BACTERIOLOGICAL POLLUTION OF RIVER KADUNA

Thesis

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BY

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DECLARATION

This is to certify that the work presented in this thesis is original. It was carried out by me at the laboratories of the Department of Microbiology, Ahmadu Bello University, Zaria and also at the laboratory of the National Water Resources Institute, Kaduna, under the supervision of Dr. N.E. Gomwalk of the Department of Microbiology and Dr. Charles Okuofu, Department of Water Resources and Environmental Engineering both of Ahmadu Bello University, Zaria, Nigeria.

The works of other investigators referred to are duly acknowledged.

No part of this thesis has previously been submitted for any degree or a diploma.

F.S. OGBONDEMINU

A.B.U., Zaria
July 1987

CERTIFICATION

This thesis entitled "Bacteriological Pollution of River Kaduna" by Ogbondeminu, F.S. meets the regulations governing the award of the degree of Master of Science (M.Sc.) of Ahmadu Bello University, Zaria, and is approved for its scientific knowledge and literary presentation.

Chairman, Supervisory Committee	24/12/87 Date
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D E D I C A T E D

To

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Late M.A. Ogbondeminu 1924-1985

Late A. Job 1953-1986

Late E.T. Ekundayo (nee Falodun) 1954-1987

Late J.O. Awolowo 1909-1987

and

to all that love cleanliness

of our water

bodies

A B S T R A C T

The bacteriological pollution of River Kaduna was investigated between November 1985 and October 1986.

The membrane filtration technique was used for the enumeration of faecal indicator bacteria which included total coliforms, faecal coliforms and faecal streptococci, while the plate count technique was used for total aerobic heterotrophic bacteria. Selective enrichment isolation of Salmonella sp., was also carried out.

The highest counts of indicators were obtained from those sites receiving some domestic wastes.

Total coliform densities ranged between 6.6 x 10^5/100 ml and 3.3 x 10^6/100 ml, while faecal coliform densities varied from 1.1 x 10^4/100 ml to 1.5 x 10^5/100 ml. Faecal streptococci counts of 1.5 x 10^5/100 ml was obtained at the most polluted site.

Total aerobic heterotrophic bacteria plate counts were often > 10^6/100 ml at sites downstream of the wastes outfalls.

Bacterial densities varied seasonally. The dry season was characterized by higher indicator bacterial densities than the wet season.

Faecal coliforms to faecal streptococci ratios show that Kaduna River is polluted by human wastes.

Klebsiella pneumoniae was the dominant enteric bacteria identified in the river water. Other species were *E. coli*, *C. freundii* and *Enterobacter aerogenes*. *Salmonella* sp. were few in the river.

The dissolved oxygen concentration was low in the vicinity of the outfalls from residential and industrial areas. High biochemical oxygen demand (BOD) and conductivities were observed at these sites especially in the dry season.

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CHAPTER 1

INTRODUCTION

Regardless of geographical location, the causes and problems of water pollution are basically the same throughout the world. Among the major sources of river pollution are wastes and wastewaters of domestic and industries of urban areas.

The introduction of these wastes and wastewaters introduces decomposable organic matter into the receiving streams. Rivers have therefore, become repositories of both treated and untreated domestic and industrial wastes.

Although rivers within limits are self purifying systems, there is tendency for them to receive wastes beyond their purification capacities and could deteriorate significantly. Consequently, the beneficial uses of the river water may be impaired. For instance, water pollution by bacterial, protozoa, helminths, parasites, toxic materials, heavy metals, long chain hydrocarbons and oils could be health hazards. It could also cause the destruction of aquatic life, detriment to agriculture and could be a costly liability to industry.

To man, one of the most serious problems arising from water pollution is the occurrence of water-borne diseases. The aetiological agents of cholera, polio, water-related gastroenteritis, dysentery, typhoid, viral hepatitis have been found to be closely related to water (Roy, 1971, Bordner and Carrol, 1972; Carpenter, 1980).

In the last two decades, there has been improvements in the economies of some developing countries in Africa. Consequently, population and industrialization of cities have grown rapidly giving rise to urbanization. This has accelerated the problems of waste disposal.

Wastes from urban centres in most of these developing countries of Africa are being indiscriminately dumped into open drains. In the absence of water pollution control and effluents discharge regulations, the disposed urban wastes, domestic and industrial wastewaters through open drains end up in streams and rivers, which are also main sources of water supply to the people and the industries.

In Nigeria, increase in population and intensification of industrial, agricultural, commercial and recreational activities are already causing considerable deterioration of the quality of our inland and coastal waters. Studies by Osuhor and Essien (1978), Odeyemi (1982) and Oluwande et. al (1983), gave clear indication of pollution of many Nigerian rivers and streams especially of those passing through urban areas.

Some workers like (Osuhor and Essien, 1978, Esu and Omololun, 1981; Beetsch, 1982, Chukwukelue, 1983, Ahmed and Beecroft, 1987), have shown that the industrial wastes and wastewaters discharged into Kaduna River contain some chemical pollutants. This could be hazardous since the river is the main source of water supply to Kaduna metropolis and the numerous industries.

The public health aspects of the disposal of the mixed wastes from Kaduna metropolis and the industries into river Kaduna has never been investigated.

In this study, bacteriological quality assessment of Kaduna River and those of the wastewater was undertaken to determine the extent of pollution of the river and the wastewaters by monitoring the densities total and faecal coliforms, faecal streptococci with total heterotrophic bacteria. Also, attempts were made to determine the relationships between the densities and distribution of total coliforms, faecal coliforms and faecal streptococci. Additionally, the isolation of _Salmonella_ _sp_. from the river was attempted.

CHAPTER 2

REVIEW OF LITERATURE

An aquatic environment is composed of both biotic and abiotic components which are closely interrelated. These interrelationships may be interrupted by several factors. One of such factors is the introduction of wastes to the waters. The extent of disruption depends on ~~the~~ volume, concentration and quality of the waste; and the self-purifying capacity of the receiving waters.

A considerable amount of work has been carried out on river pollution especially in temperate regions. Among the pioneering research in the field of stream sanitation are those of Streeter and Phelps (1925); Fair et. al (1941); Thomas (1948); and Velz (1970). They carried out investigations on various aspects of North American rivers and streams.

In recent years, the discharge of pollutional wastes into aquatic environments has had adverse effects on aquatic biota. The works of Ferris et. al (1980); Biamon and Hazen (1983); and Francisco et al (1983) bear testimony to this.

Since the early 1970s', it has become increasingly evident that waste discharges are impairing water quality in many parts of Africa. In certain cases, important sources of water supply have been destroyed. The causes of this deterioration of water quality include the accelerated growth in population coupled with increased urbanization; and the rapid industrialization of a few cities from where considerable wastes are discharged into water courses.

Effect of Industrial and Domestic Wastes On the Bacteriological Quality of Water

A survey of literature pertaining to work done in the last decade shows that industies are a major source of pollution of rivers and streams. One of the most polluting industries is the pulp and paper mill industry which is associated with a high biochemical oxygen demand ($> 3 \times 10^3 mgL^{-1}$). The work of Rokosh *et al* (1977); Huntley *et al* (1976); Hendry *et al* (1984); Couillard and Trudel (1981), and Hazen and Esch (1983) have shown that wastes from paper and pulp industries contributed to the thriving of different micro-organisms in water. Rokosh *et al* (1977) for example, measured the distribution and densities of aerobic heterotrophs, sulphur cycle bacterial and health oriented bacterial populations (coliforms faecal coliforms, and faecal streptococci), in Lake Superior, U.S.A which receives a point source pulp-mill effluent. They obtained maximum bacterial populations within 250 metres of the effluent outfall. Aerobic heterectrophs for instance, averaged 4.6×10^5, ml^{-1} in the 250 m distance.

Hendry *et al* (1982) conducted a study to detect the source of faecal indictor bacteria and to measure the resulting impairment of the quality of Sturgeon River in Ontario, Canada, which receives pulp and paper wastes. The authors found that the principal input of faecal bacteria was the paper mill. A fifty-fold increase in density of aerobic heterotrophic bacteria was obtained as a result of the nutrient rich paper-mill wastewater discharged into the river during the months of June, to August, in 1977.

Couillard and Trudel (1981) evaluated the impact of pulp and paper waste discharges on a watershed, through a study of the biological, physico-chemical characteristics of the water of St. Francis River in wiscons in U.S.A. Microbiological monitoring of anaerobic bacteria, total coliform, and sulphate-reducing bacteria revealed that the source of the organisms was municipal wastewater treatment effluents, but the persistence of the bacteria downstream of the mill was attributed to the paper mill effluents discharged into the river during summer of that year. This work revealed that paper mill effluent is a source of nutrient for bacteria in the river.

The effluents of both a nitrogen fertilizer factory and a pulp mill discharged into Albermale Sound, North Carolina, were studied by Terry and Esch, (1983). They aimed at detecting the causes of the red-sore disease epizootics. They observed that the survival of Aeromonas hydrophila was enhanced by the pulp-mill effluent and depressed by the fertilizer factory effluent. The two sources were taken as being indirect causes of the red-sore disease because of the nutrients provided to A. hydrophila which consequently multiplied to infective dose capable of

[illegible] ly multiplied [illegible]
causing the red-sore fish-disease.

One industry whose expansion in tropical areas has been considerable in the past twenty years, is the rum distillation industry. Although few studies have been carried out on the utilization, treatment and disposal of distillery wastes, there are reports by Sheehan and Greenfield (198[illegible]) [illegible] Hazen and Esch (1983); and by Francisco _et al_ (1983) while the toxic and bacteriostatic properties of the undiluted effluents were reported by Gonzalez _et al_ (1979).

Biamon and Hazen (1983) reported that drastic changes take place in temperature, dissolved oxygen, pH, inorganic and organic nutrient content, and chlorophyll _a_ concentration, when rum slops are pumped into marine bays. In this study, Biamon and Hazen found a strong correlation between the concentration of chlorophyll _a_ density of _Aeromonas hydrophila_ and the density of faecal coliforms in the rum distillery effluents. The authors also found that the densities of several pathogens including _A. hydrophila_, _Escherichia coli_, _Vibrio cholerae_ and _Pseudomonas aeruginosa_ were high in effluent plume. Survival studies with diffusion chambers showed that some of the bacterial isolates can survive and multiply in the rum effluents. They therefore, held the view that rum-distillery effluents can be an important source of potentially pathogenic bacteria in tropical environments.

In a study on bacterial chemotaxis to rum distillery effluents by Francisco et al (1983, Pseudomonas aeruginosa and Vibrio cholerae were observed by these authors to show a strong positive chemotactic response to rum distillery waste-waters, and a high oxygen uptake in the presence of this complex substrate. Rum slops, they noted, stimulates only motility in A. hydrophila and E. coli.

The dumping of pharmaceutical wastes into surface waters and the consequent effect on the microbial communities of the receiving waters have been subject of investigation. Few of the published works include those of Peele et al (1981), Singleton et al. (1983); and Grimes et. al. (1984).

The microbiological effect of undisinfected efluents of chemical, pharmaceutical and domestic sources discharged into waters of Barcelonia, Puerto Rico as investigated by Grimes et. al. (1984), indicated that undisinfected mixed wastes could be potential sources of pathogenic bacteria which are of public health significance. The authors observed on application of statistical (F-test) that the plume created around the sewage outfall, located 800m offshore and 300m below the water surface contained faecal coliforms and faecal streptococci populations that were significantly larger than counts outside the effluent plume, Salmonella and Vibrio spp, including V. Cholera non -01 serovar were isolated from the plume. These findings show how health risks may be associated with combined wastes discharged into waters.

Mitchell and Funke (1982) investigated the extent of pollution of Red-river valley of North Dakota. They identified wastewaters from the Minnesota sugar beef refinery as the source of faecal coliforms and Salmonella spp., that pollute the Red river. Salmonella populations reached 1.46 x 10^6/100ml at the eleventh day of the wastewater discharged into the water.

Pollution of water by acid wastes and heavy metals, and their public health implications

Acidification of surface water is now a recognized problem in some areas of Europe and North America. The consequence of depositing acidic substances into surface water is that water is considerably polluted. Such deposition has also been found to cause the elevation of the concentrations of major cations, heavy metals and sulphates in the waters (Wright 1983).

The potential effects of acidified water and their constituents have been under investigation for sometimes because of the health related problems that could be associated with the acidification of public and private supplies. For instance, Taylor and Symons (1984), found that acidified water supplies contained aluminium at elevated levels which may cause kidney dialysis. Young and Sharpe (1984), evaluated water quality in forty catchment cisterns and found that the cisterns contained lead, cadmium and copper, though the concentrations were below the primary drinking water standard. They also observed that the bottom sediments and the water inferface(s) had concentrations that exceeded drinking water limits for pH and cadmium.

Fulis (1984) found that surface water and shallow ground-water supplies in the Adrion Dark Region of New York State were corrossive, but that copper and lead were not present in significant concentrations to affect human health.

The discharge of acid from industries, from mine-drainage and coal-mines into rivers and streams have characteristically resulted in an environment of excessively low pH. The pollution of water by acid wastes and their effect on aquatic organisms like fish and bacteria have been reported by Hackney and Bissonnette (1978), Double and Bissonnette (1980),and Nancy et al (1983).

Hackney and Bissonnette (1978) found that a substantial portion of bacterial populations (Streptococcus faecalis, Escherichia coli, and Enterobacter aerogenes) in an acid polluted water were killed, while significant numbers were sublethally injured. Nancy et al (1983) reported on the persistence of natural populations of indicator organisms associated with sewage exposed to acid mine drainage. Indicator organisms (total coliform, faecal coliforms and faecal streptococci) were found to be rapidly killed upon exposure to the acid mine system. Only at lower temperatures were faecal streptococci found to survive better than faecal coliforms.

Effects of Wastes on Aquatic Organisms (Macro-invertebrates and Fish)

Several types of stress are frequently introduced to aquatic environments when discharges from industries and domestic wastes are applied. Industrial effluents often contain pollutants that are toxic to the biota of the receiving streams. Some affect the standing crop biomass of macro-invertebrates and fish communities in shallow waters. Among the research work on industrial effluent toxicity to aquatic organisms are those of Nyholm et. al. (1977); Gower and Buckland. (1978); Ferris, et. al. (1989), Rowe, et. al. (1983), and Sloff (1983). For example, Ferris, et. al. (1989) studied the effect of cattleskin tannery waste on the main stem of the Sebasticook River, Maine, USA. They observed that the total number of benthic invertebrates was reduced by nearly 60% in the river.

[illegible] other [illegible] isms [illegible]
[illegible] outfall [illegible] tannery [illegible].

The effect of petroleum refinery on rainbow trout (Salmon gardneri) was studied by Rowe et.al (1983). They observed that partially treated refinery effluents have adverse effects on the growth of the Salmon by causing a significant reduction in their specific growth rate.

The toxicity of crude oils and their various constituents to fishes have been investigated by Curtis et al (1979) Shukla and Panelly (1985). Curtis et al (1979) observed that crude oils and their various constituents affected different stages of the developments of the fishes studied.

Saxena and Raminder (1983) studied the effect of vegetable oil factory effluents on ovarian recrudescence in the freshwater teleost, Channa punctuatus B.1. The authors found a significant retardation of the maturation of the teleost when the ovaries were exposed to 5% sublethal concentration of the vegetable oil factory effluents. Low ovarian weights and low occurrence of stage III (Yolky) oocytes, coupled with artesia were observed in the fish.

Apart from the adverse effect of vegetable oil effluents on the reproductive cycle of fish, studies carried out by Sloff (1983) on Abramis brama (catfish) collected from River Meuse and Lake Braassem in the Netherlands showed that, skeletal deformities - deformed fins, assymetric cranium and spinal curvature of the fish could result from the discharge of treated effluents from oil refineries. Sloff (1983) was of

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the view that some disease of fish and some pathological conditions occurring in fish (especially those with unusually high prevalence like papillomata, gill-hyperplasia and redsore epizootics caused by Aeromonas hydrophila), appear to have been potentiated by pollution, or triggered off by the occurence of oil pollutants in the river. This work and several others show the extent to which pollution can affect aquatic organisms.

Pollution Studies on Nigerian Rivers, Streams and Wells; and Their Public Health Significance

The expansion of Nigerian cities and the general trend towards urbanization of rural areas have been rapid in the last two decades. This rapid growth has been accompanied by changes in the quality of the environment of our cities. For instance, in May 1979, extensive pollution of water resources and damage to properties by industrial effluents in the Ikeja Industrial Estate of Lagos was reported in some daily news papers (Anonymous, 1979 A & B).

Studies on industrial effluents discharge by Martins (1958) indicated gross pollution of surface water of some parts of Lagos by industries in the Iganmu and Apapa Industrial Estate of Lagos. Similarly, Ahmed and Beecroft (1987) investigated waste-water production at Peugeot Automobile Nigeria (PAN), Kaduna. They carried out analytical investigations on the effluent which confirmed that the highly turbid waste of PAN is grossly polluted with heavy metal ions and organics. A mean chemical oxygen demand (COD) value of 940 mg^{-1} was obtained which indicated high organic constituents in the waste. Kaduna River will be the ultimate recepient of these PAN wastes.

The pollution of some Nigerian rivers, streams and well by faecal wastes have been reported by Smith (1975); Akpata and Ekundayo (1978); and Adesiyun et al (1983). In 1973, 5.8 million litres of faeces were reported to have been dumped into the Lagos Lagoon, and just within the first three months of 1974, 7.5 million litres of faecal materials were discharged (Akpata and Ekundayo 1978). With such a high level of faecal pollutant entering into Lagos Lagoon, the users of the lagoon will be exposed to health risks.

Akinluyi (1981) isolated pathogenic micro-organisms from Niger Delta waters. Isolates include K. pneumoniae, Salmonella,sp, Shigella sp, and P. aeruginosa which are of public health significance.

Adesiyun et al (1983) analysed well waters in Katsina, for faecal pollution indicator organisms and pathogens. Faecal coliforms and non-cholera vibrio were detected in all the twenty samples they analyzed. The authors concluded that well water in Katsina could be a human health hazard.

Ajayi and Osibanjo (1984) studied the self purification process in the Ogunpa stream, Ibadan by a simulation model. They estimated reaeration and biodegradation constants of 11.45 and 3.33 [illegible] respectively. These results confirm to these authors that self purification in Ogunpa stream was fairly high.

Although literature relating to characteristics of effluents from industries and other waste sources and their effects on Kaduna river are still largely unpublished, the work of Ahmed and Beecroft (1987), that has been reviewed earlier and that of Osuhor and Essien (1978) are notable. Poor waste collection and disposal systems were among the significant factors listed by Osuhor and Essien (1978) to be responsible for insanitary practices in Kaduna capital Territory.

Application of bacterial indicators to water pollution determination

Bacterial populations especially those of faecal coliforms, faecal streptococci, *Clostridium perfringens* and *P. aeruginosa* have often been used to study regrowth phenomena in industrial and domestic effluents. Many of these organisms have been shown to be restricted in their use to areas near the source of pollution. In contrast, some sporeformers have wider applicability and can indicate remote pollution. This feature is found in *Cl. perfringens*.

Bisson and Cabelli (1980) have found that Cl. perfringens is useful as an indicator of recreational water quality, a monitoring agent for examining chlorinated drinking water and as a supplementary indicator to determine the nature and proximity of sources of faecal contamination. Despite the usefulness of Cl. perfringens as enumerated by Bisson and Cabelli (1980) earlier work by Cabelli (1978) showed that the numbers of Cl. perfringens in faeces and unchlorinated sewage is much less than observed for other indicators in use.

Some bacterial pathogens - Salmonella sp., P. aeruginosa, Mycobacterium and Staphylococcus spp have also been suggested useful as indicators in wastewater pollution studies (Scarpino 1972). The usefulness or otherwise of some of these pathogenic bacteria as indicators of water pollution is still under investigation and have not been fully established.

In most European countries today, standards, guidelines or criteria of raw water quality are framed in terms of maximum number of the bacterial indicators, to protect their water resources against water-borne and water-related diseases. Also, according to Shuval (1975), the designing of secondary treatment plants and disposal system have been fashioned to eliminate bacterial and other health-oriented organisms.

For an organisms to serve as an indicator, Bonde (1966) suggested that such an organisms or group of organisms should satisfy the following criteria:-

- the organism should be present only in the faeces of warm-blooded animals at density levels exceeding pathogen concentration.
- there should be a positive correlation between the indicator and faecal contamination and between the indicator and waters contaminated with faecal wastes.
- the persistence and regrowth characteristics of the indicator should parallel the most persistent water-borne pathogens.
- disinfection of water should produce similar kill rates for the indicator and the most resistant pathogens.
- procedures to detect the organisms must be simple and reliable, and defy false positive reactions.
- should have a high confirmation rate, so that the data may be used to enforce water-quality standards.

The above prerequisites restrict the probable candidates to total coliforms, faecal coliforms, faecal streptococci, Cl. perfringens and possibly to other anaerobic groups such as Bifidobacterium sp., Bacteroides sp., and lactobacilli.

The applications of total coliforms, faecal coliforms and faecal streptococci organisms used in this study in water pollution studies would be reviewed briefly in the next section.

The coliform index in water quality assessment

Total coliforms have been the traditional bacteriological tool for measuring the effectiveness of water treatment processes against faecal contamination (Kabler and Clarke 1960). They have also been used in assessing the quality of a variety of waters e.g. drinking water, treated effluents and irrigation waters. However, the reliability of coliforms as indicators of pollution depends on the selection of appropriate media and methods for their enumeration in water pollution surveys.

Many workers have developed and improved on some of the media and methods applicable to coliform enumeration. Among these are Barrow et. al. (1981); Vial and Geoffrey (1981); and Wright (1984).

Barrow et. al. (1981) made a comparison of the confirmatory media for coliforms and E. coli in water. Gas production by these organisms from Lauryl tryptose lactose broth (LTLB) was compared with that from Brilliant Green Lactose Broth (BGLBB), and were both compared with lauryl tryptose mannitol broth with and without, added tryptophan. They observed that at 37°C LTLB and BGLBB were both satisfactory for gas production but at 44°C, LTLB gave fewer false results, and was therefore less inhibitory than BGLBB. They concluded that the substitution of mannitol for lactose and the addition of tryptophan yielded a satisfactory medium for both confirmation of gas production and the demonstration of indole at 44°C.

Vial and Geoffrey (1981) compared membrane filteration technique (MFT) and Most Probable Number technique (MPN) with pour plate technique for enumeration of coliform organisms in surface waters. The authors held the view that MF and pour-plate techniques of coliform enumeration should complement each other to obtain a more precise results.

A new differential agar medium was developed by Wright (1984) for the enumeration of coliform organisms and E. coli. This he called Enriched Lauryl Sulphate Aniline Blue Agar (ELSAB).

Wright recommended ELSAB in preference to M-Endo Agar for membrane filteration. The media has not been tested enough for general acceptance.

The role of sediment in concentrating and harbouring coliform bacteria have been investigated by a few workers (Matson et. al. 1978; Grimes 1975 and 1980). They showed that stream sediments, beds or both can contribute significantly to harbour coliform organisms.

McDonald and Kay (1981) investigated variations in coliform bacteria concentrations during the passage of eleven precipitation induced hydrographs in two streams. They observed that increase in concentration of coliforms were in the order of 100 fold. Further work by McDonald et. al. (1982) offered explanation to the earlier observation of McDonald and Kay (1981). They stated that the surges of intestinal bacteria concentration during the rain induced precipitation hydrograph events is dependent on the characteristics of their sources. They identified two store sources within the stream system from which coliforms enter into the water column. The first store was in or near the surface of the land, while the second store might have been the stream sediments or algal sources.

Grimes (1975) investigated the release of sediment bound faecal coliforms during dredging operations of the Upper Mississippi River U.S.A. He found that faecal coliform concentrations increased significantly in the immediate vicinity of the dredging operation. This increase he attributed to relocation of bottom sediments by dredging and concomittant release of coliforms bound to sediments. In another work, Grimes (198-) found that hydraulitical dredging operation of the river led to the recovery of pathogens in greater than 70% of the water samples he analyzed. His work signifies that dredging of bottom sediments heavily contaminated with enteric bacteria could produce temporary health hazard.

Limitations to the Application of Coliform Indicators in Water Quality Assessment

The reliability of coliform as indicators of water pollution has been questioned by few workers (Gallagher and Spino, 1968; Dutka, 1973). These authors have observed that coliforms can reproduce in enriched waters and falsely indicate an elevated health hazard.

The occurrence of transferable antibiotic resistance plasmid and multiple drug resistance factors among coliforms isolated from wastewaters and pollutted waters has been documented by workers like Deboy et al (1980), Bell et al (1981) and Michael and Vennes (1985).

Apart from the question of regrowth phenomena and the occurence of several types of coliforms with antibiotic resistance strains as noted above the reliability of technique and procedures used to estimate coliform populations from water and sewage have also been frequently doubted

Several factors have been suggested that can affect the sensitivity of the membrane filter procedure in coliform detection. These include elevated turbidity of the water; injured coliforms (Lechevalier et al, 1983); high number of non-coliform bacteria (Clark, 1980); and the membrane filter type (McFeters et al, 1984; Burligame et al, 1984). This has led to the development of verification procedures. Lechevalier et al (1983) suggested that the verification rate of MF-total coliforms colonies could be improved by testing for the presence of B-galactosidase/oxidase compared with the verification procedure of gas production in lauryl tryptose broth.

The findings showed that significant under-estimations of coliform indicators densities may result particularly in water in which coliforms may be stressed or injured.

The faecal coliform Index in Water Quality Assessment

The application of faecal coliforms which includes, thermotolerant E. coli, Klebsiella sp, Enterobacter sp and Citrobacter sp as an index was comparable to those of MPN when used for faecal coliform enumeration in chlorinated effluents. Also, the method produces higher counts of faecal coliforms than the direct M-FC technique on samples from mountain streams and water containing biocide.

Green et al (1977) recommended pre-incubation period of 4 - 5 hours at 35°C followed by 15 - 18 hours at 44.5°C for standard MF procedure.

Page et al (1983) evaluated four MF methods for faecal coliform enumeration based on determination of accuracy specification, upper counting limit and recovery compatibility in six different laboratories. They obtained a recovery accuracy with pure culture ranging from 89 - 100% for M-FC, M-Tec and M-FC2 methods (the latter incorporating a 2-hour 35°C resuscitating period), but was less than 60% for MacConkey broth method. The recovery rate was highest with M-FC2 and M-Tec methods.

Recent approach towards coliform enumeration is the use of micro-MPN technique described by Hartel and Hagerdoon (1983). They compared this method with the elvated temperature standard MPN technique. A correlation of 0.86 with a 95% confidence level of $0.76 \geq \rho \leq 0.92$ was obtained. The micro-MPN technique is still being developed.

The Faecal Streptococci Index In Water Quality Assessment

Many workers have advocated the use of a streptococci index in place of or in conjuction with the coliform index for the assessment of water pollution (Geldreich and Kenner, 1969, Ranjt [illegible] and Surjya [illegible] 1970; Thaphijal [illegible] et al, 1970; Sayler et al, 1975; and Koh, 198[illegible]).

Slanetz, et al (1970); Cohen and Shuval (1973) and Kampelmacher et al (1977), have shown parallel survival of faecal streptococci with faecal coliforms and pathogens. Cohen and Shuval (1973) studying the survival of coliforms, faecal coliforms and faecal streptococci in sewage treatment plants, heavily polluted rivers, lakes and drinking water sources observed that, in general, faecal streptococci were more resistant to the natural water environment and to purification processes than the other indicator organisms, and that at point distant from the original source of pollution were often the only surviving indicators.

The work of Koh (1982) on water and wastewaters strongly supports streptococci index in water pollution studies. His findings indicated that faecal coliforms were more sensitive to chemical and physical treatment than Streptococci faecalis.

Several media are available for the enumeration and detection of faecal streptococci. In the United

Kingdom, the membrane enterococcus agar of Slanetz and Bartley (1957) is still in use, because of its selectivity and high confirmation rate (Daoust and Litsky, 1975).

Burman et al (1978) have shown that by incubating M-Enterococcus agar (M-EA) plates at higher temperature there is improvement in the confirmation rates of faecal streptococci. Development in streptococci detection involves the application of florescent antibody technique (FAT) (Abshire and Guthrie, 1971; Kenneth and Hartmann, 1983).

Kenneth and Hartmann (1983) developed a new medium called fluorogenic gentamycin thallous carbonate (FGTC) agar. The authors observed that FGTC agar will have good application in water, food and possible clinical microbiology.

The Use of Fc:Fs Quotient to Indicate the Source of Faecal Pollution

It has been suggested by Geldreich and Kenner (1969), Mara (1974) and Faechem (1975), that the ratio of faecal coliforms to faecal streptococci may be used to indicate the source of faecal pollution.

Human faeces and sewage have been shown to exhibit FC/FS ratio of 4. Conversely, in the faeces of animal, particularly those of cattle, the predominant streptococci is the S. bovis - equinus group which out-numbers the faecal coliforms to give FC/FS ratio of 8.7.

Feachem (1975) held the view that samples giving initial FC/FS ratio > 4 that decreased with time should indicate faecal pollution from human source, and those samples giving FC/FS < 0.7 which subsequently rose should indicate animal source.

The application of FC/FS ratio to identify source of pollution in tropical climate has not been fully accepted (Evison and James, 1973). This is due to difference in geographical distribution of faecal streptococci groups, as shown by the work of Oragui, (1978). It is therefore, important to verify the application of such ratio in the determination of the source of pollution in different environments.

CHAPTER 3

MATERIALS AND METHODS

MATERIALS

Study Area

Kaduna River with a drainage area of about 18, km² extends approximately 500 km in length from its source in Kujurma hills of Jos Plateau before it enters the River Niger near Pategi in Niger State of Nigeria (Appendix A). The entire Kaduna River basin covers an area of about 65, km² of which 53% is in Kaduna State.

Among the rivers which drain into Kaduna River are Romi in the south, rivers Kuyi and Gora in Rigachuku and Rigaga in the north. Along its course, about 10 km away from Kaduna is the Shiroro reservoir.

Kaduna municipality with more than 600,000 inhabitants is estimated to rise to about million by the year 2,000 A.D (Berger Inc., 1978). The municipal water supply is through Kaduna south waterworks and Kaduna north waterworks (shown in Figure 1).

The river demarcates the city into north and south. The southern part of Kaduna harbours most of the industries. The northern part of the city harbours institutions and few industries. Kaduna is highly industrialized with more than six giant textile mills, many food processing industries and breweries.

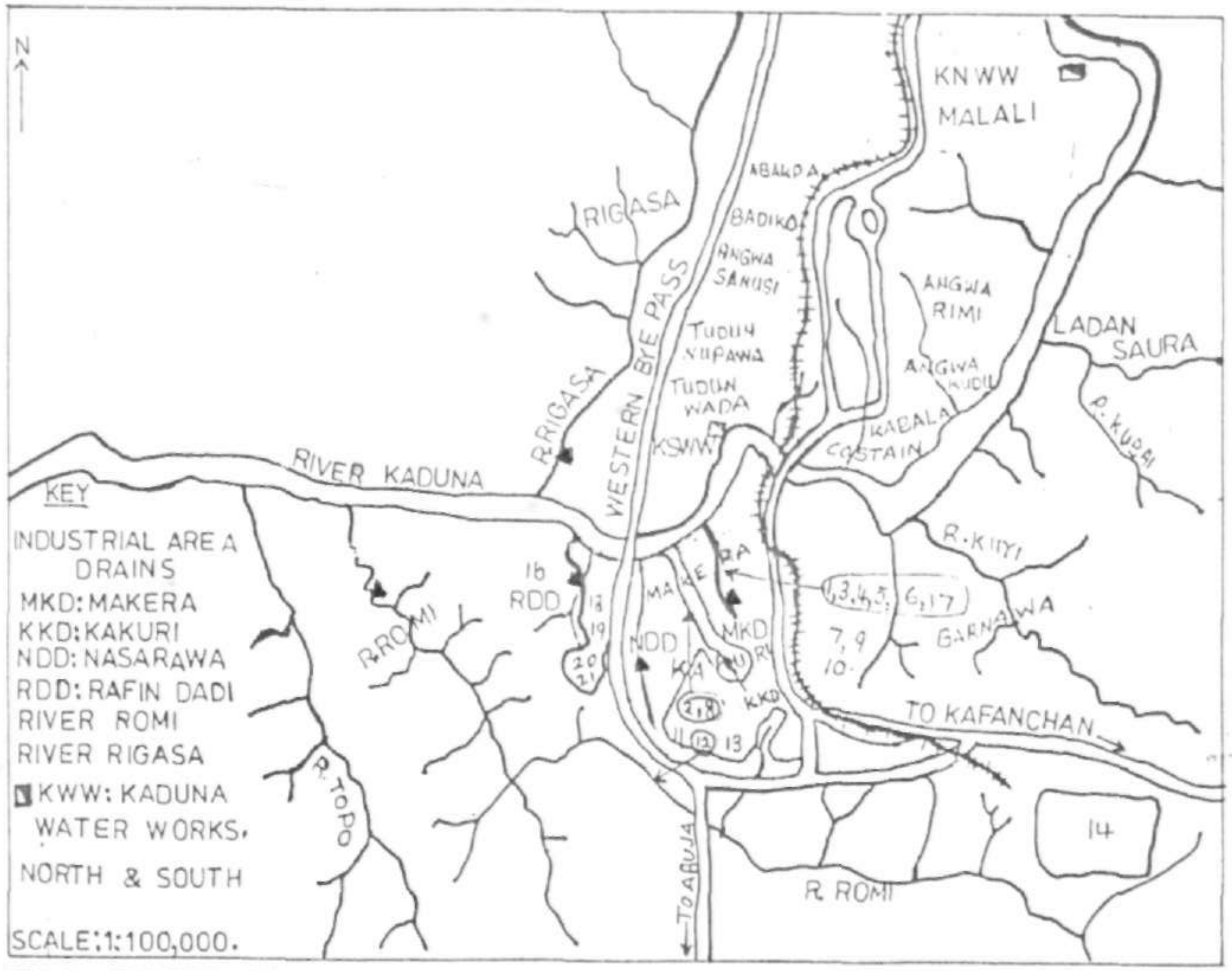

FIG 1 SKETCH MAP OF KADUNA METROPOLIS WITH THE INDUSTRIAL AREA DRAINS [▲] AND THE INDUSTRIES DISCHARGING INTO THEM, [NUMBERED]

There has been a rapid increase in the population of Kaduna over the last twenty years. Inhabitants are living on both sides of Kaduna river, but residential areas are more concentrated in the north of the river at Tudun Wada, Tudun Nupawa, Angwa Sanusi, Badiko and Abakpa. Other communities that have established near the banks of the river include the Federal Government College Malali, Angwa Rimi and Barnawa Housing Estates, Angwa Kudu, Kabala and Costain. To the south are Makera, Kakuri and Nasarawa residential areas.

The six industrial areas drains discharging into Kaduna River are the Makera, Kakuri, Nasarawa, Rafin Dadi, Rigasa and Romi . These drains with the industries discharging into them and the residential areas are shown on Figure 1. The names of the industries are listed in Appendix "B".

Description of the Main Drains Discharging into Kaduna River

Makera Drain (D-1)

This is a major drain receiving industrial wastewaters from United Nigerian Textile Mills Limited, Kaduna Textiles Mills Limited, Northern Nigerian Textile Mills Limited, Zamfara Textiles and Nigerian Breweries Limited. It enters the main river at a point about 500 m below Kaduna south waterworks intake. (Fig. 2)

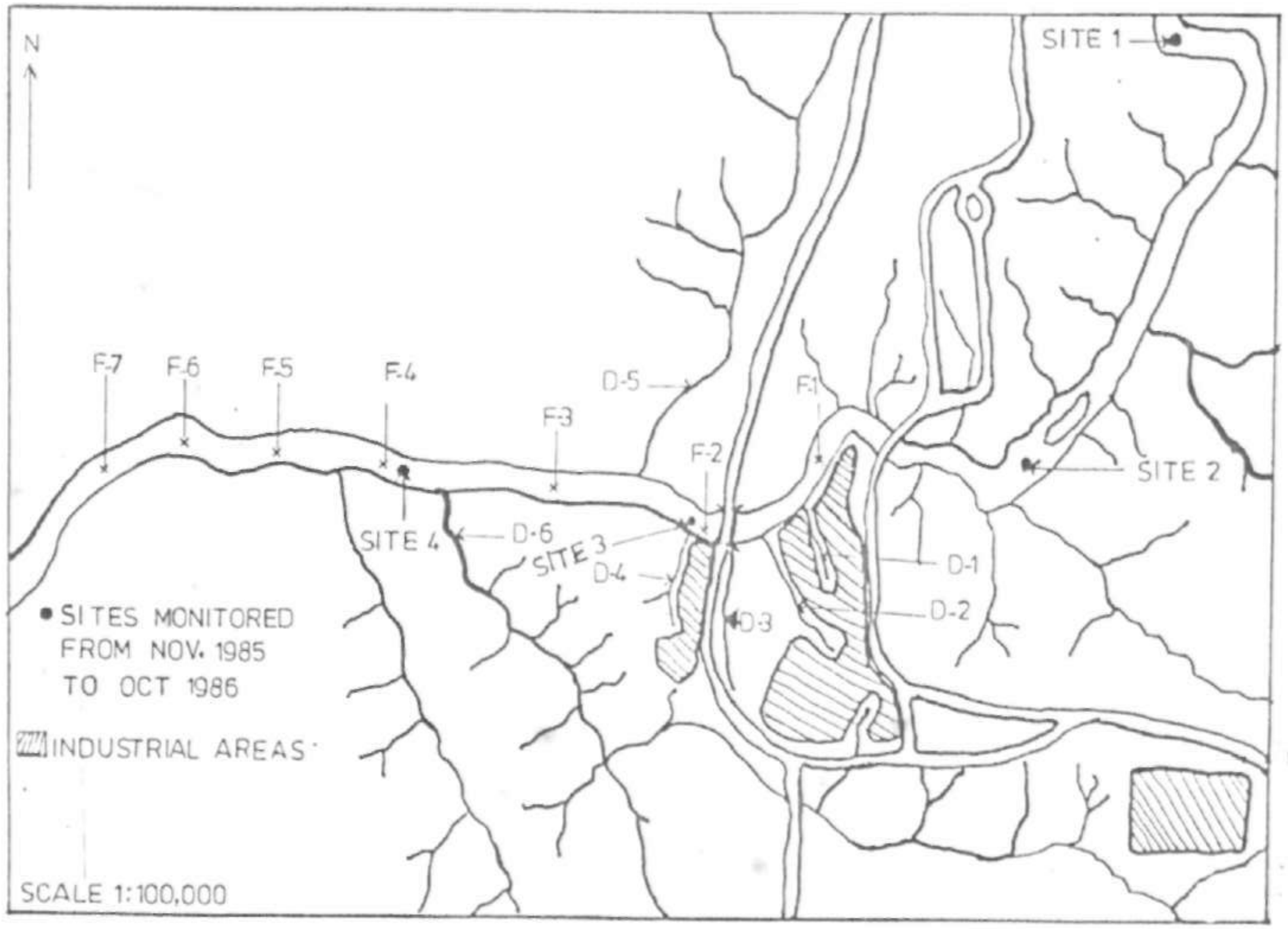

FIG. 2 LOCATION OF SAMPLING SITES (F1-F7 AND D1-D6) ON KADUNA RIVER AND DRAINS.

Human and other urban wastes litter the drain. This drain has highly odourous and coloured textile dye wastewater at the dry season period.

Kakuri Drain (D-2)

This drains part of Kakuri and Nasarawa villages carrying domestic and industrial wastewater from Norspin Textiles Limited, Arewa Textiles, Turners Asbestos, Federal Superphosphate Fertilizer Company, Nortex Nigerian Limited and Defence Industries Corporation. The wastewater is intensely coloured as Makera drain.

Nasarawa Drain (D-3)

This drains the fringes of Nasarawa village, carrying mainly sewage and other domestic wastes. It enters the river at the western bye-pass bridge at about 150 m to sampling Site 3 (Figure 2).

Rafi Dadi Drain (D-4)

This is the most important drain near Kudenda area. Drinko, Flour Mills, Berec, Chalco are some of the industries discharging into it.

Rigasa Drain (D-5)

This is one of the main tributaries to Kaduna River. Its basin serves part of Kaduna North, draining the western part of Kaduna River. It carries some urban wastes from Sanusi and Rigasa areas covering an area of about 94 km^2 (UNDP Consultants, 1978). It empties into Kaduna river at about 5 km from Kaduna south waterworks.

Romi Drain (D-6)

Its river basin forms the border development of Kaduna south. It drains Angwa Tiv and Kurasa areas. It receives industrial and domestic wastes from Nigerian National Petroleum Company, Arewa Bottling Company, Tower Aluminium Products Limited, Nigerian Bottling Company, and Peugeot Automobiles of Nigeria. Cultivated farmlands were situated along its banks.

The above described main drains were sampled between February 14 and 24, 1986, to assess their relative pollution loads, during the period of low water flow.

Sampling Sites

Locations on the river were chosen so that the effect of municipal and industrial wastewaters, cultivated land drainage, recreational areas, runoffs on the bacteriological indicators of pollution could be measured. The respective locations of the sites, the main drains, and industrial areas are shown in Figure 2. The following four sampling sites were monitored from November 1985 to October 1986:-

Description of Sampling Sites in This Study

Site 1: This is a river location just above Kaduna north waterworks intake. The site has no visible sewage drainage into it. It serves as a comparable site with relatively little or no visible source of pollution. It will provide the water quality information for Kaduna north waterworks.

Site 2: This is a river location near costain recreational park. It is downstream of Ungwan Rimi residential areas. Any pollution caused by the domestic and urban wastes through a small stream entering just above this site will be reflected here. It will provide water quality information for the recreationists at Costain Park utilizing the river for swimming especially by school-age children.

Site:3: This is a river location just below the western bye pass bridge. Any pollution caused by domestic and industrial wastes received through Makera, Kakuri and Nasarawa drains will be reflected at this site.

Site 4: This is a river location at the outskirt of Kaduna. Pollution caused through discharges from Rigasa and Romi tributaries and Rafin Dadi drains would be reflected at this site.

The following sites (F1 - F7) with the drains (D1 - D6) were monitored daily in the February survey to evaluate the variations in indicator bacterial densities with distance from site 3 above (Figure 3).

F-1: Sampling site at Kaduna south waterworks intake. This is to assess the pollution load at upstream location relative to sampling site F-2. It is about 3 km above site F-2.

F-2: Sampling site at western bye pass bridge similar to Site 3 as earlier mentioned above.

F-3: This sampling site is 8 kilometres downstream of site 2 located near Kaduna Polytechnic Farm. It could also reflect pollution loading through Rafin Dadi and Rigasa drains.

F-4: This sampling site is 13 kilometers downstream of F-2. The effect of pollution from Romi drain could be reflected at this site. Sand digging and collection are common events in this site during the dry season.

F-5 to 7: F-5, F-6 and F-7 are sampling sites at 15, 21 and 24 kilometers respectively from F-2 chosen to assess the probable self-purification of the river. These sites are all downstream from all major sources of pollution.

Washing and Sterilization of Glasswares And Filter Units

Glasswares were washed thoroughly with detergent and rinsed with hot water. Petri dishes and pipettes after washing, were sterilized in a hot-air oven for 1½ hours at 160°C (Report 71, 1969).

Washed filter holders and funnels were wrapped with aluminium foil and sterilized in an autoclave at 121°C for 15 minutes (APHA, 198).

Media and Their Preparations

The following dehydrated media were used for bacteriological analysis. M-FC agar (Difco), M-Endo Agar LES (Difco), M Enterococcus agar (M-EA (Difco), Plate count agar (Tryptone glucose yeast agar (Difco) MRVP broth (Oxoid), Simons' Citrate agar (Oxoid), Selenite broth (Difco), Triple sugar iron agar (Oxoid), Ornithine and Lysine decarboxylase medium base (Oxoid), Urea agar base (Oxoid), Motility test medium (Oxoid), Tryptone broth.

The dehydrated media were prepared according to manufacturers' instructions and specifications. Rehydration of media was with sterile distilled water and were freshly prepared prior to use.

METHODS

Collection of Water Samples

Raw water samples were collected from each of the sampling sites shown in Figure 1 in 500 ml sterile screw-crapped sampling bottles. The sampling bottle was held near its base and plunged into the water neck downward until full before the bottle was screw-capped, and transported in a portable cooler to the laboratory.

Water samples were collected between 9.00 a.m and 11.00 a.m. of each sampling day at forthnightly intervals for a 12-month period (November 1985 to October 1986).

Serial Dilution of Water Samples

Ten fold serial dilutions were made from the water samples using sterile phosphate buffer solution prepared according to standard methods (APHA, 1980). Aseptic conditions were maintained at all times during the serial dilution procedure.

Analysis of Water Samples

Quantitative enumeration of indicator organisms (total coliforms, faecal coliforms and faecal streptococci) were carried out in conjuction with total heterotrophic bacteria counts. Samples for Salmonella isolation were kept in a refrigerator in the laboratory at the National Water Resources Institute, Kaduna and analysed within eight hours of collection.

Details of bacteriological procedures shown in Figure 3 are as follows:

Determination of Total Coliforms
Density by Membrane Filteration

Total coliforms were enumerated from 10 ml of diluted water samples using the membrane filteration technique on M-Endo Agar LES as described in standard methods (APHA, 1980). Incubation of plates was at 35°C for 24 hours. The number of sheened colonies appearing on the membrane filter were counted on a Gallenkamp colony counter illuminated with in-built bulb and a colony magnifier. Counts were recorded in terms of total coliform per 100 ml of water sample.

Determination of Faecal Coliform
Density by Membrane Filteration

Faecal coliforms were enumerated from diluted water samples on membrane filters (GN-6, 0.45 µm pore size, 47 mm diameter) placed on M-FC agar plates prepared without the addition of rosolic acid (APHA, 1980; Grabow et al, 1981). All plates were first incubated at 35°C for 4 hours, after which further incubation was done at 44.5°C for 18 - 20 hours (Rose et al, 1975). The development of blue colonies on plates was interpreted as evidence of the presence of faecal coliforms. Counting of the blue colonies was done with the aid of the illuminated Gallenkamp colony counter and recorded in terms of the faecal coliforms counts per 100 ml of water sample.

Confirmation of Faecal Coliform Colonies

All target bluish colonies taken from uncrowded membranes on M-FC agar plates were streaked on prepared plates of MacConkey Agar No.3 (Oxoid); and incubated at 35°C for 24 hours. Isolates were characterized by the following biochemical tests: Indole production, Methly red, Voges-Proskauer Citrate utilization, Hydrogen sulphide production, Motility test, Ornithine decarboxylase production, and Citrate utilization (Cowan & Steel 1965, Edward & Ewing 1972). Typical biochemical characteristics reactions for enteric bacteria and Salmonella identifications are shown in Appendix "C".

Determination of Faecal Streptocci Density by Membrane Filteration

Faecal streptococci (FS) were collected on the Gelman GN-6 membrane and plated on M-Enterocuss Agar (Difco) (APHA, 1971) and incubated at 44.5°C for 48 hours. All platings were done in duplicates using standard procedures (Bordner and Winter, 1978, APHA, 1980). All red, maroon or pink colonies were counted.

Standard procedures were used to confirm faecal streptococci colonies (APHA, 1988).

Determination of Total Aerobic Heterotrophic Bacteria Density by the Pour Plate Method

Total aerobic heterotrophic bacteria densities were determined on pour plate of tryptone glucose yeast agar (APHA, 1988). 0.1 ml aliquot of the

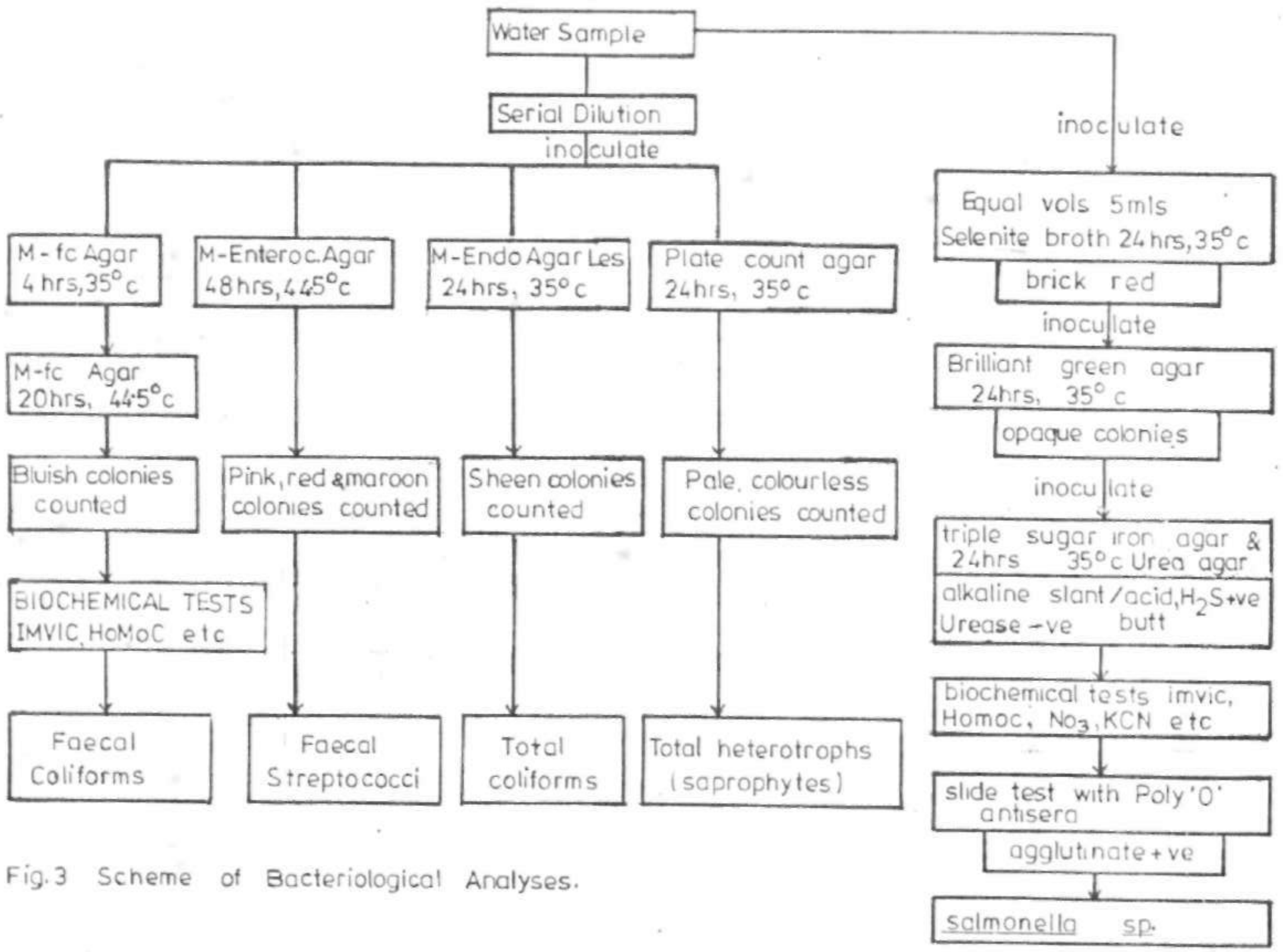

Fig.3 Scheme of Bacteriological Analyses.

serially diluted water sample was used for plating The plates were allowed to set incubated at 35°C for 24 hours. Methylene blue was applied to the surface of plates to aid in counting the opaque, colourless colonies following the staining procedure as described in Millipore manual (1967). Densities were recorded as total heterotrophic bacteria per ml of water sample.

Isolation of Salmonella

The occurence of Salmonella sp. in all the water samples were checked by inoculating 5 ml of double strength selenite broth (Difco) in tubes with 5 ml of water sample. All tubes were incubated at 35°C for 24 hours after which a loopful of the sample was streaked on Brilliant Green Agar (BGA) and incubated at 35°C for 24 hours (APHA, 1980).

Opaque, colourless colonies with red halo surrounding them were presumptively taken as Salmonella sp., and were inoculated into tubes of Triple Sugar Iron Agar (TSIA) slants. The butt of TSIA was stabbed and the slant streaked. Urea agar was also inoculated. Tubes were incubated at 35°C for 24 hours (Ewing, 1972).

Cultures yielding alkaline slant with acid butt producing hydrogen sulphide and urease negative characteristic of Salmonella sp were kept aside and subjected to biochemical tests using KCN broth, Simon Citrate, Sugars, Tryptone broth, Lysine decarboxylase broth, Oxidase and Gelatin liquefaction.

Cultures yielding reactions characteristics of Salmonella (Edwards and Ewing, 1972) were inoculated into motility test medium, to provide stock cultures which were later confirmed using Salmonella polyvalent O antisera. Positive controls were always included to confirm observed reactions.

Measurement of Selected Physico-Chemical Factors

Temperature of the water was taken on the field with Techno-laboratory thermometer.

The pH, conductivity and dissolved oxygen of collected water samples were measured in the laboratory with pH meter (Kent Model EIL 7055), conductivity meter Kent Model EIL 5007), and dissolved oxygen meter (YSI Model 57), respectively.

Biochemical oxygen demand (BOD) without suppresion of nitrification was determined following the procedure described in standard methods (APHA, 1980). Sample dilutions were made with distilled water when necessary in sterile 300 ml ground glass stoppered BOD bottles and were incubated at 20°C for 5 days. Initial and final oxygen concentrations were measured with the D.O. meter, B.O.D. was computed from the following relationship:

$$BOD_5 = \text{D.O initial} - \text{D.O final} \times \frac{1}{\text{dilution factor}}$$

Statistical Analysis of Data

The bacteriological data collected during the period of study were evaluated by statistical techniques carried out using statistical package for social sciences (SPSS) computer programming at the Computer Centre, Ahmadu Bello University, Zaria.

Statistically significant variations in the densities of measured indicator organisms between sampling locations were determined by Analysis of Variance (ANOVA).

CHAPTER 4

RESULTS

Distribution of Indicator Organisms in the Six Main Drains to Kaduna River

High bacterial densities were obtained for the drains. Table 1 shows that the minimum total coliform counts of 5.4×10^4 per 100 ml was obtained in Romi drain, while a maximum of 2.7×10^8 per 100 ml was obtained at Kakuri drain.

Makera, Kakuri and Nasarawa drains above sampling site 3 had mean total coliform densities of 1.2×10^6/100 ml, 4.5×10^6/100 ml and 2.01×10^8/100 ml respectively.

Below site 3 are Rigasa, Rafin dadi and Romi drains, these had mean total coliform densities of 1.2×10^6/100 ml, 5.90×10^7 per 100 ml, and 5.4×10^4/100 ml respectively.

Faecal coliforms had a minimum density of 1.2×10^2/100 ml at Makera drain and a maximum 4.2×10^8/100 ml at Kakuri drain. Higher mean faecal coliform densities were obtained in those drains above sampling site 3 at the Western Bye-Pass bridge, than the downstream Rafin Dadi, Rigasa and Romi drains. The mean faecal coliform densities was 1.06×10^4/100 ml at Makera drain 4.0×10^6/100 ml and 1.2×10^6/100 ml at Kakuri and Nasarawa drains respectively. Below site 3 mean

Table 1 - Mean Indicator bacterial densities in the six main drains to Kaduna River during the February Survey

Indicator Organisms	DRAINS					
	Makera (D-1)	Kakuri (D-2)	Nasarawa (D-3)	Rafia Dadi (D-4)	Rigasa (D-5)	Romi (D-6)
Total coliforms per 100 ml	1.2×10^{6}	4.5×10^{6}	2.7×10^{8}	5.9×10^{7}	1.2×10^{6}	5.4×10^{4}
Faecal coliforms per 100 ml	1.1×10^{4}	2.0×10^{6}	1.2×10^{6}	1.8×10^{6}	1.9×10^{4}	2.1×10^{3}
Faecal streptococci per 100 ml	1.8×10^{4}	1.3×10^{6}	4.2×10^{5}	5.2×10^{4}	1.8×10^{3}	4.4×10^{2}
Aerobic heterotrophic bacteria per 1.0 ml	4.6×10^{7}	1.8×10^{8}	1.5×10^{8}	4.5×10^{6}	3.1×10^{6}	8.1×10^{5}

faecal coliform densities were 1.8×10^6, 1.9×10^5 and 2.1×10^3/100 ml for Rafin Dadi, Rigasa and Romi drains respectively.

Faecal streptococci densities were generally lower than faecal coliforms in the drains. Romi drain had the lowest faecal streptococci count of 60/100 ml. The highest faecal streptococci count of 4.8×10^6 was obtained at Nasarawa domestic drain. The mean faecal streptococci densities for Makera, Kakuri and Nasarawa drains above sampling site 3 were 1.8×10^4, 1.3×10^6 and 4.2×10^5 respectively, while Rafin Dadi, Rigasa and Romi drains below site 3 had mean faecal streptococci densities of 5.2×10^4, 1.8×10^4 and 4.4×10^2/100ml respectively.

Total heterotrophic bacteria densities for Makera, Kakuri and Nasarawa drains were 4.6×10^7, 1.8×10^8 and 1.3×10^8/100 ml respectively. Below Site 3, Rafin Dadi, Rigasa and Romi drains had mean heterotroph densities of 1.5×10^6, 3.1×10^6 and 8.1×10^5/100 ml respectively. The lowest total heterotrophic bacteria density was 3.1×10^6/ml at Rigasa drain. The highest mean total heterotrophic bacteria density was 1.8×10^8/ ml at Kakuri drain.

<u>Distribution of Indicator Organisms in Seven Sampling Sites on Kaduna River During the February Survey</u>

There was a general variation in bacterial densities from sampling site F1 downstream to F7, for all indicator organisms used in this study (Table 2). However, a decrease in trend occurred at F5 through F7 for all organisms. Self-purification is evident in this sector of the river course though could be low.

The mean total coliform densities decreased from $9.2 \times 10^{[illegible]}/100$ ml at F2 to $8.7 \times 10^{4}/100$ ml at F7. Site F1 above Kakuri drain and at Kaduna south waterworks intake had lower levels of all indicator organisms than site F2.

Mean faecal coliform densities fluctuate with progressive increase in distance downstream of site F2 to F7 varying from $7.6 \times 10^{6}/100$ ml at F2 to $1.3 \times 10^{4}/100$ ml at F7.

Faecal streptococci densities varied from $3.9 \times 10^{5}/100$ ml at Site F3 to $1.9 \times 10^{3}/100$ ml at site F7. From site F3 downstream to F7 mean faecal streptococci densities decreased with distance.

The mean total heterotrophic bacteria plate counts ranged from $2.0 \times 10^{10}/1.0$ ml at site F2 to 2.4×10^{7}/ml at site F1. There was general fluctuation in total heterotrophic bacteria densities from one site to another.

Table 2 Mean indicator bacterial densities in seven sampling sites (F-1 to F-7) along the length of Kaduna River during the February Survey

Indicator Organisms	Sampling Sites With Distances (kms) on the River						
	F-1 (3) upstream	F-2 (6)	F-3 (8)	F-4 (12) Downstream	F-5 (15)	F-6 (21)	F-7 (24)
Total coliforms per 100 ml	2.0×10^5	9.2×10^7	1.7×10^6	1.0×10^5	3.4×10^5	1.8×10^5	8.7×10^4
Faecal coliforms per 100 ml	2.1×10^4	7.6×10^6	9.1×10^5	2.5×10^4	2.3×10^4	1.6×10^4	1.3×10^4
Faecal streptococci per 100 ml	1.0×10^4	1.2×10^5	3.9×10^5	1.2×10^4	2.2×10^4	2.2×10^4	1.9×10^3
Aerobic heterotrophic bacteria per 1.0 ml	2.4×10^7	2.0×10^{10}	2.0×10^8	2.7×10^8	7.9×10^8	7.7×10^8	5.7×10^9

( ) indicates distances in kilometres from sampling site F-4 taken as the reference point.

Variations in the densities of indicator organisms in four sampling sites on River Kaduna from November, 1985, to October, 1986

Total Coliforms

Total coliform densities varied at the four sampling sites throughout the period November, 1985, to April, 1986, which was the dry season.

In August, mean total coliform count of 2.6×10^4/100ml was recorded for site 1. The highest mean total coliform density of 2×10^6/100 ml was obtained at site 3 in May, 1986. From June, to August, the mean total coliform densities decreased in all the sites gradually to 10^4/100ml until September, before rising to 10^5/100 ml in October, in all the sampling sites (Fig. 4). Site 1 had maximum total coliform count $> 10^6$/100 ml in April. In May, sites 2 and 4 had their highest mean total coliform densities $> 10^6$/100 ml. Total coliform densities were significantly different from one site to another ($P < 0.001$).

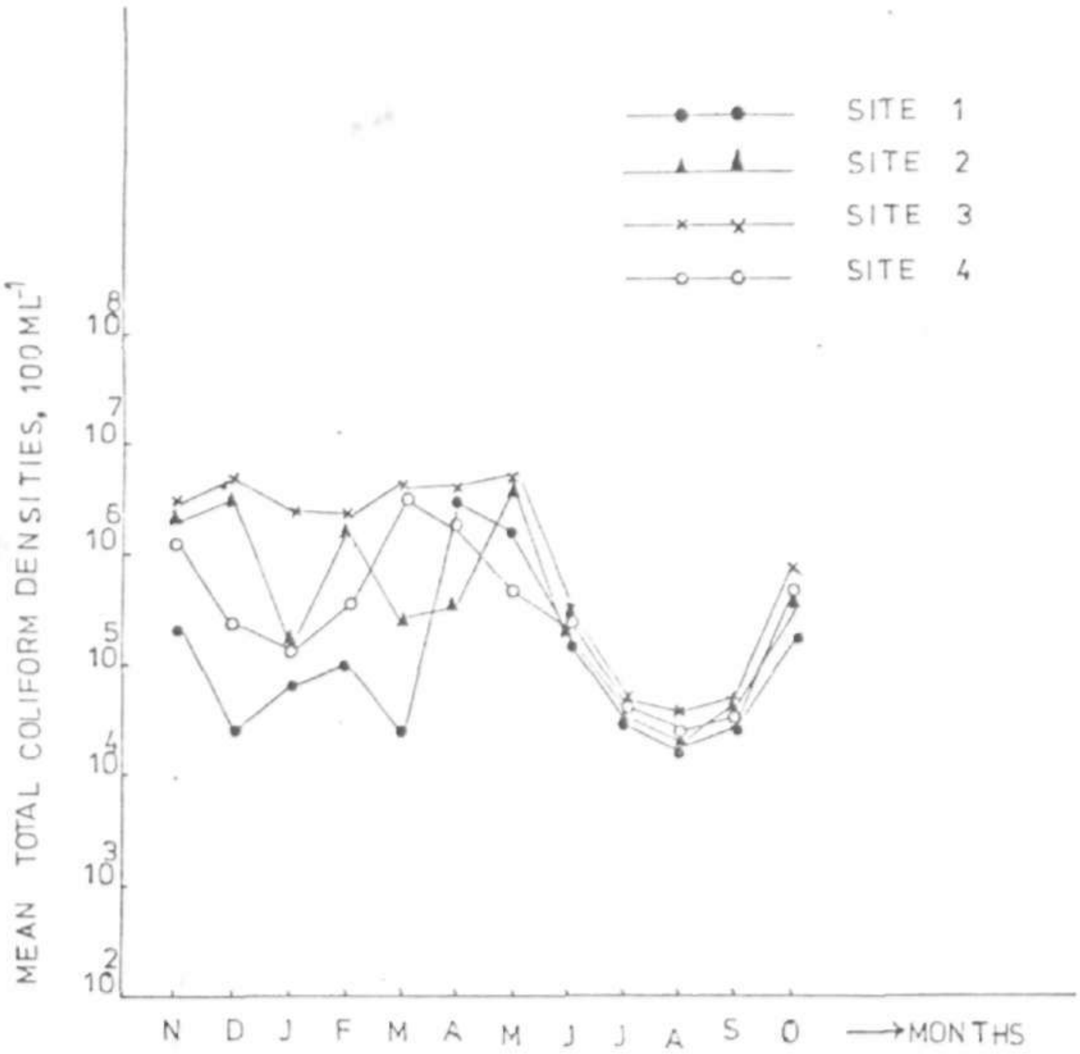

Fig-4 Mean monthly total coliform (TC) densities at four sampling sites on Kaduna river from Nov.1985-Oct.1986.

Faecal coliforms

The densities of faecal coliforms in Kaduna river varied from one sampling site to another (fig. 5). Faecal coliforms peak values occurred at different months of the year at all sampling sites. At site 1 highest mean faecal coliform density of 6.0×10^4/100 ml was obtained in April. In January 1986, mean faecal coliform density decreased in sampling sites, 2 to 4 but not in site 1, which later decreased in February to 10^3/100 ml. In May, maximum mean FC density was attained in sites 2 to 4. In June means faecal coliform densities decreased in all the sampling sites and remained fairly constant in sampling sites 2 to 4 until August. Site 1 mean faecal coliform density decreased to 10^2/100 ml in August before a gradual rise to 10^3/100 ml in September.

Faecal streptococci

Mean faecal streptococci densities in site 1 attained peak value in November, May, and October. At site 2 six peaks occurred in November, February, March, May, August and October, with mean faecal streptococci densities often lower than 10^5/100 ml. At site 3 the faecal streptococci densities reached peaks in November, March and May, with values $> 10^5$/100 ml. At site 4 the peak value of 10^7/100 ml was obtained in March, 1986. Lowest mean faecal

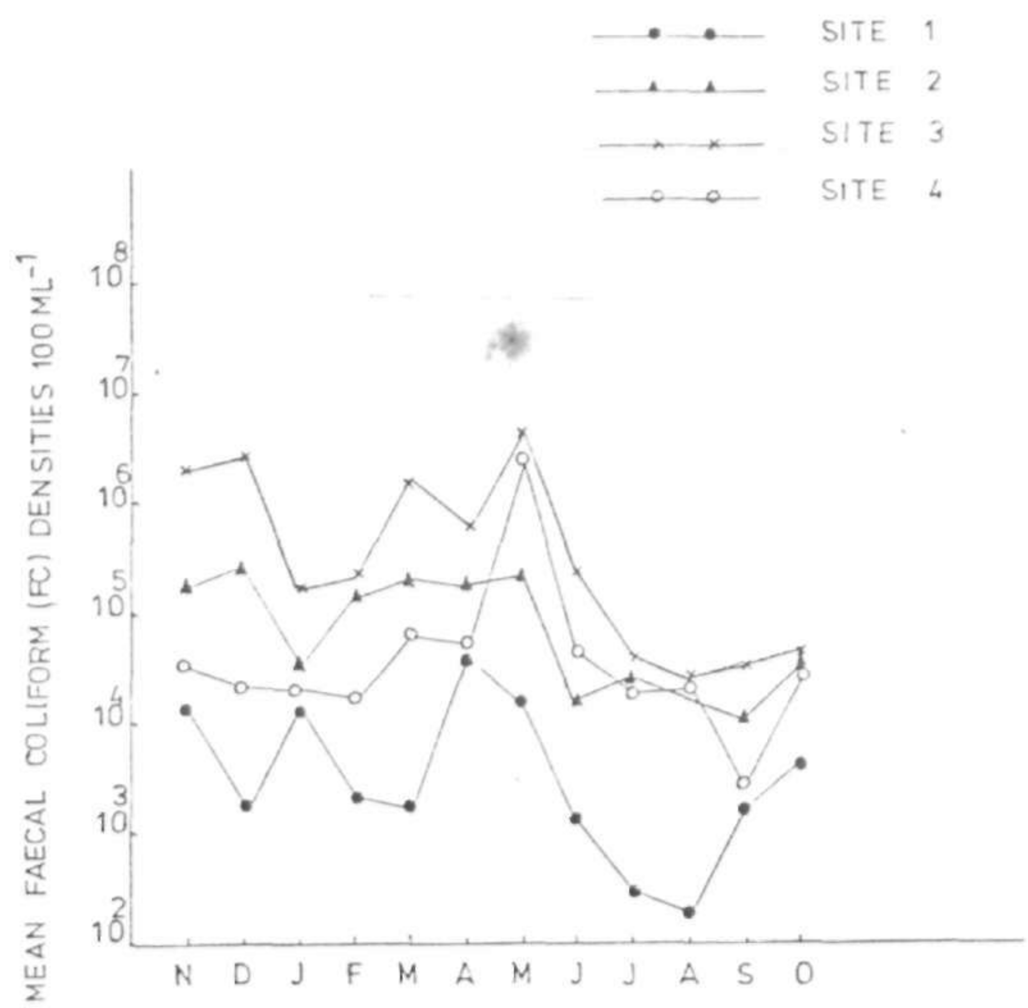

Fig. 5 Mean monthly faecal coliform (FC) densities at four sampling sites on Kaduna river. (Nov. 85 - Oct. 86)

streptococci densities were obtained between June and September in all the sampling sites with values $< 10^3/100$ ml (fig. 6). At sites 2, 3 and 4 the mean faecal streptococci densities increased in August, to $10^4/100$ ml, fell to $< 10^4/100$ ml in September before rising in October in all the sampling sites. As from December, 1985, to May, 1986 site 1 faecal streptococci mean densities behaved differently from sites 2 to 4. The mean faecal streptococci densities dropped sharply from a [illegible] value of $10^4/100$ ml in November to $10^2/100$ ml in December before the density rose gradually compared to sites 2 to 4. The mean faecal streptococci densities were significantly different by sites in Kaduna River ($P < 0.001$).

<u>Total heterotrophic bacteria</u>

Total aerobic heterotrophic bacteria in Kaduna river had mean densities that varied between $10^4/1.0$ ml and $10^6/1.0$ ml at sites 1 and 2, compared with sites 3 and 4 which varied from $10^6/1.0$ ml and $10^8/1.0$ ml (fig. 7).

Total heterotrophic bacteria mean densities $> 10^6/1.0$ ml were obtained during the dry months of November to April in all the sampling sites, with peak values in May and maintained till June, 1986, During the wet period, in July, . mean total heterotrophic bacteria densities decreased to values between 10^4 and 10^6/ ml in the four sampling sites. There was inter-site significant differences in mean

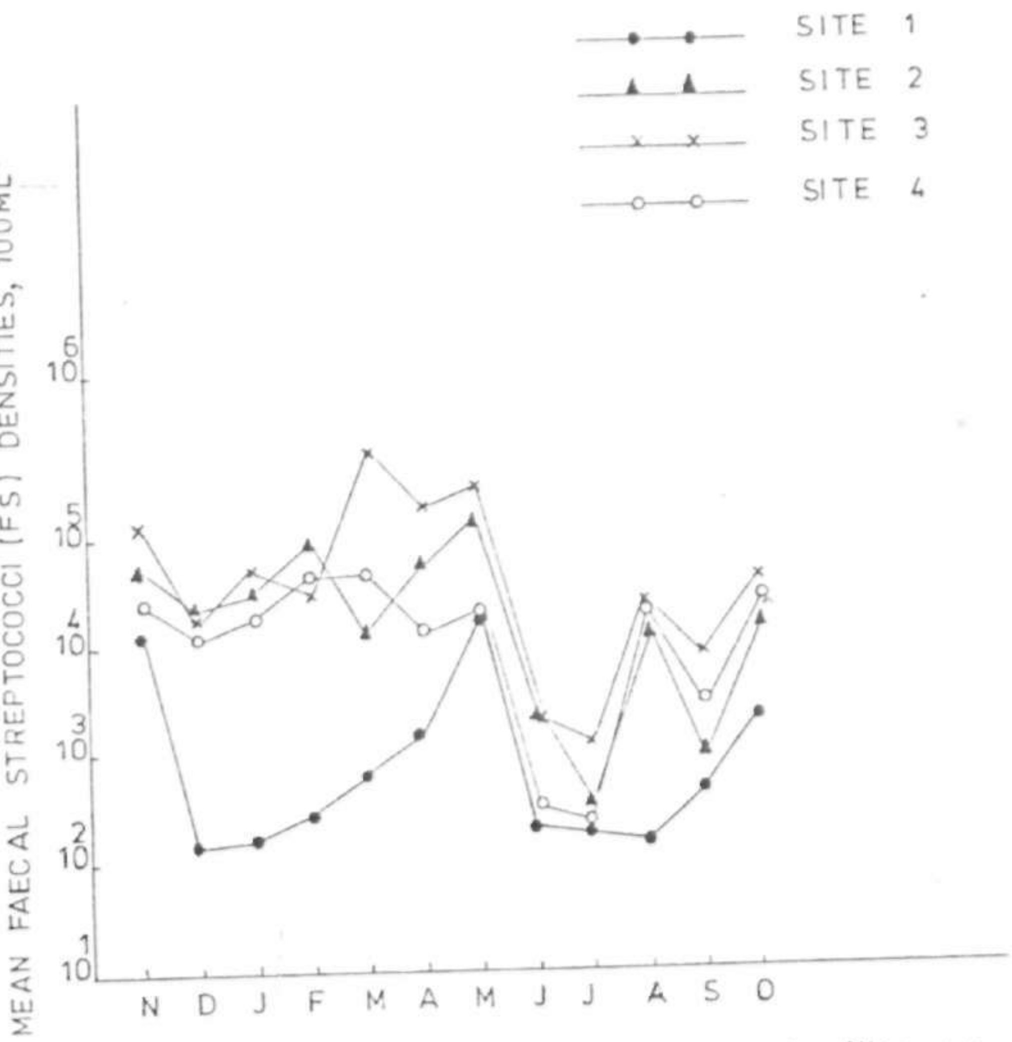

Fig. 6 Mean monthly faecal streptococci (FS) densities at four sampling sites on Kaduna river. (Nov. 1985 - Oct. 1986).

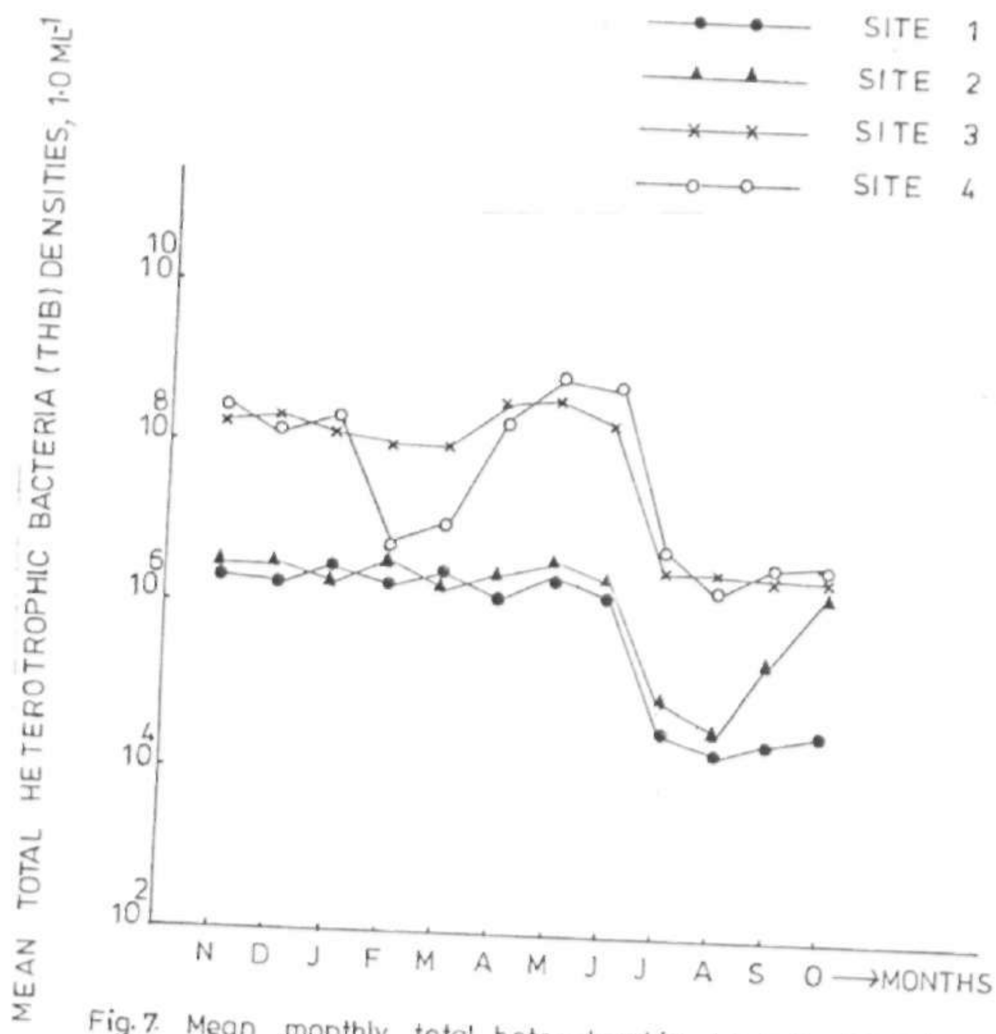

Fig. 7. Mean monthly total heterotrophic bacteria (THB) densities at four sampling sites on Kaduna river, (Nov. 1985 - Oct. 1986)

total heterotrophic bacteria densities ($P < 0.001$).

Relationship Between Faecal Coliforms and Total Coliform Densities in Kaduna River

There was variation in faecal coliforms to total coliforms ratios in Kaduna River from site to site, with a minimum of 0.0066 at site 1 and a maximum of 0.94 at site 4 (Table 3).

At site 1, the FC/TC ratios varied from 0.0066 to 0.3 with a mean of 0.0392. In effect, 3.92% of total coliforms in site 1 were essentially faecal coliforms. In site 2, 3 and 4, the FC:TC ratios were 0.3620, 0.5142 and 0.2494 respectively.

The mean monthly FC:TC ratios for the four sampling sites are illustrated in Figure 8. Sites 1, 2 and 3 had lower ratio, often < 0.2 between November and March . Site 4 had a high ratio of 0.72 in December which decreased to < 0.1 in January 1986 before rising again in February. High ratio was maintained in site 4 until September, 1986 before a drop in October 1986. Site 1 had persistently low ratio < 1.0 from March to October, 1986.

Relationship Between Faecal Coliforms and Faecal Streptococci in Kaduna River

It has been suggested that the differential die off rates of faecal coliforms and faecal streptococci of animal and human origin offer a method for determining whether or not, faecal

Table 3 - Minimum, maximum and mean values of FC/TC in Kaduna River

	FC/TC VALUES			
	Site-1	Site-2	Site-3	Site-4
Minimum	0.0066	0.0467	0.042	0.043
Maximum	0.30	0.90	0.93	0.94
Mean	0.0392	0.3620	0.5142	0.2494

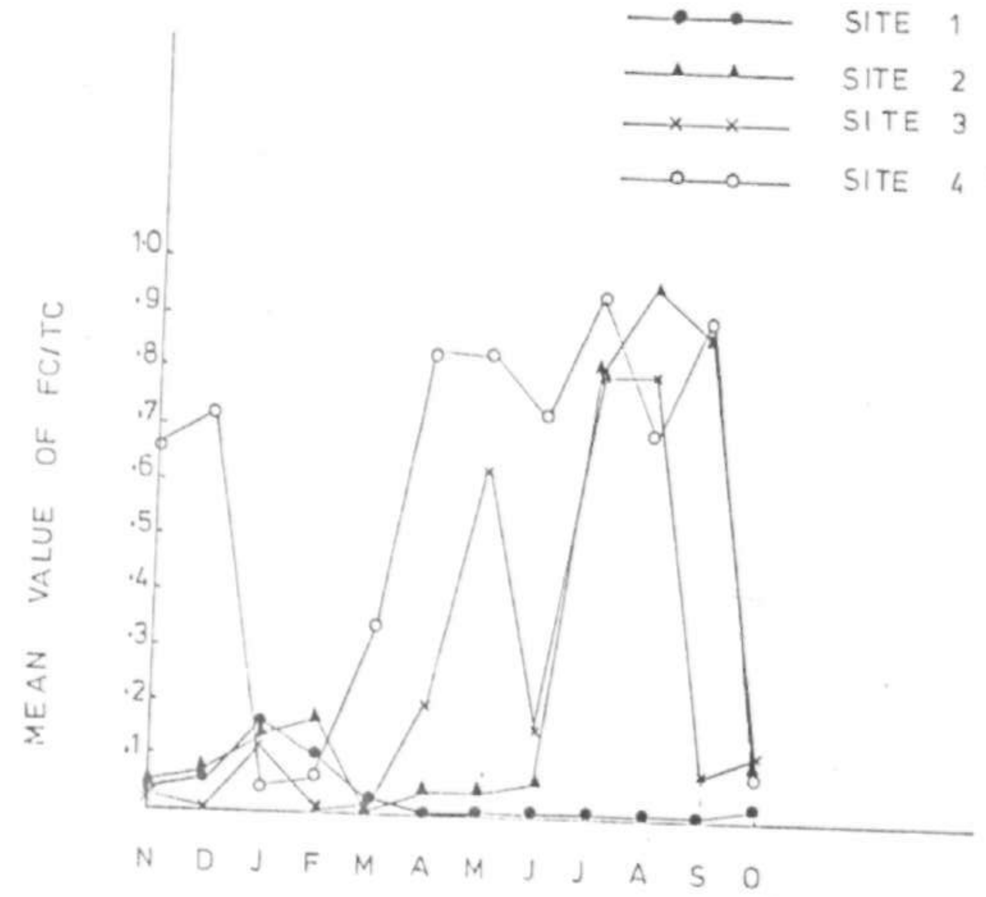

Fig.8 Mean monthly FC/TC ratios at four sampling sites on Kaduna river (Nov. 1985 - Oct. 1986).

pollution is primarily from animal or human sources. FC/FS ratios > 4 were attributed to human source while ratio < 0.7 were attributed to animal source (Geldreich, 1967 and Feachem, 1975).

During the period of study, FC/FS ratio applied to determine the source(s) of pollution of the river conformed that 47.39% of the time the pollution of the river was due to human, while 4.69% was due to animal faecal wastes. (Table 4)

Occurrence of Salmonella in Kaduna River

Four positive isolates of *Salmonella* were obtained during period of study. These *Salmonella* *sp.* were confirmed by biochemical and slide agglutination tests with polyvalent group O antisera (Wellcome).

Effect of Seasonal Variations On Indicator Bacterial Densities in Kaduna River

During the dry months of November, 1985 to January, 1986, the mean densities of all the indicator organisms were higher than the wet season values at the four sampling sites as shown in Figures 9 to 12.

The data obtained in this study showed that the densities of normal indicator organisms were lower.

Table 4 - Frequences of FC/FS ratios and the percentage occurence of faecal bacteria from different sources of pollution at four sampling sites on Kaduna River.

Pollution Source	Site 1	Site 2	Site 3	Site 4	Total % Frequency
Human	24(50)	26(54.25)	27(56.25)	14(29.17)	47.39
Predominantly human	12(25)	12(25)	11(22.92)	4(8.3)	20.31
Indeterminate	6(12.50)	8(16.67)	10(20.83)	20(41.67)	22.92
Animal	4(8.33)	1(2.08)	0	4(8.33)	4.69
Predominantly animal	2(4.17	1(2.08)	0	6(12.50)	4.69

( ) = % occurence of faecal bacterial from various sources in Kaduna River at each site.

Number of samples for each site = 48

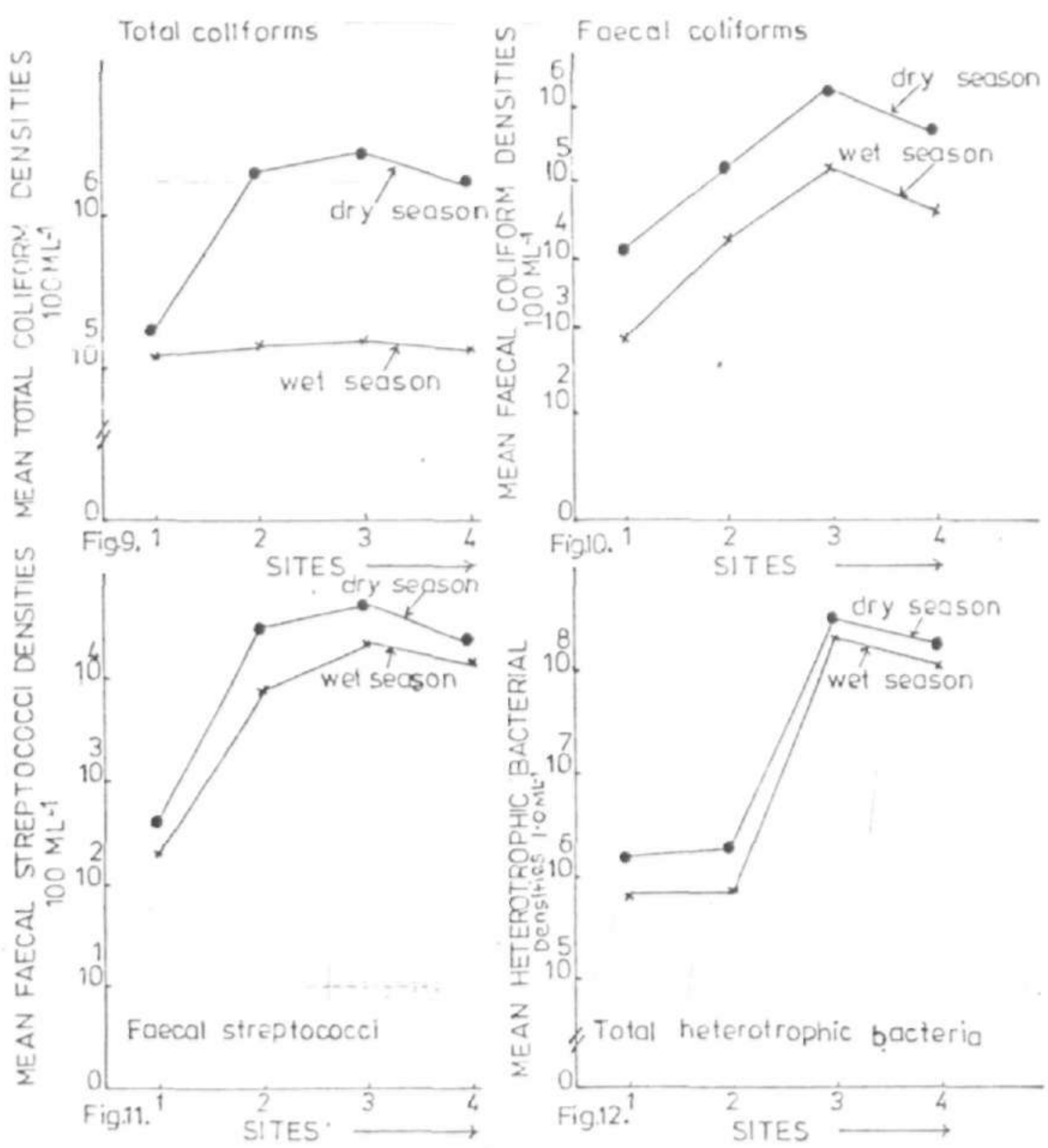

Fig 9 – 12 Comparison of mean indicator bacterial densities in dry season (Nov. to Jan.) and wet season (June to August) at the four sampling sites.

during the wet season. The effect of domestic and industrial effluents on the river water quality are more pronounced during the dry season

The mean total coliforms, faecal coliforms and faecal streptococci wet season densities in site 1 of ($1.06 \pm 1.02 \times 10^5$/100 ml), ($8.30 \pm 1.4$)$10^2$/100 ml and ($2.3 \pm 0.005$)$10^2$/100 ml respectively, were lower than their respective dry season densities of (2.85 ± 1.6) 10^5/100 ml, (1.14 ± 0.72)10^4/100 ml and (6.0 ± 4.5)10^2/100 ml in the same site 1. Similarly, higher indicator bacterial densities were obtained for sites 2 to 4 during the dry season compared to the wet season. At sites 3 and 4, total heterotrophic bacteria densities were only slightly different (Fig 12).

Identification of Faecal Coliforms

97.6% of the isolated faecal coliforms were members of the family, Entero bacteriaceae. Distribution of these isolates revealed that 54.76% were *Klebsiella pneumoniae*, 26.98% *Escherichia coli* type 1, *Citrobacter freundii*, 7.94% and *Enterobacter aerogenes*, 7.94%, while coliform related organisms that were oxidase positive formed 2.38% of the total isolates (Table 5).

Table 5 - Percentage distribution of faecal coliforms from M.FC AGAR plates from the four sampling sites on Kaduna River

Type of Organisms	Number of Isolates	Percentage of Isolates
Klebsiella pneumoniae	69	59.76
Escherichia coli	34	26.98
Citrobacter freundii	10	7.94
Enterobacter aerogenes	10	7.94
Coliform-related organisms	3	2.38
Total	126	100

Determination of Physico-chemical Factors

1. pH:

The river water was in the alkaline range during the 12-month period of study. Usually, the pH increased downstream of Site 1, although differences between sites 1 and 2 were not great, the differences between site 1 and site 3, and site 1 and 4, were quite considerable between January and April 1986 (Fig. 13). The pH ranged from 7.40 to 10.20.

2. Temperature:

The monthly temperature of the river showed some variations at the sampling sites (Fig. 14). During the dry months of February to April, when the waste waters from Makera and Kakuri drains formed the main river flow, the temperature of the river water at site 3 increased reaching 31.5°C. The minimum temperature of 24.5°C was attained in the month of December during the cold harmattan period.

3. Dissolved Oxygen:

The dissolved oxygen content of the river showed differences between the sites during the period of November, 1985 to June, 1986.

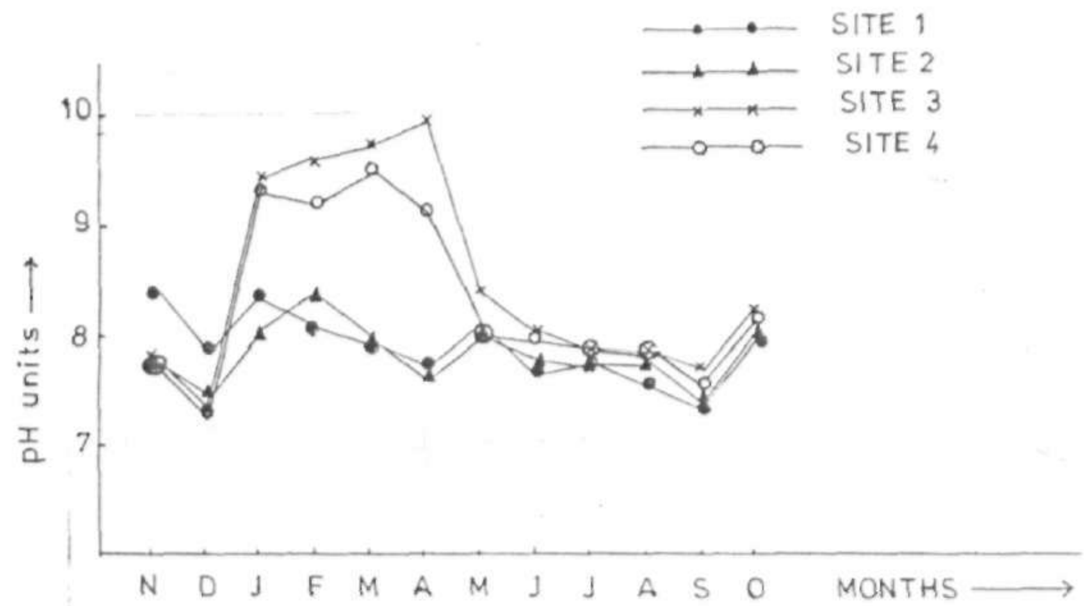

Fig.13 Mean monthly variations in pH at four sampling sites on Kaduna river. (Nov 85 – Oct 86).

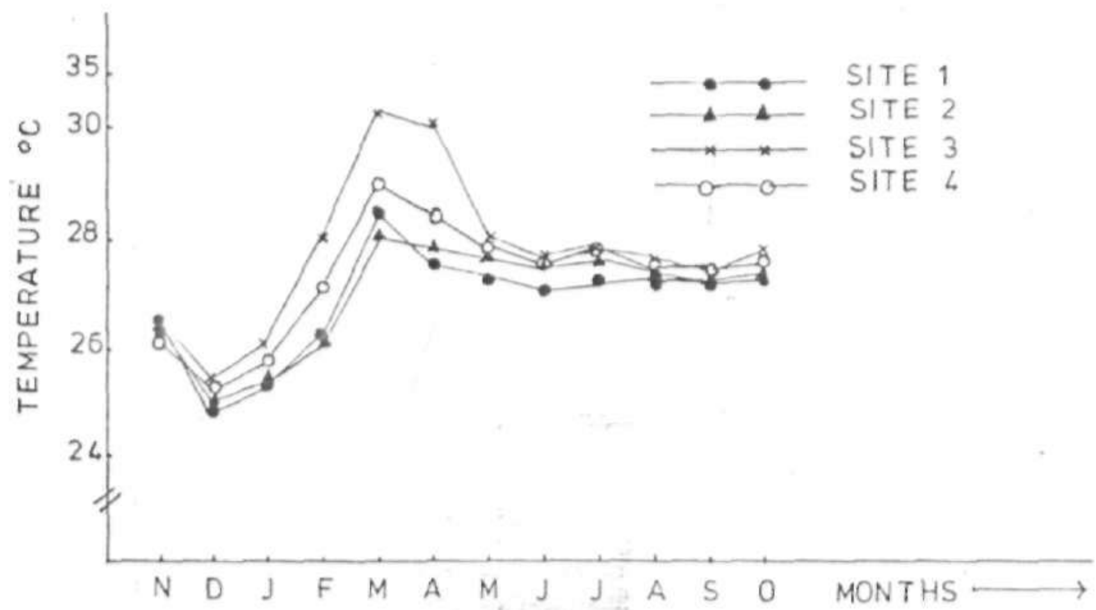

Fig.14 Mean monthly variations in temperature (°C) at four sampling sites on Kaduna river. (Nov. 85 – Oct.86)

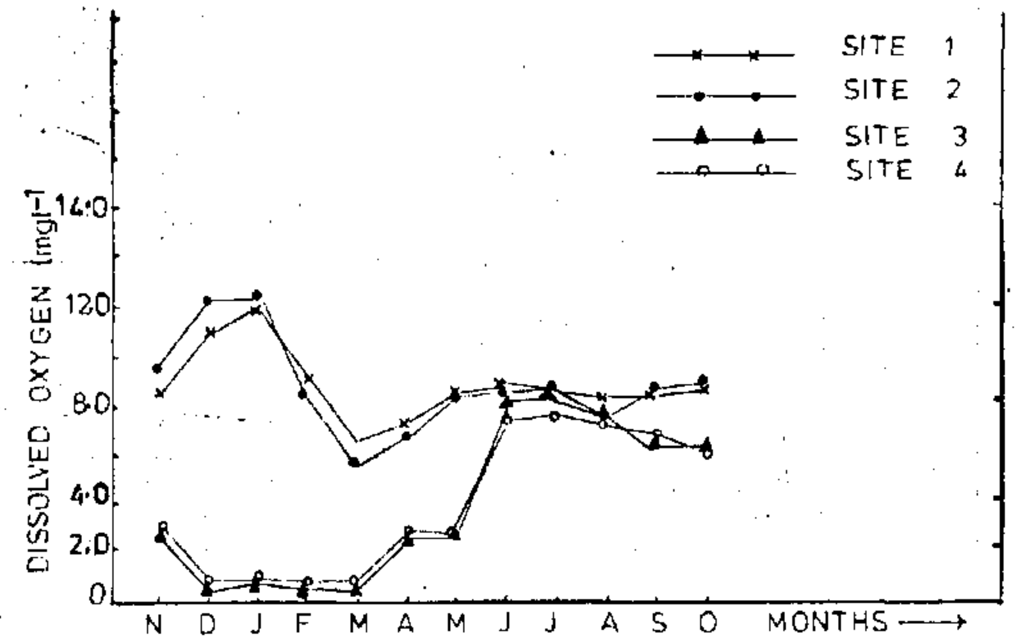

Fig. 15 Mean monthly variations in disolved oxygen concentrations at four sampling sites on Kaduna river (Nov. 85 – Oct. 86)

... At site 1, the water appeared to be well oxygenated with oxygen concentrations often > 5.0 mgl^{-1}, although in March, 1986 an oxygen concentration of 6.75 mgl^{-1} was recorded at site 1.

A sites 3 and 4, there was a considerable drop in the oxygen concentrations especially in the dry months of November to April. Severe oxygen depletion of < 1.0 mgl^{-1} was recorded at sites 3 and 4 between December 1985 and March 1986 (Fig. 15).

Conductivity:

The results of ionic concentration measurements revealed considerable differences between the sampling sites. Site 2 had lowest conductivity value of 90 µmhos cm^{-1}, sites 3 and 4 were characterized by high conductivities with a maximum of 1,900 µmhos cm^{-1} attained in March (Fig. 16).

Biochemical Oxygen Demand:

There was a marked increase in Biochemical Oxygen demand concentrations at sites 3 and 4 compared to sites 1 and 2 (Fig. 17). Maximum BOD (12 mgl^{-1}) was obtained at site 3 in March, while BOD value < 1.0 mgl^{-1} was recorded for Site 1.

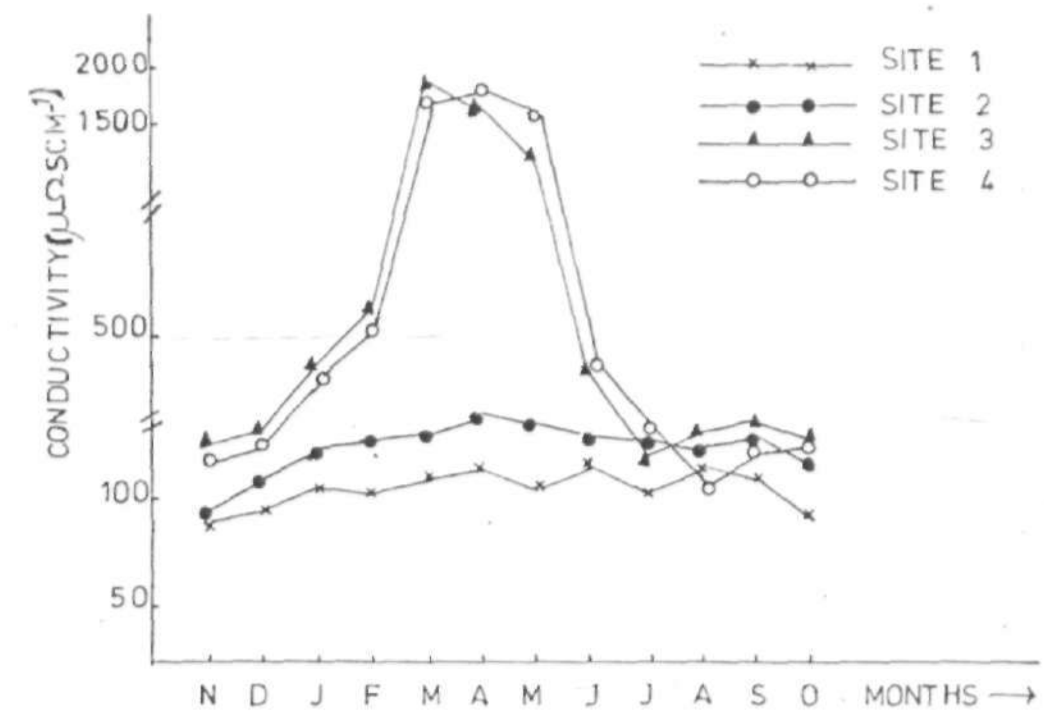

Fig.16 Mean monthly variations in conductivity (ionic concentrations) at four sampling sites on Kaduna river. (Nov. 85 – Oct. 86)

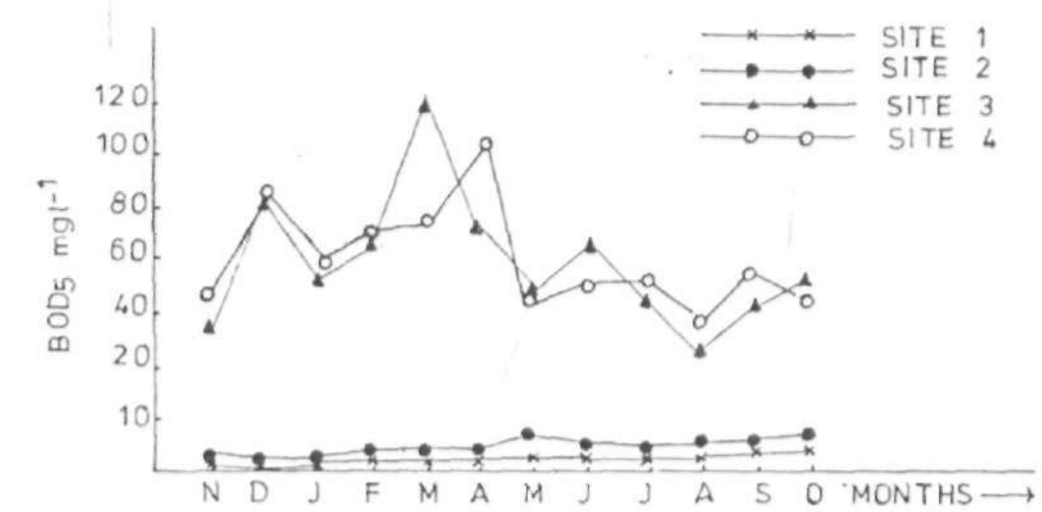

Fig.17 Mean monthly variations in Biochemical Oxygen demand at four sampling sites on Kaduna river. (Nov. 85 – Oct. 86)

CHAPTER 5

DISCUSSION

Distribution of Indicator Organisms In the Drains

The results of this study show that the drains are polluted by faecal bacteria as high densities of indicator organisms were obtained in the drains during the period of investigation.

Earlier work by Osuhor and Essien (1978) showed that Sarduuna and Tudun Wada township drainage systems which drain into Kaduna River were heavily polluted by coliforms and some chemicals. In this study, the six main drains to Kaduna River namely, Makera, Kakuri, Nasarawa, Rafin Dadi, Rigasa and Romi drains appeared to be major sources of pollution of the river. They are characterized by high indicator bacterial densities.

Domestic wastewater contaminated by faecal wastes often contain high number of indicator organisms. In this study, drains associated with domestic waste-waters were found to contain high faecal coliforms and streptococci densities.

Nutrient present in raw domestic sewage and in effluents from sewage treatment plants, food processing operations, and textile mills can contribute biodegradable products that support the multiplication and or regrowth of coliforms organisms (Kitrell and Furfari, 1963). In this study, coliform organisms obtained in high densities could be due to these organic and inorganic nutrients from the domestic and industrial wastewaters. Ahmed and Beecroft (1987) obtained high levels of organic and inorganic contaminants in Kaduna Peugeot Automobile wastewater, which eventually drained into the river through Romi drain. Findings similar to those in this study have been documented in some other regions. Blosser et al (1971), Coleman et al (1974), and Hendry et al (1982) obtained high densities of total coliforms in some industrial and domestic wastewaters and the receiving waters they investigated.

Textile mill effluents contained organic pollutants which are nitrogenous compounds that influenced the survival of bacteria. Fertilizer factory effluents also have been known to be an important source of eutrophication (Stanley and Hobbie, 1981). They significantly increased conductivity, pH, nitrate and phosphate levels in the receiving waters. Kakuri and Makera drains contained fertilizer factory discharge. This could have contributed to high total aerobic heterotrophic bacterial densities of 1.8 x 10^8 1.0ml^{-1} obtained in Kakuri drain in this study.

The figures obtained in this study for microorganisms in the wastewaters of the drains demonstrate that combination of industrial wastes with domestic sewage for instance in Kakuri drain, may not favour the reduction of the microorganisms because high densities of indicator organisms were obtained. This sustenance effect of the wastewaters on indicator organisms as obtained in this study cannot be a surprise because visual observation of the wastewaters in the drains during the dry season revealed that fresh human faecal waste was discharged directly from houses into the drains. At Kakuri, the drain serves more as an open sewer.

During the period of water shortage, the inhabitants of Kakuri usually dig pits on the path of the drain to collect water for domestic use. This practice could be dangerous for their health. Waste stabilization ponds could be constructed, so that the wastewaters could be retained there and treated before discharge into River Kaduna.

<u>Bacterial Distribution in Kaduna River</u>

The range of densities of total coliforms, faecal coliforms and faecal streptococci of 1[illegible]-10^6/100 ml at various sites were within the range reported for polluted water in other places. For instance, Bradley and Emurvon (1968), found that urbanization increased faecal coliform counts from 100/100 ml to > 10^5/100 ml on the Mirongo River in Uganda.

At the vicinity of site 1, a bridge was under construction which involved the dredging of the river bed during the period of this study. Such operation has been known to disturb and relocate bottom sediment with the release of coliform bound to sediments (Grimes 1975, 1980). Resuspension of bacteria into the overlying water with backward flushing of the river could cause abnormally high coliform counts at upstream and within the vicinity of the bridge construction. This type of activity occurring close to site 1, could partly account for the high total coliform counts occasionally obtained at Site 4.

At site 2, wastewaters from Ahmadu Bello University Teaching Hospital, Police College areas, Angwa Rimi drained through a small rivulet entering into Kaduna River at Costain Park, and with the consistent use of the river water for swimming by recreationists at Costain Park, this could cause high levels of indicator organisms at this site. Adjacent to the park is a farmland often irrigated. This is capable of flushing faecal and non-faecal coliforms into Kaduna River. Also, children were often defeacating directly into the river and at the banks. It might suffice to mention the need for toilet facilities at the Costain Recreational Park for visitors, this will reduce the indiscriminate faecal pollution of the river at this site.

Total coliforms representing both human and non-human sources of coliform, were higher than faecal coliforms and faecal streptococci in River Kaduna as obtained in this study. Highest total coliform counds were obtained for site 3 in all cases. This could be as a result of higher waste inputs into this site though Makera, Kakuri and Nasarawa drains. Also along the river bank at site 3 and close to it, are farmlands sometimes fertilized by organic manure and also are being irrigated by the river water, this could flush out soil, plant and animal coliform organisms into the river which invariably caused elevation of total coliform densities.

Sand digging for building is being carried out close to site 3 on the river bed, this can also contribute to high total coliform counts obtained at this site.

The effects of Rigasa, Rafin Dadi and Romi drains causing the flushing of bacteria into the river combined with the sand digging operations of the river bottom could also be responsible for the elevated indicator bacterial densities in site 4

Several generalizations can be drawn from the data obtained during the period of study. Higher coliform counts occurring during the dry season and early part of wet season in April/May suggest the survival of the coliforms in Kaduna river water for a long time or the persistence pollution of the river with faecal wastes. The flushing of bacteria t through excessive run-offs at the onset of the rain is responsible for the May, 1986 abnormal increase in bacterial densities in the river.

When the rain came in June/July 1986, rapid die off-rate with increase in river water volume, high dilution ratio and faster flushing rate of the river can explain the rapid decrease in coliform densities in Kaduna river. By the peak of the raining season in August, the lowest faecal coliforms and faecal streptococci densities were obtained.

The lower faecal streptococci counts often obtained in this study compared with faecal coliform counts may be due to differences in their survival rates. Morris and Weaver (1954) observed a lower survival rate for faecal streptococci than faecal coliforms, while Koh (1982) investigating the survival rate of faecal streptococci and faecal coliforms observed a higher survival rate for the former organism in disinfected waters.

In Kaduna river faecal streptococci do not appear to fluctuate more than faecal coliforms though it occurred in lower densities than faecal coliforms. Survival studies for these groups of organisms should be attempted for a valid judgement of their relative usefulness in pollution studies in tropical waters where temperature seldom falls below 26°C.

Thaphyal / et. al. (1970) observed a correlation coefficient of 0.34 between total coliforms and faecal streptococci in waters of varying pollution in India. In this study a correlation coefficient of 0.305 was obtained between total coliforms and faecal streptococci. The close agreement between these two results might suggest the usefulness of faecal streptococci as indicator of water pollution in the two regions.

Total aerobic plate count of heterotrophic bacteria can be interpreted as reflecting input of microorganisms from non aquatic sources, as well as describing the trophic conditions of a given habitatXXX (Rao and Jurkovic 1976). The fluctuation in total heterotrophic bacteria densities at the sampling sites on Kaduna river, may be a result of either or both conditions.

The large progressive increase in total heterotrophic bacteria densities at sites 3 and 4 compared to sites 1 and 2 indicate growth of these bacteria in response to high nutrient levels in the river obtained through waste inputs from the drains.

High biochemical oxygen demand and chemical oxygen demand were obtained for the drains lts, discharging into Kaduna river (Osuhor and Essien 1978; Chukwukelue 1983; Ahmed and Beecroft 1987). According to Kenney et. al. (1971) nutrient enrichment favours the growth of resident bacterial populations of a receiving water and may support their survival.

High nitrate and phosphate concentrations were obtained for the effluent discharges into Kaduna river (Chukwukelue 1983). This can therefore favour the survival and multiplication of microorganisms in the river, and can explain the high densities of heterotrophs as obtained in sites 3 and 4.

Bacteria serve as indicators of pollution generally under polysaprobic conditions, when the total counts reach 10^6 or more organisms per milliliter. With progressive self-purification in a river system, bacterial number are reduced, the total count drops to 10^6/ml under α-and B- mesosaprobic conditions. A water with a total count of 100 or fewer organisms per ml is classified as oligosaprobic (Hawkes, 1975). Kaduna River at all the sampling sites had total aerobic heterotrophic bacteria counts $> 10^6$/ml from November 1985 to June 1986. This enables Kaduna River to be classified as being polysaprobic during the period of study.

The number of bacteria in river waters are naturally quite variable and depend on a wide variety of factors. Access of soil and organic matter and increase in temperature may be responsible for increases in bacterial numbers (Keller, 1960). All these factors are important under Nigerian conditions of climates, where the year is amarkedly divided into dry and wet seasons. The results of this study show that there is seasonal variability of indicator bacteria in Kaduna River. During the drier months of February to April, 1986 nutrient build up . . . have been rapid due to shallow nature of the river and lower flushing rate of the river; high densities of indicator bacteria were therefore obtained. It could be assumed from this study, that, health hazard that could be associated with the river use during the drier months might be higher than during wet season. Epidemiological studies are required to confirm this speculation especially in view of the continuous utilization of Kaduna River for swimming, fishing, water supply and abstraction for industrial uses.

Water quality criteria (EEC, 1975) required that raw water should not have more than 2.0×10^{3}FC/100 ml with upper limit of 2.0×10^{4}FC/100 ml. WHO (1973) stated that water with a total coliform counts of 5.0×10^{4}/100 ml is unacceptable for human consumption and must be treated.

For most of the months, raw waters at sites 2 to 4 fall into category . A3 of EEC standard (1975) which requires intensive - physical and chemical treatment, extended treatment with disinfection, decantation, filtration and adsorption before use, especially during the dry season of November, to April.

Raw water abstraction at Kaduna south waterworks called for reconsideration. From this study, the bacteriological water quality at this intake is at the upper limit 2.0×10^4 FC/100 ml of the EEC standard. In case of any bacterial build up in the upstream, the river water at the intake would be affected.

The occurence of amany pollution sources along Kaduna River course within the city limits account for interruption of self-purification of the river. Only beyond site F4 were processes of bacterial self-purification in the river evident. From Site F5 through F7, bacterial densities slowly decreased progressively with distance. Kaduna River during the dry month of February had a low water exchange as the wastewater formed the main river flow during the period of [illegible] purification investigation. Further work is necessary to [illegible] the rate of self-purification of the river from bacterial contamination [illegible]

Strobel (1968) reported that the relationship between FC and TC varies with the sources of pollution, level of sewage treatment and characteristics of the receiving waters and precipitation. Orsanco Waters Users Committee (1971) suggested that higher FC/TC ratios might indicate proximity of inefficient wastewater treatment operation or conditions where treatment facilities are being by-passed during the storm run-offs. In Kaduna River, high FC/TC ratio were obtained. This could be due to lack of efficinet sewage treatment plants. In Kaduna, the disposal of human wastes are mainly through septic tanks and pit latrines. Defaecation in the bush or near water sources is often the practice. This is unsatisfactory and could account for the high level of faecal bacteria in Kaduna River and in the drains. Low FC/TC ratio- on the other hand, has been attributed to after-growth of some groups of the indicator bacteria especially Aerobacter aerogenes and Klebsiella sp., as noted by Orsanco Water Users Committee (1971), and Knittel et al (1977), resulting in abnormally high total coliforms and a a low quotient of FC/TC . In tropical water after-growth of coliform bacteria have been found to be favoured by the warm tropical climate (Evison and James, 1973). In Kaduna River, where temperature seldom falls below 26°, this could have favoured the regrowth of the indicator organisms. Since several factors may influence the overall value of FC/TC ratios, as earlier discussed above, the variations obtained in Kaduna River is not unexpected. A year observation is inadequate to rely on overall average, therefore, the monthly means as obtained in the study might be useful, in assessing the relative faecal pollution of the river from FC/TC quotients.

Geldreich *et al* (1976) suggested the use of FC/FS ratio to assessing pollution sources rather than relying solely on FC densities.

The generally high levels of faecal bacteria in Kaduna River was found to originate primarily from human during the period of study. Pollution from other sources other than human was indicated by the results. The data therefore, emphasize the importance of defining non-point sources pollution such as surface run-offs, livestock wastes, in addition to point sources as obtained in definite drains when assessing the bacteriological water quality of Kaduna River.

The percentage of isolates on M-FC Agar plates confirmed faecal coliforms were higher than those obtained in the studies of Grabow *et al* (1981; Presswood and Strong (1978); for temperate waters.

The principal faecal coliforms that were found in Kaduna River were predominantly *Klebsiella pneumoniae* followed by *Escherichia coli*; *Citrobacter freundii* and *Enterobacter aerogenes*. *Klebsiella* sp., occurred at higher percentage than the other three biotypes. This species has been known to occur in water polluted by industrial effluents and was indeed capable of outgrowing indigenous microbiota according to Knittel et al (1977). In this study, 51.76% of faecal coliform isolates were *K. pneumoniae*.

Mara and Oragui (1985) obtained 60% K. pneumoniae in some rivers studied in Nigeria. The high prevalence of these enteric bacteria also support the other findings in this study that there is gross faecal pollution of Kaduna River.

Claudon et al (1971) and Weibel et al (1974) have found that urban drainage that are heavily contaminated contain salmonella. However, in this study, only four water samples were found to contain Salmonella sp. This low incidence of salmonella in Kaduna River could be due to several factors. It could be a function of the pathogenic organism itself because Salmonella are known to have a rapid die-off rate. Other factors associated with domestic and industrial sewage, such as heavy metals, organic materials, toxic pollutants, and chloride residues may have secondary effects on the isolation of the pathogens in the river. Further studies are needed to quantify and identify probable Salmonella sp. obtained in Kaduna River, and the factors affecting their survival in Kaduna River.

This study was carried out using standard indicator bacteria and it is possible that the domestic and industrial wastes inputs caused changes in other types of bacteria not used in the investigation.

[illegible] sediment [illegible]

Physico-Chemical Water Quality Effects on Kaduna River

In general, the discharge of industrial and domestic wastes into Kaduna River alter the pH which tends to be alkaline.

The efflunts from Makera and Kakuri drains, which are mainly industrial in nature enter the river at a temperature of about 32°C to 35°C. However, this do not alter the river temperature significantly except in the dry months of February to early part of April when the drains provide the greater volume efflow. In the wet season, the volume of river water and ambient air temperature seem to have been responsible for keeping the temperature of the water fairly constant.

The dissolved oxygen concentration illustrated the effects of the wastewaters on the water quality of Kaduna River. A value as low as 0.25 mgl^{-1} as obtained at sites 3 and 4, shows a case of severe oxygen depletion during the dry season. From April through October, due to dilution of the wastewaters by agitation, precipitation and aeration there occurred an improvement in the oxygen content at both locations.

October, due to dilution of the wastewaters by pwecipitaiton, there occured nan improvement on the oxygen content at both locations. Adequate oxygenation occurred in upstream locations at sites 1 and 2, with oxygen concentrations often > 5.0 mgl^{-1}, throughout the period of study. During the dry season, with decrease in effluent dilution resulting in higher biochemical oxygen demand (B.O.D.) values in the region of effluent addition at site 3 and 4 caused a decrease of dissolved oxygen to 0.3 mgl^{-1}. Dissolved oxygen levels in both downstream locations of site 3 and site 4 are similar, therefore, re-oxygenation process in Kaduna river does not appear to be rapid, between the two locations.

The values of conductivity (ionic concentrations) are partly dependent upon the nature of the various dissolved substances in the water. There is considerable difference between the conductivity of the river water at Site 1 and Site 3 due to the effect of the industrial effluents being discharged into the rivers through Makera and Kakuri drains, which are essentially textile effluents.

The high $B.O.D._5$ obtained in site 3 and 4 compared with site 1 with mean $B.O.D_5$ of [illegible].5 mgl^{-1} appear to correlate with low oxygen concentrations occurring at site 3 and site 4, [illegible]

[illegible]

The continuous discharge of effluents from Makera, Kakuri and Nasarawa drains could have the effect of flushing large amount of organic materials into the river which increased the B.O.D. of the river water at sites 3 and 4. Increased flow due to upsurge of water from tributaries to Kaduna River during the wet season dilutes the concentration of the organic materials and the B.O.D. falls.

CONCLUSIONS

From the results of this study, the following conclusions could be drawn:

1. High indicator bacteria (total coliforms, faecal coliforms and faecal streptococci) densities were obtained in Kaduna River as a measure of faecal pollution of the river. Bacterial densities, varied randomly in time, in general increased with downstream movement to sampling site 3, but tends to decrease thereof outside the urban influence.

2. The main drains to Kaduna River were the main sources of the pollution.

3. FC/TC and FC/FS quotients applied to the river indicated gross-human pollution with indication of animal waste input to a lesser extent. The FC/FS ratios obtained in this study emphasize the need to consider non-point sources as well as point sources of pollution in assessing the bacterial quality of Kaduna River.

4. *Klebsiella pneumoniae* was the predominant faecal coliform isolate obtained in this study. Other species include *Escherichia coli*, *Citrobacter freundii* and *Enterobacter aerogenes*.

5. From comparing FC, FC and FS densities during the wet and dry season, high bacterial densities were obtained during the dry season than the wet season.

6. High incidence of faecal bacterial densities indicate high health risks, the occurrence of even a few *Salmonella* sp. in Kaduna River is evidence of a polluted water.

RECOMMENDATIONS

The following recommendations are advanced for implementation by Kaduna State Government:

(i) There is urgent need for the enactment and enforcement of effluent discharge regulations in the state.

(ii) Utilization of the wastewaters for irrigation by local farmers should be discouraged until the wastewaters are adequately treated.

(iii) The public should be educated of the health risks associated with the utilization of the polluted river for swimming and other recreational activities.

(iv) The diversion of wastewaters into low-cost stabilization ponds for adequate disinfection should be considered.

For further studies on the wastewaters and the river, the following areas of research are suggested:

(i) Prevalence of waterborne infections in communities using the wastewaters and the polluted river should be investigated.

(ii) Survival studies of enteric bacteria and pathogens in the wastewaters and the river require investigation.

(iii) The role of microorganisms in some biochemical processes of denitrification, mineralization and amonification should be studied.

(iv) Determination of coliform bacteria and pathogens in the river sediment is essential for a more precise assessment of the extent of faecal pollution of the river.

(v) The microbial flora of freshly caught fishes from the polluted river should be investigated.

(vi) Correlation of bacterial populations with physicochemical parameters of the river require detailed investigation.

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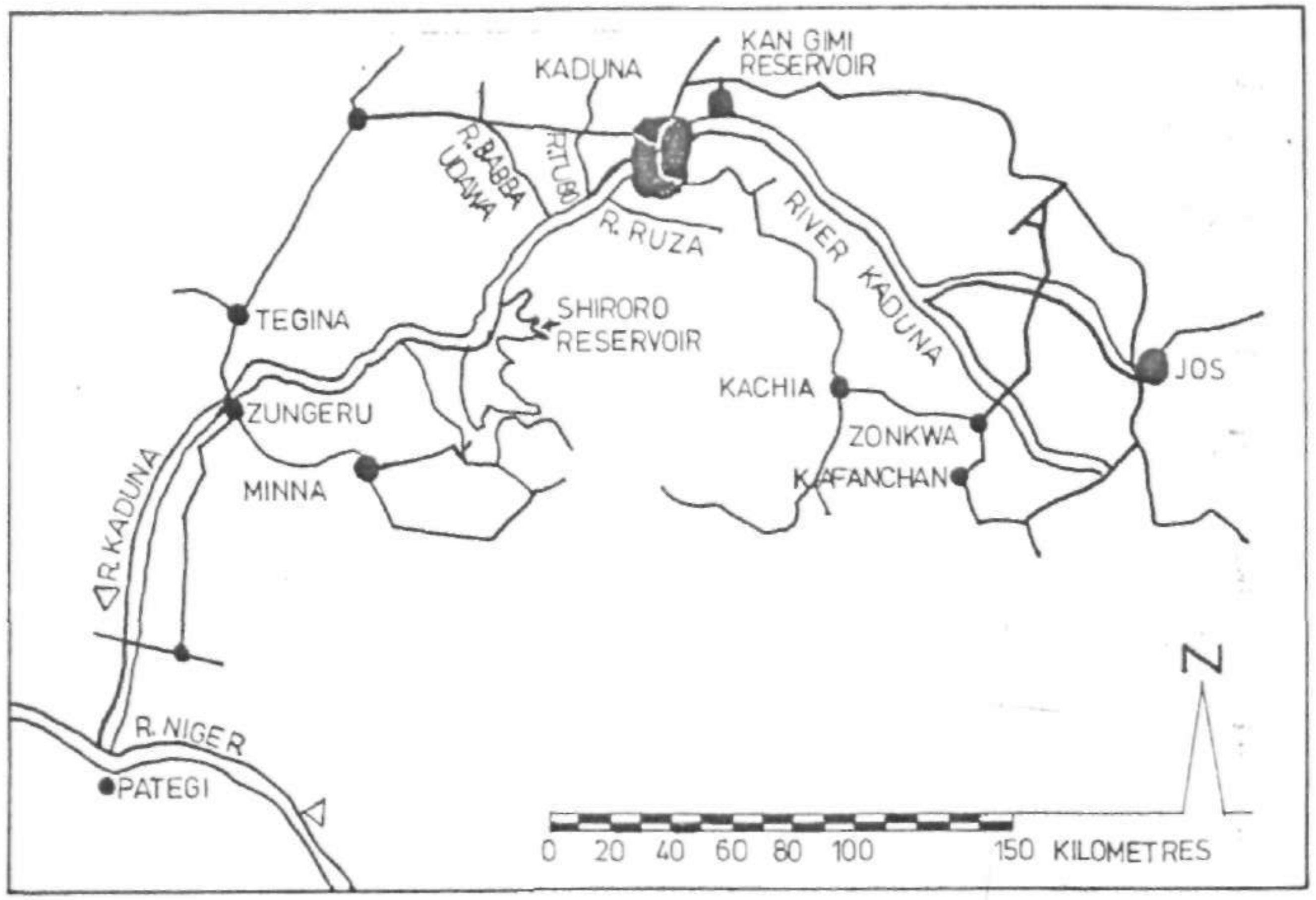

APPENDIX A : KADUNA RIVER WATER COURSE

APPENDIX [illegible] - Names of Industries Numbered in Figure 1

Identification Number	Industries
1.	United Nigerian Textiles Limited
2.	Federal Superphosphate Fertilizer Company
3.	Zamfara Textiles Limited
4.	Nigerian Breweries Limited
5.	Kaduna Textiles Limited
6.	Northern Nigerian Textiles Limited
7.	Norspin Company
8.	Arewa Textiles Limited
[illegible]	Turners Asbestos
10.	Nortex Nigerian Limited
11.	Defence Industries Corporation
12.	Peugeot Automobiles Nigerian Limited
13.	Surgical Products Nigeria Limited
14.	Nigerian National Petroleum Company
15.	Nigerian Bottling Company
16.	Derec Nigeria Limited
17	Chanchangi Oils Nigeria Limited
18.	Flour Mills Nigeria Limited
19.	Chelco Nigeria Limited
20.	Drinko Nigeria Limited
21.	Nigerian Grains Production Company

APPENDIX 'C' - Typical Biochemical Characteristic Reactions For Enteric Bacteria and Salmonella Identification

Tests	*E. coli*	*C. freundii*	*E. aerogenes*	*K. pneumoniae*	*Salmonella sp.*
Indole	+	−	−	−	−
Methyl Red	+	+	−	−	[illegible]
Voges Proskauer	−	−	+	+	−
Citrate (Simons)	−	+	[illegible]	+	[illegible]
H_2S production	−	+	−	−	+
Motility	+	+	+	−	+
Ornithine decarboxylase	[illegible]	−	+	−	[illegible]
Lysine decarboxylase	+	−	+	+	+
Urease	−	+	−	+	−
Gelatin liquefaction	−	−	+	+	−
KCN	−	+	+	−	−
Glucose (gas)	+	+	+	+	+
Sucrose	[illegible]	±	+	[illegible]	−
Lactose	−	+	+	+	
Mannitol	+	−	+	+	+
Oxidase	−	−	−	−	−
Nitrate reduction	ND	ND	ND	ND	+

ND = Not determined

Sources: Cowan and Steel (1965)
Edward and Ewing (1973)
McFaddin (1977)

APPENDIX 'D' - Relationship Between FC/FS Values and Indicative Sources of Pollution

FC/FS = X Range	Indicative Sources of Pollution
$X \geq 4$	Human wastes
$4 > X \geq 2$	Predominance of Human wastes in mixed pollution
$2 \geq X \geq 1$	Uncertain of Interpretation (Indeterminate)
$1 > X > 0.7$	Predominace of animal wastes in mixed pollution
$0.7 \geq X$	Livestock or Poultry wastes

Source: Goldreich (1976)