The Chemical and Biological Recovery of an Organically Polluted Sandy Beach in Natal, South Africa following the Diversion of Effluents to an Offshore Pipeline

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Abstract

Domestic and industrial wastes which previously were discharged into the surf zone in the vicinity of Durban, South Africa, have subsequently been diverted to two offshore pipelines. The pipelines were designed, on the basis of oceanographic data, to prevent undesirable concentrations of effluent reaching the shore zone. An extensive investigation over a ten year period has revealed, as expected, that the diversion has resulted in a substantial improvement in the biological and chemical conditions of the beaches. The offshore environment to which the effluents were diverted has not been materially affected. The detailed findings of the investigation have been published. This paper deals with a survey of chemical and faunal parameters in an organically polluted beach which revealed that a period of approximately six months was required for the beach to revert from an enriched to an unenriched state, once all the effluents had been diverted. Ground water, particle size variation and sand movement may have influenced the rate of recovery.

Introduction

Two offshore submarine pipelines were introduced during 1968 and 1969 to facilitate the disposal of domestic and industrial wastes from the city of Durban, South Africa. The wastes were previously released through a number of pipes discharging into the surf zone. An extensive oceanographic survey was undertaken by a combined team from the National Institute for Water Research and the National Physical Research Laboratory of the Council for Scientific and Industrial Research prior to the construction of the pipelines. This was done to determine the patterns of water movement, and other factors which influence the dilution and transport of the effluent, in the area of the proposed pipelines. A theoretical treatment of the oceanographic data revealed that two pipelines, 1,37 and 1,22 metres in diameter, extending 4,1 and 3,1 kilometres offshore respectively would adequately disperse the effluent and prevent undesirable concentrations reaching the shore zone. These pipelines were constructed at a cost of R4,5 million. An extensive investigation of the chemical and biological conditions of the beaches and nearshore areas was conducted between 1964 and 1974 in order to confirm the efficiency of the offshore pipeline disposal system and monitor its effects on the environment.

The investigation was undertaken in two phases. During the first phase, between 1964 and 1968, methods for measuring the degree of pollution, using both chemical and biological parameters, were developed, and sites of contamination demarcated. This phase of the investigation included both polluted and unpolluted areas, so that pollution criteria, for the sandy beaches and nearshore sediments of the Natal coast, could be defined. Conditions before and after the commissioning of the offshore pipelines were compared in a second phase of the investigation (1969 to 1974). The findings of both phases of the investigation have been published (Livingstone 1969, 1976; Livingstone *et al* 1968; Oliff *et al* 1967 a, b; National Institute for Water Research 1968, 1972, 1974).

A unique opportunity arose during the latter part of the investigation to study the rate and extent of recovery of an organically polluted beach following the diversion of effluent from the surf zone to one of the offshore pipelines. This paper deals with the results of that study. The beach concerned lies in the vicinity of the mouth of the Umlaas canal (29° 58′ S, 30° 59′ E) approximately fifteen kilometres south of Durban. Figure 1 illustrates the location of the beach in relation to the Umlaas canal and the offshore pipelines.

At this stage, although the majority of the effluents had already been diverted to the offshore pipelines and a degree of recovery had taken place (National Institute for Water Research, 1972) an organic industrial effluent continued to be discharged from a plant which produces alcohol from molasses. Approximately 90 000 ℓ d^{-1} of effluent with a 5 day Biochemical Oxygen Demand of 10 000 mg ℓ^{-1} and 2 000 mg ℓ^{-1} of sus-

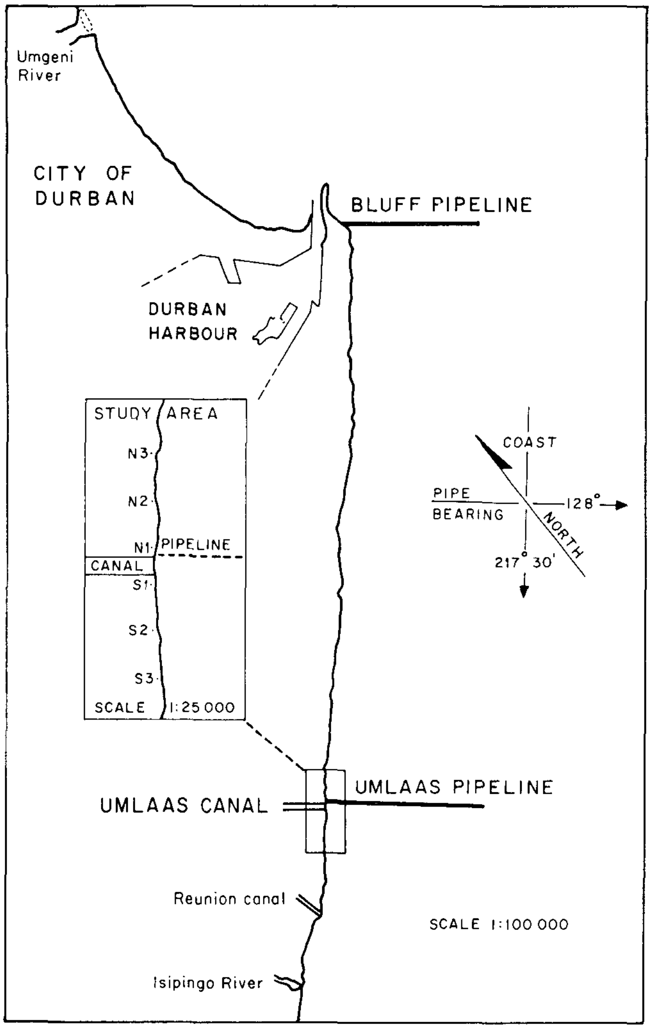

Figure 1
Location map.

pended solids was being discharged directly onto the shore and its effects were apparent over a kilometre or so of the beach, north and south. The canal itself carried some organic matter but the level was low. In November 1971 this effluent was also diverted to the offshore pipeline and a study of the final recovery of the beach became possible.

Survey Methods

Samples were taken on the north and south banks of the canal and at approximately 300 metre intervals for 900 metres along the beaches, to the north and south of the canal (Figure 1). Samples were taken at monthly intervals until February 1972, and then at progressively longer intervals until February 1974. Eleven surveys were completed. Data collected during eight earlier surveys at approximately the same sampling points have been included in the overall evaluation.

Samples were taken at low water of spring tides on all occasions, the sampling points being situated at approximately mean tide level. Sediments were dug from just below the water table. Interstitial water samples were extracted using a probe and hand suction pump. Surf water samples were collected in the sea adjacent to the sampling points.

The sediments were analysed for Kjeldahl nitrogen (Strickland and Parsons, 1965) and for easily oxidisable material as determined by the alkaline permanganate value (Standard Methods, 1946). Mean particle sizes were determined by the method of Emery (1938).

The interstitial and surf water samples were analysed for alkaline permanganate value (Standard Methods, 1946) and total phosphorus (Menzel and Corwin, 1965). In addition, measurements of salinity, dissolved oxygen, ammonia, nitrate and nitrate were carried out following the methods of Strickland and Parsons (1965).

Eighteen litres of sediment were dug from below the water table at each sampling point. The fauna was separated from the sediment by means of vigorous stirring, decanting and sieving through a net with a mesh diameter of 235 microns.

Results and Discussion

Figures 2, 3 and 4 illustrate the trends of the mean values of the various parameters for all stations in each survey with time.

Before the commissioning of the Umlaas offshore pipeline in November 1968 the beaches within one kilometre of the Umlaas canal were recorded as being heavily polluted due to the discharge of effluents from the canal into the surf zone. Subsequently organic enrichment of the sand remained high due to

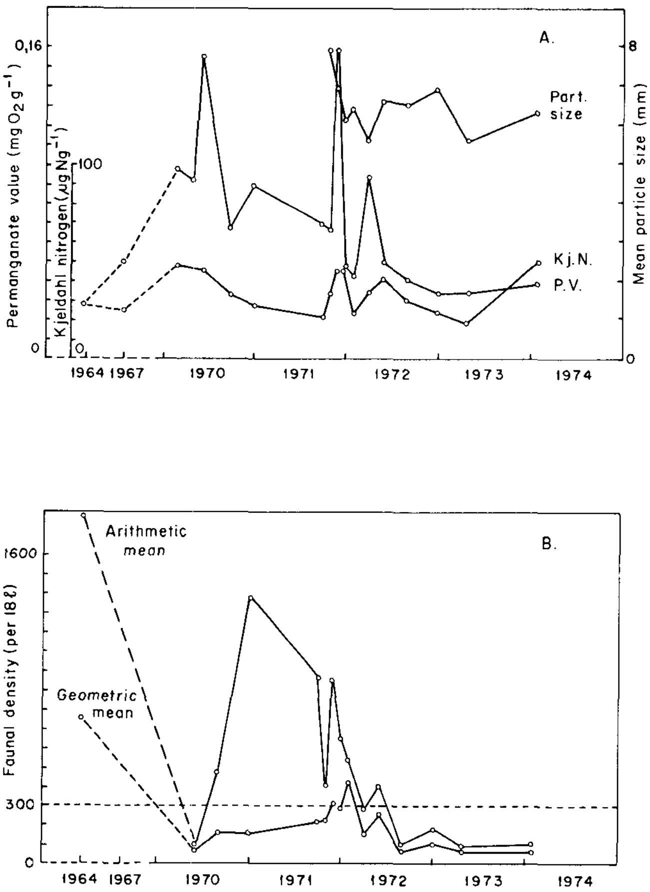

Figure 2
Mean variation in (A), the permanganate value, Kjeldahl nitrogen content and particle size, and (B), the faunal density of the beach sediments in the vicinity of the Umlaas canal.

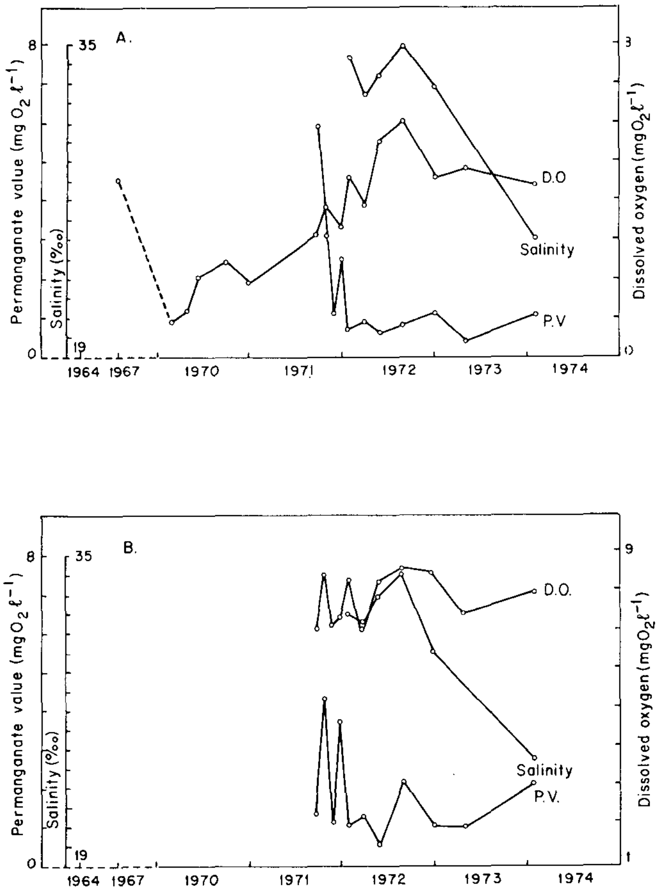

Figure 3
Mean variations in permanganate value, salinity and dissolved oxygen in (A), the interstitial and (B), the surf water in the vicinity of the Umlaas canal.

the continued discharge of the organic industrial effluent onto the beach. It was only when this effluent was diverted to the offshore pipeline in November 1971 that substantial chemical and biological recovery of the beaches commenced.

Permanganate values

Judged by the permanganate value of the sand (Figure 2A), the beaches were enriched between 1970 and 1972. The maximum individual level recorded was 0,674 mg O_2 g^{-1} on the north bank of the canal in June 1972, but this was an exception as the beach had, in general, been improving since January 1972. During the last four surveys the mean permanganate value did not exceed 0,050 mg O_2 g^{-1} which is below the upper limit of 0,060 mg O_2 g^{-1} suggested by Oliff *et al* (1967a) as acceptable for unpolluted beaches. This value has been marginally exceeded only on the north and south banks of the canal in September 1972 and on the south bank in February 1974. The permanganate value of the interstitial water (Figure 3) dropped rapidly following the diversion of the effluent.

Kjeldahl nitrogen

The Kjeldahl nitrogen content of the sand was generally low throughout the survey (Figure 2A), only once exceeding the acceptable maximum level of 100 μg N g^{-1} established by Oliff *et al* (1967a) as indicative of unpolluted conditions. It is probable that this was due to the nature of the effluent, which consisted mainly of carbohydrate rather than nitrogenous materials.

Dissolved oxygen

The dissolved oxygen in the interstitial water (Figure 3A) has proved a useful parameter for assessing the condition of the beach. While the effluent was discharging onto the beach the dissolved oxygen was low, the minimum individual level being zero on the north bank of the canal in October 1971. It increased rapidly after November 1971. The dissolved oxygen of the surf water was consistently high throughout the survey (Figure 3B).

Nutrients

The concentrations of ammonia and total phosphorus in the interstitial water (Figure 4A) decreased rapidly after the diversion of the effluent. This was particularly noticeable in the immediate vicinity of the canal where, on the north bank, the total phosphorus concentration dropped from more than 1 000 μg P/ℓ^{-1} to 39 μg P/ℓ^{-1} in six months, and the ammonia concentration dropped from more than 1 000 μg N/ℓ^{-1} to a minimum of 87 μg N/ℓ^{-1} in ten months. The nitrate and nitrite concentrations (Figure 4A), on the other hand, did not follow a recognisable trend. No recognisable trend was apparent in the nutrient parameters of the surf water (Figure 4B).

Bacteriological quality

Bacteriological corroboration of the improvement in water quality in the vicinity of the Umlaas canal is reflected in *Escherichia coli* I indices derived from two surf sampling stations,

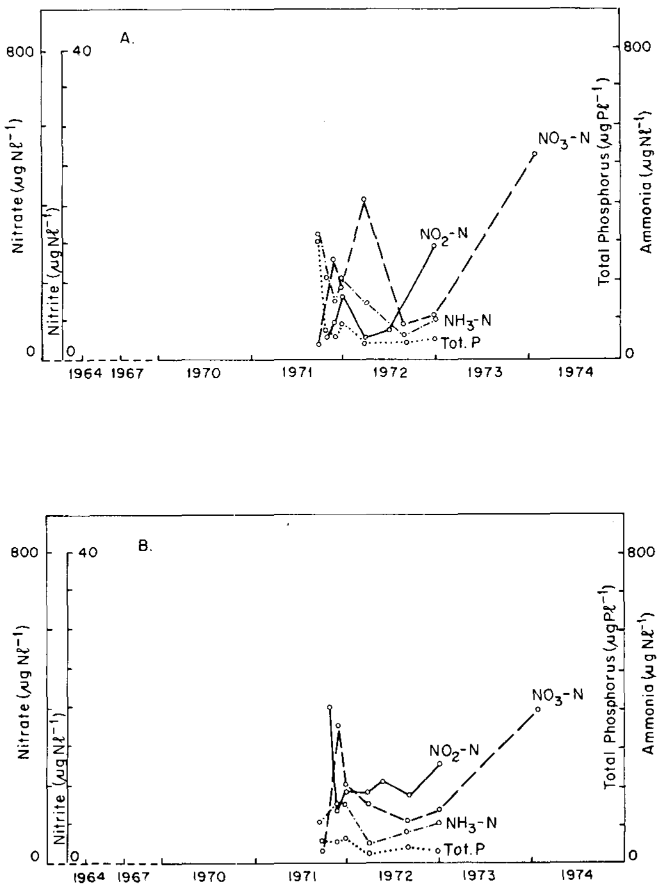

Figure 4
Mean variations in the nitrate, nitrite, total phosphorus and ammonia levels in (A), in the interstitial and (B), the surf water in the vicinity of the Umlaas canal.

one immediately to the north, the other immediately to the south of the canal; the relevance of either station's results depending on the direction of the nearshore current. Three bacteriological runs on the southerly station in October 1964, elicited the results 2 400, 1 300 and 340 *E. coli* I per 100 mℓ respectively. In March 1967, the situation was worse, the station to the north showed 2 450 *E. coli* I per 100 mℓ, while that to the south showed 99 200 *E. coli* I per 100 mℓ. This deterioration was probably due to an increase in the effluent load brought about by industrial and urban expansion. It is reasonable to assume that in the absence of the new treatment works and pipeline, the bacteriological picture of these surf stations would have continued to deteriorate. In marked contrast to this, the findings on both the north and south stations for November 1973, after the diversion of all the effluents, were 4 *E. coli* I per 100 mℓ.

Faunal counts

As higher levels of organic pollution generally support denser faunas, faunal changes were assessed on the basis of density. Oliff *et al* (1967a) found faunal density to be a reliable indicator of biological activity and hence also the long term state of enrichment or pollution of a beach. An attempt was made to incorporate species diversity in the evaluation but this was abandoned due to the exceptionally wide range of densities encountered. The predominant organisms recovered from the samples were nematodes, oligochaetes; the archiannelid genera *Polygordius* Schneider, *Protodrilus* Hatschek and *Saccocirrus* Bobretzky; the pisionid polychaetes *Pisione africana* Day and *Pisionidens indica* (Aiyur and Alikunhi) and the interstitial isopod *Angeliera phreaticola* Chappuis and Delamare. In order to assess the overall changes in faunal density, geometric and arithmetic means were calculated for all samples in each survey. These were plotted against time (Figure 2B). High mean faunal densities were recorded in 1964. Considerably lower figures were recorded on the next sampling date in mid-1970, followed by increasing values during 1971 and a gradual decline from 1972 onwards. In the light of the known pattern of effluent flow in the vicinity of the canal these trends are expected. The high values recorded in 1964 can be attributed to the direct discharge of organic effluents and the lower figures in mid-1970 to the diversion, in November 1968, of these effluents to the offshore pipeline. The high levels of faunal density during 1971 and the subsequent decrease are correlated with the discharge of the organic industrial effluent which continued to flow onto the beach until it too was diverted to the offshore pipeline in November 1971.

Although arithmetic and geometric means have been used to illustrate the general trends in faunal density, it must be mentioned that considerable variation in faunal counts occurred frequently. The mean values therefore do not reflect accurately the situation at individual stations. High arithmetic means were usually brought about by high faunal densities at a few of the stations, while geometric means were less affected by occasional high results. This effect can be seen in Figure 2A where divergence of the arithmetic and geometric means is greatest when faunal densities are high and least when faunal densities are low. The degree of divergence of the two means can thus be used as a measure of uniformity of the faunal density for a particular series of samples. On this basis uniformly low faunal densities are seen to have been present from September 1972 onwards indicating unenriched conditions in the beaches. On only two occasions since that date did the faunal density exceed the 300 organisms per 18 litres level, suggested by Oliff *et al* (1967a) as the limit for unenriched conditions. On both occasions this occurred on the south bank of the canal and the marginal level of the increase suggests low level localised enrichment. From September 1972 onwards the beaches have generally remained unenriched.

Extraneous factors

Before a conclusive assessment of the recovery of the beach can be made, other factors which may have influenced beach condition need consideration. Three of these factors are sand movement, particle size variation and the influence of ground water. All of these factors can be expected to vary seasonally, in response to the prevailing weather and sea conditions. A slight deterioration of the beach was observed in April 1972 after earlier signs of a recovery in January and February. This was probably due to the erosion of sand during this period which caused the beach level to drop by at least one metre with exposure of lower, still enriched, layers of sand.

Particle size may influence the recovery process in two ways. Firstly, coarser sediments may allow more rapid flushing out of pollutants than finer sediments, thus speeding up the recovery process. Secondly, we have found that fine sediments normally tend to contain higher concentrations of organic materials, presumably because they trap organic matter, silt and debris in the smaller interstices and have larger surface areas available for adsorption. However, since the mean particle sizes remained fairly constant throughout the survey (Figure 2A) it is reasonable to conclude that the reduced concentration of organic materials was in fact due to diversion of the effluent.

The high nitrate concentrations recorded during February 1974 (Fig 4A) were probably due to ground water movement from a residential area above the beach and may be associated with the system of septic tanks which still operates in the area. The survey of February 1974 was made after heavy rains and ground water was observed to be flowing strongly. This was also borne out by greatly reduced salinity levels in both the interstitial and the surf water (Figures 3A and B).

No evidence was obtained of regular seasonal variations in the other parameters that were measured.

Beach recovery

Considering the overall changes which occurred in both the chemical and faunal parameters after the diversion of the effluent, a period of approximately six months was required for the beach to revert from an enriched to an unenriched state. The recovery apparently took place in two stages. Firstly, rapid recovery soon after the diversion of all organically laden effluents from the surf zone, followed by deterioration possibly as new areas of polluted sand were exposed by erosion and, secondly, final recovery to its present condition. It must be borne in mind that each case of organic pollution is unique and that the rate and extent of recovery depend on many variables.

Offshore effects

During 1972 two surveys were made of the chemical and biological conditions in the vicinity of the discharge of the offshore pipeline to which the effluents were diverted. On neither occasion was evidence of enrichment obtained and it therefore appeared that the calculated dispersion of effluent was in fact being attained. It is clear that the diversion of the effluent, while greatly benefitting the beach environment, did not materially affect the offshore environment.

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The Activated Sludge Process Part II – Dynamic Behaviour

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