewage from both towns as the numbers of faecal organisms were 100- to 1000-fold greater than that in water above the falls.

The level of pollution downstream of Victoria Falls Town was also greater than that in sections of the river between the two towns. This observation, coupled with the persistence of high counts for a distance of at least 18·6 km indicates that both discharges have a major impact on the quality of the river water.

Discussion

Escherichia coli and faecal coliforms are favoured by most workers as the faecal indicators of choice (Cabelli 1978). This is because *E. coli* comes closest to meeting the characteristics required of an indicator organism. It is abundant in faeces and sewage, absent or in very small numbers from other environmental sources, easily detected and enumerated, but unable to grow in most aquatic environments (Anon. 1982b). Very low numbers (1 in 100 ml) can be detected, making *E. coli* a very sensitive indicator of faecal contamination. High counts

Table 2. Most probable numbers of presumptive coliform organisms, faecal coliforms and *Escherichia coli* downstream of Victoria Falls and above Victoria Falls Town sewage outfall

Site number*	MPN count/100 ml					
	Presumptive coliform organisms		Confirmed faecal coliforms		Confirmed *E. coli*	
	14/10/86	9/12/86	14/10/86	9/12/86	14/10/86	9/12/86
9	nd†	$8{\cdot}7 \times 10^4$	nd	$5{\cdot}5 \times 10^3$	nd	$5{\cdot}5 \times 10^3$
10	nd	$3{\cdot}5 \times 10^5$	nd	$2{\cdot}5 \times 10^4$	nd	$1{\cdot}1 \times 10^4$
11	$>1{\cdot}8 \times 10^3$	$4{\cdot}0 \times 10^3$	$>1{\cdot}8 \times 10^3$	absent‡	$>1{\cdot}8 \times 10^3$	absent
12	$>1{\cdot}8 \times 10^3$	$2{\cdot}2 \times 10^5$	$1{\cdot}8 \times 10^2$	$1{\cdot}7 \times 10^4$	$1{\cdot}8 \times 10^2$	$1{\cdot}4 \times 10^4$

* Sites are numbered as in Fig. 1.
† Not determined.
‡ Dilutions of sample before examination too great for detection of organism.

Table 3. Most probable numbers of presumptive coliform organisms, faecal coliforms and *Escherichia coli* downstream of Victoria Falls Town sewage outfall

Site number*	Position downstream of the sewage outfall (km)	Date Sampled	MPN Count/100 ml	
			Presumptive coliform organisms	Confirmed *E. coli*†
13	0	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
14	0·3	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
15	1·4	14/10/86	$1{\cdot}6 \times 10^3$	$1{\cdot}6 \times 10^3$
16	1·6	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
17	2·1	9/12/86	$1{\cdot}7 \times 10^5$	$1{\cdot}7 \times 10^4$
18	3·3	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
19	4·0	9/12/86	$8{\cdot}0 \times 10^3$	$5{\cdot}0 \times 10^3$
20	4·8	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
21	5·8	9/12/86	$9{\cdot}2 \times 10^5$	$2{\cdot}7 \times 10^4$
22	6·1	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
23	7·6	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
		9/12/86	$1{\cdot}7 \times 10^4$	$5{\cdot}0 \times 10^3$
24	9·5	9/12/86	$3{\cdot}3 \times 10^4$	$1{\cdot}7 \times 10^4$
25	10·1	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
26	10·8	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
27	11·3	9/12/86	$1{\cdot}3 \times 10^4$	$8{\cdot}0 \times 10^3$
28	11·6	14/10/86	$1{\cdot}6 \times 10^3$	$1{\cdot}6 \times 10^3$
29	12·6	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
30	13·1	9/12/86	$4{\cdot}9 \times 10^4$	$3{\cdot}3 \times 10^4$
31	13·6	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
32	14·4	14/10/86	$>1{\cdot}8 \times 10^3$	$>1{\cdot}8 \times 10^3$
33	14·9	9/12/86	$7{\cdot}0 \times 10^4$	*See footnote*†
34	16·8	9/12/86	$1{\cdot}1 \times 10^5$	$1{\cdot}2 \times 10^4$
35	17·6	14/10/86	$1{\cdot}6 \times 10^3$	$1{\cdot}6 \times 10^3$
36	18·4	14/10/86	$1{\cdot}6 \times 10^3$	$1{\cdot}6 \times 10^3$
37	18·6	9/12/86	$1{\cdot}7 \times 10^4$	$1{\cdot}4 \times 10^3$

* Sites are numbered as in Fig. 1.

† Faecal coliform counts were equal to *E. coli* counts at all sites except at site 33 where faecal coliforms were $7{\cdot}0 \times 10^4$ and *E. coli* $3{\cdot}3 \times 10^4$/100 ml.

indicate heavy and recent pollution; low counts intermittent or minor pollution (Anon. 1982b). The use of *E. coli* as an indicator organism has been criticized, however, because counts cannot be directly correlated with the presence or numbers of enteric pathogens, or disease in the exposed population (Anon. 1982b). Furthermore, faecal coliforms may multiply in some environments where pathogens such as viruses are not found. It is for this reason that *E. coli* is preferred (in Europe) as an indicator instead of faecal coliforms when sewage contamination is being assessed (Berg 1973). *Escherichia coli* of human and animal origin cannot be distinguished but this is of less concern since warm-blooded animals can harbour organisms pathogenic to man.

The MPN method used to estimate the number of bacteria in the present study, is subject to large errors. The upper limit of the estimated number of organisms is about three times the MPN value and the lower limit is between one third and a quarter. Thus, although the MPN method is extremely sensitive when samples contain small numbers of indicator organisms, it is not precise. Differences must be interpreted with caution (Anon. 1982b) and trends indicated by frequent sampling are more valuable than those from single, spot samples. The methods and incubation conditions used in this study do not take account of injured bacteria which occur in some aquatic environments (Austin *et al.* 1981). Moreover, the traditional media for coliform tests, BGLBB and MacConkey broth, used in this study, contain bile salts and peptone, the composition of both of which is variable (Abbiss *et al.* 1981; Anon. 1982b; Wright 1984). In developing countries more defined media are not always available so these considerations must also be borne in mind when interpreting the results of water bacteriology.

In this study sampling was done only twice because the Zambezi River in this area is navigable only at times of low flow (August to mid-December). It is also far from the investigating laboratory. Rafting is hazardous because of many rapids. It was not possible, therefore, to follow the usual advice that bacteriological examinations are most useful when they are repeated frequently. In addition to all these considerations variations in the input and quality of sewage from a community alters with the activities of the population in the short term (hourly, daily and weekly) and over a longer time as a result of seasonal factors (Tchobanoglous 1979). These could not be considered in this study.

The need for controls over the sanitary quality of waters used for recreational purposes has been recognized by public health and environmental officials for many years (Cabelli 1978). Guidelines and standards vary from one country to another and many countries have none at all. Two bacteriological criteria are most frequently used to define polluted water; a total coliform count of $>1000/100$ ml and a faecal coliform count of $>200/100$ ml (Cabelli 1978). Since Zimbabwe does not have any guidelines, the latter was used to assess the pollution levels observed in this study.

The Zambezi River upstream of the Victoria Falls would be considered suitable for recreational activities. The slight pollution that arose from the two flush toilets on Kandahar Island, game drinking opposite sites 2 and 3, and from chalets, a hotel and a caravan park on the river bank opposite sites 4, 5 and 6 was localized in its impact although additional sampling in the area of site 4 might have determined times when that section of the river would be unsuitable for use.

Coliform counts for the river between Victoria Falls and the Victoria Falls Town outfall, although lower than those downstream of the outfall, exceeded the guidelines 100-fold. It is clear that Livingstone also discharges raw Sewage or effluent to the Zambezi River at a point upstream of the Victoria Falls Town outfall.

Below the outfall of Victoria Falls Town the river is grossly polluted. The faecal coliform counts were 350 times those in unpolluted water (Table 3) and pollution persisted for at least 18.6 km downstream, where levels exceeded the guidelines by a factor of 7.

The pollution impact of both discharges is probably considerably greater than either of them alone.

Despite the limitations of this study it clearly demonstrated the gross pollution of the Zambezi River due to the disposal of sewage from both towns. The high dilution, the turbulence of the river and its inaccessibility to humans and warm blooded animals have not afforded the degree of protection of river water quality which was the justification for relaxing the criteria for discharge consent.

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