ECOLOGICAL STUDIES OF UPPER GANGA- IDENTIFICATION AND REPRESENTATION OF THE STATE OF THE RIVER

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of
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By

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SEPTEMBER, 1988

DEDICATED

TO

MY BROTHER

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **ECOLOGICAL STUDIES OF UPPER GANGA - IDENTIFICATION AND REPRESENTATION OF THE STATE OF THE RIVER** in fulfilment of the requirement for the award of the Degree of Doctor of Philosophy, submitted in the Department of BIOSCIENCES AND BIOTECHNOLOGY of the University is an authentic record of my own work carried out during a period from 15th November, 1984 to 20th September, 1988 under the supervision of **Dr. R.P. Mathur.**

The matter embodied in this thesis has not been submitted by me for the award of any other Degree.

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ABSTRACT

Ganga originating from the snow clad peaks of Himalayas represents a mighty river (2525 km) of Indo-gangetic plains. The river passes through large number of urban settlements, industrial complexes and agricultural sectors. As a result of these activities, the river constantly receives diverse waste matter, both from domestic sources as well as industries which impair its intended use. The upper stretch of the river (under study) is believed to be least polluted, still its scientific justification needsto be worked out.

The fact that ecosystem change with pollutional stress, has led the biologists to estimate water quality by quantifying such changes. Extensive studies have been made on the organisms and their communities to evaluate the degree of pollution in important rivers of the world. However, little information is available regarding the biological evaluation in Indian rivers, including the river Ganga.

Despite having pollution load to a varying degree along its different reaches the proverbial purity of the Ganga is often ascribed to the possible quick natural control of microbial imbalances in its water. But precise information regarding this property of Ganga water is not available.

Considering these facts the present study was undertaken. The work was carried out in two phases, in the first, the river was monitored at maximum possible locations in the study area for a wide spectrum of quality parameters in order to estimate the gross system state. In the second phase some laboratory studies were performed to explore the role of native biotic components on the survival characteristics of indicator bacteria.

The 509 km stretch of the river from Badrinath to Narora travels a distance of 242 km from Badrinath to Rishikesh in the hills and the rest 267 km stretch upto Narora in plains, represents the upper Ganga. In all 15 sampling stations were selected considering abstractions, additions, specific major point sources of pollution, accessibility and maximum representation of the aquatic system. The samples were taken from these stations once in two months.

In the first phase data pertaining to the following parameters was generated for a period of two years (Dec. 1984 - Dec. 1986);

1. Plankton (phytoplankton and zooplankton)
2. Benthos (macroinvertebrates)
3. Bacterial flora
   - (a) Heterotrophs
   - (b) Indicator bacteria
     - (i) Coliform - Total coliform and Faecal coliform
     - (ii) Faecal streptococcus
4. Enteric viruses
5. Physical and chemical parameters - Temperature, ORP, pH, conductance, turbidity, DO, BOD, COD and nutrients.

The results indicated that physico-chemical environmental conditions were generally suitable for the growth and regeneration of biotic components. Phytoplankton concentration was observed to be more than zooplankton. The rainfall and surface runoff was found to be the important factor in determining the seasonal fluctuations. Concentrations of phytoplankton and DO decreased on the onset of monsoon to reach lowest value during high flood.

The exact opposite trend was observed for turbidity, BOD, COD, zooplankton and decomposers which reached highest value in the monsoon period. Although the organic pollution appeared to be of low order, a comparable dependence was noticed between the organic load and heterotrophic bacteria. The study pointed out the healthy state of the ecosystem of upper Ganga, even the spatial variation lead to gradual decline in the health of the system.

To get more insight into the community structure, eight diversity - Simpson's D, Shannon's H', evenness, Hurlbert's PIE, McIntosh's M, Keefe's TU, Gleason's d, Margalef's d and Menhinick's d, and four similarity (or dissimilarity) indices - percent similarity, Bray-Curtis dissimilarity, Pinkham-Pearson's similarity and Euclidean distance were applied on the phytoplankton data. Hurlbert's PIE and Keefe's TU produced the identical values and complementary to Simpson's D. Thus any one of them could be applied. Correlation coefficient among the indices themselves showed that Gleason's and Margalef's indices bear significant relationship with Shannon's index and therefore could be used as an alternative for quick and simple evaluation. The diversity values obtained by various indices have been compared. A possibility of the conversion of the values was evaluated between the indices which have given the highest degree of correlation. The application of diversity together with evenness and similarity is suggested to resolve the community structure more efficiently.

Variation in indicator bacteria was very significant. At no place the coliform satisfy the recommendations of water quality objectives for organised outdoor bathing. Variation in faecal streptocossus and faecal coliform was somewhat similar, though values were far smaller. Both faecal coliform and faecal streptococcus were well within the limits at most of the locations as per suggestions of Geldreich. The t-statistics as well as temporal variations

in coliform and faecal streptococcus indicated the increasing addition of faecal waste towards plains. FC/FS ratio suggested the mixed nature of faecal pollution (man and animals) in the catchment.

A comprehensive water quality monitoring study was undertaken on Ganga river at the town of Haridwar during April 13th and 14th, 1986 on the occasion of major religious congregation where a reported 6.5 million people bathed in the river. The impact of community bathing was found statistically significant on the total coliform in addition to pH, ORP and DO. The violation in existing coliform limits and the absence of entric viruses were observed.

Comparative investigations on the survival characteristics of Escherichia coli and faecal streptococcus in Ganga water of Haridwar, strongly suggested that faecal streptococcus survive longer then E. coli. T_{90} values for faecal streptococcus (136 hrs) was found four times higher than E. coli (32 hrs). The longer survival of faecal streptococcus supports their suitability as indicator of faecal pollution over coliforms. The bacterial decay in both the cases followed the first order equation :

$$N_t = N_o e^{-kt}$$

Survival of these bacteria was mainly dependent on the presence of protozoan predators. The role played by native bacteria was of secondary importance and their effect was only exerted when protozoans were artificially reduced. The rate of predation by aquatic microfauna was observed to be of high order.

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NOTATIONS AND ABBREVIATIONS

Symbol	Meaning
D	Simpson's diversity index
H'	Shannon's diversity index
K	Number of taxa in either sample or a population
M	McIntosh's diversity index
n & N	Number of individuals in a sample/population
n	Number of observations
n_i & N_i	Number of individuals in species i of a sample/population
PIE	Hurlbert's probability of interspecific encounter index
p_i	n_i/n
S	Number of species (or genus) in sample/population
TU	Keefe and Bergersen's diversity index
V'	Evenness (H'/H_{max})
π_i	N_i/N

Abbreviation	Expansion
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
COV	Coefficient of variance
DO	Dissolved oxygen
d/s	Downstream
FC	Faecal coliform
FS	Faecal streptococcus
hrs	Hours
JTU	Jackson's turbidity unit
MF	Membrane filter
MPN	Most probable number
min	Minimum
max	Maximum
ORP	Oxidation reduction potential
PSC	Percent similarity
SD	Standard deviation
T_{90}	Time required for 90 percent decay
u/s	Upstream

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LIST OF SAMPLING STATIONS

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2.	Nandprayag
3.	Rudraprayag
4.	Srinagar
5.	Devprayag
6.	Rishikesh
7.	Satyanarayana
8.	Hari ki Pauri upstream
9.	Hari ki Pauri downstream
10.	Kan'khal
11.	Balawali
12.	Bijnor
13.	Garhmukteshwar
14.	Anupshahar
15.	Rajghat Narora

CHAPTER - 1

INTRODUCTION

Water is the prime constituent of human environment. Like any other living organism, man needs it, in the first place for his physiological existence and secondly for other organised uses such as domestic water supply, irrigation, industries, power generation and propagation of fish and wild life.

Rapid growth of human population and rise in the living standards coupled with exploitation of resources have put heavy demands on the existing environmental components. They may be through urbanization and growth of population centres, or by introduction of industries and deployment of auxiliary means in agriculture, which have disturbed or even destroyed the natural, healthy quality of water bodies in many regions. These water bodies have become unsuitable for many beneficial uses for which they were utilized earlier.

Furthermore, there is an increasing demand for good quality water in every corner of the world. The protection of water bodies is not only urgent in the areas which are heavily polluted, but also necessary as precautionary measure for the conservation of natural resources.

Water quality management programme of a basin requires reliable data on existing water quality, the influence of anthropogenic activities and the present and planned uses.

1.1 The Ganga Basin

Ganga, the mighty Indian river, originates from the snow-clad peaks of Himalaya, is the life line of millions of Indians. From its source to its entry into the Bay of Bengal, it travels a distance of around 2525 km. The river with

its well knit tributaries drains the Ganga basin, which encompasses an area of more than a million square kilometers (1060,000 km^2) spread over four countries, India, Nepal, Bangladesh and China (Chaphekar & Mhatre, 1983).

The Ganga has by far the largest river basin in India (15th in Asia and 29th in world) draining as much as 861404 km^2 within the country , covering more than a quarter (26.2%) of India's total geographical area. The river drains eight states, the percentage of total area shared by each state being as follows - Uttar Pradesh 34.2, Madhya Pradesh 23.4, Bihar 16.7, Rajasthan 12.5, West Bengal 8.4, Haryana 4.0, Himachal Pradesh 0.6 and Delhi 0.2 (DasGupta, 1984).

The basin has large surface water and ground water resources. The annual flow in the basin is 468.7 billion cubic metres which accounts for 25.2% of India's total water resource. Out of this only 142.6 billion cubic metres is consumed in the basin. Irrigation alone accounts for more than 94% of total basin consumption whereas domestic and industrial sector use only 2.9 and 2.8% respectively. Due to the much higher intensity of rainfall in the Himalayan region, the streams which joins the Ganga from North contribute more than 60% of the water flowing in the Ganga basin. The Peninsular streams contribute the remaining 40% water. Flow characteristics of the Ganga varies greatly with seasons, being highest during its wet season (June to September) receiving more than 70% of total annual rainfall. In 1977, the total population of the basin was estimated at about 242.1 million (37% of the country) of which 84% (202.9 million) lived in the rural areas and 16% was distributed over 629 urban centres in the basin (DasGupta, 1984).

The Ganga basin has shown an annual increase of 2.5% in its population in the decade 1971-81, with an average density of 297 persons per km^2,

compared to 196 for India in 1981. The density variation from region to region within the basin is fairly large (from 8 person per km^2 in the Himalayan district to 1072 person near the out fall of the Ganga in Howrah district in West Bengal). An annual increase of 7.3% in urban population in the same decade reflects the increasing magnitude of urbanization in the basin (Singh, 1987).

1.2 The Ganga River System

The main stream of the river Ganga, the Bhagirthi, originates from the ice cave of Gaumukh ($30^{\circ}55'N$, $79^{\circ}7'E$) at the snout of Gangotri glacier in the Garhwal portion of Western Himalaya, at an elevation of about 4100 metres. The Alaknanda, the sister stream of Bhagirthi rises beyond Mana pass, 8 km away from Badrinath ($30^{\circ}44'29''N$, $79^{\circ}29'41''E$, 3123 m above msl) joins it at Devprayag. It is below this confluence, the united stream is known as Ganga river. After a run of some 267 km, it emerges into Indo-Gangetic plains at Haridwar (elevation 288 m), where it swells into a mighty system, 750 m wide (approximately).

Ganga receives hardly any major tributary till it is joined from the left by the Ramganga at Kannauj. At Allahabad (1050 km from the source) it is joined from the right by its twin Yamuna, which originates from Yamnotri glacier ($30^{\circ}58'N$, $78^{\circ}27'E$) in lower Himalayas at 6320 m above msl, (Fig. 1.1). It is from Allahabad downstream that the river receives several major tributaries at more frequent intervals, the Tons and the Son from the right and the Gomati, Ghaghara, Gandak, Burhi Gandak and Kosi from the left, till the Ganga reaches the head of its delta at Farakka below Rajmahal bend (DasGupta, 1984). Consequently the volume rises rapidly at each confluence and water quality changes at each turn according to the character of the contributing stream.

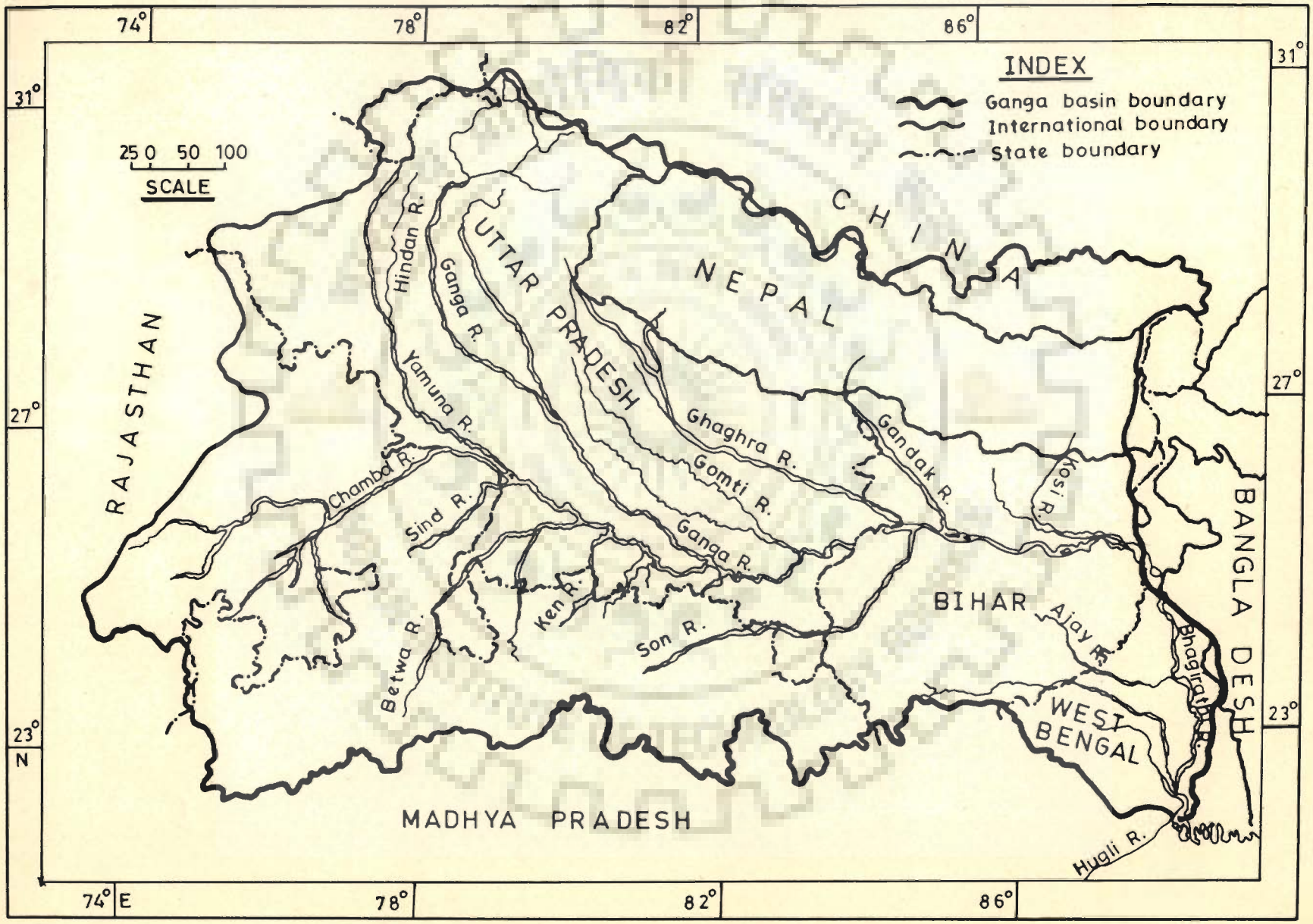


FIG. 1·1 : THE GANGA BASIN GANGA RIVER WITH MAIN TRIBUTARIES

From its origin to its entry into the Bay of Bengal, river Ganga passes through large number of urban settlements, industrial complexes and agricultural sectors. After meeting the water requirement of these sectors, it receives diverse waste as a return from these activities, which impair its quality. There are 29 class-I cities (population $> 10^5$), 23 class-II cities ($10^5 >$ population $> 5 \times 10^4$) and 48 towns ($5 \times 10^4 >$ population $> 10^4$) on its bank. Out of them only 5 class-I cities and 5 towns have the sewerage system and 10 class-I cities have partial sewerage treatment systems (Malkani 1985). The wastewater from rest of the urban sector flows through open drains and finally finds its way into the river.

Since the scale of pollution also depends on the degree of dilution and velocity of flow of water, it is necessary to maintain a minimum discharge in the river especially at critical points e.g. urban settlement and industrial sectors. Unfortunately, this is not kept in view while tapping the river for irrigation or power generation.

Mass bathing is a common practice at pilgrim centres on the banks of river Ganga during religious festivals. Kumbha, a six yearly congregation was observed on April 13th and 14th, 1986 at Haridwar. During this period an estimated 6.5 million pilgrims took a dip in the river water. Apart from this other human activities like washing, wading, floral offerings, cremation of dead and post cremation activities e.g. disposing of ashes etc., causes considerable pollution of the river water. Despite having pollution load to a varying degree along its reaches, it is claimed that the Ganga has great self purifying capacities.

1.3 Basic Ecological Pattern

An ecosystem is a biological system composed of organisms, their physical

environment and the materials and energy they process. It is characterized by complex biogeochemical cycles and interrelationships which maintain the system in a dynamic balanced state thereby delimiting the particular environmental quality (Deptt. of Environ., Canada 1972). The structure of a community in an ecosystem reacts in dynamic equilibrium with the change in environmental conditions.

The degradation of putrescible matter in surface water proceed in a sequence of phases characterized at first by reductive, and later by oxidative processes. If the putrescible matter, such as domestic wastewater, is discharged into a river, various phases of decomposition will occur successively in the downstream direction (natural self-purification). It is assumed that the river represents a continuous fermentation system. The in put of large quantity of biodegradable organic matter stimulates the microbial decomposition and forces the community in the direction of heterotrophy. Such situations tend to restrict the floral and faunal variety. The species tend to disappear from streams in a definite order as the degree of pollution increases. The resulting biocoenoses comprise species that prefer a strictly limited range of conditions and other which tolerate a broad range of conditions.

In the downstream section where the microbial biomass has reached its maximum, the substrate had been utilized to a large extent, the cell number subsequently decreases as a result of grazing by Protozoans & Rotifers, flocculation, autolysis etc.

Microbial degradation results in an increase in nutrient supply for photoautotrophic organisms, which become progressively more abundant downstream. Thus increasing the productivity over heterotrophic activity and restoring the quality of the ecosystem.

1.4 Significance of the Biocoenoses

Since the structure of biotic community is largely determined by the average water quality predominating in a given segment of the river, conclusions about the quality of water may be drawn from the organisms present. Measurable characteristics of the ecosystem, which provide information of the quality of water might be (1) by determining the state of communities and change in their structure, (ii) using organisms as indicators of water quality, especially with respect to the content of putrescible organic matter and (iii) measuring the quantity of organisms in excess of their natural level, thus causing nuisances and deterioration in water quality.

Chemical analysis have the advantage of great precision and clarity but they carry a considerable bias. Since the value of analysis stands and falls with the representativeness of the samples, chemical composition, particularly in the event of intermittent inflow or of accidents may change rapidly and drastically over time, thus requires many samples to characterize the average properties of the river segment under consideration.

Biological inventory depends largely on season, but presents a very reliable picture of the average situation since the community of organisms cannot adapt itself to rapid sudden changes. If a food processing industry, for example, stopped the addition of its waste into the river for some time, the chemical analysis would show a change in water quality, but the presence of specific filamentous flora in the biological film at the bottom would pinpoint the type of previous pollutional load (Uhlmann,1979). Thus frequency of sampling may skip some important observations by chemical analysis but organisms would preserve the information and indicate. Organisms through their presence, number and behaviour can integrate many different environmental changes

over a long period (Sastry, 1988). It can also provide considerable information on the character, metabolism and constitution of a water, but can not calculate the incoming sewage load in terms of sewage concentration or mass flow. The combined view of chemical and biological performance is therefore particularly valuable in case of contradictions.

It is thus evident that it is both necessary and possible to adopt a biological approach to ensure the environmental quality by quantifying the changes in ecosystem.

1.5 Choice of Indicator Group

A number of groups of organisms could be used for evaluation of quality of river water e.g. bacteria, phytoplankton, zooplankton, macroinvertebrates, fish, or their taxonomic sub-groups. Several studies on the ecology of the algae from diverse kinds of habitats have proved that their presence and prevalence in the water indicate the sum total of their environmental conditions (Palmer, 1969; Archibald, 1972; Rai, 1978; Kamat, 1981; Chawla et.al. 1986; Bilgrami & Dutta Munshi, 1985). Benthal macroinvertebrate community has been used extensively for the measurement of water quality in European countries (England, Denmark, Scottland). A number of workers have shown that zooplankton population in the river is a good indicator of trophic nature (Arora, 1966; Mahajan, 1981).

The most important parameter from the view point of drinking water quality criteria is the presence of pathogenic organisms. For routine control purpose the direct search for the presence of specific pathogenic agents in water is impracticable. Therefore, water bacteriologists have evolved simple and rapid tests for the detection of intestinal organisms that are easier to isolate and identify. Indicator bacteria, coliform, faecal coliform

and faecal Streptococcus project a reliable picture of faecal pollution of water and are indicative of pathogens in the water system (Geldreich, 1970; Geldreich & Kenner, 1969).

The ecosystem criteria like heterotrophic activity of microganisms, the structure and distribution of the community, photoautotrophic activities and the presence of indicator organisms due to various saprobic systems are also indicative of self purification capacity of the river in terms of secondary effects.

With few exceptions all aquatic biologist agree that it is possible to estimate water quality according to the organisms and their communities, and to classify the water and compare the aquatic environment of different water bodies. Recent water technology extends the requirements for biological water analysis to drinking water, sewage, industrial wastes and all biological processes of treatment. Thus there is a need of universal biological scale of water quality comparing the communities of all habitats under all circumstances.

1.6 Ecological Studies of the Rivers

In the early sixties UNESCO initiated the first ever multi-disciplinary study on the major rivers of the world, which led to considerable advances in the understanding of some aspects of life of the rivers. Besides the well known hydrological features, hydrobiological aspects and primary geochemical cycles operating in different sectors of the rivers have been studied in some of the major rivers of temperate zone in the European continent and North America. This was conducted by international team of scientists from different desciplines (KrishnaMurthi, 1986).

Literature has revealed that most of the work on the lotic ecosystems has been done by taking into account only one or few components of the ecosystem. One of the most important advances in river ecology has been an integrated review on fresh water quality by Hynes (1970), which provided a review of macroinvertebrate representatives of world wide streams with emphasis on morpho-behavioural adaptation to flowing water.

A detailed review dealing with the ecological aspects of algae in streams and rivers, has been presented by Hynes (1970) and Whitton (1975). A number of rivers from Europe and North America have been studied by various workers, like river Thames, Essex stour, Lee (England), James, Sacramento (USA), Danube (USSR) for plankton and Rhine (Germany), Yamuna (India) Nile (Africa) Lower Missouri, Ohio (North America) for zooplankton (Whitton, 1975).

Compared to the rivers of temperate zones, very little sustained work has been done on the hydrobiology of tropical rivers, including the major river systems of the Indian sub-continent. So far there are only few scanty records regarding the effect of organic pollution on Indian rivers. Yamuna (Ray et.al. 1966), Khan (Rama Rao et.al. 1978), Cauvery (Paramasivam and Sreenivasan, 1981) Pawana, Mutha, and Mula (Gunale and Balakrishnan, 1981), Jhelum, (Vass et.al. 1977) are some of the rivers which have been studied from ecological angle in limited zones.

Some hydrobiological data on Ganga have been collected at specified points like Kanpur (Saxena et.al. 1966), Allahabad (Ray et.al. 1966). These are too fragmentary to draw any clear picture concerning the dynamics of the riverine ecosystems.

Concentration of coliform bacteria is usually used as an index of civic pollution. Various rivers of the world have been surveyed with regard to

the impact of bacterial population on water quality, Hull (Goulder, 1981), Aires (Milner and Goulder, 1984), Welsh (Nuttall, 1982) of England, Ogilvie and Swift (Albright et.al. 1980), Meduxnekeag and Dunbar (Bell et.al. 1982), Athabasca (Geesey and Costerton, 1979) of Canada, Nile (Saleh, 1980) of Egypt, Nida (Starzecka, 1980) of Poland, Tisza (Hegedus et.al. 1980) of Hungary, Tigris (Mutlak et.al. 1980) of Iraq, Sagami (Maeda, 1980) of Japan.

Work on bacterial survey of Indian rivers is relatively poor. Mathur (1965) have investigated the seasonal distribution pattern of coliform bacteria in Yamuna river in Delhi. Bilgrami and Dutta Munshi (1985) have reported the concentration of coliform in Ganga river from Patna to Farakka.

One of the major aspect of the self-purification of the rivers is the natural control of the microbial imbalances. Wuhrmann (1972) compared the death rate of coliform bacteria in various rivers of the world (Ohio, Missouri, Tennessee, Cumberland) and recorded the comberland river below Nashville with a high death rate (T_{90} = 10 hours). Apart from the effect of conventional microfauna in the control of bacterial population, the direct proportionality between size of native bacterial population and the rate of extent of decline of the population of Escherichia coli has been made on marine water (Mitchell, 1972; Mitchell and Nevo, 1965; Mitchell et.al. 1967). Precise information however, on the bacteriocidal quality in Indian rivers is still lacking.

In 1977, Central Pollution Control Board initiated a regular water quality monitoring programme in the Ganga basin under basinwise pollution control task. In its first phase, Yamuna was monitored at 15 sampling stations for physico-chemical and bacteriological parameters from 1977 to 1979 at a

seasonal frequency (CBPCWP, 1982). In second phase, the Central Board with the co-operation of State Pollution Control Boards (Uttar Pradesh, Bihar and West Bengal) surveyed the river Ganga with the network of 41 monitoring stations throughout the stretch of the river from Haridwar to Diamond Harbour during 1980-82 (Das Gupta, 1984). This agency has neither undertaken the mountainous stretch of the river above Haridwar for monitoring nor the biological parameters were given any weightage.

Bilgrami and Dutta Munshi (1985) have presented a limnological survey of Ganga from Patna to Farakka at six sampling stations. They have recorded 175 algal species from this zone.

1.7 Ganga Action Plan

It was against the above background that in the beginning of sixth five year plan, Planning Commission launched a programme to bring the University system into active participation in Eco-development (Planning Commission, 1981). A coordinated action research project for the integrated study of the Ganga basin was one of its major theme. As a result of this, an integrated environmental research programme on the Ganga was initiated by the Department of Environment, Govt. of India, in 1983.

For the effective implementation of the programme the entire river, from its source to its mouth in the Bay of Bengal, has been divided into three major stretches : (a) Upper Ganga, from origin to Narora (b) Middle Ganga, from Narora to Ballia (c) Lower Ganga, from Ballia to Hoogly. Each stretch was assigned to a group of universities. Fourteen universities located all along the Ganga participated in the above programme. Effectively, the studies can be said to have been conducted from Dec. 1984 to Dec. 1986.

The upper Ganga stretch (about 710 km) which includes river Bhagirthi, Alaknanda and Ganga upto Narora, was allotted to a group of three universities (Garhwal University, Gurukul Kangri University and Roorkee University). Out of this, 509 km of upper Ganga (Alaknanda and Ganga upto Narora) was undertaken by University of Roorkee, Roorkee, under the head "Pollution Modelling of Upper Ganga Basin". The main objective of the project was to apply statistical and system analysis technique on the generated microlevel data to project a clear picture of the state and extent of pollution of Ganga ecosystem. The present study was incorporated as a part of the research project.

1.8 The System Under Study

1.8.1 The river

The 509 km stretch from Badrinath ($30^{o}44'29"N$, $79^{o}29'41"E$), nearer to the source of Alaknanda, to Narora ($28^{o}14'32"N$, $78^{o}21'51"E$) lying in the north-west of Uttar Pradesh between latitude 28^{o} and 31^{o}, longitude 78^{o} and 80^{o} is being defined as upper Ganga, excluding Bhagirthi which has not been considered in this study. The stretch so defined originates in the district Chamoli and flows through the boundaries of twelve districts (Fig. 1.2). After a run of first 240 km passing through greater and lower Himalayan belt, the river reaches Rishikesh situated in the sub-Himalayan tract (Shiwalik range). In this mountainous zone a number of tributaries having their sources at high altitudes join the river Alaknanda viz. Dhauli Ganga at Vishnuprayag, Birahi Ganga between Vishnuprayag and Nandprayag, Nandakini at Nandprayag, Pindar at Karnprayag and Mandakini at Rudraprayag (Fig. 1.2). Finally it joins river Bhagirthi at Devprayag.

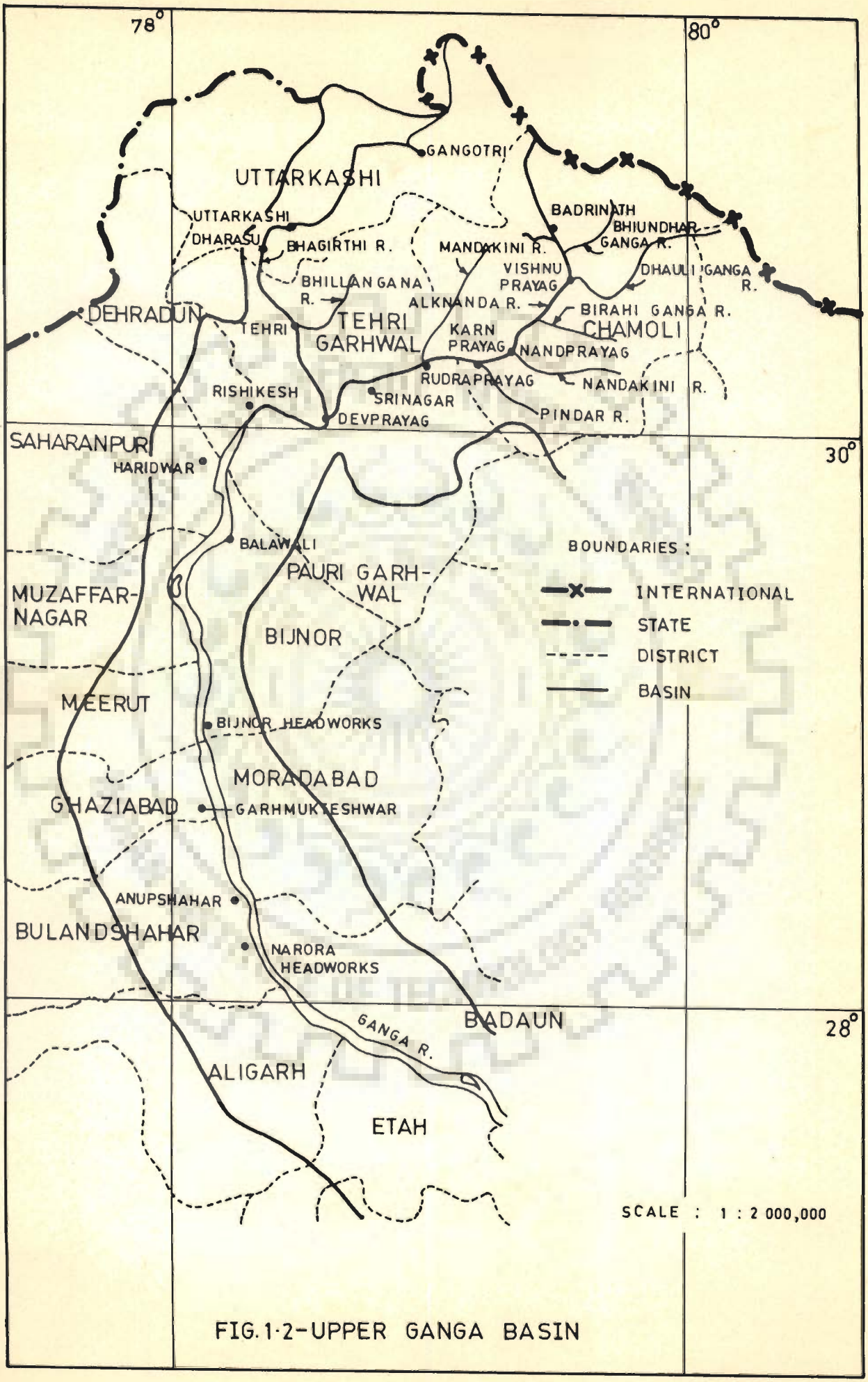


FIG. 1·2 – UPPER GANGA BASIN

The river makes a steep descent with an average slope of 30.6 m km^{-1} in the first 70 km upto Nandprayag of its longitudinal profile. Afterwards its gradient is not so steep in the remaining hills (upto Haridwar) with an average slope of 3.04 m km^{-1} (Fig. 1.3). The river has formed deep valleys, sometimes narrow and sometimes broad in accordance with lithology.

Being supported by large snow-fields and glaciers, all the Himalayan tributaries of the Ganga river are characterized by well regulated flow and assured supply of snow melt water throughout the year.

After Rishikesh, it turns south-westwards for another 30 km in foot-hills and cuts across the Shiwalik range at Haridwar to debounch on to the vast Indo-Gangetic plains. In this zone river water is diverted into the Chilla canal at 8 km downstream of Rishikesh to generate the hydro-electric power. This water again joins the headstream at 21 km downstream of Rishikesh (at Bhimgoda). In the leanflow season, the river in this 13 km zone have the only flow from river Song which joins the stream at Satyanarayana. At Haridwar 60% of its water is diverted into the upper Ganga canal leaving little flow in the Ganga for next 80 km or more. In the upper Ganga plains it flows in the south-east direction with an average gradient of about 0.47 m km^{-1}.

This stretch of the river is thought to the be relatively unpolluted, but not surveyed adequately.

1.8.2 The climate

The area located at 4000 m and above are mostly snow-bound throughout the year. The winter depressions cause snow fall for most of the days of the three months from January to March, above 1800 m. Even in the summer months, the temperature remain well below 20°C in this region. In the

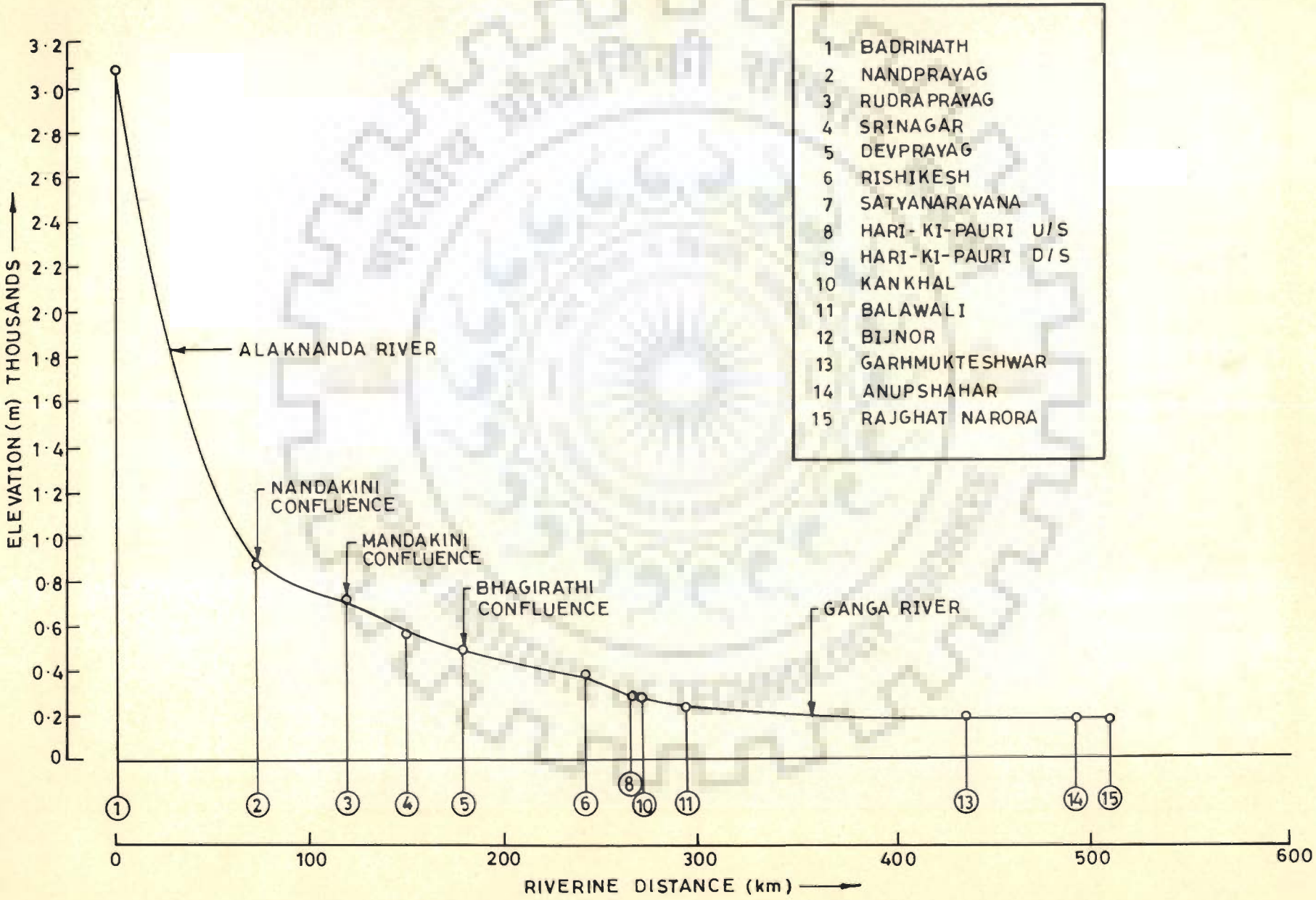


FIG. 1·3 : L- SECTION OF UPPER GANGA RIVER

mountainous zone below 1800 m, the valleys experience hot streamy tropical climate in the summer months. The valley winds in narrow valleys and heavy fog during winter in wide valleys, are conspicuous features of the weather in this region.

The monsoon commences towards the end of June and ceases by the middle of September. April and May are rather marked by thunder and occasional hailstorms. In May and first half of June, prior to monsoon, convectional rain occurs in small amounts (12 to 25 mm) on some days, often at high elevations. The zone of maximum precipitation both in summer and winter, lies between 1200 and 2100 m elevation. Annual rainfall ranges from 800 - 2500 mm. 50% of the rain is in the form of snow in the higher reaches of the region (Singh, 1987).

Owing to its complicated relief, the microclimate are of considerable importance which usually differ from valley to valley, according to the direction of ridges, degree of slope, sunny or shady aspects of the slope, intensity of forest cover and nearness to glaciers.

In the plain region, the gradual rise in temperature which starts from February, becomes more rapid by March and continuous till May, June. In this hot season the maximum temperature touches the mercury level upto 40°C. The air temperature starts falling off with the onset of monsoon, from the later half of June, rendering the weather more and more humid. The rainy months, from July to September account for over 90% of total annual rain fall. The post monsoon is characterized by a sudden fall in temperature and rain fall. The cold weather period extends from December to February. January is the coldest month with the mercury often falling below 10°C.

The incidence of winter rains in the region, distinguishes it from the middle Ganga plains.

1.8.3 The river flow

The flow of Ganga varies enormously seasonally. The winter season is the lean flow period. Increase in temperature in summer months results in an increase in the flow due to melting of ice from the higher altitude. In the monsoon the river flow comprises direct storm runoff. At this time the flow values are several times, higher than the rate in the lean flow period. For example, at Rishikesh the lean month is February with a mean rate of flow of 155 m^3 sec^{-1}, while August has the highest mean rate of flow 3159 m^3 sec^{-1}, which is 20 times higher (based on 1971-1981 data, Das Gupta, 1984).

1.9 Outlines of the Problem

The objective of the study presented herein covers the following basic features :

(i) to explore the biological spectrum pertaining to upper Ganga river ecosystem at selected locations,

(ii) quantification and depictions of the changes in the state of ecosystem induced by pollution or stress at different locations, in terms of community diversity and similarity,

(iii) to explore the extent and possibilities of bacterial indicator organisms in the evaluation of water quality and assessment of the compliance of results with the present water quality standards vis-a-vis the current water use as well as the suitability and limitations of the same in the existing conditions,

(iv) to provide the scientific justification to the proverbial purity of Ganga river, which is often ascribed to the bacteriocidal property of its water.

For a meaningful assessment of the aforestated objectives, an in-depth study at maximum possible locations in the upper Ganga region was made. The investigations included the following aspects :

(i) qualitative and quantitative survey of photoautotrophic (phytoplankton) and heterotrophic (zooplankton and heterotrophic bacteria) component in the water, to present the general state of the ecosystem,

(ii) physico-chemical parameters like pH, temperature, oxidation-reduction potential (ORP), conductivity, turbidity, dissolved oxygen, biochemical oxygen demand and chemical oxygen demand of the river water, which influence the state of ecosystem,

(iii) enumeration of indicator bacteria, and enteric viruses,

(iv) rate of decrease in bacterial number (Bacterial self-purification), a major aspect of natural purification by means of grazing, autolysis etc.,

(v) the effect of mass bathing on water quality at selected location, and

(vi) the possible effect of the effluent discharge of pharmaceutical industry on the pre-ponderance of aquatic and extra-aquatic fungi in the ecosystem in a selected zone.

CHAPTER - II

SAMPLE NETWORK AND METHODS

FIELD STUDIES

The reliability of data in water quality depends largely on properly scheduling sampling programme and measurement system network. The data would be as precise as is the planning.

2.1 Sampling Programme

Planning of the sampling programme was done taking into account the objectives of the analysis, the parameters and methods of measurement. Efforts were made to centralise the aim of sampling to achieve the representativeness and validity of the samples.

2.1.1 Sampling stations

In order to assess the general state of ecosystem in the form of conventional biological, bacteriological and physico-chemical parameters, fifteen sampling stations covering a 509 km stretch of Ganga from Badrinath to Narora, were established (Figs. 2.1 & 1.2)). Stations were fixed considering the abstractions, additions, specific major point sources of pollution, accessibility and maximum representation of the aquatic system. These sampling stations are defined in Table 2.1.

2.1.1.1 Badrinath : Situated in the alpine zone of high Himalayan hills, adjacent to the source of the river Alaknanda, it was recognized as the first sampling station (Plate 2.1). Due to heavy snow fall in winters, it remains covered with snow, and is accessible and inhabitable only from May to October. Being an important centre of pilgrimage, the station attracts a fair number of pilgrims

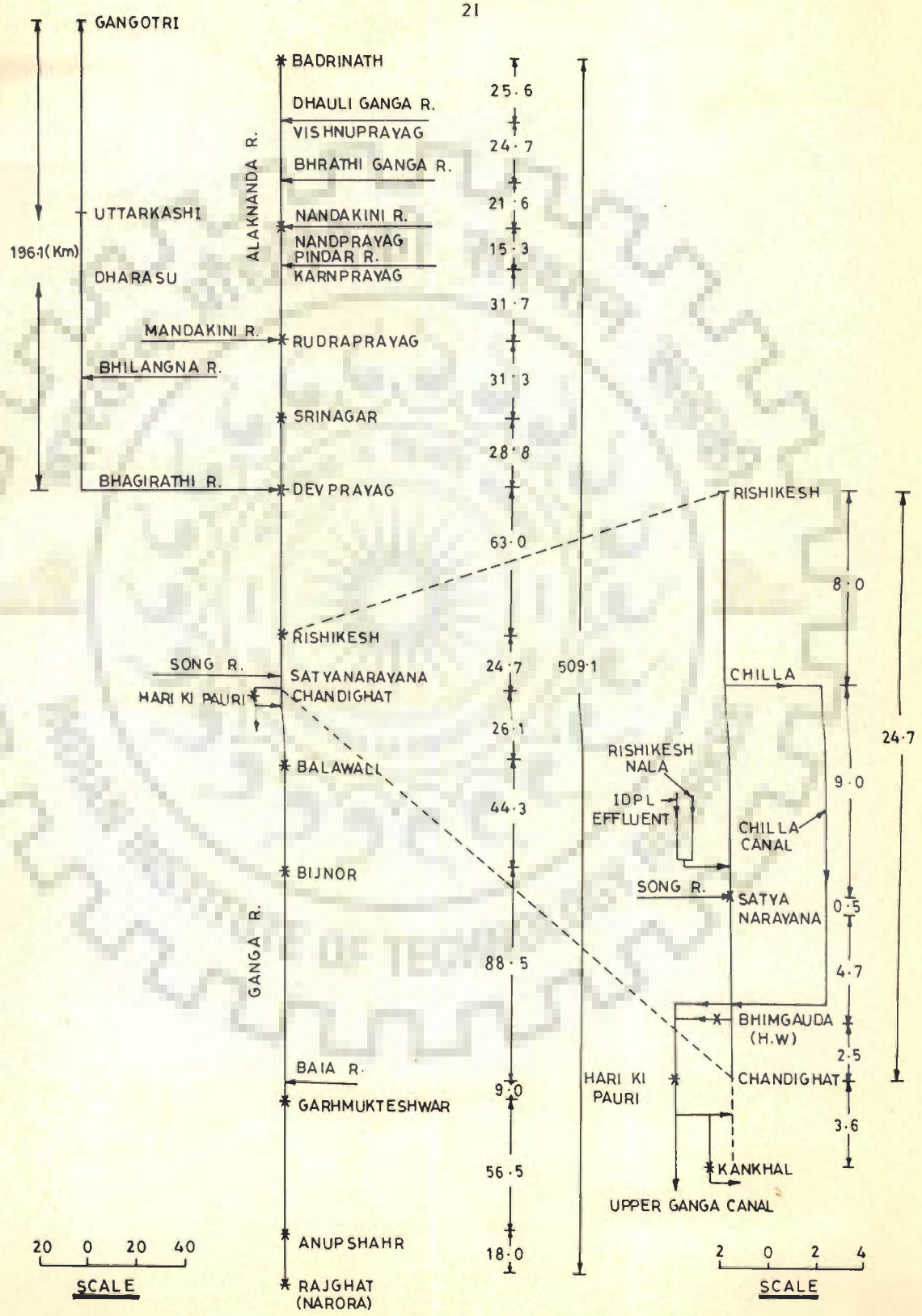


FIG. 2·1 – SCHEMATIC DIAGRAM OF UPPER GANGA RIVER SYSTEM

TABLE 2.1 : Topographic Characteristics of Sampling Stations

Sampling Stations	Altitude (m)	Distance from Badrinath (km)	Morphology of bed	Type of sediment
Badrinath	3086	0	Mountain stream	Boulders
Nandprayag	880	71.9	Hill stream	Boulders & pebbles
Rudraprayag	725	118.9	Hill stream	Boulders & pebbles
Srinagar	570	150.2	Hill stream	pebbles
Devprayag	500	179.0	Hill stream	pebbles
Rishikesh	348	242.0	Foothill stream	pebbles & gravel
Satyanarayana	-	259.0	Foothill stream	pebbles sandy gravel
Haridwar	288	266.7	Canalized bed in Foothills	pebbles sandy gravel
Kankhal	277	270.3	Canalized bed in plain alluvium	Gravel sandy with few pebbles
Balawali	230	292.8	Natural wide bed in high plains	Silt
Bijnor	-	337.1	Natural wide bed in high plains	Silt
Garhmukteshwar	195	434.6	Natural wide bed in high plains	Silt
Anupshahar	180	491.1	Natural wide bed in high plains	Silt mud
Rajghat Narora	176	509.1	Natural wide bed in high plains	Silt mud

and tourists during this period. There are few hot springs (temp. 35°C approx.), the water from which is collected in organized pools known as Tapta Kund, the only alternative for bathing there. The effluent from Tapta Kund finally meets the river.

2.1.1.2 Nandprayag : It is the place where tributary Nandakini joins the river Alaknanada. Nandprayag, a very small town of warm temperate zone of Himalayas, is situated on both the banks of Nandakini river. The town is inhabited by a small population.

2.1.1.3 Rudraprayag : This sampling station is at the confluence of tributary Mandakini, originating from Kedarnath hills (Plate 2.2). Inspite of being a small town, it accommodates a small floating population on way to Badrinath and Kedarnath in accessable months. The domestic effluent discharged into the river is of low order. It is from this station that the river enters the tropical zone. Soil erosion as result of road construction is significant in valley (Plate 2.7).

2.1.1.4 Srinagar : It is a busy town situated on the bank of Alaknanda in Himalayan region. The importance of the place is increased by the presence of educational institutions and business centre. A sizeable number of tourists prefer over high stay here, during their journey to high hill stations. Around 500 m downstream of point domestic waste discharge of Srinagar, is the sampling station located.

2.1.1.5 Devprayag : This sampling station is at the confluence of Alaknanda and Bhagirthi (Plate 2.3). As the construction of Tehri dam, 42 km upstream, on river Bhagirthi is in progress, the water of Bhagirthi is turbid as compared to Alaknanda, even in the lean flow season. Bathing activity is not very prominent at this station.

2.1.1.6 Rishikesh : It is the point where river completes its mountainous course and entres foothills. The sampling station is situated upstream of Rishikesh town known as Laxmanjhoola (Plate 2.4). It is an important religious and tourist centre. Occasional bathing activity is observed here. Downstream of Rishikesh town, most of the water of Ganga diverted to a power canal at Chilla Headworks, leaves neglegible flow in the river in lean flow season (Plate 2.5).

2.1.1.7 Satyanarayana : At this sampling station tributary Song joins the Ganga and contributes a major amount of flow during lean flow season. The effluent of the Indian Drugs & Pharmaceutical Limited (IDPL) factory after treatment, and domestic waste discharge of Rishikesh township meet the river at about 300 m upstream of this point through a channel (Plate 2.6).

2.1.1.8 Hari ki Pauri : The well organized banks of the river abstraction coming out of Bhimgoda barrage, in Haridwar ($29^{o}57'24"N$, $78^{o}10'23"E$) is known as Hari ki Pauri. The most densely populated town on the bank of upper Ganga river is famous for mass bathing. The water of Chilla canal joins the river at Bhimgoda Headworks, the entrance point of the river at Haridwar. River abstraction leaves the town at Mayapur and flows for 3500 m through Hari ki Pauri zone. To study the effect of mass bathing on water quality, two sampling stations were selected in this zone - one representing Hari ki Pauri upstream at Bimgoda for reference and another 3000 m downstream of the Bhimgoda as Hari ki Pauri downstream.

2.1.1.9 Kankhal : This station is located on abstraction channel. After the diversion of most of the flow in upper Ganga canal from Mayapur barrage, a marginal flow is left in this channel which joins the river back. Bathing and post cremation activities are observed at this point throughout the year.

2.1.1.10 Balawali : This sampling station is few hundred meters downstream of railway bridge (Saharanpur-Lucknow). The river passes through agricultural sectors in this region. The river banks are used for cremation of dead by burning.

2.1.1.11 Bijnor : It is about 500 m downstream of Bijnor barrage from where the Madhya (middle) Ganga canal is proposed. A big agricultural sector surrounds the river in this zone. Cremation activities are prominent around this station.

2.1.1.12 Garhmukteshwar : 10 km upstream of this station the water from Ramganga feeder meets the river. On the right bank a religious town, Brijghat is located. Intense bathing is observed throughout the year. The banks are also used for cremation.

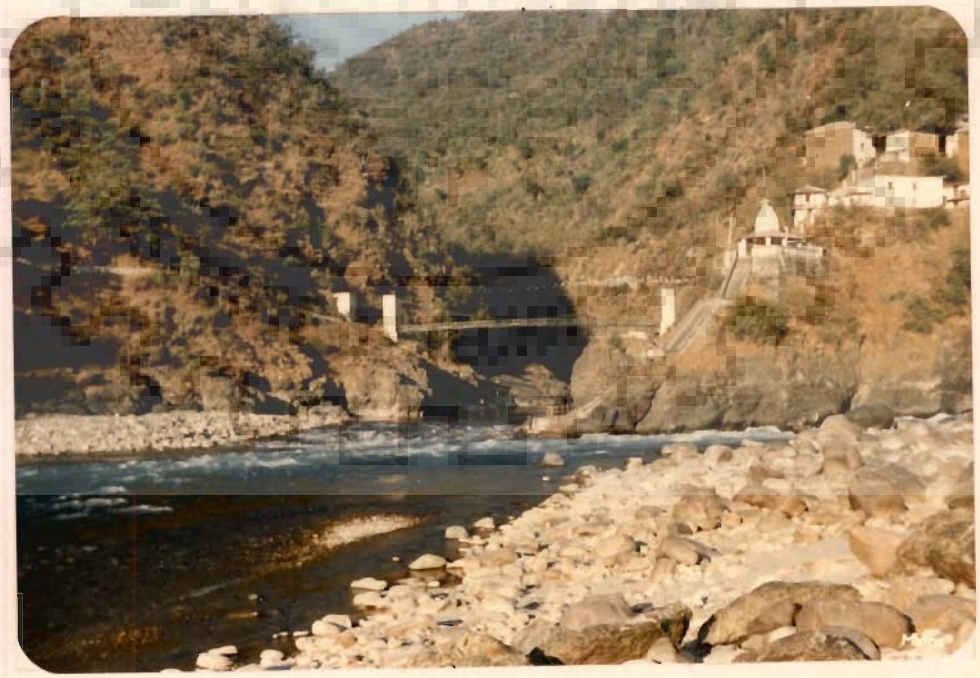
2.1.1.13 Anupshahar : It is located downstream of Anupshahar town which is situated on the right bank of the river. In the upstream, a channel draining the domestic waste discharge of twon, joins the river. The right bank is generally used for bathing and cremation purpose (Plate 2.8).

2.1.1.14 Rajghat Narora : It is the last sampling station of the study area. A small town situated on the right bank is one of the tourist centre in upper Ganga plains. The bathing activity is common at this station.

2.1.2 Frequency

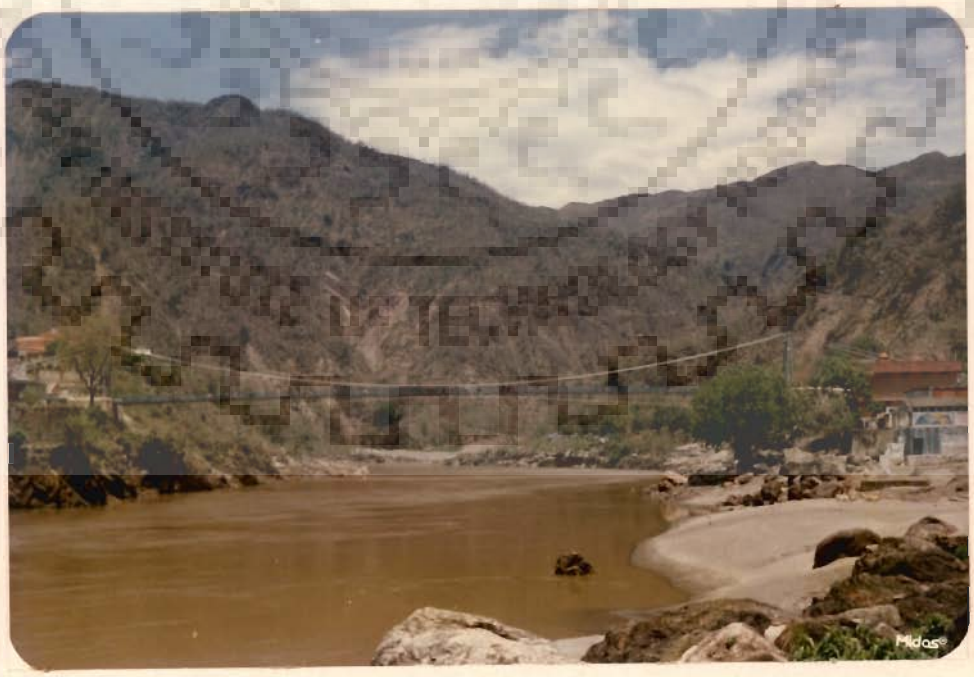
The study was conducted for two years from December 1984 to December 1986. During this period, the water samples were collected at a frequency of once in two months. Considering the amount of efforts available for sampling and analysis, it was decided to follow a seasonal frequency for two determinants at selected stations-enteric viruses and benthal macroinvertebrate community.

2.1 A VIEW OF ALAKNANDA AT BADRINATH

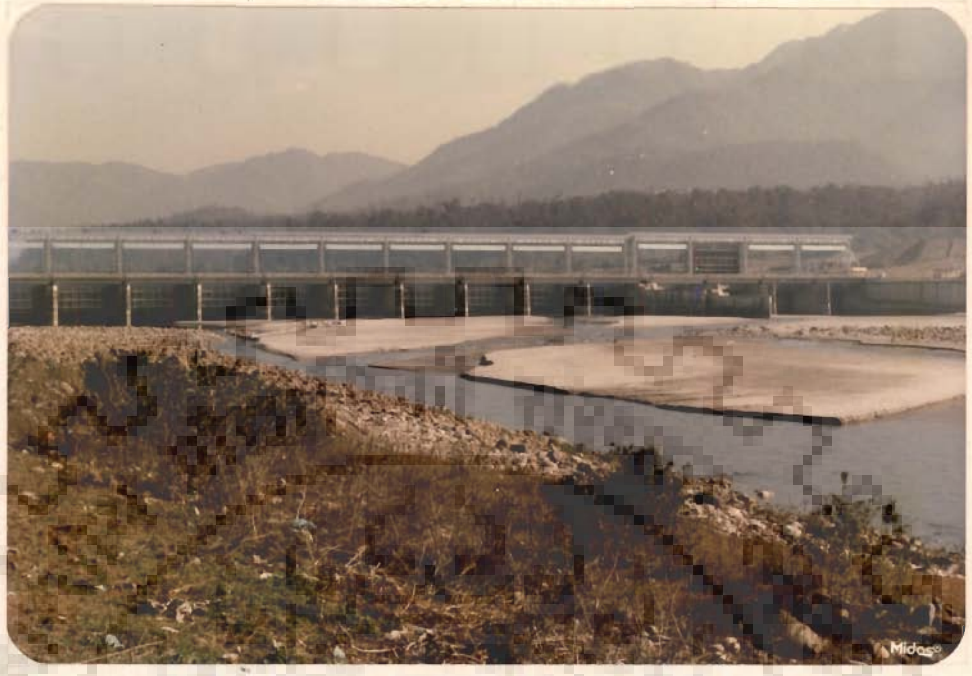


2.2 CONFLUENCE OF MANDAKINI AT RUDRAPRAYAG

2.3 CONFLUENCE OF BHAGRITHI WITH ALAKNANDA



2.4 GANGA ENTERING PLAINS AT RISHIKESH



2.5 RIVER CONDITION DOWNSTREAM CHILLA HEADWORKS

2.6 RIVER GANGA AT SATYANARAYANA, LEANFLOW CONDITION

2.7 VISIBLE EROSION IN THE ALAKNNDA VALLEY

2.8 EFFLUENT DISCHARGE AT ANUPSHAHAR

2.1.3 Representativeness of samples

The representativeness of a water sample is a function of the uniformity of the sample composition across the section of the water body. In the turbulent hilly stretch, where the accessibility is limited and the river represents a well mixed condition, grab samples were collected. At the confluence of various tributaries with main river, the samples were taken downstream of confluence, giving due regard to the mixing and stabilization distances. In the plain terrains on the other hand, where the lateral mixing of additions takes place generally after a considerable time and distance, integrated samples across the section of the river were collected.

2.1.4 Sampling techniques

All the samples were taken from upper 0.5 m layer of water. As the quickly flowing upper reaches of the river has low plankton density, the planktonic samples were concentrated in order to get the count in appropriate countable range. The sample size dependency of some of the diversity indices to be worked out, constrained the same procedure for the remaining stretch, even with higher plankton density. Hundred litres of water collected by a bucket of 10 litres was filtered through a plankton net of bolting silk no.25, with a mesh size 55 µm to collect the plankton samples. The total community was transferred to a clean 250 ml polyethylene bottle and the final volume was made up 100 ml with filtered water. Generally the preservation was avoided as it may result in the transformation of shape and size of some of the individual organisms, making the identification difficult. Whenever it was necessary, two parallel samples were taken, one without preservation and the other preserved immediately using 4% neutralized formaline.

Water samples for bacteriological examinations were usually taken from a depth of 0.3 to 0.5 m below the surface and not less than 0.5 m from the bottom. Bacteriological water samples were collected in sterile narrow mouthed glass bottles of 250 ml capacity with ground-in stoppers. The volume of sample was approximately 150 ml, which was sufficient to perform all the bacterial tests.

For the study of enteric viruses in water, the samples were collected in polyethylene bottle of 12 litres capacity. From one location or from different locations of a sampling spot, 3 multiple samples of 10 litres each were taken at a time. Five sampling stations viz. Satyanarayana, Hari ki Pauri downstream, Kankhal, Garhmukteshwar and Anupshahar were selected for viral evaluation, considering the domestic waste additions.

Separate samples for physical and chemical parameters were collected in 5 litres polyethylene bottles simultaneously. Samples for determination of dissolved oxygen were collected in 300 ml BOD bottle and preserved immediately.

In hilly stretch efforts were made to collect the quantitative samples of benthal macroinvertebrate community by a surber sampler with a sampling area of 50 x 50 cm of river bed and bolting silk net no.20 (mesh size 65 µm). The delineated area was hand sampled as much as possible. The dislodged animals swept back by the current were collected in the net. At last the substratum of the area was disturbed to allow the remaining animals carried into the net.

The contents of the net was transferred to a white tray. In this way at one sampling station about 10 locations were sampled. The animals were separated and sorted into major taxa. The sorted animals were collected in different tubes and preserved in 70% ethanol.

As the benthic invertebrate communities of the riffle reaches, where the water flows rapidly over the stony eroding substratum, are more sensitive to change in water quality than the communities in the muddy depositing substrata of the slow flowing deep rivers (Sladecek et.al. 1982), the hilly reaches of the stretch from Nandprayag to Haridwar were selected for this purpose.

For extra aquatic fungi, the floating dead organic matter was collected from surface water with the help of a hand net. These fragments were dried in surface sterilized blotting paper and placed in culture tubes having PDA (potato dextrose Agar) medium.

2.2 Parameters and Anlytical Operations

Biological, bacteriological and physico-chemical parameters were evaluated according to the methods specified in 'standard methods for the examination of water and wastewater' (APHA - AWWA - WPCF 1980).

2.2.1 Biological parameters

The flora and fauna were identified upto generic level as specific identification of all the forms was not possible.

2.2.1.1 Plankton : The device employed for both phytoplankton and zooplankton counting was Sedgwick-Rafter (SR) cell of 50 x 20 x 1 mm with a total capacity of 1 ml. One ml of well mixed concentrated sample was transferred using a large bore pipette to SR cell. Both phyto and zooplankton were counted in 100 random fields (Chambers), simultaneously under 40 times magnification with a Metzer compact inverted microscope. The average number per chamber was multiplied by the enumeration factor to obtain the total number of individuals per genus in the concentrates. The counting of one sample was made in

triplicate. High magnification upto 450X was used for the identification. The identification was performed with the help of Edmondson(1959), Smith (1950), Desikachary (1959), Needham and Needham (1962) for phytoplankton and Edmondson(1959), Pennak (1978), Calaway and Lackey (1962) and Needham and Needham (1962) for zooplankton.

2.2.1.2 Benthal macroinvertebrates : The animals were identified with the aid of stereoscopic microscope under 20X magnification, although a compound microscope upto 100X magnification was also used for the examination of their details necessary for identification. Pennak (1978) was used as a guide for the identification of macroinvertebrates together with Needham and Needham (1962) and Edmondson (1959).

2.2.2 Bacterial parameters

The collected water samples were immediately inoculated for coliform, faecal streptococcus and total heterotrophic bacteria. For the incubation in the field a portable, (battery operated) incubator was used. The temperature of incubation was $35^{\circ}C \pm 0.5^{\circ}C$ and the time was 24 hrs or a multiple of this as per specification for different tests.

2.2.2.1 Coliform bacteria : Population of total coliform was enumerated by MPN and MF techniques as per standard methods. Three tubes of MacConkey broth (purple) were used for each dilution for MPN coliform counts. For MF counts 0.45 u millipore membranes were used with nutrient pads supplied with m-endo medium. Three membrane were developed for different dilutions of sample.

2.2.2.2 Faecal coliform : Further identification of coliform group was made by IMViC reactions on pure cultures, isolated from confirmed fermentation tubes

of MacConkey borth. The density of faecal coliform in the sample was estimated by Escherichia coli percentage and total MPN count of the sample.

2.2.2.3 Faecal streptococcus : The density of faecal streptococcus was quantitated by multiple tube technique using Glucose azide broth for presumptive and Glucose azide-ethyl violet broth for confirmatory test as per WHO-reference hand book (Suess, 1982).

2.2.2.4 Total heterotrophic bacteria : The preponderance of heterotrophic bacteria was enumerated in terms of standard plate count bacteria using Nutrient agar (1.5%) as culture media.Three plates were inoculated with different dilutions of one sample.

2.2.3 Fungal analysis

Martin's Rose bengal streptomycin agar and PDA media were used for isolation and culture of fungi. Identification was performed with the help of Sparrow (1959).

2.2.4 Pretreatment of water sample for entric viruses

Concentration of viruses from samples was done by "Adsorption to and elution from aluminium hydroxide" method (Suess, 1982). As $Al(OH)_3$ adsorbs viruses at low pH, the $Al(OH)_3$ suspension was added in recommended amount to the bacterial free water sample, at pH 6. After 2 hrs stirring $Al(OH)_3$-virsus complex was recovered by filtration. The viruses were eluted from the complex with 5-10 ml beef extract solution (30 g l^{-1}) at pH 7. The concentrated sample were transported in sterilized glass bottles of 25 ml capacity to Respiratory Virology Division, Patel Chest Institute, Delhi University Delhi, in ice for the isolation and identification of enteric viruses.

2.2.5 Physical and chemical parameters

The determination of pH, oxidation reduction potential (ORP), conductance and temperature were done on the spot with the help of a portable testing kit. The measurements of the physico-chemical parameters included turbidity, DO, Biochemical Oxygen Demand and Chemical Oxygen Demand.

LABORATORY STUDIES

Due to obvious difficulties of investigation in natural system, it was preferred to investigate dynamics of bacteria in laboratory with the river water from Hari ki Pauri. The samples from this location were transported to the laboratory in 40 litres polyethylene vessels, rinsed with sterilized distilled water.

2.3 Rate of Removal of Enteric Bacteria in Ganga Water

2.3.1 Experimental

Batch studies were performed in order to establish the death rate curves of two groups of enteric bacteria viz. faecal coliform and faecal streptococcus. The river water was filter sterilized by passing through millipore membrane (0.45 μm porosity) under reduced pressure. To make the filtration easier the water was first passed through whatman 41 (8 μm porosity). The experiment was conducted in five flasks of 2 litres capacity each. 1000 ml of sterilized sample was added to each of the first four flasks.

The indigenous bacteria and protozoan were cultured in respective culture media from the same water sample, simultaneously, 24 hrs before the start of experiment.

Few drops of 24 hrs bacterial culture were added to 2nd and 3rd flask and few drops of 24 hrs protozoan culture were added to 3rd and 4th flask. Efforts were made to give the final concentration of bacteria and protozoa of the order of the river sample, calibrated in preliminary experiments. To the 5th flask only the natural river water sample was added.

The cultured test organisms (E. coli and faecal Streptococcus) were inoculated in same amount in the flasks by adding the drops of homogeneous mixture. The flasks were placed at room temperature.

2.3.2 Measurement

The flasks were examined for E. coli and faecal streptococcus count 24 hourly. Three replicates were made for each sample. T_{90} values were calculated for both organisms in different conditions and death rate curves were plotted.

2.4 Estimation of Bacterial Predation by Aquatic Microfauna

2.4.1 Experimental

Predation by aquatic microfauna was determined by batch culture following the technique of Sorokin and Kadota (1972). Samples of river water were supplemented with 50 ppm glucose in order to record significant growth of the populations. Two sets of five bottles of the capacity 1.25 litre were prepared. PVC dark bottles were used. In the first set, the predators were removed by filtering the water through whatman no.41 filter paper (porosity 8 μm). 95% of bacteria were recovered in the filtrate and microscopic examination proved that most of the microfauna was removed by filtration. The second set of bottles containe the river water without any treatment (bacteria and

predator). The sample size in each bottle was 800 ml. The experimental set up was placed at the room temperature. Samples for total heterotrophic plate count and microfauna were analysed initially, after 24 hrs and then at an interval of 48 hrs upto the 15th day. The experiment was performed thrice.

2.4.2 Estimation

The bacterial productivity of the sample without predator could be written as

$$P = N_t - N_o \qquad \text{(Number } l^{-1} t^{-1})$$

where N_o and N_t are bacterial counts of predator free water after 0 and t hrs respectively.

While the productivity of the sample with predator

$$P = C_t - C_o + G$$

where C_o and C_t are bacterial count of water with predator after 0 and t hrs respectively and G is the predation in bacterial number $l^{-1} t^{-1}$.

After combining the results of the two sets

$$G = N_t - N_o - C_t + C_o$$

Since $N_o \simeq C_o$

$G = N_t - C_t$ and the coefficient of predation,

$kg = G/t$ (number $l^{-1} t^{-1}$).

CHAPTER - III

ECOLOGICAL PARAMETERS

An ecosystem is a very delicate unit of nature. The change in one component modifies the other. In such a dynamic balanced system a stress in the form of pollution changes the fabric on which life depends. This change under pollutional stress has led to the search of means of quantification. Since the middle of 19th century organisms have been used as indicators of specific properties of aquatic environment. The first indicator system was, however, not established until the beginning of 20th century. Indices that summarise a large information have appealed to scientists for a long time, but its widescale use in ecology is quite recent. Two main approaches to study the pollutional stress have been used.

(i) measures based on community structure.

(ii) measures based on indicator organisms.

3.1 Community Structure

There are two basic types of indices depicting community structure, diversity and similarity indices. Diversity indices attempt to combine the data on abundance of species in a community into a single number which indicates the state of community. In similarity indices two communities are compared, one of which is often a control (also include its compelement dissimilarity indices).

These indices are normally applied to any community - benthos, plankton, nekton, or periphyton, or to a given taxonomic group.

3.1.1 Diversity indices

Diversity is the condition of being diverse and is also equated with variety. The simplest measure of diversity in biological systems is the number of species present. Such a measure, however, ignores the fact that the communities with the same number of species can be quite different if the relative abundance of species vary markedly. It has long been recognized that diversity is a function of both the number of species and number of individuals in a sample.

The most widely used and agreed definition of diversity in biological system is of Margalef (1958), restated by Pielou (1966) and Hurlbert (1971), which states that ecological diversity is a function of the number of species present and the evenness with which the individuals are distributed among these species. Pielou (1975) defined diversity as "the richness and variety of natural ecological communities". Odum (1971), however, maintained diversity as being ratio's between number of species and "importance values" such as biomass or number. It is generally agreed that diversity is a parameter of community structure involving species and their abundances, for the taxa considered.

The nature of diversity and how exactly to measure it, have been of much concern to ecologists. Margalef (1969) stated that diversity can be expressed by a monotonous function having a maximum when all elements belong to different class. Hurlbert (1971) noted that diversity can increase as evenness increases, despite a slight decrease in species number.

Cairns (1977) described a diversity index as a numerical expression that can be used to make comparisons between communities. He stated that diversity index is probably the best single means of assessing biological integrity in

fresh water streams and that it is less effective or possibly inappropriate in lakes and seas. The diversity indices, which are considered in the present work, are categorized on the basis of the approaches, the proposer have used.

3.1.1.1 Simpson's index : Simpson's D : Simpson (1949) defined the measure of "concentration of the classification" in a population being the probability that the two individuals chosen at random and independently from the population will be found to belong to the same group. The Simpson's D as it is known today, originally called 1 in his 1949 note, is claimed to be an unbiased estimation.

$$D = 1 = \sum_{i=1}^{S} \frac{n_i (n_i - 1)}{n(n - 1)}$$

Williams (1964) opined that Simpson's D is independent of any theory about the form of frequency distribution of abundances, but is not entirely independent of sample size.

Others, Keefe and Bergersen (1977), have stated that D is either independent of sample size or only mildly dependent. Odum (1971) claimed that Simpson's D is not a diversity index, but a dominance index, as he did not approve the relative weights given to rare and abundant species in the index. However, it has been substantially used as the basis for other indices of diversity (Hurlbert's PIE, Keefe and Bergersen's TU).

Simpson's diversity ranges from 1 when there is only one species present (minimum diversity) to 0 when S = n (maximum diversity). McIntosh (1967), Hurlbert (1971) stated that the complement of this index (1-D) is related to diversity.

3.1.1.2 Information theory : Diversity indices derived from information theory have received considerable attention and have been commonly used. These are recognized by verstality in reducing hordes of numbers and species to a comparable figure.

Weiner (1948) stated that extent of information in a system is a measure of the degree of disorganization. One of the main proponents of information theory, Shannon (1949), was of the view that if one has a set of probabilities, p_1, $p_2 \cdots p_n$, a measure can be found of how much choice is involved in the selection of the events or how "uncertain one is of the outcome". This is a measure of information. Wilhm (1967) has further stated that information content is a measure of uncertainity and a measure of diversity. Thus uncertainty, information content, diversity are equated.

There are two main information indices, Brillouin's H and Shannon's H'. From these the other two measures, redundancy and evenness were developed.

Shannon's H' : The best known diversity index is Shannon's H'. It has occasionally been referred as Shannon-Weaver index because Shannon published his paper, with another paper of Weaver in a book form.

In 1949 Shannon based on a set of possible events (probabilities) $p_1, p_2 \cdots p_n$, stated that one could find out a measure of selection of the event. He looked for three properties of this measure.

- it should be continuous in the p_i;
- if all p_i are equal ($p_i = 1/n$) than H' should be monotonic increasing function of n. With equally likely events there is more choice or uncertainty when there are more possible events;

- if a choice be broken down into two successive choices the original H' should be the weighted sum of individual values of H'.

Shannon claimed that only H' satisfying the three properties is

$$H' = -k \sum_{i=1}^{S} p_i \log p_i$$

where k amounts to a choice of unit of measure and is normally 1.0.

Margalef (1972) discussed the question of an upper limit of H' and argued that it can not be infinity. It is a log function, and is asymptotic. He noted that a value of H' equal to 5.0 was the maximum value for ecosystems. Dills and Roger (1974) however observed that though H' is seldom greater than 10, it can theoretically go to any positive number. In practice however 5.0 is the limit for most biological studies.

Kaesler and Herricks (1979) worked out the hierachial diversity from the values of H', in hierarchy for order, family, genus and species. They recorded a very high rank correlation between generic diversity and species diversity. They suggested that purpose of environmental monitoring might best be served by working at generic level, rather than the species level.

This is particularly true when an index of diversity is to be used as major comparative and communicative tool. Marshall (1982) also observed, the insignificant difference between the information function index values calculated at generic and species level.

Redundancy : The first reference to redundancy in the use of information theory in ecology is credited to Margalef (1958). He noted that organisation signifies redundancy, which is related to the value of a sum of terms and also

to how the individuals are distributed amongst the species. However, other workers do not seem to agree with Margalef.

The index referred currently as redundancy was described by Patten (1962). This is a ratio of H' values.

$$R = \frac{H' \max - H'}{H' \max - H' \min}$$

Patten (1962), Wilhm (1967) gave

$$H'max = \log N\,! - S \log (\tfrac{N}{S})\,!$$

$$H'min = \log N\,! - \log (N - (S - 1))!$$

Pielou (1975) however gave H'max as log S

Patten's redundancy ranges from 0 at high evenness to 1.0 at low evenness. Wilhm (1967) claimed that redundancy is inversely proportional to the wealth of species but has a small positive correlation with numbers of individuals. He also noted that it resembles Simpon's D.

Hurlbert called Patten's Redundancy as a measure of relative species unevenness and used its complements V' as a measure of evenness.

Evenness : There have been several attempts at proposing an index to measure the 'evenness' or distribution of individuals into species of a community. Hurlbert (1971) noted that species enenness has usually been defined as the ratio of observed diversity to maximum diversity. In 1966 Pielou proposed (H'/H'max) to measure eveness and defined it as J' (Pielou 1975).

Hurlbert quoted, Sheldon (1969) as claiming that J' is dependent on species richness. He suggested that the complement of Patten's (1962) redundancy be used as an index of evenness. Which he claimed, is independent of S.

$$V = \frac{H' - H'min}{H'max - H'min}$$

He called (H'/H'max) a V' type index, however, V' type index seems to be most commonly used in the literature (Price, 1973; Reed, 1978). Reed (1978) found that diversity values were closely related to evenness.

Evenness has generally been referred to H' but is not always so. If one writes V' as $\Delta / \Delta max$ and $V = (\Delta - \Delta min)/(\Delta max - \Delta min)$ then any diversity index can be substituted for Δ that has a minimum and/or maximum value. As such evenness is only as good as the index one uses. Hurlbert suggested its use with his index (PIE).

3.1.1.3 Hurlbert's 'Encounter' index : Hurlbert's PIE : Hurlbert (1971) noted that potentially each individual in a community can encounter or interact with every other individual of the (N)(N - 1)/2 potential encounters in a community of N individuals

$$\sum_{i=1}^{S} (N_i)(N - N_i)/2$$

encounters involve individuals belonging to different species, thus dividing the second by first.

$$PIE(\Delta_i) = \sum_{i=1}^{S} \left(\frac{N_i}{N}\right)\left(\frac{N - N_i}{N - 1}\right) = \left(\frac{N}{N - 1}\right)\left(1 - \sum_{i=1}^{S} (p_i)^2\right)$$

PIE (Δ_i) is the probability of interspecific encounters or the proportion of potential encounters that is interspecific.

If an individual enters a community and encounters two individuals at random, PIE is the probability that they belong to different species. Thus PIE is the complement of Simpson's D or rather an approximation of the complement. Hurlbert's and Simpson's indicies are thus closely related.

Hurlbert opined that since the species richness of a collection generally increases with N, the comparison of species richness of different collections requires the collections to be reduced to a common size.

Hurlbert proposed Δ max and Δmin for PIE to calculate the evenness as

$$PIE_{max} = \left(\frac{N}{N-1}\right)\left(\frac{S-1}{S}\right)$$

$$PIE_{min} = \left(\frac{N}{N-1}\right)\left(\frac{(2N-S)(S-1)}{N^2}\right)$$

Goodman (1975) stated that none of the commonly used diversity indices reflect a biological mechanism except for Hurlbert's PIE which does but is not extensively used. Hurlbert (1978) used PIE as the basis for the niche overlap index and also the basis of measure of interspecific crowding and niche breadth.

3.1.1.4 McIntosh's 'Ecological distance' relative : McIntosh's M **:** In 1967 McIntosh proposed his index, based on "Euclidean ecological distance". The 'distance' between two communities is the square root of the sum of the squared differences

$$D_{ab} = \sqrt{\sum_{i=1}^{S} (X_{ia} - X_{ib})^2}$$

where X is the measure of ith species in sample a and b respectively, if the samples are identical then $D_{ab} = 0$.

McIntosh claimed that any sample of a community can be identical as a point in space, real or imaginary and equalling

$$\sqrt{\sum_{i=1}^{S} (n_i)^2}$$

This is equivalent to a distance value of a sample with no individuals. He claimed that the index above is dependent on the number of individuals in the sample and on their distribution into species, and hence a good measure of diversity. It is inverse of diversity index and that it has a maximum value when one species has most of the individuals and the others have only one individual each. Thus the above expression was described as the complement of diversity. It also goes up with sample size. He claimed the index directly related to diversity is the complement of the above.

$$1 - \sqrt{\sum_{i=1}^{S} (n_i)^2}$$

However, McIntosh decided to take the "point" away from n giving an index of diversity

$$n - \sqrt{\sum_{i=1}^{S} (n_i)^2}$$

He decided to express his index as a proportion of the absolute maximum diversity (where S = N) which is $N - \sqrt{N}$, thus, McIntosh's index equals :

$$M = \frac{n - \sqrt{\sum_{i=1}^{S} (n_i)^2}}{N - \sqrt{N}}$$

This ranges from 0 to 1.0 and could be equated with evenness such as Pielou proposed because it takes the measured diversity/maximum diversity.

3.1.1.5 Theory of runs : Theory of runs is the most recent development in diversity indices. The first index based on theory of runs was proposed by Cairns et.al. (1968), but its most recent literature is that of Keefe and Bergersen's (1977) TU, which has much common with Simpson's index as Hurlbert's work.

Cairns et.al. introduced the sequential comparison index (SCI) as a biologically based water quality index and provided means for an investigator with limited taxonomic expertise to assess the impact of changes in water quality. The calculation of index is based on differences in shape, colour and size of successively compared pairs of organisms. If an organism being examined is identical with the previous organism considered, it is the part of same 'run', if it is not, it is the part of new 'run'. Thus, more the runs in a given number of organisms, the greater the diversity of the sample.

Keefe and Bergersen pointed out the high variability between workers making the counts, which impairs its value as a useful monitoring tool, despite having a strong intuitive appeal and essence of the species diversity concept.

Keefe and Bergersen's TU : Keefe and Bergersen (1977) presented an index which retained the intuitive appeal and simplicity of SCI and reduced the workers variability encountered with SCI. They explained that if we call the number of observed runs among n organisms r_n, the original index proposed by Cairn et.al. (1968) is simply the rather abstract term r_n/n, the sample number of runs per specimen. Cairns and Dickson (1971) later incorporated a weighting factor with r_n/n to accomodate differences among samples in numbers of taxa observed. If population mean number of runs per specimen is denoted by μ_r then r_n/n can be considered an estimate of μ_r. They stated that Mood in 1940 using the theory of runs showed that

$$\mu_r = 1 - \sum_{i=1}^{k} (\pi_i)^2 \quad \text{(approximately)}$$

where k = number of taxa present and π_i = population proportion in the ith taxon, $i = 1,\ldots,k$.

Keefe and Bergersen replaced the population taxa proportion by sample taxa proportions in the above formula and claimed it as T.

$$T = 1 - \sum_{i=1}^{k} (p_i)^2$$

But they themselves stated that T is slightly biased and proposed an index TU which they claimed unbiased estimator of μ_r.

$$TU = 1 - \left(\frac{n}{n-1}\right) \left[\sum_{i=1}^{k} (p_i)^2 - \frac{1}{n} \right]$$

It ranged from 0 to 1.0. They equated 1-TU with Simpson's D, but they have not explained how TU was derived.

3.1.1.6 Guesses by data fitting : Basically, this group of index is arbitrary and no theoretical explanation is attempted which relates the index to the biological world. The index formulated by various authors corresponds with the author's feelings on whether it fits the data best. These indices have been widely used and are continued to be so, despite the lack of explanation.

Gleason's index : Wilhm (1967) mentioned that Gleason in 1922 considered a linear relationship between number of species and logarithm of total number of individuals in the sample.

$$\text{Gleason's } d = S/\ln N$$

This index commonly gives values ranging from 0 to over 30 depending on sample size. Menhinick (1964) claimed that the index varies greatly with sample size, because both numerator and denominator change with sample size but not by a constant.

Gleason's index has not been used extensively in recent literature, and is replaced by Margalef's index.

Margalef's index : Margalef (1958) cited the index

$$d = S - 1/\ln N$$

as the simplest diversity index calling it 'by no means worst'. It is based on the dubious assumption of Gleason. It differs from Gleason's only by unexplained substraction of 1.0 from the species number, which makes little difference at large numbers.

Menhinick criticized Margalef's index for the same reasons as Gleason's index. Wilhm (1967) concluded that Margalef's index correlates less with number of individuals (Sample size). It is also felt that Margalef had developed this index to confirm specifically to Shannon's H', to parallel it as closely as possible and thus save the time of working out H'.

Menhinick's index : Menhinick (1964), working on insect population suggested $S/\sqrt{N}$ as a diversity index to replace both Gleason's and Margalef's index. With $S/\sqrt{N}$ he felt he could compare different sample sizes.

Wilhm (1967) concluded that the correlation with number of individuals of Menhinick's index exceeded that of Margalef's index. Although Menhinick's index also correlates highly with number of species present. Murphy (1978) concluded that Menhinick's index is dependent on sample size on purely theoretical ground.

3.1.2 The use of diversity indices in aquatic systems

Information theory have been extensively used in aquatic ecosystems, principally Shannon's H'. A substantial amount of aquatic data was collected by Wilhm (1967, 1968, 1970), Margalef (1958). They have recommended its use as an index of water quality.

Colwell and Futuyjama (1971) used H' to measure niche breadth, Chutter (1972) was one of the first to compare H' with biotic indices. He suggested the importance of correlation of diversity index with chemical quality. Dills and Roger (1974) working on acid mine drainage pollution found H' most promising index. They believed that diversity indices would be of considerable value when a comparison can be made of stressed and unstressed stretches of an aquatic system.

Balloch et.al. (1976) discussed H' in relation to both diversity and biotic indices and felt that H' is a suitable criterion of water quality. They believe that H' has advantage since it does not consider the kind of species present and has a disadvantage because it ignores indicator species. But this criticism is invalid because being an index of community structure, it reflects abundances of species, not specific indicator species. Belloch felt that H' was limited owing to the need for more rigorous and consistent quantitative procedures and longer computation time but that with computer facilities it might have a fruitful future.

Murphy (1978) felt that there is a marked temporal variation in H' and Margalef's index. He suggested the superiority of biotic indices over diversity to assess water conditions, Reed (1978) used H' and Pielou's evenness in small artificial aquatic ecosystem, working with plankton, periphyton, microbenthos, macrobenthos and microcrustacea.

Hughes (1978) conducted a critique on factors affecting H' other than pollution, for benthic macroinvertebrates. He noted that Shannon's H' has been calculated on a variety of taxonomic levels from species to family and sometimes on a mixture of taxonomic levels and sometimes these values from different taxa were compared when it is quite meaningless. Only H' derived

from same taxonomic level should be compared and if details of taxonomic level is not mentioned, the H' value quoted is worthless. He calculated the H' values from one set of data at six different taxonomic levels and suggested that sampling methods, size, time of the year and taxonomic level of the six factors examined (depth and duration in addition to these four) are the important factors of consideration when comparisons for different areas are to be made.

Patten's Redundancy index was used by Wilhm (1967), Wilhm and Dorris (1968) on aquatic ecosystem. Of the evenness indices V' type have been preferred over V type (Reed 1978).

Hurlbert's PIE have been used rarely (Goodman 1975; Hurlbert 1978). McIntosh's M have not been used for aquatic systems.

Keefe and Bergersen's TU also does not appear to have been evaluated in the published literature. Wilhm (1967) used both Margalef's and Menhinick's indices for aquatic macroinverteberates and found a good correlation with number of species.

The greatest use of any diversity index in aquatic ecosystem would be that of H', which is still in use - Tunnicliffe (1981), Sarkar (1983), Leewis (1985) and Hughes (1978). Hughes (1978) concluded that although diversity is useful index of community structure they can not stand alone as indices of environmental quality.

3.1.3 Similarity indices

Similarity indices are often used in plant ecology for ordinating samples relative to the overall similarities and then examining the major gradients

for correlation with environmental factors. A similarity index is basically a measure of similarity of the structure of two communities. Different species may compare abundance in particular species (similarity of areas in term of shared species) or abundance in any species (similarity of area by species number). Although they are measures of community structure, they can not give a value for one community alone as diversity indices do. Though they have been used in terrestrial ecology, particularly for plants (Greig Smith 1964), they are of particular use if water pollution is suspected from a point source, and upper and lower communities can be compared. However, it is always necessary to have a clean control water body near by.

The similarity indices which are of common use in aquatic systems and are being applied presently for the community comparison of different stations of upper ganga are the followings :

3.1.3.1 Percentage similarity : Brock (1977) stated that percentage similarity (PSC) was the original index used for community similarity and was discussed by Whittaker in 1952, and used by Whittaker and Fairbanks (1958) to compare copepod communities of small lakes and ponds. This index is

$$PSC = 100 - 0.5 \left(\sum_{i=1}^{k} | a - b | \right)$$

where a and b are, for a given species, percentage of total samples A and B which that species represents.

Brock noted that PSC fails when the relative proportions of taxa remain the same but the overall abundance changes. However, this fault may not be important in pollution studies as severe effects tend to alter dominance relationships and if the balance of taxa is nearly identical then the communities may be functionally the same.

3.1.3.2 Bray-Curtis index : Dyer (1978) used an index given by Poole (1974) and quoted as Bray-Curtis dissimilarity, which is defined by

$$D = \frac{1}{2} \sum_{i=1}^{S} | p_{i1} - p_{i2}|$$

where p_{i1}, p_{i2} are the proportion of species i in the sample 1 and 2.

Dyer stated that a dissimilarity analysis such that of Bray-Curtis can exploit information that is not utilized by diversity analysis. The complement of this index has been used extensively as a niche overlap index (e.g. Hurlbert 1978; Hanski 1978). The index consider both abundance and species number.

Hurlbert (1978) gave a slightly different version of Whittaker and Fairbanks' similarity as

$$1 - \frac{1}{2} \left(\sum_{i=1}^{S} |p_{i1} - p_{i2}| \right)$$

Which is in fact the complement of the Bray-Curtis dissimilarity. Thus, Bray-Curtis dissimilarity (in percentage) is complementary of PSC.

3.1.3.3 Pinkham and Pearson's index : Pinkham and Pearson (1976) discussed various situations in which similarity indices fail to depict changes in community. They stated that indices that examine species abundances or species occurances are inadequate for pollution surveys. They suggested that by comparing species compositions simultaneously more reliable analysis of data is provided. They defined X_{ia} and X_{ib} as the number of individuals in the ith taxon for station a and b respectively. To compare species composition, smaller of X_{ia}, X_{ib} is divided by larger of X_{ia}, X_{ib}, sum of k values are averaged by k. Pinkham and Pearson gave the formula, the most recent similarity index as ;

$$B = \frac{1}{k} \sum_{i=1}^{k} \frac{\min.(X_{ia}, X_{ib})}{\max.(X_{ia}, X_{ib})}$$

They noted that B could be used with any desirable variable, such as biomass and is not limited to the number of individuals.

Brock (1977) compared B with PSC and found that the two do not always agree. B measures change in rare species number whereas PSC is not very sensitive. Chutter (1978) stated that similarity indices do not necessarily reveal information about the pollution status of the water as they are inclined to the influence considerably by non-chemical environmental factors.

3.1.3.4 Euclidean or 'Ecological' distance : Dunn and Everitt (1982), Sneath and Sokal (1973), Clifford and Stephenson (1975) discussed euclidean distance which is a dissimilarity measure. The distance between the two community is the square root of the sum of the squared differences

$$D_{ab} = [\sum_{i=1}^{k} (X_{ia} - X_{ib})^2]^{1/2}$$

where, X is the measure of species i in sample a and b.

It was claimed as a simplest and oldest similarity coefficient. Clifford and Stephenson (1975) noted that in an ecological context Euclidean distance gave considerable weighting to abundant species. Gatz (1979) working on community organisation in fishes used it as a niche overlap index. The index formed the basis of McIntosh's M (McIntosh 1967).

Similarity indices could be a tremendous aid in water pollution work. Dyer (1978) commented that dissimilarity and similarity indices have played an important role in recent ecological literature. Unfortunately this has appeared to be scanty in aquatic ecology. If similarity indices are found to be more

sensitive to changes in community structure than diversity indicies then their use for water pollution is obvious.

3.2 Indicator Organism Approach

An indicator organism can indicate either clean or polluted conditions. An approach to water pollution making use of indicator organism concept is the use of biotic indices. These indicator organisms are test species picked for their sensitivity to various parameters.

3.2.1 Biotic indices

The biotic index is defined as an index of water pollution based on a study of biota. The term is vague and wide and as such could also cover both diversity and similarity indices. A biotic index however, is likely to be specific for one (or few) particular type of pollution, as the indicator organisms can not be equally sensitive to all types of pollution.

The biotic indices are also unlikely to be universally applicable, as the indicator organisms shall vary widely and as such no biotic index will work universally. Thus these are pollution specific and geographically specific. King and Ball (1964) stated that one of the most generally accepted biological techniques is that of using indicator organisms. They appeared to be attractive to water control and research authorities particularly in Britain, USA and South Africa.

But is was not possible to evaluate these indices due to inadequate knowledge about the sensitivity/tolerance of the benthic macroinvertebrates in the upper Ganga region.

CHAPTER - IV

BACTERIAL INDICATORS

The greatest dangers associated with water quality are due to direct or indirect contamination of water body by the excrements of warm-blooded animals including man. A risk of human and animal health is involved by the ingestion of pathogenic organisms, discharged by a carrier in water or by the consumption of food that has become contaminated by such a sewage or sewage polluted water. Therefore, it is important to observe whether pathogenic agents are present in water system and at what level.

For routine monitoring purposes the direct search for the presence of pathogenic organisms in water is impracticable. Therefore, a need was felt by the water bacteriologists to evolve an indicator organism that could show the presence of pathogens in water.

The first bacteriological standard was adopted by U.S. Public Health Service in 1914, which regulated interstate carrier water supply (Mitchell 1972). The standard was based on bacillus coli group and defined them as those micro-organisms that were able to grow on lactose-peptone broth, incubated for 2 days at $37^{\circ}C$ and produce gas. Later it was claimed that the group isolated by this type of analysis included many forms that were omni-present in nature. Various studies have been made to be more specific with regard to isolating bacteria of undoubted faecal origin.

In WHO international standards for drinking water (1971), the indicator organisms listed are coliform bacteria, E. coli, faecal Streptococcus, and anaerobic spore-forming organisms. The most important criteria of indicator is that its presence should indicate the presence of pathogens, in like manner

the absence of it should indicate a safe water system. Dutka (1973) suggested four criteria that indicator organisms should meet.

(i) to occur in greater number than the intestinal pathogens,

(ii) not to proliferate to greater extent in the aquous environment than the enteric pathogens,

(iii) to be more resistant to disinfectants and natural processes than the pathogens,

(iv) to yield characteristic and simple reactions enabling as much as possible the unambiguous identification of the indicator.

4.1 Total Coliform

The term coliform bacteria refers a group of bacteria of the family Enterobacteriaceae of Eubacteriales and distinguished by being able to ferment lactose. The current coliform group is essentially the same group of micro-organisms that has served since 1914 as indicator of faecal contamination of water.

Since the inception of the coliform standards microbiologists have argued over the reliability of using the coliform group to measure the degree of human contamination. The marked difference between the natural die-away of members of coliform group and other faecal organisms or nonbacterial pathogens have raised the possibility to isolate pathogens from water system in which coliform counts are negligible.

Evison and James (1973) showed that the types of intestinal bacteria found in geographically distant area were about the same, only with the exception of certain forms of Citrobacter spp and Klebsiella spp. It appears

therefore, that the use of coliforms as indicators of human contaminations should be valid irrespective of geographical locations. Dutka (1973) presented data on the relationship between coliform and salmonella in St. Lawrence river. He noticed a high ratio of coliforms to salmonella in all the samples investigated, so high in many instances, that a large factor of safety existed.

The coliform group is still the most reliable indicator of potable water. American National Research Council report on Drinking Water and Health (1977) stated, "it would be undesirable and extremely risky to substitute any organism for the coliform group now, although research studies that comapre other indicator organisms with coliform are warranted" (from Pipes 1982).

4.2 Faecal Coliform

Increasing reports on the recovery of coliform organisms from non-faecally contaminated environment and multiplication of coliforms in some natural environment, forced the bacteriologist in the separation of faecal from non-faecal coliforms.

Research investigations on the significance of faecal coliform bacteria in the environment have demonstrated that this pollution indicator system have an excellent positive correlation with warm-blooded animal contamination. Geldreich (1970) showed that large number of warm-blooded animals do indeed discharge faecal coliform. Thus faecal coliform determination does not distingush between human and animal faecal contaminations. The fresh water fishes do not have a permanent intestinal flora and that faecal coliform are only present in fish owing to the high level in surrounding water (Geldreich and Clarke 1966).

Geldreich (1970) claimed the use of faecal coliform bacteria as a single parameter for monitoring recreational water on the basis of faecal coliform and pathogens (Salmonella) correlation. The data collected from numerous streams indicate a sharp increase in the frequency of Salmonella detection when faecal coliform densities are above 200 organisms $(100\ ml)^{-1}$ of fresh water. In the range of 2000 faecal coliforms $(100\ ml)^{-1}$, Salmonella isolation was nearly 100% frequent. Dutka (1973) indicated that the ratio of faecal coliform to Salmonella is also large, and claimed it a more reasonable indicator.

Therefore, the use of faecal coliform rather than total coliform as an indicator of water quality is more directly related to the actual degree of faecal contamination.

The validity of faecal coliform is also questioned in literature. In 1955-56 infectious hepatitis epidemic in Delhi provided one apparent case where faecal coliform counts failed to give warning of a grossly contaminated water supply. In that case large number of infectious hepatitis virus remained viable after passage through the water treatment plant, even though the faecal coliform level had been reduced to $\leqslant 2\ (100\ ml)^{-1}$. Therefore, absence of E. coli does not ensure absence of enteric viruses from the system (Dennis 1959).

4.3 Faecal Streptococcus

Another group which has been used as indicator of faecal pollution is the faecal streptococcus. These bacteria belong to family streptococcaceae, and are characterized by their ability to grow at 45^{o} C and to grow in concentrations of sodium azide.

The sanitary significance of faecal streptococcus was evaluated by Geldreich (1970). He has demonstrated that faecal streptococci were present

in greater number than coliform bacteria in faecal discharge from animals, dogs, cats and wild animals. In contrast, the faeces from man and the domestic wastewater contained at least 4 times as many faecal coliforms as faecal streptococci.

As Streptococcus faecalis survives longer than faecal coliform in storm water, faecal streptococci especially S. faecalis may be functional in situations where the coliform test is of limited value. It is claimed that faecal streptococci may be useful on relatively clean streams and lakes used for recreation (Pipes 1982).

Although present in large number in faeces, they are considerably less numerous than the coliform group in human faeces and thus are less sensitive indicators of human faecal contamination. Therefore, the occurrence of faecal streptococci in water indicates faecal pollution and absence suggests little or no warm-blood animal contamination.

4.4 Indicator Ratios

The ratio of indicator organisms, faecal coliform/faecal streptococcus (FC/FS) has been employed to provide some insight into the source of faecal contamination. FC/FS ratio has been utilized more frequently to determine whether the pollution was of human or animal origin (Geldreich and Kenner 1969 ; Feachem 1974 ; Geldreich 1972).

As stated earlier, the faecal streptococci were present in greater number than coliform bacteria in the faeces of animals. In human faeces, however, faecal coliform were found in greater number than the faecal streptococci. Geldreich and Kenner (1969) reported that FC/FS ratio for human faeces and domestic wastewater were grater than 4, and for animal faeces, separate storm-

water systems and farm drainage were less than 0.7. The range of values between 0.7 and 4 is apparently not well defined with respect to the source of faecal contamination. Later the ratio of FC/FS for warm-blooded animals other than human was shifted from < 0.7 to < 1.0 (Suess 1982), as some animals have this ratio > 0.7 but < 1.0.

Geldreich and Kenner (1969) suggested that the ratio should be applied carefully. As upon entering the stream, the levels of each of the microorganism may be affected by numerous environmental factors and differential microbial die-off, the ratio for the stream samples would only be useful during the initial 24 hrs of downstream travel from the point of discharge.

Geldreich (1970) claimed the human and non-human faecal pollution concept, as an unwise assumption. He stated that pathogenic organisms can be present in the excreta of poultry, livestock, cats, dogs and wild animals, as evident from literature and on the otherhand the fresh water fish may become actively infected with human pathogens after exposure to contaminated water and carry these organisms to clean stream recreational areas.

Another group of microorganisms advocated as indicator of faecal pollution is the anaerobic sulfite-reducing spore formers, belonging to family Bacillaceae. The organism of primary interest is Clostridium perfringens. The spores persist long after coliform have died out both in natural aquatic environment and disinfection. The culture methods are adequate for special investigations but are difficult to apply on a routine basis. The use of this indicator is suggested to provide supplemental information on good quality waters.

Pseudomonas aeruginosa noted for its resistance to antibiotics and associated with eye and ear infections, has been proposed as an indicator for

swimming pool and recreational waters. Cabelli et.al. (1976) claimed it to be ubiquitous in environment and apparently does multiply under natural conditions, hence is not a good indicator of faecal contamination of the systems.

4.5 Bathing and Recreational Water Quality Standards

Mass bathing is an attribute of Hindu religion and is manifested in Indian rivers especially river Ganga at religious places situated on its bank. The primary water quality criteria for various classes of water identified under the policy for water pollution control in India are derived from the criteria developed in other part of the world especially, the United States of America, the United Kingdom, West Germany and Japan for the designated best uses (Chaudhuri 1981).

Typically, class B water are those that are considered suitable for bathing and recreational purposes, including water contact sports. In India these water are required not to exceed 500 coliform organisms $(100\ ml)^{-1}$ during any month. If the count is noticed to be more than 500 MPN $(100\ ml)^{-1}$, then the criteria would be satisfied that during a period of time not more than 5% of samples show greater than 2000 MPN $(100\ ml)^{-1}$ and not more than 20% of the sample show greater than 500 MPN $(100\ ml)^{-1}$ (Chaudhuri 1981).

Efforts in the development of standards were based on the acceptable upper limit for total coliform that will denote no health rish to the people using the water. Waite (1984) on the basis of the review of various state and municipal criteria in the United States, noticed upper limit of total coliform, for recreation and bathing from 50 to 3000 organisms $(100\ ml)^{-1}$. The highest allowable coliform level was approximately sixty times greater than the lowest

permissible level. The most widely used criteria was not to exceed an average of 1000 coliforms $(100\ ml)^{-1}$ during any monthly sampling period nor to exceed 2400 $(100\ ml)^{-1}$ in more than 20% of the samples. Foster et.al. (1971) examined the bathing water quality standards and noticed a variation of 20 times to 1000 times in the international standards based on coliform group. He pointed out that total coliform of 1000 $(100\ ml)^{-1}$ is arbitrary and has no real epidemiological basis, and questioned the validity of such a standard.

The Indian coliform objectives which are based on criteria developed in other countries has no public health basis and is offered with no supporting evidence that it would adequately protect the health of bathers.

On the other hand Foster et.al. (1971) pointed out the study made on bacterial densities in Hubbard brook stream, the results of which were compared to the US standard (1000 MPN $(100\ ml)^{-1}$). Several stations free from faecal contamination were questioned as being satisfactory clean bathing areas. Waite (1984) stated the use of coliform standard may cause an undue restriction on recreational use of water systems. As the situation of high coliform count could arise because of storm water run-off which is known to contain large concentration of coliforms, although this would not necessarily indicate faecal contamination of water system.

It is evident from the study made by Bilgrami and Dutta Munshi (1985) on Ganga river than no one station could satisfy the water quality fit for bathing, based on the present objectives. Same is the case with the important point of mass bathing in the zone under study. However, hardly an information regarding the incidence of epidemic has been reported.

Stevenson (1953) found that threshold coliform value in lake Michigan beaches was 2300 $(100\ ml)^{-1}$ and for recreational reach of the Ohio river

to be 2700 (100 ml)$^{-1}$. At these values and above there was a singinificant increase in the incidence of swimmer's illness.

The use of faecal coliform rather than total coliform, as indicator of recreational water quality, is suggested. Geldreich (1970) showed a sharp increase in the frequency of detection of Salmonella when faecal coliform level was greater than 200 organisms (100 ml)$^{-1}$. Thus a standard of approximately 200 faecal coliforms (100 ml)$^{-1}$ would be a reasonable standard for protecting recreational waters. Foster et.al.(1971) stated 10 states in the United States have established an allowable faecal coliform limit varying between 70 and 1000 faecal coliform (100 ml)$^{-1}$, the most common being 1000 (three states) and 200 (six states) (100 ml)$^{-1}$.

The faecal streptococcus limit was fixed by Geldriech as below 100 organisms (100 ml)$^{-1}$ for recreational waters untill the methodology which exclude the streptococcus strains of limited sanitary significance evolves. But it may be unrealistic unless confirmed by parallel faecal coliform examination.

The recreational standard by their nature can not be as precise as far drinking water. In the later case, the occurrence of any coliform at all means that the water may be unsafe for human consumption and requires further treatment. However, using these standard for bathing some level of acceptable concentration of microorganisms could be allowed.

CHAPTER - V

RESULTS AND DISCUSSION

5.1 General State of the Ecosystem

General state of the ecosystem has been ascertained in the form of conventional physical, chemical, biological and bacterial parameters. The emphasis had been more an spatial variability with the temporal variations at selected stations.

5.1.1 Physico-chemical characteristics

The physico-chemical characteristics of water are the determining factors of the pattern of aquatic life. These characteristics as recorded during the course of Ganga river under Study period are summarized in Table 5.1.1 in the form of range, standard deviation and mean values of the selected determinants i.e. temperature, pH, ORP, conductance, turbidity, Biochemical Oxygen Demand, Chemical Oxygen Demand, Dissolved Oxygen and Nutrients (Nitrogen sulphates and Phosphates).

5.1.1.1 Temperature : The surface water temperatures exhibited an expected seasonal pattern. The maximum value of 28^{o}C was observed at Anupshahar and Narora in summers of 1985, while the minimum of 8.6^{o}C was recorded at Nandprayag in the winters of 1985 excluding Badrinath where temperatures did not fall below 4^{o}C during the three surveys in monsoon and post-monsoon seasons.

Figure 5.1.1 depicts the mean temperature variations at various sampling sites. The values were almost in an increasing order along the course of the river upto Bijnor. From Bijnor to Narora the values were nearly same. The

Table 5.1.1 Physico-chemical Determinants of Upper Ganga (Minimum, Maximum, Mean and Standard Deviation)

Stn. No.	STATIONS	Water Temperature (^{o}C)				Conductivity (μ mhos)				Turbidity (JTU)			
		x min	x max	$\bar{x}$	SD	x min	x max	$\bar{x}$	SD	x min	x max	$\bar{x}$	SD
1.	Badrinath	4.0	8.0	6.0	2.83	22.47	24.85	23.66	1.68	110.0	400.0	225.0	205.1
2.	Nandprayag	8.6	18.4	13.34	3.48	23.78	269.84	132.95	76.93	5.0	800.0	151.4	289.4
3.	Rudraprayag	9.7	18.9	14.69	3.50	18.20	210.00	128.61	63.80	10.0	1000.0	176.4	364.7
4.	Srinagar	9.8	19.0	14.57	3.78	24.90	178.18	124.55	53.95	5.0	800.0	146.4	290.0
5.	Devprayag	10.7	19.5	16.23	3.67	28.50	174.42	138.35	53.92	10.0	1500.0	246.4	553.6
6.	Rishikesh	10.6	20.3	16.69	3.54	98.44	171.34	136.16	23.14	25.0	1000.0	214.1	350.6
7.	Satyanarayana	18.0	26.4	22.96	3.59	418.00	519.43	468.43	39.12	20.0	650.0	147.1	225.2
8.	Hari ki Pauri 1.	11.7	21.0	17.52	3.07	158.36	232.13	174.39	25.65	20.0	1200.0	227.1	431.7
9.	Hari ki Pauri 2.	11.8	21.0	17.27	3.61	149.00	247.65	175.54	32.48	20.0	1100.0	218.6	392.7
10.	Kankhal	12.0	21.0	17.19	3.60	160.50	260.00	179.98	30.54	20.0	1000.0	211.4	355.4
11.	Balawali	12.5	24.0	19.84	4.50	163.78	463.36	237.54	103.17	20.0	1200.0	225.7	433.5
12.	Bijnor	12.1	27.0	21.94	5.88	170.13	423.68	267.52	93.00	25.0	1200.0	242.8	423.7
13.	Garhmukteshwar	14.9	26.0	21.97	4.93	56.00	297.96	221.83	87.18	25.0	1200.0	290.0	401.7
14.	Anupshahar	14.7	28.0	21.93	5.63	163.71	307.20	211.56	46.86	30.0	1200.0	283.6	415.7
15.	Narora	15.4	28.0	21.70	4.66	160.50	265.60	224.10	45.59	30.0	1200.0	255.7	420.4

Contd.....

Table 5.5.1 (Contd.....)

Stn. No.	STATIONS	pH				ORP			
		x min	x max	$\bar{x}$	SD	x min	x max	$\bar{x}$	SD
1.	Badrinath	8.07	8.90	8.49	0.58	155	275	215.0	84.8
2.	Nandprayag	7.60	8.55	8.28	0.33	100	318	221.7	64.7
3.	Rudraprayag	7.96	8.85	8.46	0.28	117	256	208.8	43.7
4.	Srinagar	7.87	8.65	8.32	0.31	95	270	209.4	55.3
5.	Devprayag	7.88	8.53	8.30	0.23	113	284	213.3	52.2
6.	Rishikesh	7.88	8.76	8.48	0.30	112	291	208.1	59.9
7.	Satyanarayana	7.78	8.63	8.24	0.31	105	260	178.7	56.0
8.	Hari ki Pauri 1.	7.53	8.85	8.50	0.45	118	242	195.7	44.2
9.	Hari ki Pauri 2.	7.60	8.89	8.51	0.42	120	243	195.0	42.8
10.	Kankhal	7.42	8.85	8.48	0.48	125	240	196.0	42.8
11.	Balawali	7.57	8.74	8.39	0.40	119	321	211.3	70.0
12.	Bijnor	7.48	8.67	8.19	0.44	176	285	214.7	40.5
13.	Garhmukteshwar	7.94	8.65	8.41	0.24	200	240	220.4	17.7
14.	Anupshahar	7.88	8.70	8.45	0.29	170	272	209.7	33.6
15.	Narora	7.70	8.72	8.47	0.36	176	221	194.8	14.7

Contd.....

Table 5.5.1 (Contd.....)

Stn. No.	STATIONS	D.O. (mg l^{-1})				BOD (mg l^{-1})				COD (mg l^{-1})			
		x min	x max	$\bar{x}$	SD	x min	x max	$\bar{x}$	SD	x min	x max	$\bar{x}$	SD
1.	Badrinath	7.00	9.31	8.16	1.63	0.10	0.30	0.20	0.14	0.31	0.75	0.53	0.31
2.	Nandprayag	7.30	10.00	9.08	1.10	0.25	1.69	0.81	0.44	0.92	3.00	1.65	0.75
3.	Rudraprayag	7.30	11.18	9.39	1.40	0.25	1.65	0.65	0.48	0.57	2.60	1.27	0.71
4.	Srinagar	7.50	11.83	9.32	1.18	0.25	2.23	1.03	0.78	0.80	2.60	1.68	0.79
5.	Devprayag	7.00	10.57	8.98	1.27	0.25	0.95	0.71	0.38	0.92	6.01	2.06	1.76
6.	Rishikesh	7.60	11.25	8.97	1.40	0.30	1.50	0.84	0.47	0.80	2.50	1.55	0.70
7.	Satyanarayana	7.00	8.00	7.60	0.36	0.14	3.35	1.55	1.07	0.61	4.08	2.63	1.16
8.	Hari ki Pauri 1.	7.30	10.89	8.79	1.38	0.36	1.75	1.13	0.53	1.28	3.60	2.53	0.92
9.	Hari ki Pauri 2.	7.90	10.60	8.81	1.15	0.86	2.60	1.49	0.62	1.06	3.80	2.69	1.14
10.	Kankhal	6.90	10.25	8.65	1.23	0.36	2.70	1.38	0.76	0.50	3.80	2.58	1.11
11.	Balawali	7.20	10.19	8.65	1.16	0.50	2.75	1.61	0.85	1.60	5.00	3.09	1.11
12.	Bijnor	7.04	9.93	8.46	0.88	0.50	3.50	1.98	1.02	2.29	6.00	3.92	1.48
13.	Garhmukteshwar	7.00	9.84	8.42	0.92	0.70	2.00	1.24	0.53	1.47	6.27	3.42	1.49
14.	Anupshahar	7.20	11.30	8.41	1.45	0.72	2.50	1.73	0.59	2.04	5.80	3.70	1.32
15.	Narora	7.00	10.48	8.59	1.38	0.78	2.41	1.67	0.52	2.04	6.70	3.81	1.47

only point which deviated significantly, was Satyanarayana where the lowest coefficient of variation (0.156) and lowest range of temperature (18-26°C) were observed. Both maximum and minimum values recorded were high in comparison to upstream and downstream stations because of the contribution of Song river.

5.1.1.2 pH : Both spatial variability as well as seasonal variability in pH value at different stations were observed to be insignificant (Table 5.1.1, Fig. 5.1.1). The values were found to be in alkaline range all the time. In general the lower pH values were recorded in monsoon (7.42 - 8.10 in 1985) while the values were usually higher in winters (8.3 - 8.89 in 1985). The minimum value of 7.42 and maximum value of 8.89 were observed at Kankhal and Hari ki Pauri downstream respectively. The prevailing value of pH of the river water provides a favourable environment to stream biota.

5.1.1.3 Conductivity : Conductivity reflects the mineral/ionic status of the system. The range of mean conductance for the mountainous part (Nandprayag to Rishikesh) was 124.55 - 136.16 μ mhos. In this stretch the deviation of values was of very low level. Further down at Satyanarayana there was a sudden spurt to 468.43 μ mhos due to the effect of highly mineralized tributary Song. This tributary has its catchment in lime deposits of Timli and rock phosphates of Maldeota. The flow of water at Satyanarayana is also very low as bulk of the water is diverted in a power channel. It is at this section the Song adds the mineral load. At Hari ki Pauri the values came down due to dilution with the Chilla return water. From Kankhal downwards the values attained a range of 211.56 - 267.52 μ mhos (Table 5.1.1, Fig. 5.1.1).

The temporal changes in the values of conductivity were quite distinct. Values showed major increase during lean flow season with low values in

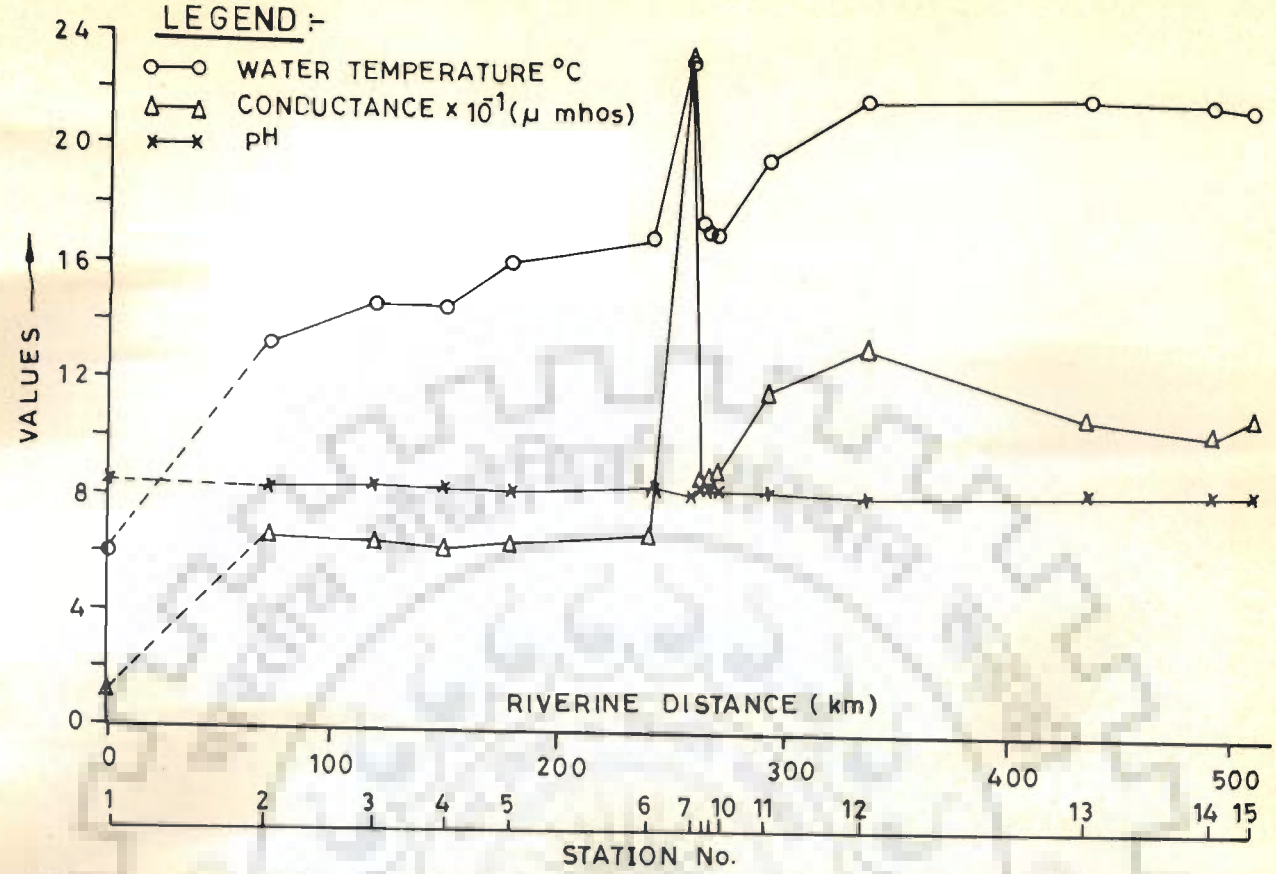


FIG. 5·1·1 - SPATIAL VARIATION OF WATER TEMPERATURE, pH & CONDUCTANCE

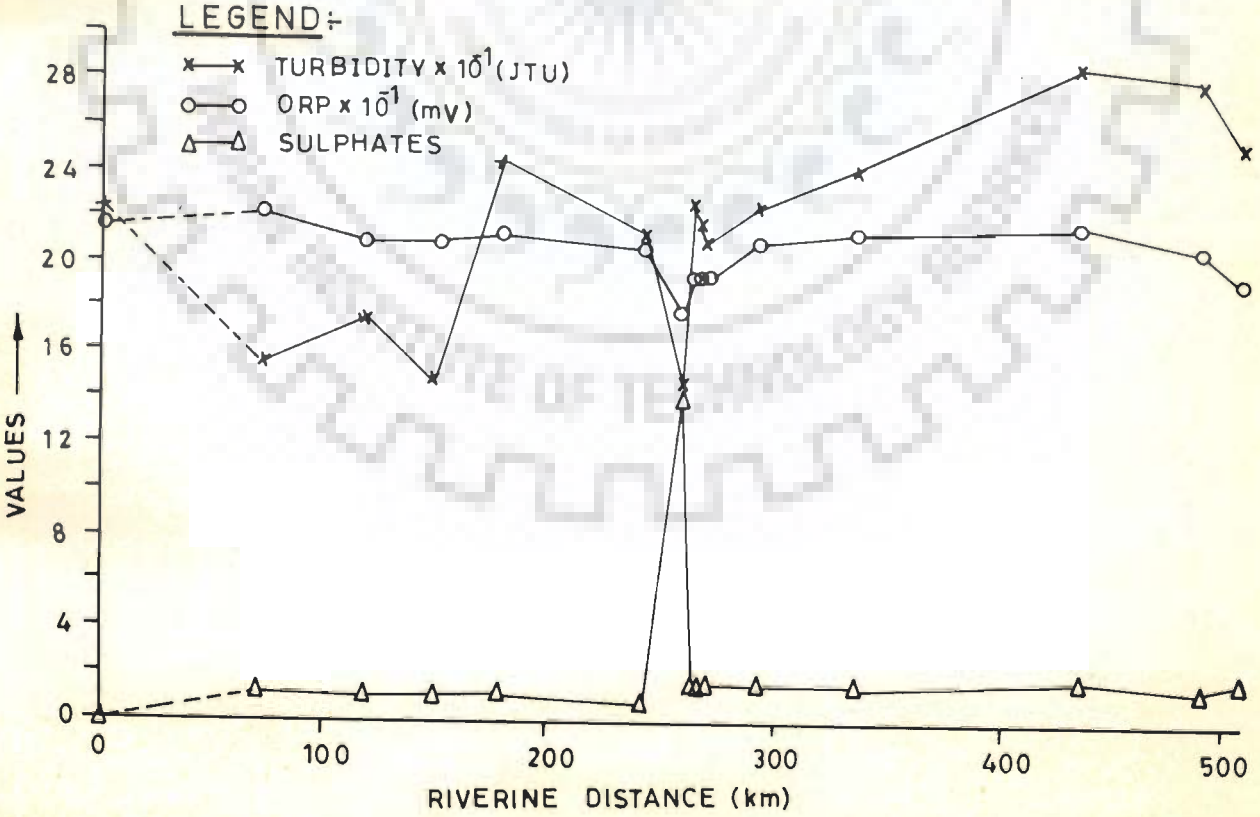


FIG. 5·1·2 - SPATIAL VARIATION OF ORP, TURBIDITY AND SULPHATES

the high flow season, indicating a typical dilution pattern. It is due to this seasonal pattern, the mean value at Badrinath, sampled 2/3 times in monsoon season, was observed as 23.66. The highest co-efficient of variation was observed at Nandprayag and lowest at Satyanarayana.

The comparison of these values with the values of the stretch of lower Ganga from Patna to Farakka (Bilgrami and Dutta Munshi 1985) reveals comparatively poor nutritional status of upper Ganga.

5.1.1.4 Turbidity : The turbidity of river varies appreciably in different seasons. High turbidity was observed at all the sampling stations during monsoon period (range 400-1500 JTU). The low values of 5-30 JTU were observed during lean flow season, the winter, upto Balawali, while the lowest range from 25-30 JTU was observed during postmonsoon season in the remaining stretch. The spatial variations were also significant (Fig. 5.1.2). In mountainous stretch the values increase significantly due to the addition by the tributaries at different sampling stations. The value comes down at Rishikesh due to reduced turbulence and marginal settling of suspended solids, and again decreases at Satyanarayana as Song carries relatively low turbidity even during monsoon. From Kankhal downward the turbidity showed a gradual increase upto Garh-mukteshwar. The values exhibited marginal decrease at Narora which may be due to settling at Narora head work.

The turbidity was observed high almost throughout the year in plains from Garhmukteshwar to Narora in comparison to hills.

5.1.1.5 Oxidation reduction potential (ORP) : As evident from Fig. 5.1.2 the mean values did not show fluctuation throughout the stretch, the values ranged between + 179 and + 221 mV. During the entire study period the values

were not observed below 100 mV (Table 5.1.1). It indicated the absence of reducing conditions in the system. However, in the lower reaches the values were slightly lesser than those in mountainous reaches.

5.1.1.6 Inorganic nutrients : Nutrients level have been observed to be greatly low throughout the region. The concentration of both nitrite and nitrate-nitrogen were below the detectable limits (0.01 mg l^{-1}).

The only point where the concentrations of phosphate were in detectable range was the confluence of Song river, as it carries the water through phosphate mines. The values range from 0.01 - 0.1 mg l^{-1} with an annual average of 0.07 mg l^{-1}. Downstream of Satyanarayana the phosphates were observed only upto 4 km at Raiwala averaging 0.015 mg l^{-1} and falls below detectable limit as it reaches Haridwar.

The sulphate concentrations varied between < 0.1 - 20 mg l^{-1} from Badrinath to Rishikesh and < 0.1 - 40 mg l^{-1} from Hari ki Pauri downstream upto Narora. The only station to deviate was Satyanarayana again, where a ten fold rise in the sulphate was attributed to the confluence of Song river (Fig. 5.1.2). The value at this spot ranged from 102 - 265 mg l^{-1}.

5.1.1.7 Dissolved oxygen (D.O.) : Without adequate amounts of dissolved oxygen at all the times a viable stream community cannot exist. The oxygen content of water of upper Ganga was relatively high at all stations during the entire period of investigation (Table 5.1.1). The average values varied between 7.6 and 9.39 mg l^{-1}. The overall trend in D.O. concentration was fairly consistent throughout the stretch but a deviation was noted at Satyanarayana. The comparatively low values at this station resulted due to the discharges of IDPL antibiotic factory upstream, but the depletion was marginal. Thus D.O. shows relatively small regional and seasonal fluctuations.

In Fig. 5.1.3 the oxygen saturation values are plotted. It demonstrated very clearly the good oxygen supply in the study area. During winters the values of over 100 percent were not infrequent. Relatively low saturation values were observed during monsoon. However, these were not on any occasion less than 75% , except Badrinath. Relatively high values during monsoon and low in premonsoon season at Badrinath exihibited a typical pattern of snowfed stream. These findings are in agreement with observations made on an arctic and a subarctic river basin by Schreier et.al. in 1980.

The saturation values showed a steep increase in the highly turbulent zone from Badrinath to Rudraprayag. After Rudraprayag the general trend is of a gradual increase in saturation values as one proceeds downwards except downstream of Srinagar, Satyanarayana and Hari ki Pauri. At these stations the decline is attributed to the human activity and point and nonpoint discharges at these places.

5.1.1.8 Chemical oxygen demand (COD) : COD is an estimate of organic material in fresh waters. The mean values of COD registered as well as the extremes are presented in Table 5.1.1. In the mountainous stretch from Badrinath to Rishikesh COD values are low, in the range 0.53 to 2.06 mg l^{-1}, the lowest being at Badrinath. In foothills the values are nearer to 2.5 mg l^{-1}, while in plains from Balawali to Narora, the values were between 3.09 and 3.92 mg l^{-1}. At Bijnor the value was found to be highest which could be attributed to the presence of organised cremation by burning. At those points where oxygen saturation values decrease due to the impact of domestic and industrial effluent, the COD values showed and upward trend (Fig. 5.1.4).

5.1.1.9 Biochemical oxygen demand (BOD) : BOD of the water samples in the area studied was usually low. The total range was from 0.10-3.50 mg $O_2 l^{-1}$.

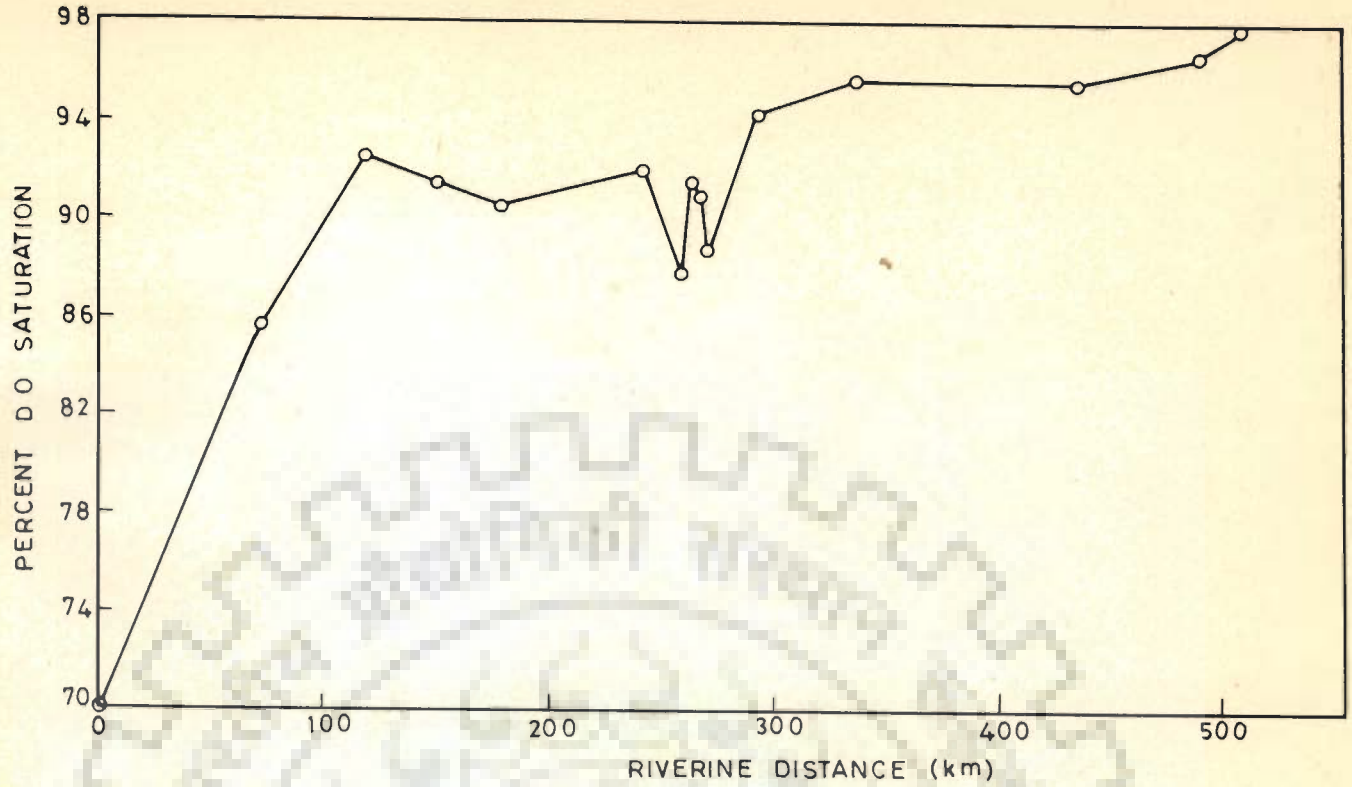


FIG. 5.1.3 – SPATIAL VARIATION OF PERCENT DO SATURATION

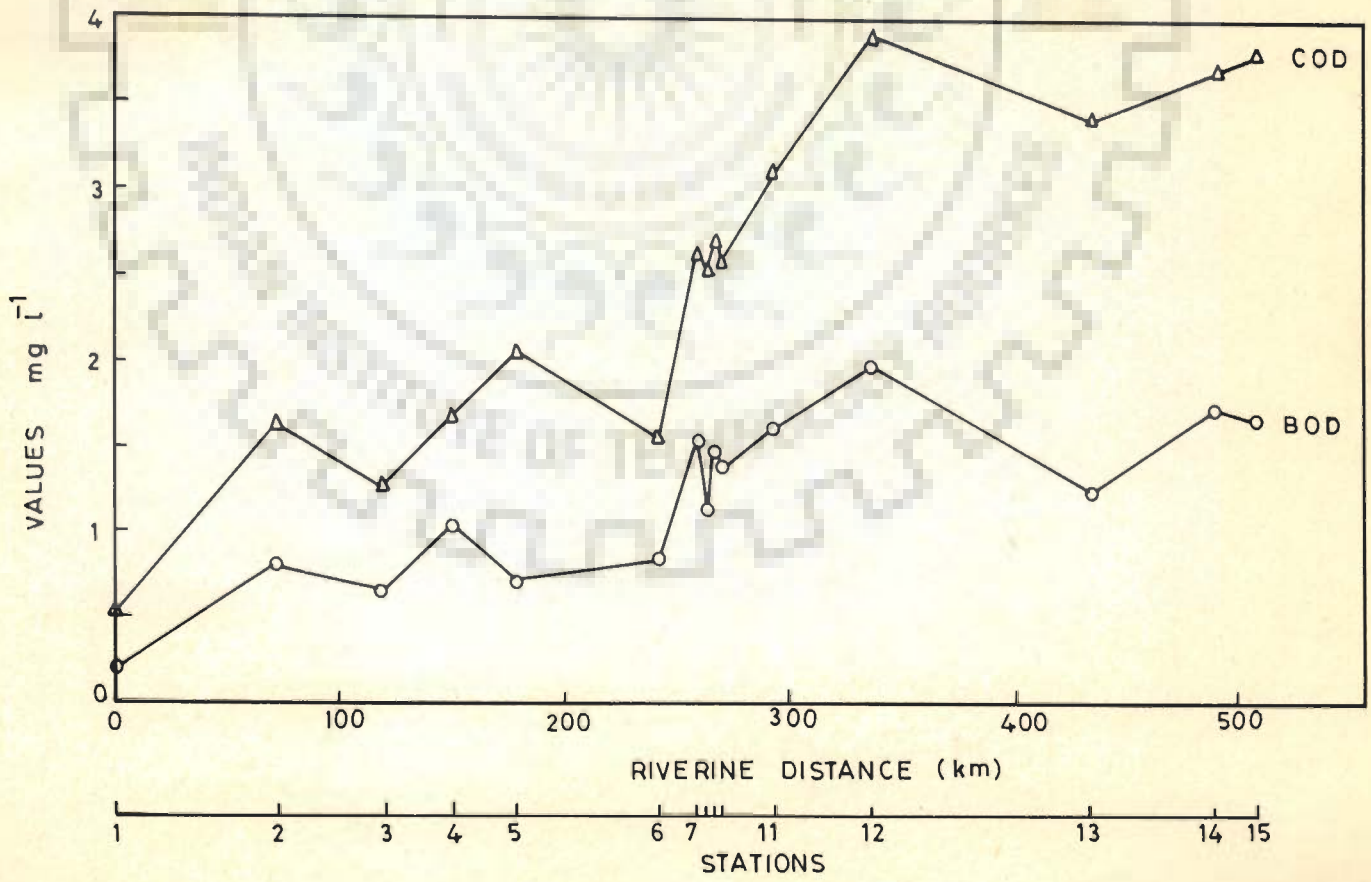


FIG. 5.1.3 — SPATIAL VARIATION OF COD AND BOD

As can be seen from Table 5.1.1, mean BOD values were registered between 0.20 and 1.98 at Badrinath and Bijnor respectively. The spatial pattern followed the pattern of COD values (Fig. 5.1.4). The only point of disagreement was Devprayag where the BOD values decreased slightly.

In general the BOD values were high in monsoon and postmonsoon season. The low values were recorded during summers. Low BOD values and high oxygen values indicate the vigorous assimilation activity in the the upper Ganga.

During the entire period of investigation the values were observed below the limit set for waters for outdoor bathing by Pollution Control Board (3.00 mg l^{-1}), at all the stations except Satyanarayana and Bijnor. At these two stations the 90 percentile values were registered below the limit.

Thus compared with other areas exposed to human activities, the area studied seems to be unpolluted and presents pristine standards.

5.1.2 Biocoenoses

The biota of the upper Ganga was found to include elements from ecologically different biotopes. The dynamics of their development appear to be influenced not only by changes in the physical and chemical factors but also by variations in water discharge.

5.1.2.1 Phytoplankton : Phytoplankton of lotic ecosystem has been defined in a variety of ways. Hynes (1970) distinguished suspended algae derived from periphyton from the phytoplankton. Holmes and Whitton (1980) regarded both categories as extremes of a continuum and rejected any arbitrary separation of populations. Nevertheless the importance of sufficient retention time to

allow the development of true phytoplankton has been demonstrated in the Thames where Lack (1971) reported an inverse relationship between phytoplankton density and discharge. However, in a tributary of Thames (kennet) he found a positive relationship between density and discharge, suspended algae being sloughed from the periphyton during period of high flow. An inverse relationship between phytoplankton and discharge in upper Ganga which echo that of river Thames, indicate the presence of true phytoplankton in its water column.

During the entire period of investigation 51 genera were recorded. The presence and degree of occurrence for each genus are summarized in Table 5.1.2.

Of the encountered genera 25 were diatoms, 23 of which were pinnate and two centric diatoms. Cymbella spp. and Diatoma spp. were the most frequent and abundant diatoms throughout the stretch, although much frequent in upper reaches. Diatomella spp., Diploneis spp., Meridion spp., Navicula spp., Nitzschia spp., and Stauroneis spp. were present most of the time at nearly all the sampling spots. These genera also exhibited definite seasonal abundance pattern, being most abundant during winters or summers and tend to disappear from the system during monsoon. Most of the dominant genera recorded in Ganga in association indicated clean water environment (Kamat, 1981). The other diatom genera enumerated were rare. Seven genera accounted for less than 5% of the numbers at particular station, during a particular season. Gyrosigma spp., and Pinnularia spp., were present during winters, where as Cocconeis spp. was recorded during postmonsoon only. Ceratoneis spp. in winters, Cymetopleura spp. in summers and Cylindrotheca spp. and Eunotia spp. in monsoon were recorded at one or two points only.

Table 5.1.2 Degree of Occurrence of Phytoplankton Genera at Different Sampling Stations

(Cluster analysis : V = highly frequent, IV = frequent, III = moderately frequent, II = less frequent and I = rare)

TAXA	STATIONS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MYXOPHYCEAE															
Anabaena spp		I	I												
Lyngbya spp					I								I		
Merismopoedia spp			I	I	I	I		I	I		II		II	II	I
Oscillatoria spp			I		II	I	I	I	II	I	I		I	I	
Phormidium spp.	IV	IV	III	III	III	II	III	IV	III	III	II	II		I	I
Spirulina spp.					I						I	I	I	I	I
CHLOROPHYCEAE															
Ankistrodesmus spp.											I				
Chaetophora spp.				II	II		I		I		II		I	I	I
Cladophora spp.					I		II	I	I	II	I	I			
Closteriopsis spp.		II	I	I	I	II		I	I	I	II	II	II	I	II
Coelastrum spp.											II	II	I	I	I
Eudorina spp.					II										
Hydrodictyon spp.		III	III	III	III	III	II	II	I	I	II	II	II	II	II
Kirchneriella spp.							I								
Microspora spp.													I		
Oedogonium spp.													I	I	I
Pediastrum spp.												I	I	I	
Protococcus spp.								I					II	II	II
Scenedesmus spp.		II	I					I	I		I		I	II	I
Selenastrum spp.		I	I	I		I							I	I	I
Spirogyra spp.	III	III	III	III	III	III	III	IV	III	V	III	IV	IV	III	IV
Spirotaenia spp.						I									
Stigeoclonium spp.						I									
Ulothrix spp.		I			II	I	I	I	I						I
Zygnema spp.					I	I	I		I	II	I		I	I	

Contd.....

Table 5.1.2 (Contd.....)

TAXA	STATIONS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
XANTHOPHYCEAE															
Tribonema spp.													I	I	I
BACILLARIOPHYCEAE															
Centrales															
Cyclotella spp.		I	I	II	I	III	II	II	I	I	I	I			
Stephanodiscus spp.	II	III	I	I	II	II		I	I	I			II	I	I
Pinnales															
Achnanthes spp.	II	III	IV	IV	III	IV	II	II	II	I	II	II	I		
Asterionella spp.		III	I	II		II		II	II	II	I	I	I	II	IV
Caloneis spp.		I	II	III	II	II	V	IV	IV	IV	III	II	II	III	III
Ceratoneis spp.								I	I						
Cocconeis spp.	II		I			II	I	I	I	I	I	I	I		
Cylindrotheca spp.						I									I
Cymatopleura spp.					I										
Cymbella spp.	II	V	IV	V	V	V	V	IV	V	V	IV	IV	IV	IV	III
Diatoma spp.	IV	V	V	V	V	V	V	V	V	V	IV	IV	IV	V	IV
Diatomella spp.		IV	III	I	III	II	I	II	II	II	II	II	I	I	II
Diploneis spp.		II	III	II	II	I	IV	I	II	II	II	II	II	I	I
Eunotia spp.							I								
Fragilaria spp.		I	I	III	I	I	II	IV	II	I	II	II	IV	IV	IV
Frustulia spp.		I	I	III	I	I	III	II	I	I	II	II			
Gyrosigma spp.				I		I	I	I	I	I			I	I	II
Hantzschia spp.		III	III	III	III	III		III	III	III	II	I	I		
Meridion spp.		III	III	III	III	IV	IV	I	II	II	II	II	II	II	I
Navicula spp.		I	III	III	III	II	IV	I	II	II	III	II	I	I	
Nitzschia spp.		IV	IV	V	IV	III	II	III	IV	III	II	II	II	II	I
Pinnularia spp.				II	I		I	I	I		I	I	I	I	I
Stauroneis spp.	II	II	III	III	IV	IV	V	III	III	III	IV	IV	IV	IV	IV
Synedra spp.		II		III	II		II	II	I		II	I	IV	II	IV
Tabellaria spp.		I	II		III	I					I		I	II	II

The distribution of the non-diatom forms was considerably more patchy than that of the diatoms. At various times there were 19 genera of green algae, 6 of blue green algae and 1 of xanthophyceae, identified in quantitative collection. The most frequent chlorophycean algae were Hydrodictyon spp. and Spirogyra spp. Four genera Coelastrum spp., Microspora spp., Oedogonium spp. and Pediastrum spp. were recorded only in summers at few points in the lower stretch. The other seasonal forms registered were Eudorina spp., Kirchneriella spp. in summers, Spirotaenia spp. in monsoons and Stigeoclonium spp. in winters only.

The most common blue green aglae was Phormidium spp. It is interesting to note that this genus was most frequent in mountainous stretch and its degree of occurrence decreased in plains. Anabaena spp. and Lyngbya spp. were restricted to summers only where as Spirulina spp. appeared in plains in monsoon season.

Tribonema spp. the only member of xanthophyceae was encountered in summers at last three stations, as it prefers slower current.

A comparison of phytoplankton at different sampling spots has been made in order to disclose differences, if any, in the participation of fundamental structural elements of the microvegetation. Distribution of the individuals over the three main phytoplankton groups (bacillariophyceae, chlorophyceae, myxophyceae) are given in Fig. 5.1.5, expressed as percentage values of the plankton content at various stations (including zooplankton).

On the whole a numerical predominance of diatoms among the phytoplankton was observed during the greater part of the year. The pH of the system (alkaline) also favoured their growth (Philipose 1960; Kamat 1965). This predominance is virtually undisputed during the colder season from

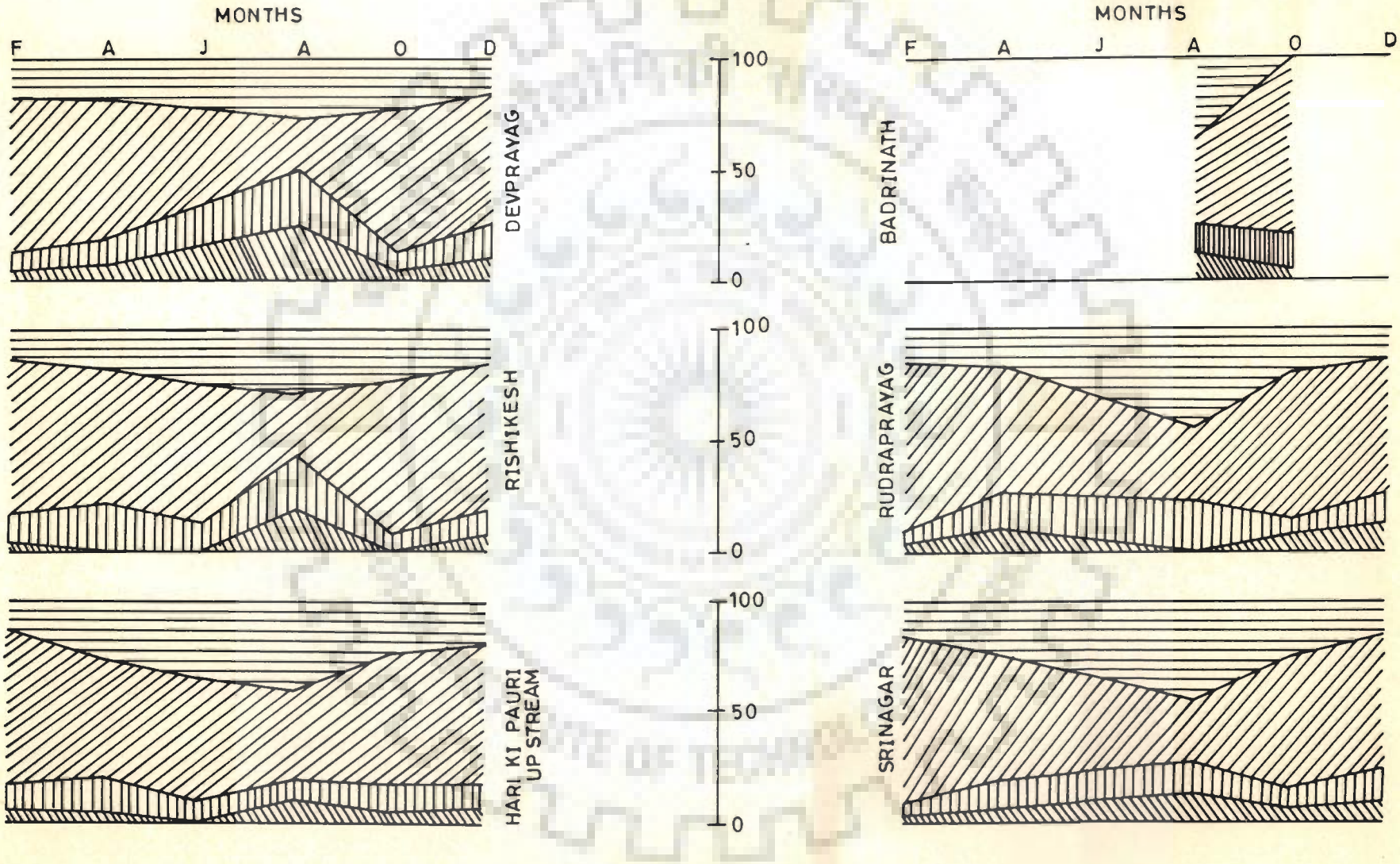


FIG. 5·1·5 Contd.....

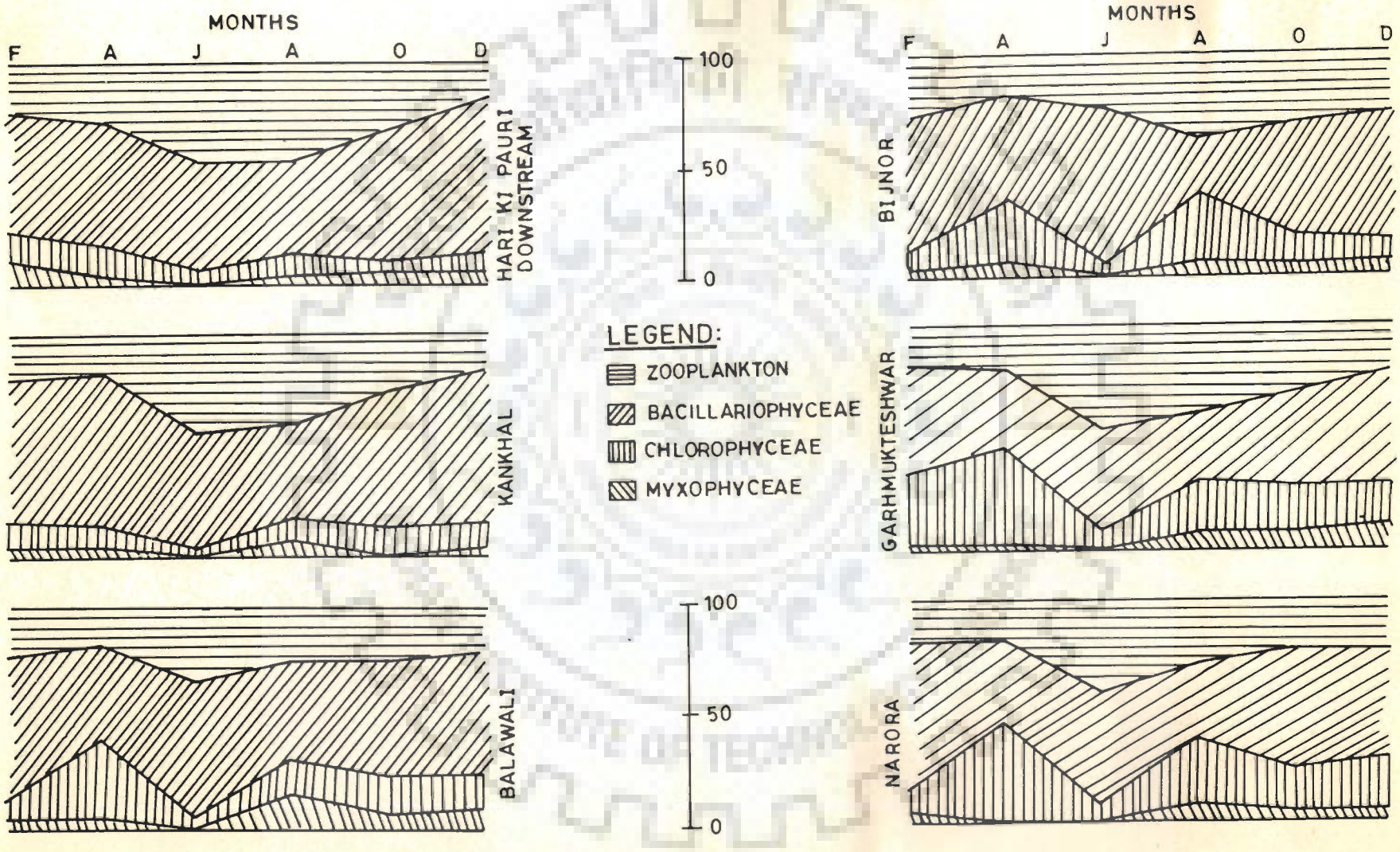


FIG. 5·1·5 – TEMPORAL VARIATIONS IN THE PERCENTAGE OF INDIVIDUALS OF MAIN PLANKTONIC GROUP AT DIFFERENT STATIONS

December to February. After an inconspicuous winter peak in the development of diatoms, there was a decrease in the standing crop of phytoplankton at all the stations, as a result of which the relative concentration of zooplankton increased. During summers a rich representation of green algae was observed in the lower stretch from Balawali to Narora. On the onset of monsoon the percentage of these algae decreased. Regarding seasonal changesin the chloroplycean members - a slight variation in the percentage in upper reaches was noted. Except a few stations (e.g. Rudraprayag) the relative number of blue green algae showed their high representation during monsoon throughout the stretch.

The changes occuring from season to season in the total number of phytoplankton individuals and genera are depicted in Fig. 5.1.6 at three representative stations from different regions. The high numbers recorded during February were caused by high dominance of diatoms. During the monsoon months, there was a sharp fall in the standing stock value which showed an upward trend from August onwards. An abrupt fall in the phytoplankton density is attributed independently or collectively to the high turbidity, rainfall and flood during the rainy season. High density of phytoplankton during spring-summer has also been observed by Albright et.al. 1980 in two sub-aretic Canadian rivers.

The number of genera also followed a similar seasonal pattern, being high during.February and low during monsoon period.

The impact of seasonal fluctuations was comparatively high on diatoms (Fig. 5.1.7). As may also be seen from the figure, diatoms account for highest number among the phytoplankton in this region. These were superceded only during the summer months by chlorphyceaen algae in plains.

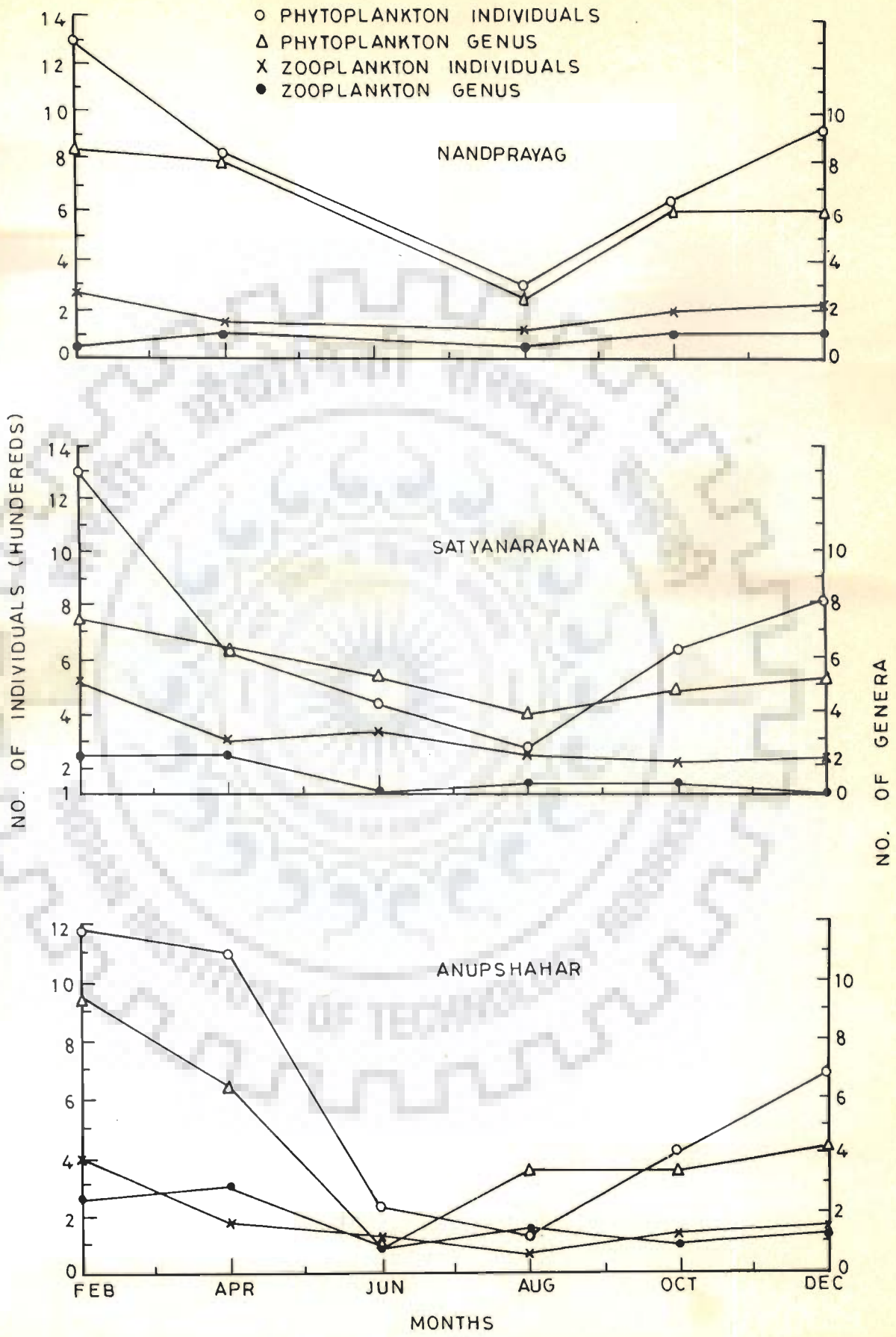


FIG. 5.1.6 –TEMPORAL VARIATION OF PHYTOPLANKTON AND ZOOPLANKTON GENERA AND INDIVIDUALS AT SELECTED STATIONS

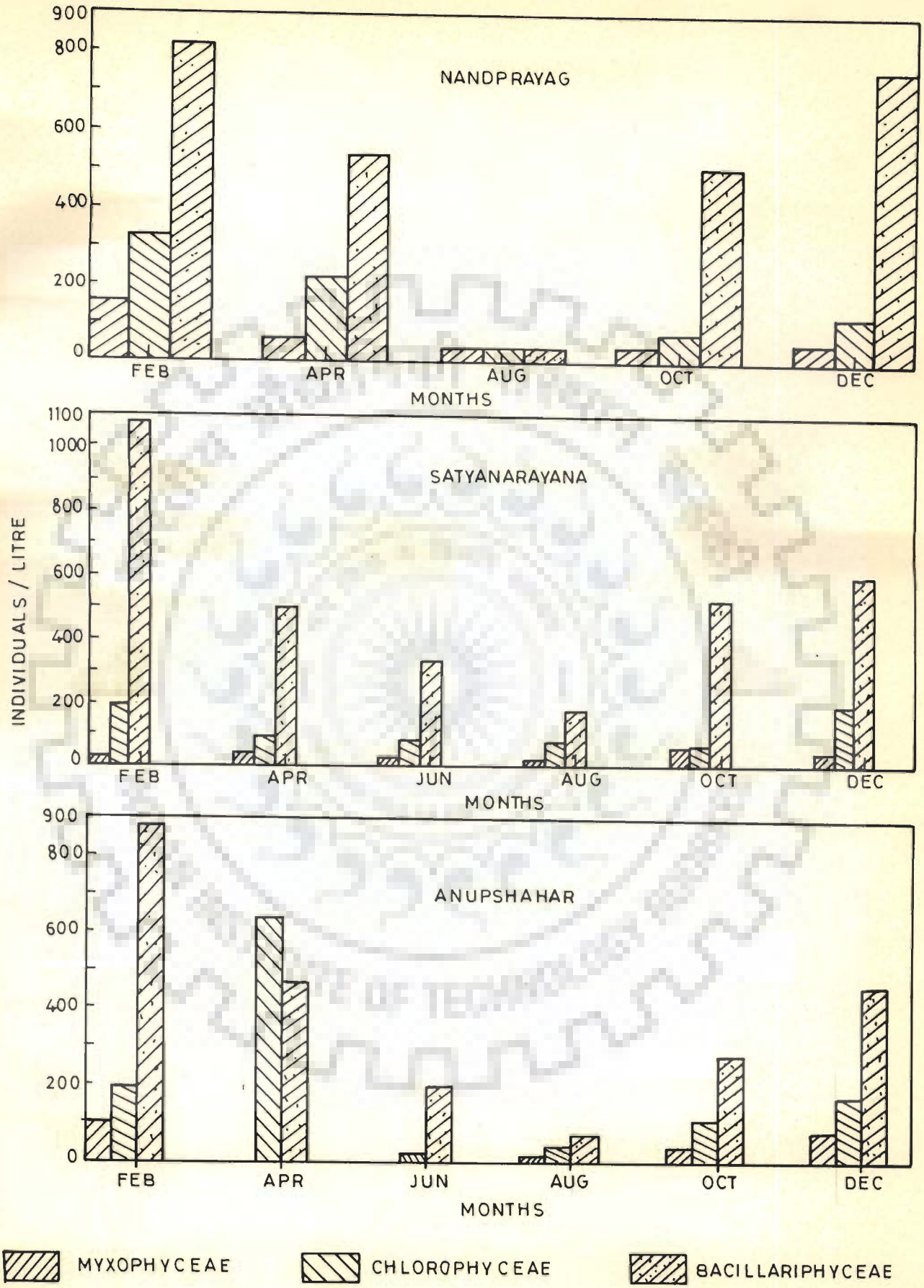


FIG. 5.1.7 – TEMPORAL VARIATION OF MAIN PHYTOPLANKTONIC GROUPS AT SELECTED STATIONS

The diatoms density showed an inverse relationship with turbidity, despite the fact that high turbidity indicates the possibility of high silicate level in water, which is essential for diatom growth. This type of relationship was also observed in lower Ganga by Bilgrami and Dutta Munshi (1985). Myxophycean algae show a comparatively insignificant seasonal changes.

In the spatial distribution the density of phytoplankton increased significantly upto Devprayag (Fig. 5.1.8). This may be attributed to the effect of tributaries, reduction in current velocity and partially to the sufficient retention time for their development in the snowmelt stream. It took 180 km riverine distance to touch its maximum mean value at Devprayag, which is approximately 4 times the value of Badrinath. Downstream of Devprayag the mean values decreased significantly upto Bijnor. The decline in mean values was associated with a number of factors, a significant contribution in the turbidity by Bhagirthi in the downstream of Devprayag, a greater development in its zooplankton at Satyanarayana, mechanical damage of sensitive forms by fast current at Chilla power station situated Rishikesh downstream significant bathing activity at Hari ki Pauri and Kankhal and cremation at Balawali and Bijnor.

The restoration of phytoplankton was observed downstream of Bijnor upto Narora. Figure 5.1.8 also provides an impression of generic abundance at various sampling sites. The highest mean value were recorded at Nandprayag and Devprayag whereas the lowest was observed at Bijnor (excluding Badrinath). Despite an increase in the mean phytoplankton density the mean genera number decreased significantly at Srinagar due to the disappearance of few forms as a result of domestic discharge. The overall difference in the genera abundance was less pronounced throughout the stretch. Except at Badrinath ,the mean values were between 8 and 12.

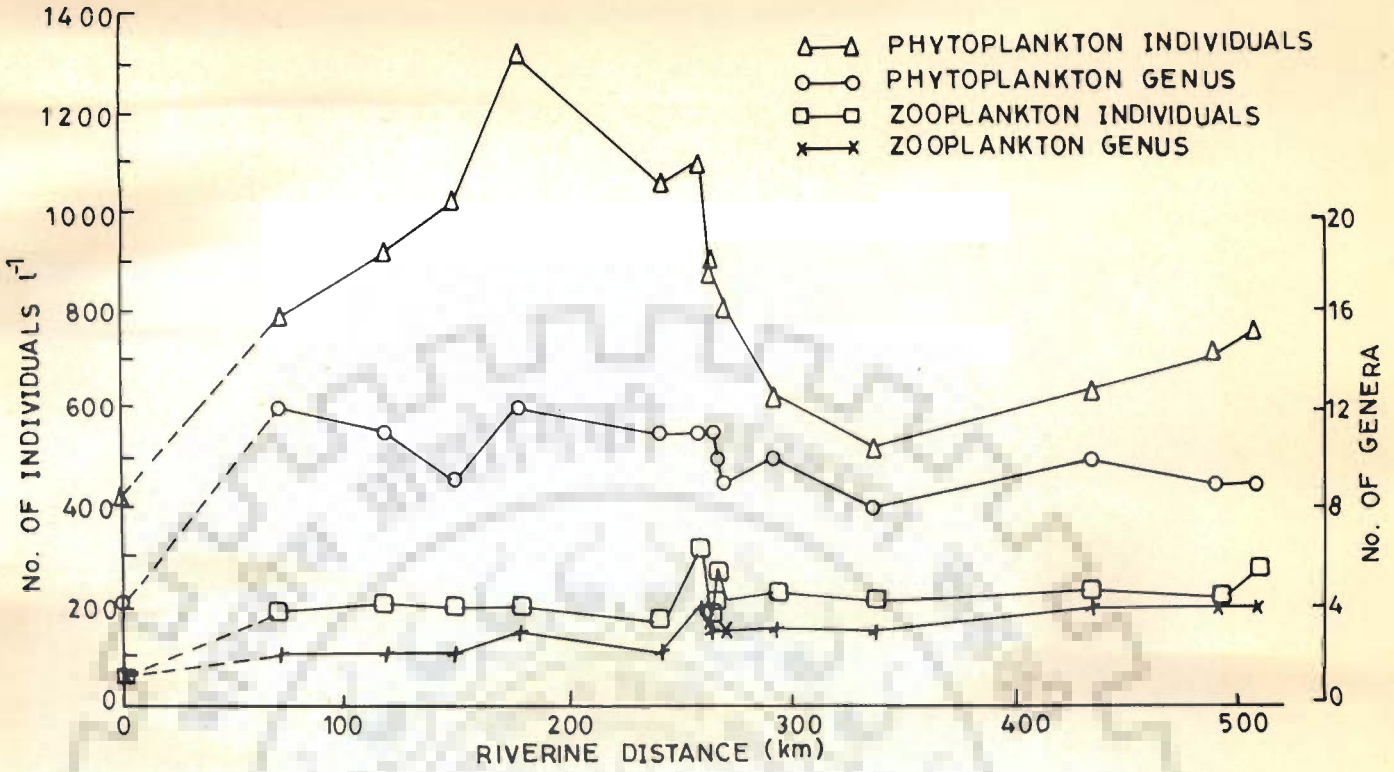


FIG. 5·1·8 – SPATIAL VARIATION OF PHYTOPLANKTON AND ZOOPLANKTON GENERA AND INDIVIDUALS

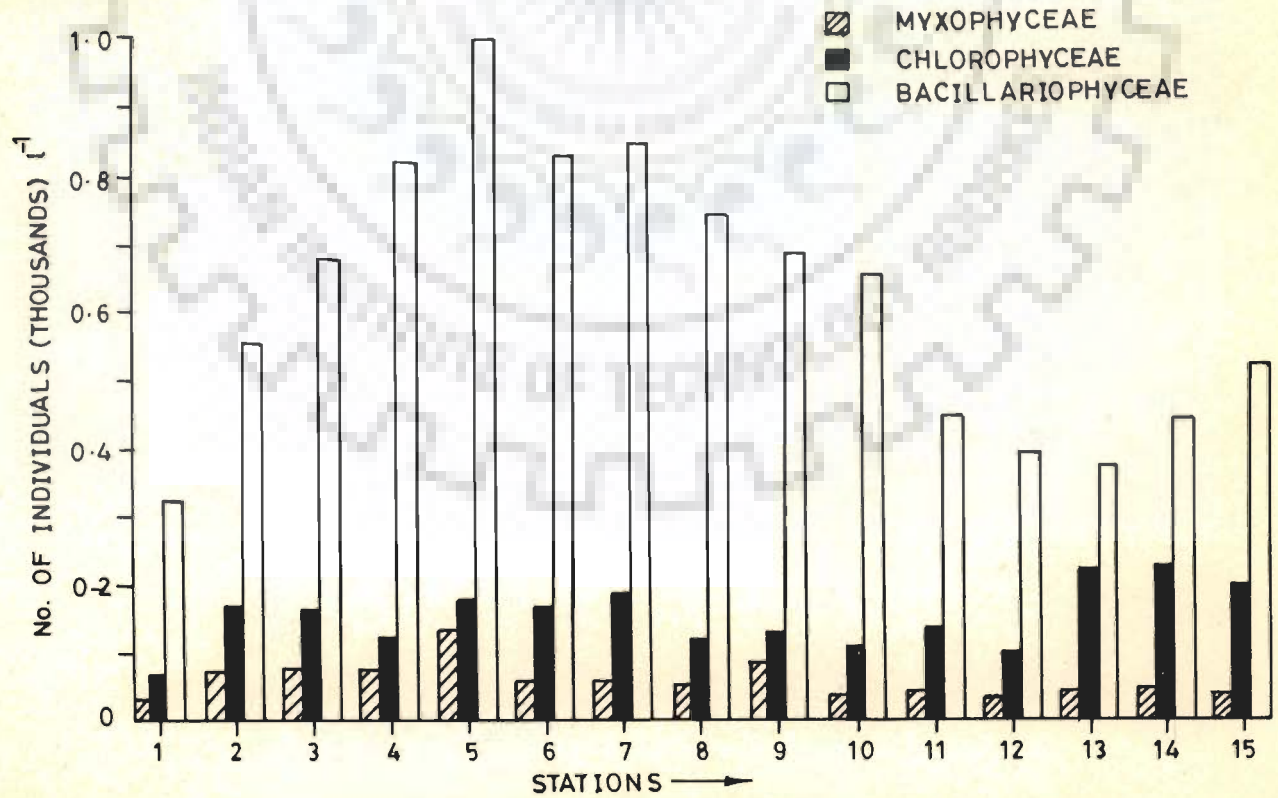


FIG. 5·1·9 – SPATIAL VARIATION OF INDIVIDUALS OF MAIN PHYTOPLANKTONIC GROUPS

As may be seen from Fig. 5.1.9 diatoms forced the phytoplankton to follow their pattern in the spatial distribution also, being its major constituent. The highest abundance of chlorophycean 227 l^{-1} was observed in plains at Anupshahar where as the lowest was recorded at Badrinath, 69 l^{-1}. The Myxophycean were lowest in number ranging between 29 l^{-1} at Badrinath and Bijnor and 129 l^{-1} at Devprayag.

It can be stated that (contrary to what was hopefully expected) within the study area no species assemblages consistent over some length of time exist. In fact the whole area contains only one association, with variations in species composition according to season and local anomalies in environmental circumstances.

5.1.2.2 Zooplankton : Zooplankton, one of the integral part of the lotic community, constitute a relatively small portion of the total planktonic community, the mean values ranging from 11% to 27% of total plankton composition. They were mainly represented by the protozoans. Rotifers, cladocerans and copepods accounted for little contribution during summer and winter periods in lower stretch.

Out of the 22 genera recorded, 15 were protozoans. Rotifers and copepods were represented by three genera each where as Daphnia spp. was the only cladoceran registered.

The zooplankton were represented by one genus Tetrahymna spp. at Badrinath. This representation gradually increased upto Narora, where 14 genera were recorded all round the year (Table 5.1.3). The cluster analysis of percent frequency of occurrence, presented in Table 5.1.3 show that not even a single genus was registered as highly frequent. Colpoda spp. was recorded

Table 5.1.3 Degree of Occurrence of Zooplankton Genera at Different Sampling Stations

(Cluster analysis : V =highly frequent, IV = frequent, III = moderately frequent, II = less frequent and I = rare)

TAXA	STATIONS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PROTOZOANS															
Acanthocystis spp.													I	I	
Actinophrys spp.		II	I	II	II		I	I	I	I	I		III	II	I
Amoeba spp.						I	III	I	II	II	II	II			I
Astasia spp.							I	II	II	II	I	I	II	I	II
Colpoda spp.		III	III	II	III	II	IV	II	III	III	III	IV	IV	IV	II
Euplotes spp.						I					I				
Lionotus spp.							II	I	I	I			I	II	II
Loxodes spp.			I	I	I	II	II	II	II	II	II	I			
Oicomonas spp.														II	I
Oxytricha spp.				I	I	II	II							II	I
Paramecium spp.		I			II		II								I
Plagiophrys spp.								I	I						
Tetrahymena spp.	II	III	III	III	III	III	I	I	I	I					
Trachelophyllum spp.							I	II	II	II	II	II	I	I	
Vorticella spp.				II	I		I			I	III	II	IV	III	II
ROTIFERS															
Dicranophorus spp.												II		II	
Testudinella spp.											I	I			
Trichotria spp.											I	I			I
COPEPODS															
Cyclops spp.															I
Diaptomus spp.															I
Limnocalanus spp.														I	I
CLADOCERANS															
Daphnia spp.														II	I

V = 80-100, IV = 60-80, III = 40-60, II = 20-40, I = 20 per cent.

as the only protozoan of frequent occurrence at Satyanarayana and in lower plains. Rest of protozoans were moderately or less frequent.

High turbidity and low phytoplankton density during monsoon resulted in the elimination of the certain filter feeder zooplankton, cladocerans and copepods. Sabaneeff (1952) opined that turbidity may interfere with the feeding apparatus of these animals where as Rylov (1940) noted the sinking of the cladoceran due to silt accumulation in their digestive track (from Whitton 1975).

Heaps of agricultural and urban residue which is carried into the river alongwith the rain water during monsoon season as decomposable organic matter, expectedly served as food supply for certain protozoans. Due to this, the decrease in the density of zooplankton was of lesser magnitude in comparison to phytoplankton despite of manifold increase in water discharge (Fig. 5.1.6). It was also supported by the percentage composition of plankton (Fig. 5.1.5). Such a trend indicates relatively poor pollutional load in this stretch of the river Ganga.

The zooplankton densities were recorded between 0 individuals l^{-1} (at Badrinath during post monsoon season) and 450 individuals l^{-1} (at Hari ki Pauri downstream during monsoon season) whereas the highest zooplankton percentage of total plankton was recorded at Nandprayag during monsoon.

The spatial variations of zooplankton are shown in Fig. 5.1.8. The zooplankton show a gradual increase in the density as well as in their genus richness from Badrinath to Narora. The first peak of relatively high magnitude was recorded at Satyanarayana both in terms of density and genetic richness. This high mean density was the effect of human activity on the development of zooplankton populations. The other two peaks of lesser magnitude at Hari ki Pauri downstream and Narora were the outcome of domestic effluent and

high bathing activities in the upstream region.

The annual mean density ranged from 52 individuals l^{-1}, minimum being at Bardinath maximum 323 individuals l^{-1} at Satyanarayana.

5.1.2.3 Benthic macroinvertebrates : A total of 15 macroinvertebrate taxa were recorded, including 3 genera of plecoptera, and tricoptera each, two genus each from coleoptera and odonata. Diptera was represented by Chironomus larvae only, whereas highest number of genera were recorded from ephemeroptera.

From a high of 13 taxa at Nandprayag and Rudraprayag, the number dropped to 8 at Srinagar and to 7 at Satyanarayana and Hari ki Pauri downstream (Table 5.1.4).

The high diversity of benthic macroinvertebrates and dominance of plecopteran nymphs (Acroneuria spp. and Peltoperla spp.) at Nandprayag and Rudraprayag confirmed relatively clean stream environment as this key group was placed on the top in the list of organisms in order to disappear as degree of pollution increases in most of the biotic indices (Chandler 1970; Sladecek 1973). The stream at these stations could be marked as cleanest (IX and X class) according to the Trent river board biotic index with more than one plecopteran nymph species and 10 + groups. Accordingly the presence of chrironomus spp. larvae present at Srinagar, Satyanarayana, Hari ki Pauri up and downstream may indicate relatively poor and polluted stream environment but the presence of plecopteran or ephemeropteran nymphs (next to plecoptera in the list) support the unpolluted healthy state of the system at these location.

The occurrence of pollution tolerant forms in clean water cannot be denied. Such a situation at these locations also suggested the selection of

Table 5.1.4 Occurrence of Benthal Macroinvertebrates at Some Sampling Stations

TAXA	STATIONS							
	Nandp.	Rudrap.	Sringr.	Devp.	Rshik.	Satya.	HKPu/s	HKPd/s
	2	3	4	5	6	7	8	9
Plecoptera								
Acroneuria spp.	D	D	*	*	*			
Isoperla spp.	*	*		*	*	*	*	
Peltoperla spp.	D	D	*	*	*		*	
Ephemeroptera								
Ephemerella spp.	D	D	*	*	*		*	
Ametropus spp.	*				*		*	*
Baetis spp.	*	*	*	*			*	
Heptagenia spp.	*	*		*	*	*		
Odonata								
Dromogomphus spp.	*		D	*	*			
Hyponeura spp.	*	*		*	*		D	*
Trichoptera								
Rhyacophila spp.	*	*				*	*	*
Hydropsyche spp.	D	D	*	*	*	*		*
Leptocella spp.		*						
Diptera								
Chironomus spp.		*	*			D	*	D
Coleoptera								
Gyrinus spp.	*	*		*	*	*		*
Psephenus spp.	*	*	*	*	*	*	*	*

D Dominent

* Present

pollution sensitive form as a basis of classification of environment and not the pollution tolerant forms as in Palmer's (1969) Biotic index.

Leptocella spp. larvae were present only at Rudraprayag. Psephenus larve from coleoptera was the only member present almost at all the stations. At Devprayag and Rishikesh none of the form showed a clear dominance over the others.

5.1.2.4 Decomposers : Microorganisms form an important biotic component of an ecosystem. Their rich and manifold enzymatic abilities break down all sorts of organic matter. Thus the microorganism support the energy flux through the ecosystem and the cycling of mineral elements. Because of their ubiquitous character, many taxonomic groups of microorganisms may participate in decomposition processes in aquatic ecosystems.

Heterotrophic bacteria : The heterotrophic bacteria under go greater spatial and temporal fluctuations. The annual mean count of heterotrophic bacteria in water sample from different sampling sites are presented in Fig. 5.1.10. The perusal of figure shows a steep rise in the concentration at Satyanarayana and Hari ki Pauri downstream. Increase at Satyanarayana was attributed to the confluence of IDPL effluent and Rishikesh sewage. Subsequent decline was because of dilution through Chilla return water. The impact of constant high community bathing at Hari ki Pauri zone, Hari ki Pauri downstream and Kankhal is clearly discernable downstream. The subsequent decrease in bacterial numbers is due to dilution as the river abstraction returns back to main river at Balawali. Further the values increase gradually from Balawali upto Narora due to constant addition of domestic, agricultural waste and bathing load in this zone. The bacterial number increased moderately at Srinagar, specially during late summer and monsoon due to substantial increase

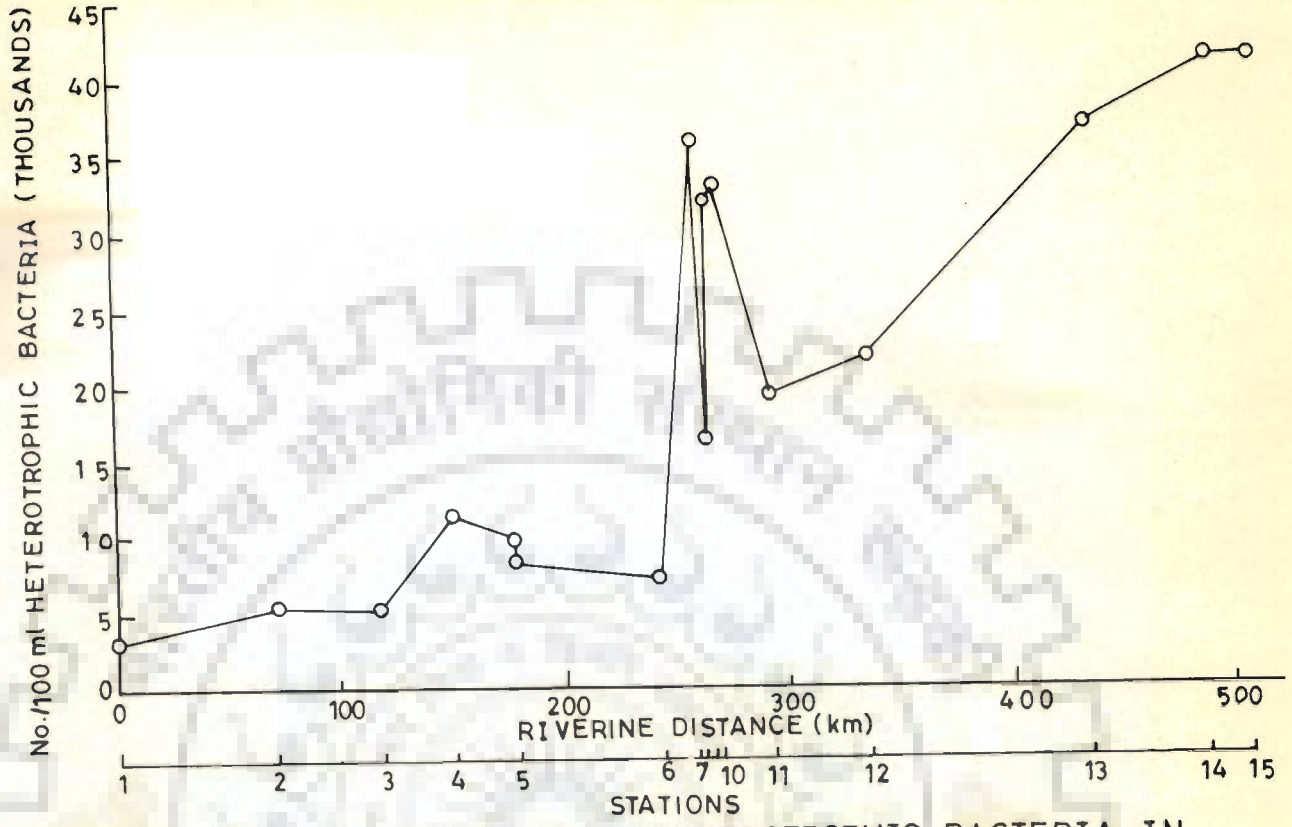


FIG. 5·1·10–SPATIAL VARIATION OF HETEROTROPHIC BACTERIA IN THE WATER OF UPPER GANGA

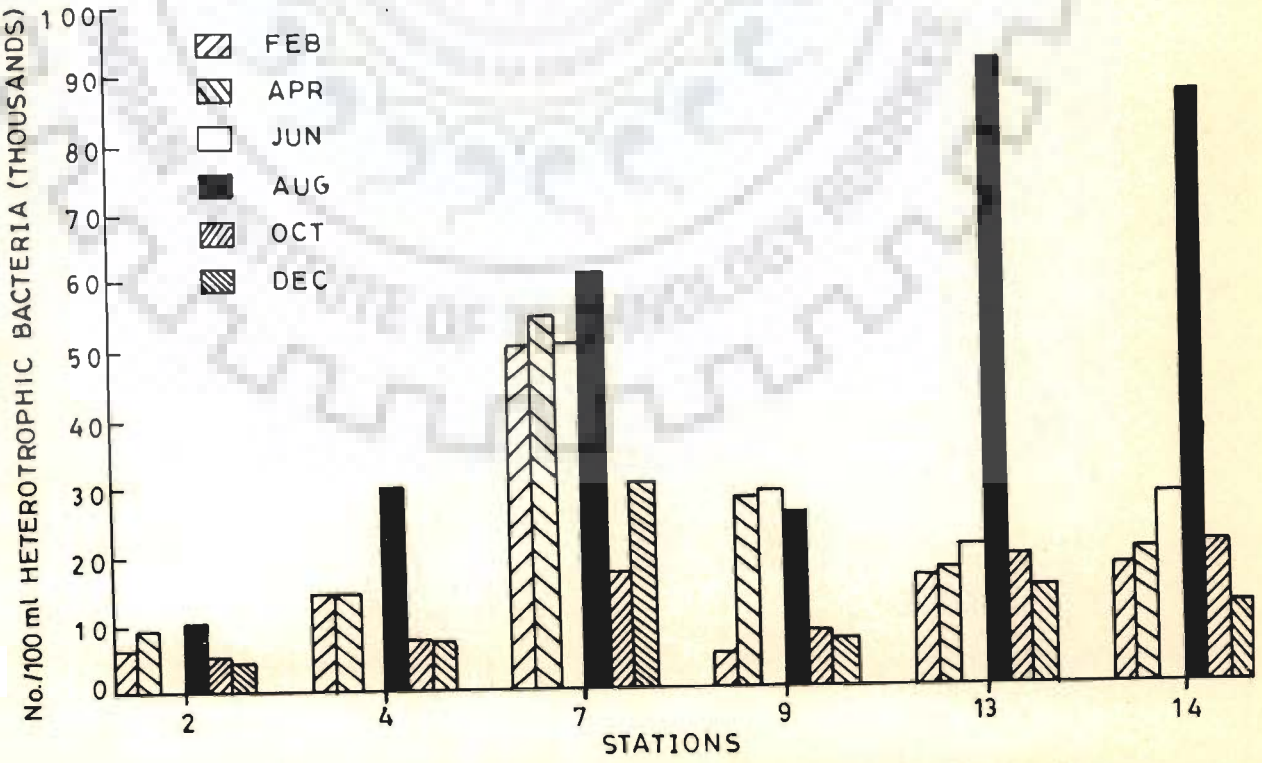


FIG.5·1·11–TEMPORAL VARIATION OF HETEROTROPHIC BACTERIA AT SELECTED STATIONS

in the floating population. The tributaries at Nandprayag and Rudraprayag adds marginal bacterial load where as Bhagirathi dilute it slightly at Devprayag.

Figure 5.1.11 illustrates some examples of bacterial distribution pattern at different seasons. The fluctuations in the mountainous zone were of low order in comparison to plains. The seasonal changes at all the stations were remarkably similar. The values were found minimal during winter and maximum in the monsoon. Comparatively high values at Satyanarayana during the lean flow season can be attributed to the absence of dilution at this spot.

Since many zooplankton act as predator to bacteria, the winter and summer decrease of organic matter in water, leaves the population of bacteria as only alternative food for them, thus depleting the bacterial concentration. Another reason for this decrease may be less favourable nutritive conditions for the group. Accordingly high values during monsoon are most likely due to comparatively high concentration of organic matter, particularly the easily degradable organic matter.

Fungi : Fungi especially the extra-aquatic ones play a significant role as decomposers in the aquatic ecosystem. These were investigated qualitati - vely only few kilometers downstream of point discharge of combined effluent of IDPL factory and Rishikesh sewage. The total number of forms were much higher at the confluence than at upstream of confluence. Among the determin- able fungi the commonest observed at the meeting point of effluent were Phythium spp., Mucor spp. Phycomyces spp., Aspergillus spp., Penicillium spp., Candida spp., Geotrichum spp. and Alternaria spp. Out of these only Aspergillus spp. and Alternaria spp. were observed upstream also. In the downstream region the forms disappear gradually with time and subsequent dilution. At Hari ki Pauri the members of only genera Aspergillus (A. niger, A. candidus and Aspergillus spp.) were recorded. It is evident from

positive correlation between fungal species and biochemical oxygen demand, that most of the fungus ascertain their entry into the system with effluents high in easily degradable organic substances.

5.2 Ecological Indexing

The community structure indices represent mathematical models of community change. With respect to pollution one would expect that as concentration of pollutant increases in a system, the mathematical model would indicate increased purturbations or harmful effects on the community. Such an index is just one of the tools that can be used to acquire some insight into the nature of community.

From the standpoint of environmental quality, it is not the absolute concentration of a pollutant that is of interest but the ultimate influence on environment. Because the local community represents an integration of all the stresses acting upon it, measurement of diversity and similarity can be more informative. In the present study, the phytoplankton populations were used to evaluate the generic diversity and similarity indices discussed in 3.1.

5.2.1 Diversity

The values of diversities obtained are presented in Figs. 5.2.1 to 5.2.8. The samples resulted from 100 to 5213 individuals during monsoon (Bijnor) and winter (Devprayag) respectively and from 3 to 22 genera during monsoon (Anupshahar) and summar (Devprayag) respectively. Despite this variability, the range of diversities were of moderate order.

5.2.1.1 Spatial and temporal variations : The values obtained from Shannon information function H' varied as:

2.14 (Anupshahar) to 2.98 (Devprayag) in summers

1.63 (Garhmukteshwar) to 2.48 (Rishikesh) in winters

0.67 (Anupshahar) to 2.21 (Satyanarayana) in monsoon

1.29 (Badrinath) to 2.43 (Devprayag) in post-monsoon.

The seasonal pattern as measured by H' at different sampling stations are shown in Fig. 5.2.1(b). A marked decline in the values during monsoon at all the stations indicated a negative effect on the community. This as discussed in 5.1.2.1 may be attributed to the elimination of most of the forms due to high sediment load. An increase in the values at all the stations during summers reflected the more varied planktonic flora and improved stream conditions.

The highest value of H' observed at Satyanarayana during monsoon, may be due to the contribution of low turbidity by Song river as shown by turbidity values (Table 5.1.1 and Fig. 5.1.2), where as, the lack of sufficient dilution of IDPL effluent at this station during winter and summer, affected the community adversely, thus lowering the value of H' in comparison to up and downstream stations. The sum of these conditions narrowed the range of temporal variation of H' values at Satyanarayana.

The lowest mean value of H' was recorded at Badrinath (Fig. 5.2.1(a)). This was expected, as planktonic flora and fauna takes time to establish itself in the snowmelt stream and Badrinath is not far from the origin. The mean value was also influenced by the nonavailability of data during winters and summers. Hilsenhoff (1977) criticised H' on the same ground, that it indicates that small cold stream may be polluted, whereas they have naturally low diversity.

Otherwise, excluding Badrinath, the range of mean values was very narrow, from 1.860 at Anupshahar to 2.386 at Nandprayag. In spatial variation a decline in the values at Srinagar, Hari ki Pauri d/s and Bijnor downstream

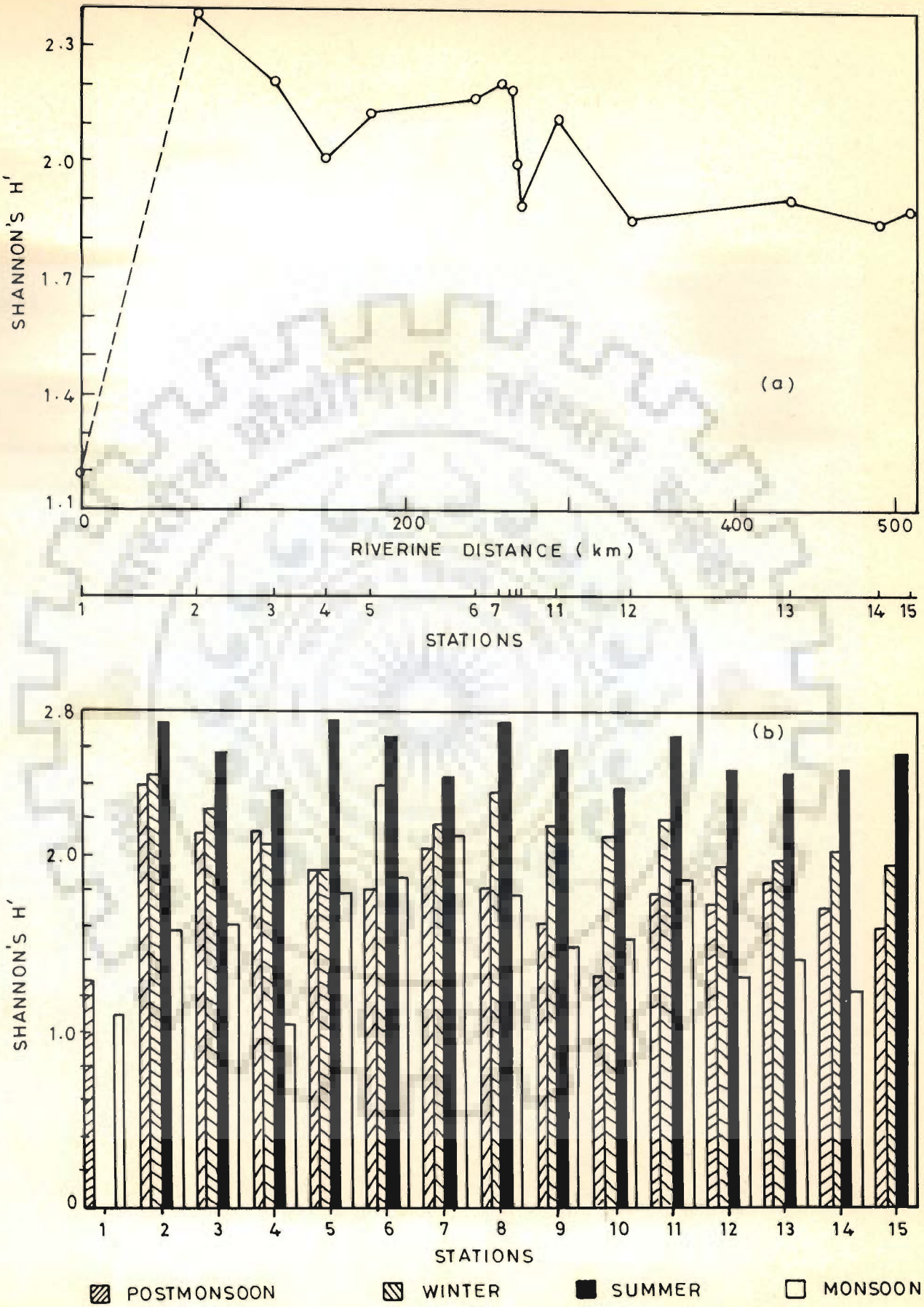


FIG. 5.2.1 — SPATIAL AND TEMPORAL VARIATIONS OF SHANNON'S H'

stations is fairly evident. Although the spatial pattern shown in Fig. 5.2.1(a) did not seem very consistant in all the seasons, due to the difference in the magnitude of temporal variability at different stations.

It has been stated that a low diversity can indicate pollution. It certainly can, but a low diversity value is not always a result of pollution, rather only a result of change in community structure, which may be natural. It could be better justified by evenness of redundancy.

Stress causes dominance of only tolerant species. In other words the individuals in more polluted environment should be less evenly distributed. A system attains its maximum diversity at a particular richness level under conditions of absolute evenness.

Figure 5.2.2 depicts the spatial as well as temporal variations in evenness V'. In no sample the value was recorded below 0.80 or 80% of ideal evenness. A high evenness at Bardinath (0.966) indicated absence of intrageneric competition. Thus environmental factors other than pollutional stress should be responsible to lowering down the value of H'. Also a high diversity does not always indicate a mature system. For instance at confluences diversity can increase just because mixing of two water types and thus two plankton types. So is the case at Devprayag, where H' show an marginal increase over Srinagar, whereas evenness V' show a decrease. A decrease in the values of both H' and V' at Rudraprayag, Srinagar, Hari ki Pauri d/s and Balawali downwards may be attributed to the human activities at these places. High values of evenness during monsoon also indicated that a slight increase in BOD during this season have no severe negative impact on the community.

It is evident from the results that the communities having similar evenness may have different diversity, e.g. at Kankhal the similar values of V'

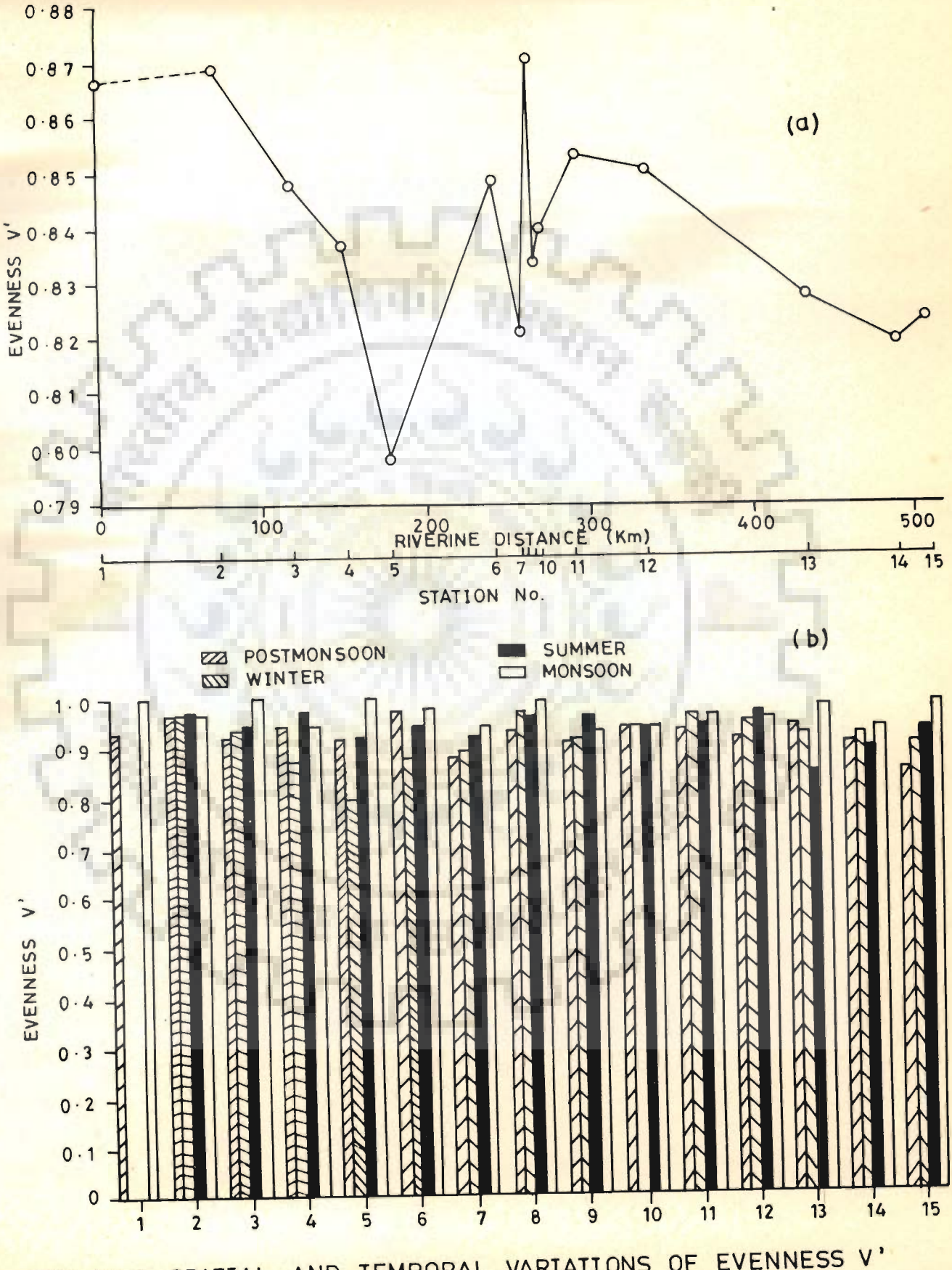


FIG. 5·2·2 – SPATIAL AND TEMPORAL VARIATIONS OF EVENNESS V'

during post-monsoon and winter (0.944 and 0.942) have different H' (1.308 and 2.085). On the other hand different V' values 0.919 and 0.802 during post-monsoon and winter at Devprayag have approximately similar H' values (1.906 and 1.920) respectively. This suggests that the use of both diversity and its evenness may be more informative to measure the environmental quality.

The evenness V was also computed by H'max and H'min values, as per Patten (1962). These values were found similar to V' values upto 2 decimal places, whereas redundancy (R) values were recorded complementary to V. Both R and V were not worth mentioning here.

The values obtained for PIE ranged from 0.481 during monsoon at Anupshahar to 0.946 during the summers at Balawali. The winter lowest value 0.668 and winter highest 0.913 were recorded at Devprayag and Rishikesh respectively. The values varied from 0.691 at Narora to 0.909 at Nandprayag in post-monsoon period. The lowest value in summer was recorded 0.828 at Anupshahar whereas in monsoon the values did not increase beyond 0.899 (Satyanarayana).

The spatial trend for PIE was found similar to H', with slight disagreements i.e. Devprayag and Satyanarayana (Fig. 5.2.3(a)). A significant increase in the H' values at these stations over their upstream stations during summer, monsoon and post-monsoon months was noticed as an expression of high S values. Whereas, this difference of S values reflected a marginal difference in the PIE values. The range of mean values was recorded still narrow (0.791 to 0.895). With its minimum and maximum values again at the same locations as for H'. The temporal variation as shown in Fig. 5.2.3(b) show a remarkably similar trend as H'. As was expected the magnitude of variation was consistently less than those of Shannon's H'.

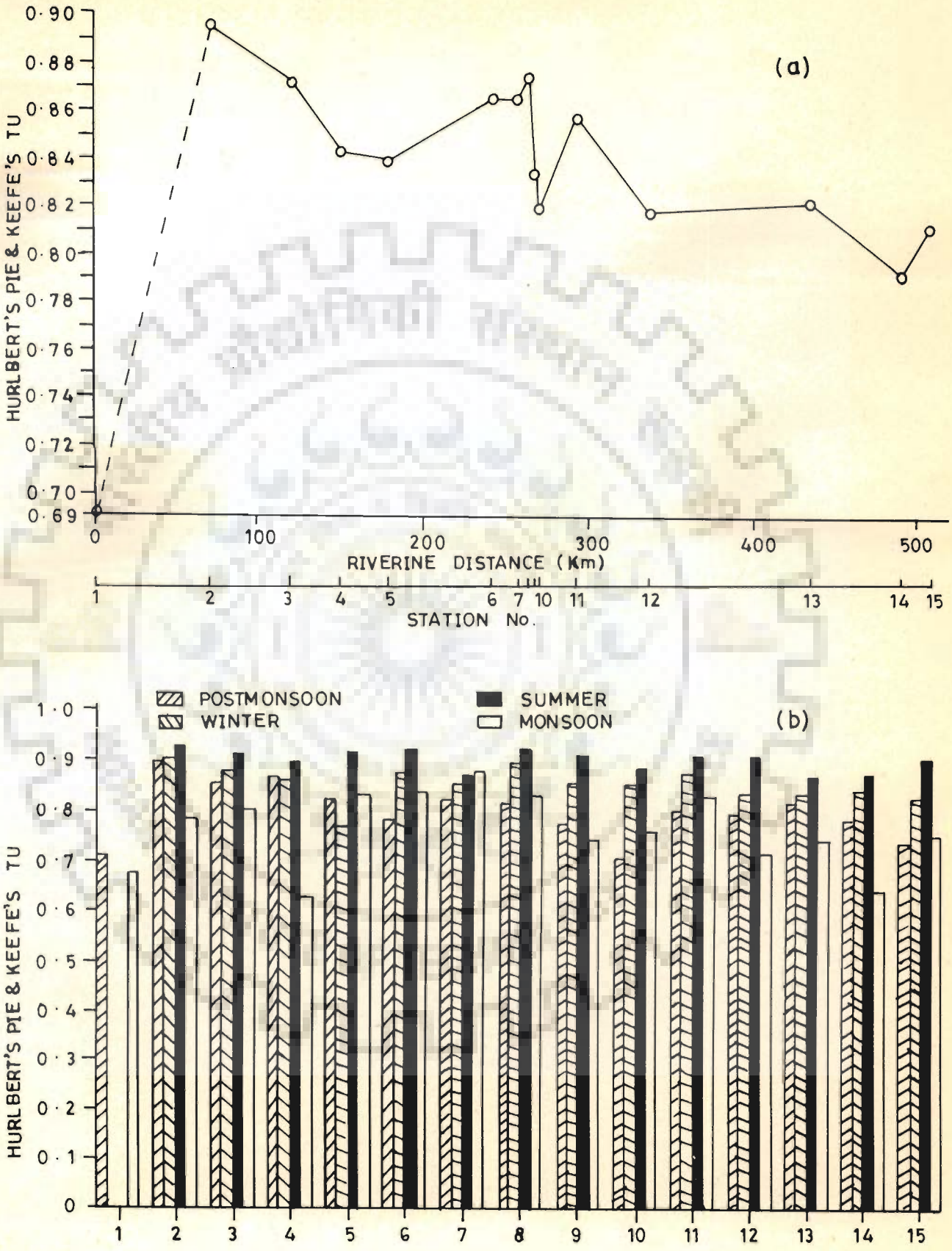


FIG. 5·2·3—SPATIAL AND TEMPORAL VARIATIONS OF Hurlbert's PIE AND Keefe AND Bergersen's TU

The V and V' computed with PIE max and PIE min show that the evenness did not go below 80% of ideal evenness any time during the entire study period.

A PIE value of 1.00 is the indication of healthiest community because of the absence of intrageneric competition (1 - PIE) on the same trophic level (Hurlbert, 1971). Only at few occasion the PIE values were recorded below 0.70. The high mean values as well as evenness were indicative of a good health of the community and relatively low intrageneric competition.

As Hurlbert's approach of formulating PIE was opposite of Simpson's approach for D, the values computed for D were complementary of PIE (D = 1 - PIE). In other words Simpson's diversity measures the intraspecific competition (Intrageneric in present case) or stress or negative effects on the community. The spatial as well as temporal variation shown in Fig. 5.2.4(a) and (b) were the mirror images (opposite) of the variations for Hurlbert's PIE.

Keefe and Bergersen equated 1 - TU with Simpson's D. The results of TU were in echo with PIE upto the 4th decimal places, hence were not graphed separately.

The trend for McIntosh's M was observed similar to PIE or TU in the raw data, as well as in spatial and temporal variations (Fig. 5.2.5(a) and (b)). However, the values were recorded lower than PIE. The maximum mean value (0.711) recorded at Nandprayag was nearer to the minimum mean value (0.692) of PIE at Badrinath, but much smaller than the second lowest mean value (0.791) of PIE. A marginal increase in the variability of M values over PIE values was observed.

As McIntosh expressed his index as a proportion of absolute maximum diversity, it could be looked at as a measure of evenness. A decrease in

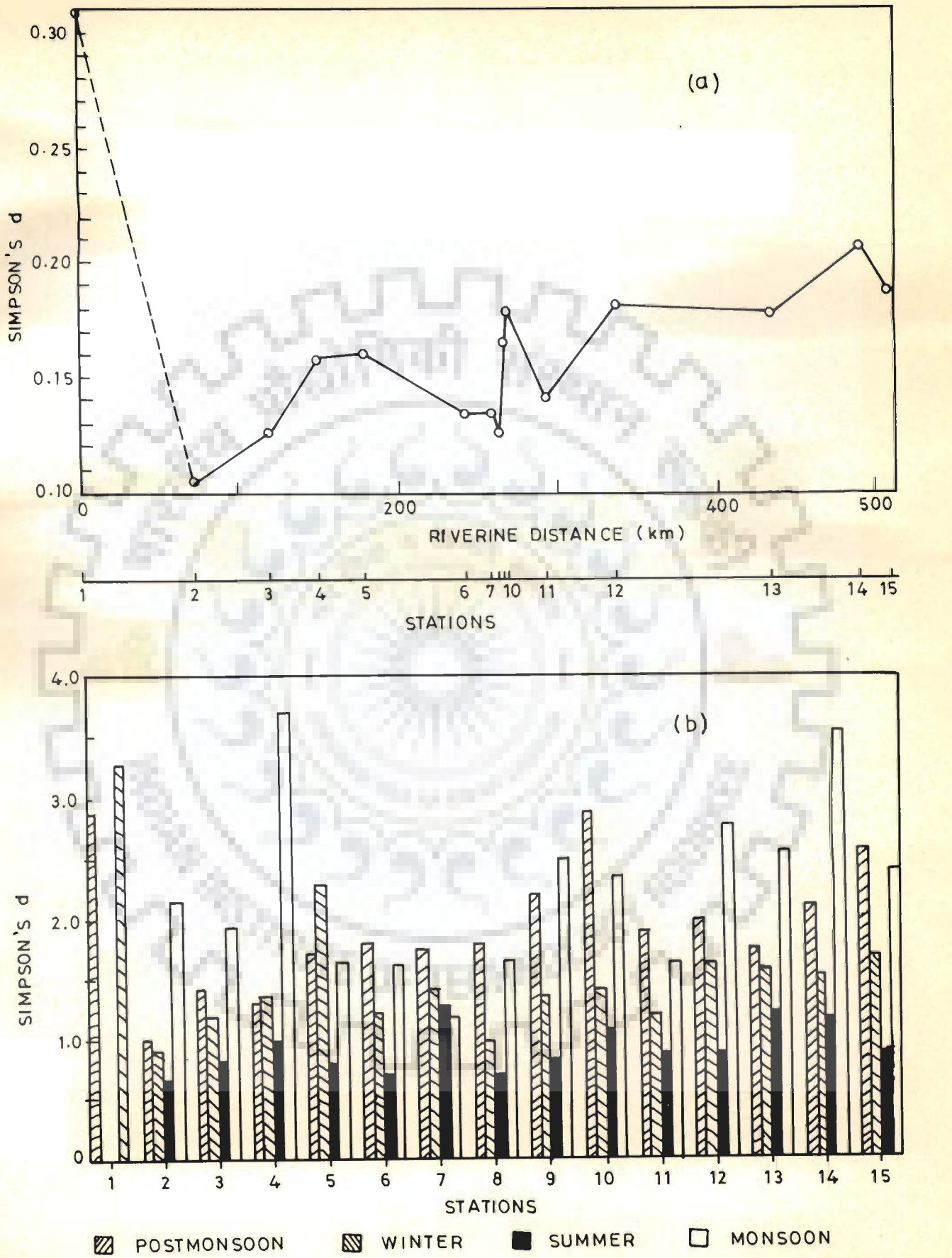


FIG. 5.2.4 – SPATIAL AND TEMPORAL VARIATIONS OF SIMPSON'S d

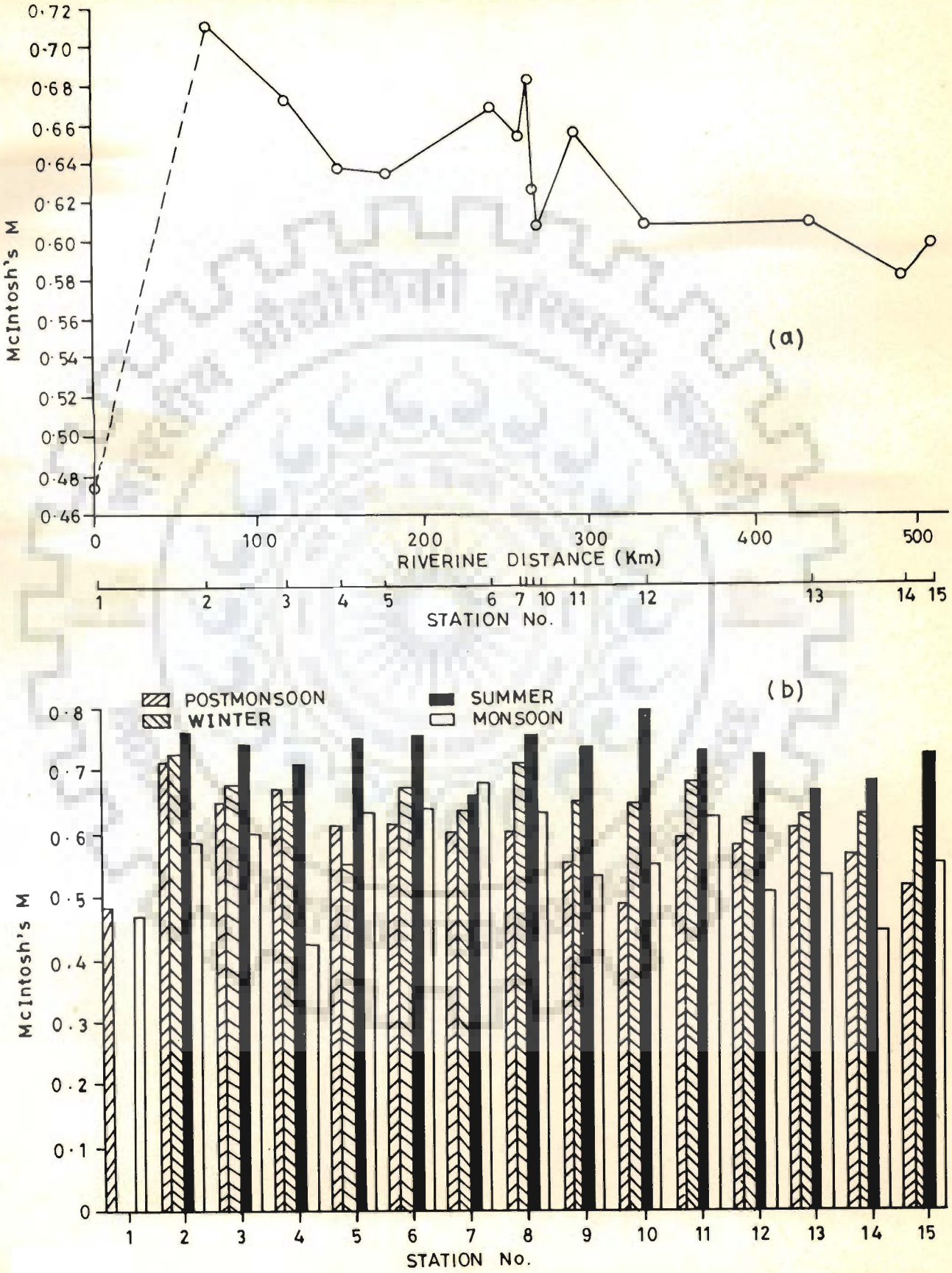


FIG. 5·2·5 – SPATIAL AND TEMPORAL VARIATIONS OF McIntosh's M

the mean values of M at Devprayag and Satyanarayana (in comparison to H' values) was effected by an increase in the unevenness of the community at these locations.

The M values ranged from 0.296 at Anupshahar in monsoon months to 0.786 at Balawali during summer months. The entire extremes for M values were observed at same locations, in same months as for PIE values.

The values obtained from Gleason's index varied from 0.357 at Anupshahar during monsoon to 3.401 at Devprayag during summers corresponding to the lowest and highest S values recorded. It is worth mentioning, that the presumption (it is based on), is not always true as the relationship between S and ln N is not always linear. Despite the involvement of high degree of subjectivity the results obtained were comparable with other indices, as the sample size was maintained throughout the study area and period. The diagreement in the mean values at some places with other indices (considering the number of individuals per species) were the expression of nonlinear variations between numerator and denominator values (Fig. 5.2.6(a)).

The index followed a similar pattern in both spatial as well as temporal variations, as Shannon's H', PIE and M (Fig. 5.2.6(a) and (b). The mean diversity varied from 0.623 at Badrinath to 1.898 at Nandprayag. The second lowest mean value was recorded 1.271 at Bijnor. The extreme value recorded during different seasons were : 0.357 at Anupshahar to 1.597 at Rishikesh in monsoon, 0.605 at Badrinath to 1.905 at Nandprayag during post-monsoon, 1.021 at Anupshahar to 2.046 at Rishikesh during winters and 1.334 at Srinagar to 3.401 at Devprayag during summers. Because the changes seen for S/ln N were bigger even than for Shannon's H', it tend to give results more easily interpretable.

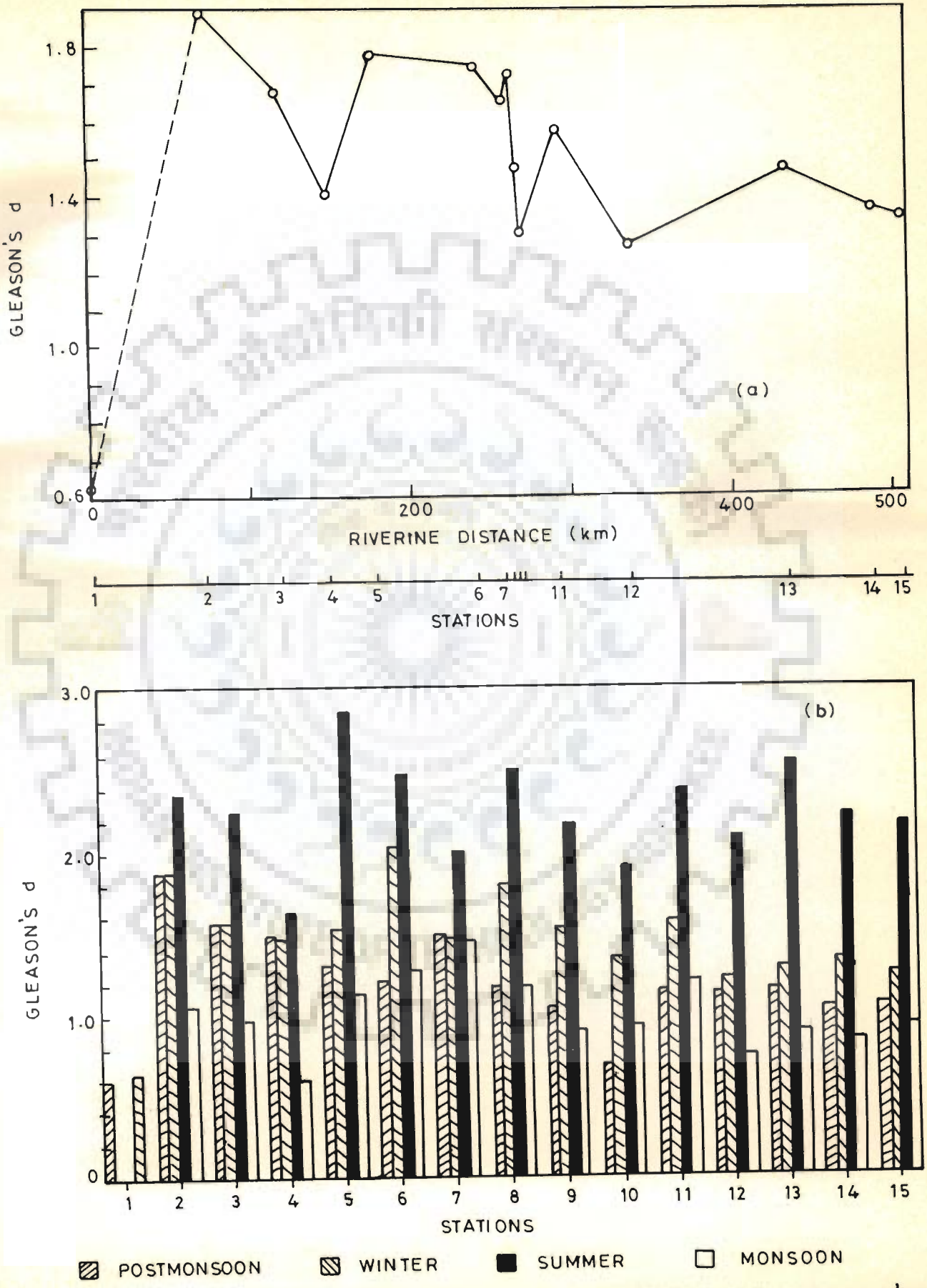


FIG. 5.2.6 — SPACIAL AND TEMPORAL VARIATIONS OF GLEASON'S d

These values were reduced marginally by Margalef by the substraction of 1.00 from the species number, thus reducing the maxima and minima to 3.246 and 0.179 respectively. Otherwise as expected the trends and the variation in the values of Margalef's diversity were identical to Gleason's (Fig. 5.2.7(a) and (b).

Menhinick's index still reduced the values by increasing the denominator from $\ln N$ to $\sqrt{N}$. The spatial variations graphed in Fig. 5.2.8(a) were in agreement with Gleason's. The increase in the post-monsoon values over the winter values in mountainous stretch was the effect of significant increase in individuals during winter over post-monsoon, which increased the denominator significantly in Menhinick's index than Gleason's index. The remainder show a similar trend in the temporal variations as Gleason's index (Fig. 5.2.8(b)). The values ranged from 0.122 to 0.866 during same seasons at same locations as two extremes for Gleason's index.

The values of diversity indices lead to suggest, that the temporal development for whole study area follows a yearly cycle with a distinct spatial pattern.

5.2.1.2 Comparison of the results : A considerable variation existed between number of genera and number of individuals in different seasons at different sampling stations. Thus it was possible to compare the diversity indices over a large range of numbers. Since most diversity showed a high coefficient of correlation with number of genera (Table 5.2.1), they follow a trend of genera number more closely than individuals.

The values of H' varied from 0.672 to 2.977 corresponding to the two extremes for genera recorded. This index had a high coefficient of correlation (0.935) with number of species. As maximum possible diversity at a

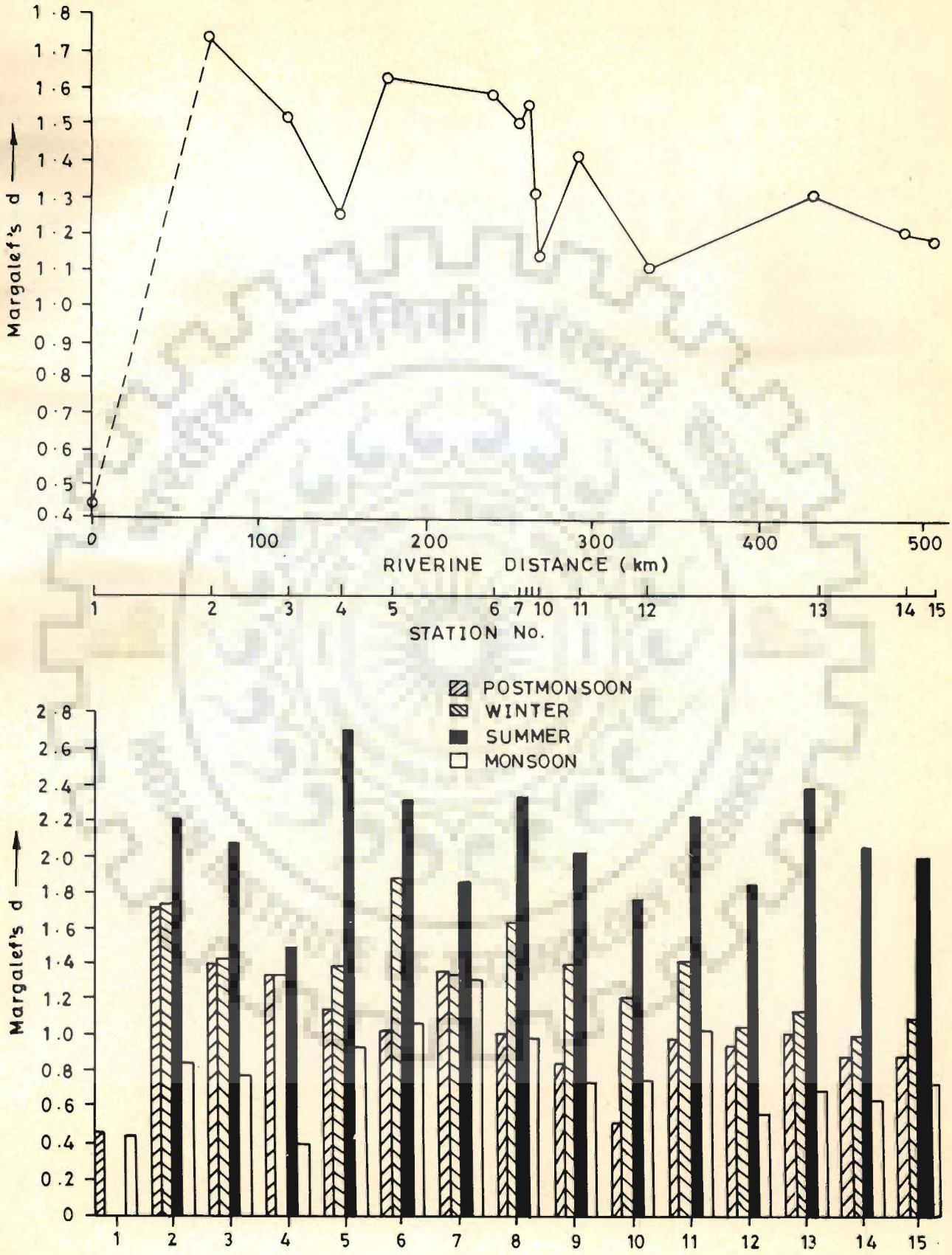


FIG. 5·2·7–SPATIAL AND TEMPORAL VARIATIONS OF Margalef's d

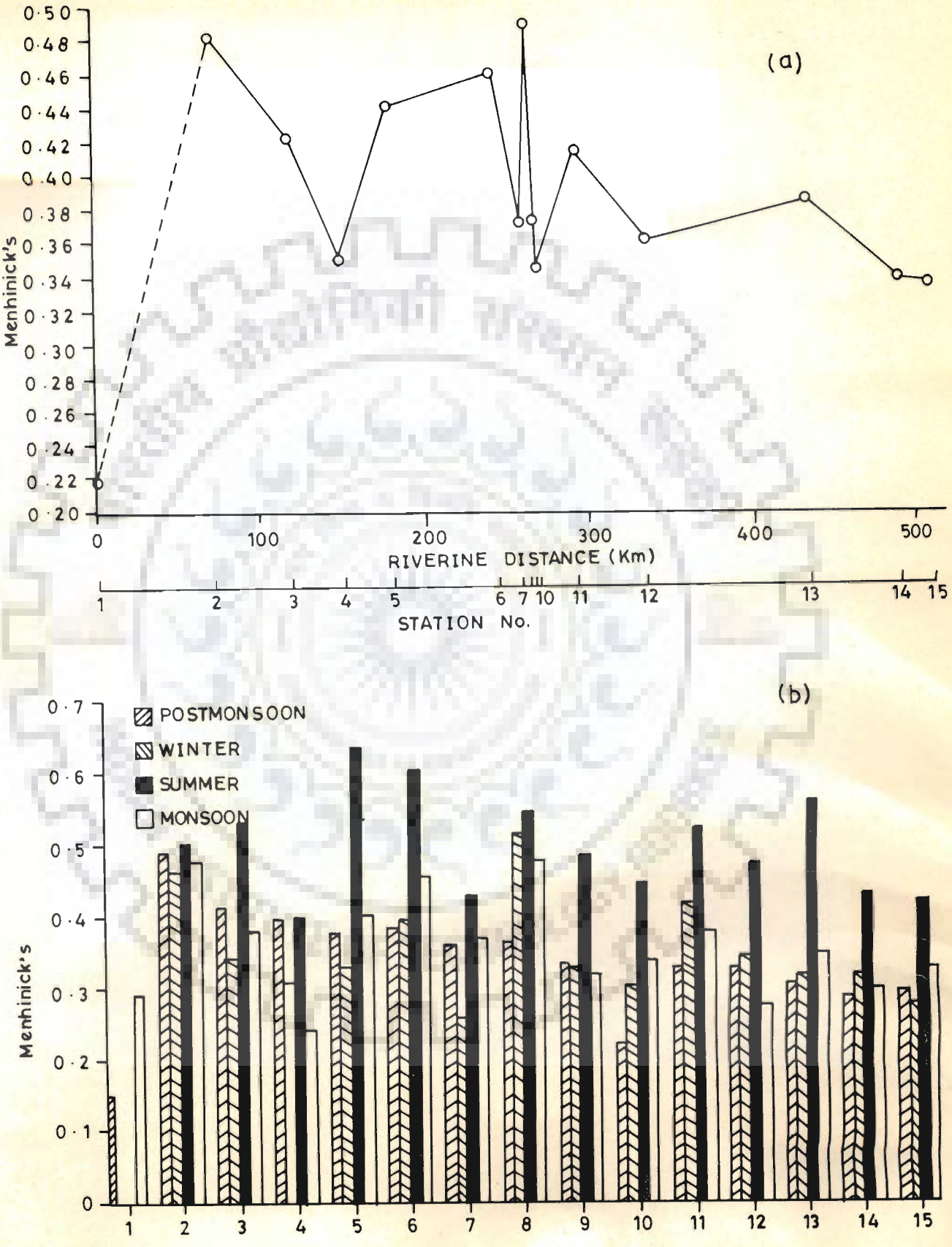


FIG. 5·2·8 – SPATIAL AND TEMPORAL VARIATIONS OF Menhinick's d

particular number of species can be achieved if the individuals have an absolute even distribution of individuals among the species and in no case the H' in the system was recorded below 80% of maximum diversity (evenness), this correlation was justifiable As the wealth of the genera was associated with the number of individuals positively (0.540), the index also show a poor positive correlation with number of individuals (Table 5.2.1).

The association of Hurlbert's PIE, Simpson's D as well as Keefe and Bergersen's TU with genera number was observed low in comparison to H' and still low with number of individuals. The lowest correlation with number of individuals was shown by McIntosh's M. This low correlation with number of individuals indicated the least sample size dependency (Wilhm, 1967). All these indices also show a significant correlation with each other.

Gleason's and Margalef's index were closely associated with each other ($r = 0.999$). Despite the lack of theoretical explanation and consideration of the abundance of individuals by which each species is represented in the community, both Gleason's and Margalef's index correlated closely with Shannon's H'. Both these indices had highest correlation with the genera number and low correlation with individuals in comparison to H'. The high correlation of Margalef's index with species wealth was also observed by Wilhm (1967). Thus Gleason's index conforms just as well to Shannon's H, as Margalef's index.

A poor correlation with number of genera even at high evenness, as well as with indices, Menhinick's index did not appear to be a precise measure of stream health as reflected by phytoplankton community.

The upper limit or defined maximum limit of index in case of D, PIE, M and TU have an advantage over Shannon's H', but the changes provided

Table 5.2.1 Correlation Coefficient (r) Between Diversity Indices Values

	S	N	D	H'	PIE	M	V'	Gl-d	Mr-d	Mn-d
S	1.000									
N	+0.540	1.000								
D	-0.777	-0.241	1.000							
H'	+0.935	+0.394	-0.937	1.000						
PIE	+0.778	+0.246	-1.000	+0.938	1.000					
M	+0.802	+0.205	-0.988	+0.951	+0.987	1.000				
V'	-0.144	-0.521	-0.202	+0.053	+0.198	+0.266	1.000			
Gl-d	+0.971	+0.356	-0.815	+0.946	+0.816	+0.854	-0.047	1.000		
Mr-d	+0.976	+0.377	-0.817	+0.950	+0.818	+0.853	-0.060	+0.999	1.000	
Mn-d	+0.535	-0.269	-0.620	+0.626	+0.619	+0.687	+0.240	+0.721	+0.702	1.000

S = No. of genus ; N = No. of individuals ; D = Simpson's D ; H' = Shannon's H' ;
PIE = Hurlbert's PIE ; M = McIntosh's M ; V' = Evenness ; Gl-d = Gleason's index ;
Mr-d = Margalef's index ; Mn-d = Menhinick's index.

by these indices are also narrow and makes interpretation difficult. Perkins (1983) also observed changes in M and D smaller than H' and inferred the difficult interpretation.

Evenness did not show any significant correlation neither with number of genera, individuals nor with any other index as the evenness in all the samples was observed significantly high.

Some authors compared the community indices with chemical parameters such as pH, alkalinity, conductivity. BOD, salinity etc. and claimed that certain index is better when it has a high correlation with chemical data (Chutter 1972; Dills and Roger 1974; Hilsenhoff 1977). Chutter (1972) claimed that Margalef's index follows changes in stream better than other diversity indices on scrutiny of Wilhm's data. The desirability of diversity index correlating with the chemical data does not look justifiable An organism reacts to all aspects of his environment. A community has resulted from the summation of influences of which crude chemical parameters are only one small part. There is no reason why community structure should be closely correlated with chemical parameters. There will be no doubt about basic correlations between high diversity, low BOD and COD, high DO, low turbidity and moderate flow rates. However a diversity index can not be picked on the ground of such correlations.

5.2.1.3 Conversion of values : The results obtained in the present study refer to values computed from the same samples, comparing the scale of different indices used.

Figure 5.2.9 depicts the behaviour of corresponding values represented on axes of equal dimension, but, obviously, subdivided in their relative scales. In this way it was observed, that the indices having a significantly high corre-

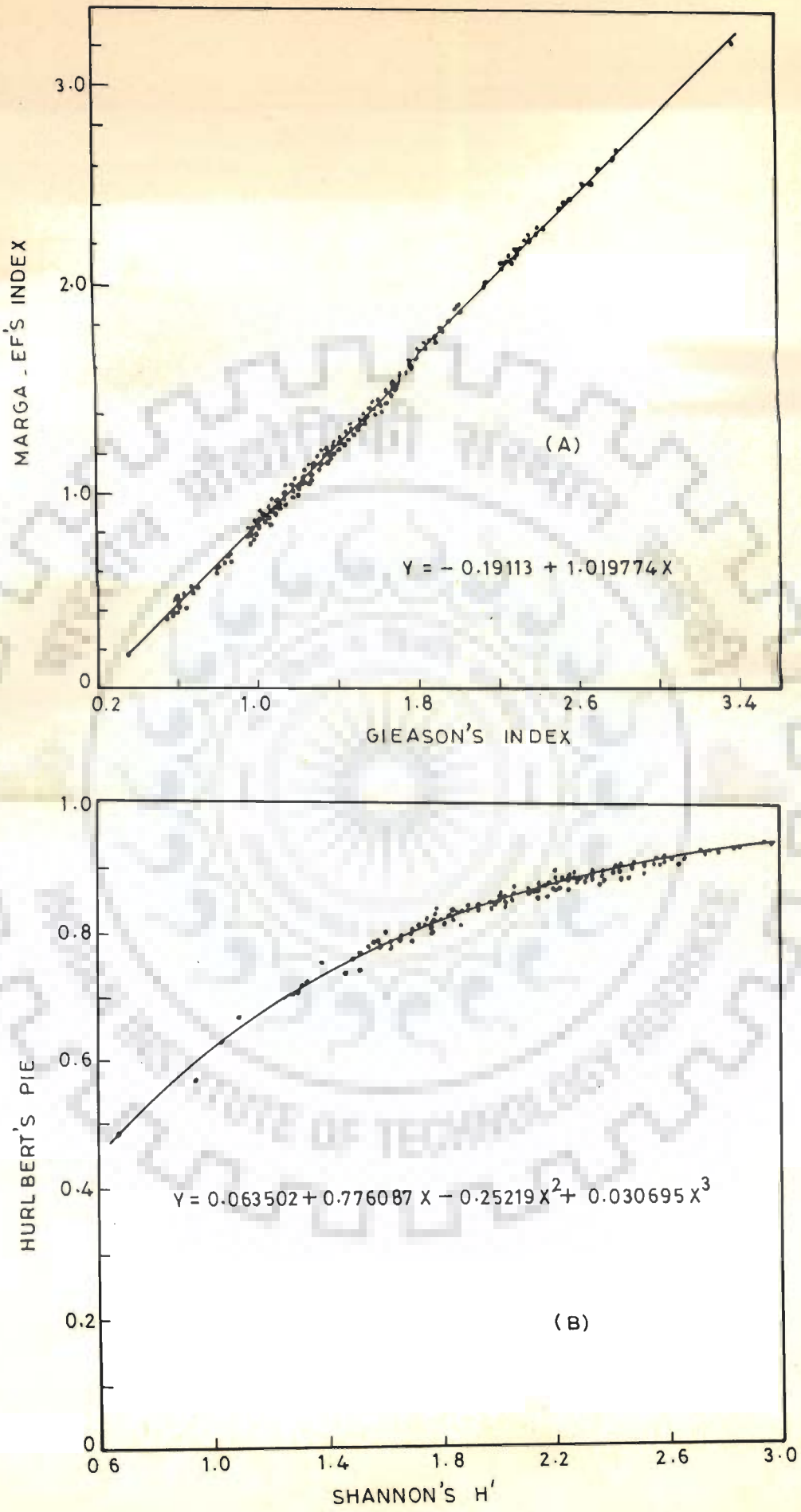


FIG. 5.2.9 (CONTD.)

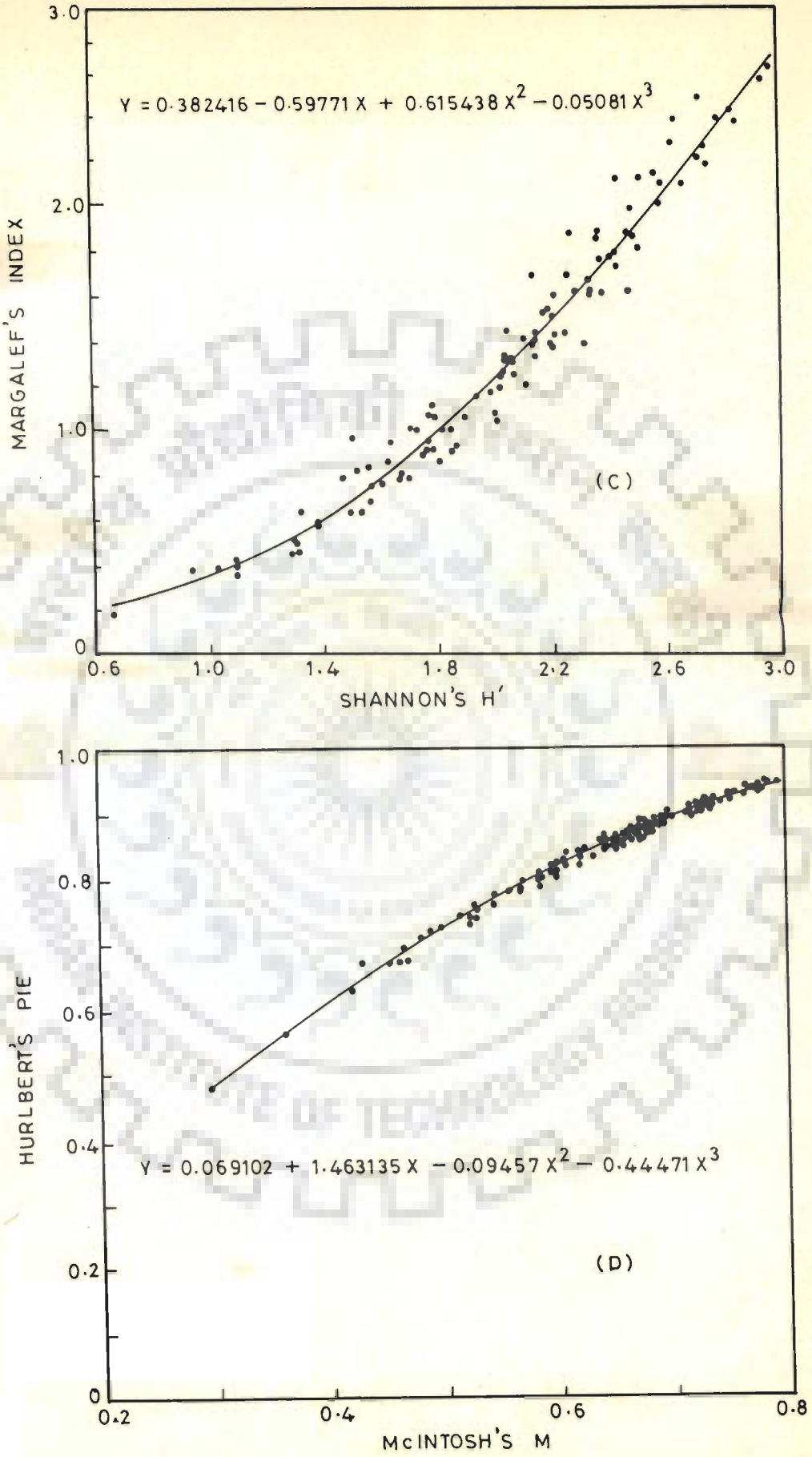


FIG. 5.2.9 – CORRELATION BETWEEN THE VALUES OF THE DIVERSITY INDICES H', PIE, M, MARGALEF'S AND GLEASON'S INDEX

lation between them (PIE-H, PIE-M, H-Margalef, H-Gleason's etc.) provided an acceptable fit, Gleason's and Margalef's index show a correlation of very high degree and produced an ideal regression line. Menhinick's index produced considerably low correlations with other diversity indices making the regression line completely unacceptable, hence not plotted here. An analogous situation was observed for the correlations between the evenness and other indices.

Between the scale of different indices which present the highest correlations, a tentative process of conversion is possible, utilizing as factors of correspondence, the values of regression lines considered as a linear set of the average points of the values of dispersion. Figure 5.2.9 provides the possible conversion of the values between H'-Margalef's index-Gleason's index, PIE-H' and PIE-M for the system. An indirect conversion of indices value is also possible (such as H to M via PIE) but the factor of error will also increase in such conversions. The values of PIE may generate the values for Simpson's D and Keefe's TU directly, hence were not included in this section of discussion.

5.2.2 Similarity

Diversity values do not reflect an idea of a particular species composition of a sample. Thus a change wherein one species is replaced by another as a result of environmental alteration, would not be detected by the measurement of diversity alone. The degree of specific changes between samples were measured with index of similarity or dissimilarity of community structure, which combine information both on species present and their relative abundance.

To ascertain that fifteen sampling stations situated all along the upper Ganga were comparable with respect to their phytoplanktonic community

structure, the phytoplankton community at each station was compared with the phytoplankton community at all stations. The mean values were calculated and the matrix obtained, was subjected to cluster analysis.

The dendrograms summarizing the result of percentage similarity appeared in Fig. 5.2.10. The fifteen stations were segregated into four tight clusters. The degree of homogenity between the stations of each cluster was more than 64%. The mountainous stations formed a single cluster. In this cluster highest similarity was observed between Rudraprayag and Srinagar (72%). But Nandprayag and Devprayag joined the cluster at relatively low similarity, which may be attributed to the difference made by tributaries in the community structures. The lowest similarity between Badrinath and rest of the stations of the cluster is fairly evident.

The four stations of foothill region formed a different cluster. Highest resemblence between phytoplankton community of two stations was observed between Hari ki Pauri u/s and d/s (87%). Kankhal showed a resemblance of 86% with these two stations. Despite significant stress due to bathing load at Hari ki Pauri zone, as also indicated by diversity, these stations have a high degree of homogenity, as it takes time for the flora and fauna to re-establish itself in the changed environment and the distance between these stations is small. Satyanarayana joined the rest of stations of this group with 70% similarity.

The remaining five stations formed two clusters. Balawali and Bijnor alone formed one cluster at 72% similarity, while Anupshahar, Narora and Garhmukteshwar joined each other with more than 70% community similarities. The four clusters were merged to form one cluster, within a narrow similarity range in a sequence.

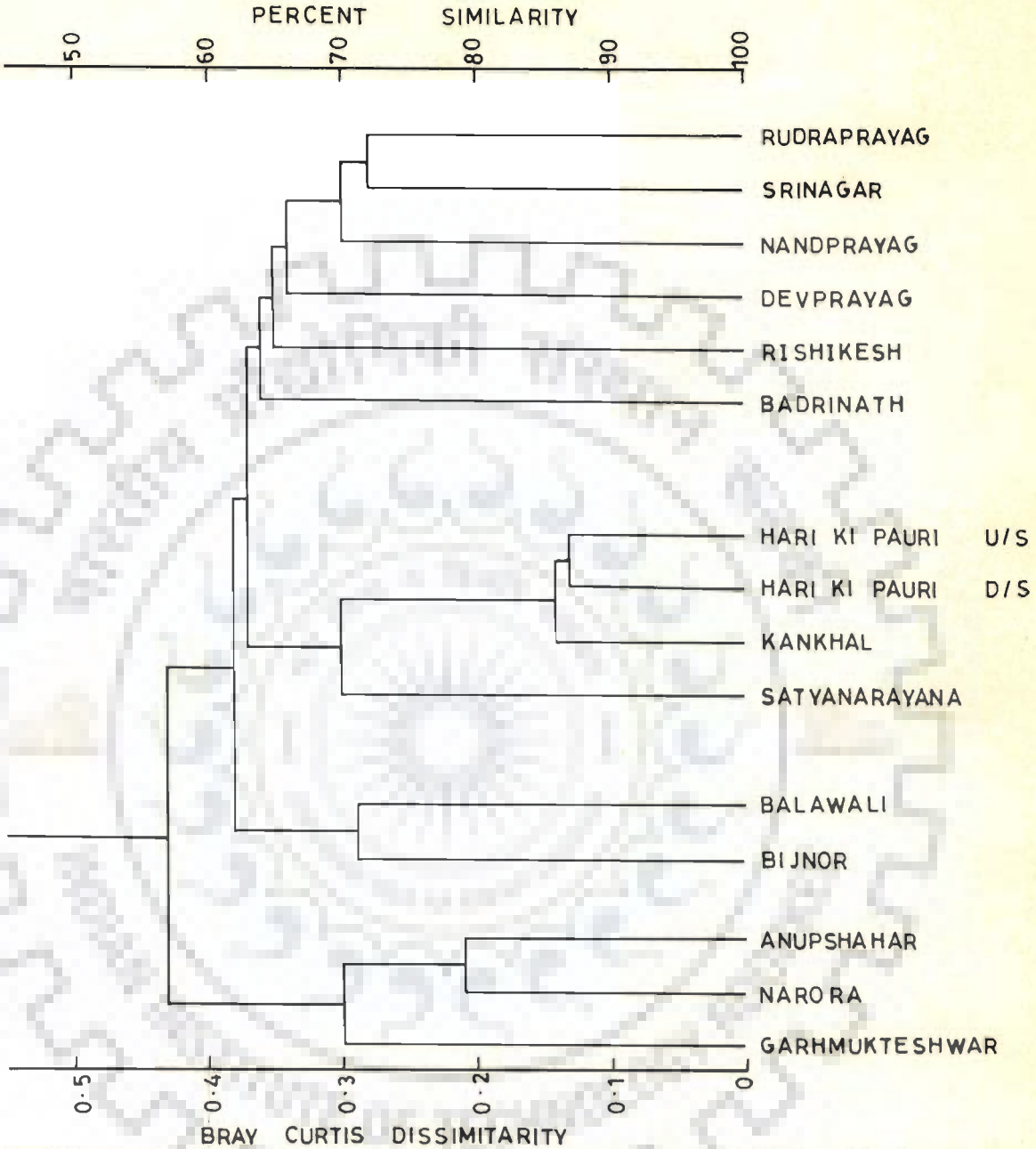


FIG. 5·2·10 – DENDROGRAM OF PERCENT SIMILARITY IN PHYTOPLANKTON COMPOSITION OF DIFFERENT STATIONS

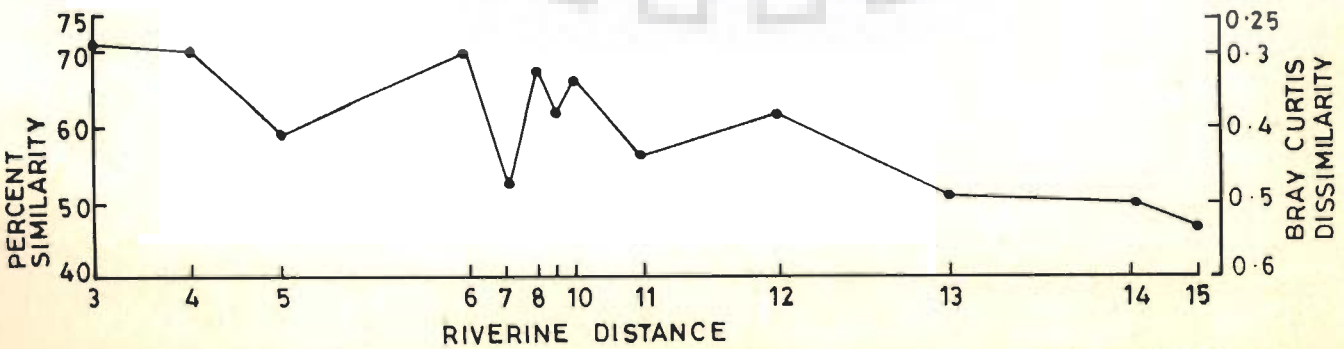


FIG. 5·2·11 – PERCENT SIMILARITY IN PHYTOPLANKTON COMPOSITION WITH REFERENCE TO NANDPRAYAG

Bray-Curtis dissimilarity produced the results complementary to percentage similarity on 100 times reduced scale. Thus both percentage similarity and Bray-Curtis dissimilarity could be summarized on opposite scales together (Fig. 5.2.10).

Pinkham and Pearson's index is claimed to have a different area of sensitivity in the community structure in comparison to percentage similarity. It measures the changes in rare species number where the percentage similarity shows a greater response to variation in dominant forms and relationship between dominant and semidominant forms.

As no incidence of clear dominance was observed in the study area and the taxa were highly even in distribution (measured by evenness), both percentage similarity and Pinkham-Pearson's index agreed with each other in the pattern of similarity. Although the similarity measured by Pinkham and Pearson's index was relatively low, the basic clusters were the same (Fig. 5.2.12). According to this index Anupshahar was much similar to Garh-mukteshwar than Narora and all the five stations of plains in two clusters joined to form one cluster (disagreement with PSC). The highest similarity registered by this index was 0.71 (71%) between Hari ki Pauri u/s and d/s.

Euclidean distance consider the abundance of each taxa, whereas the PSC consider the relative abundance (in per cent) of taxa. Because of this difference the Euclidean distance register a change with change in overall abundance, although the relative proportion of the taxa remain the same, but PSC registers similarity as long as relative abundance remains the same. The dissimilarity measured by Euclidean distance gave slightly different separation of clusters (Fig. 5.2.14), Nandpyarag and Rudraprayag were much similar to each other. One station from mountainous region (Srinagar) replaced

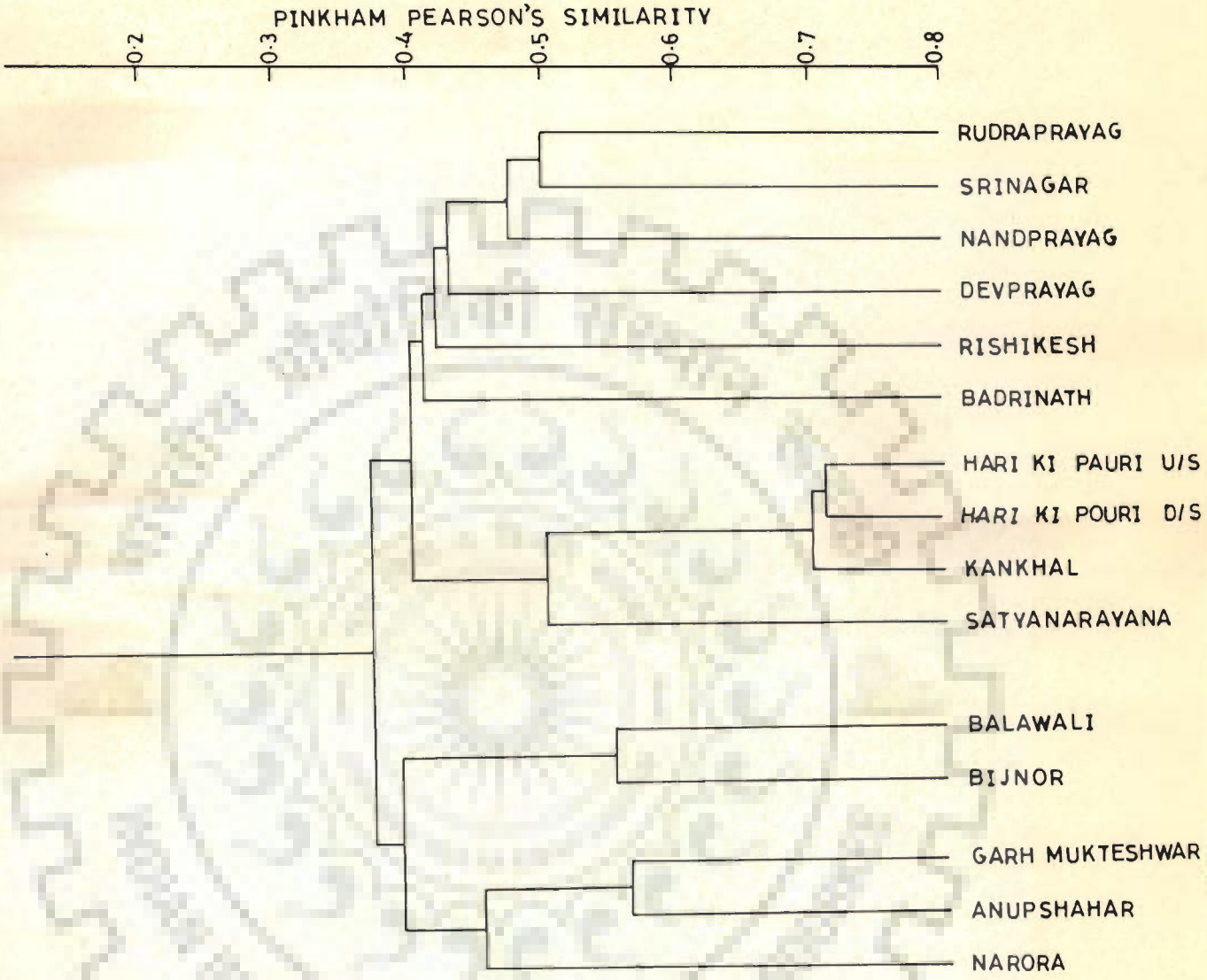


FIG. 5·2·12 – DENDROGRAM OF PINKHAM AND PEARSON'S SIMILARITY IN PHYTOPLANKTON COMPOSITION OF DIFFERENT STATIONS

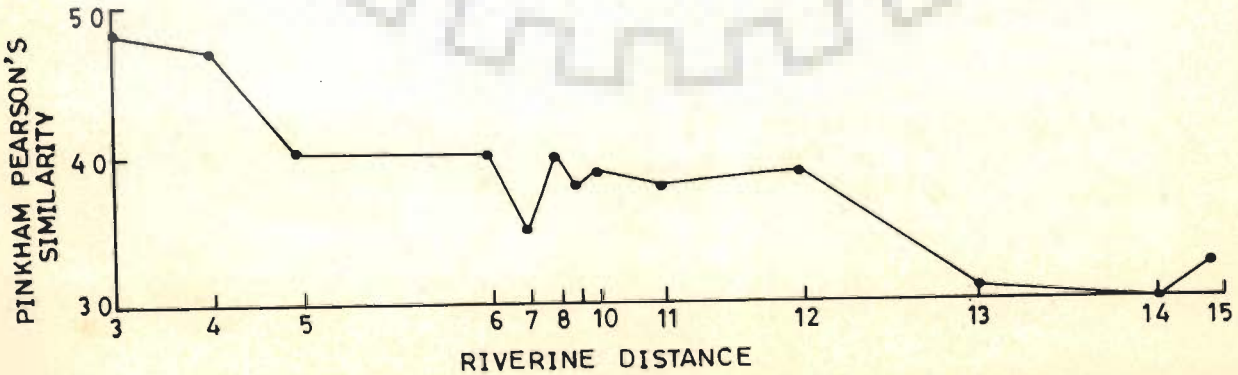


FIG. 5·2·13 – PINKHAM PEARSON'S SIMILARITY IN PHYTOPLANKTON COMPOSITION WITH REFERENCE TO NANDPRAYAG

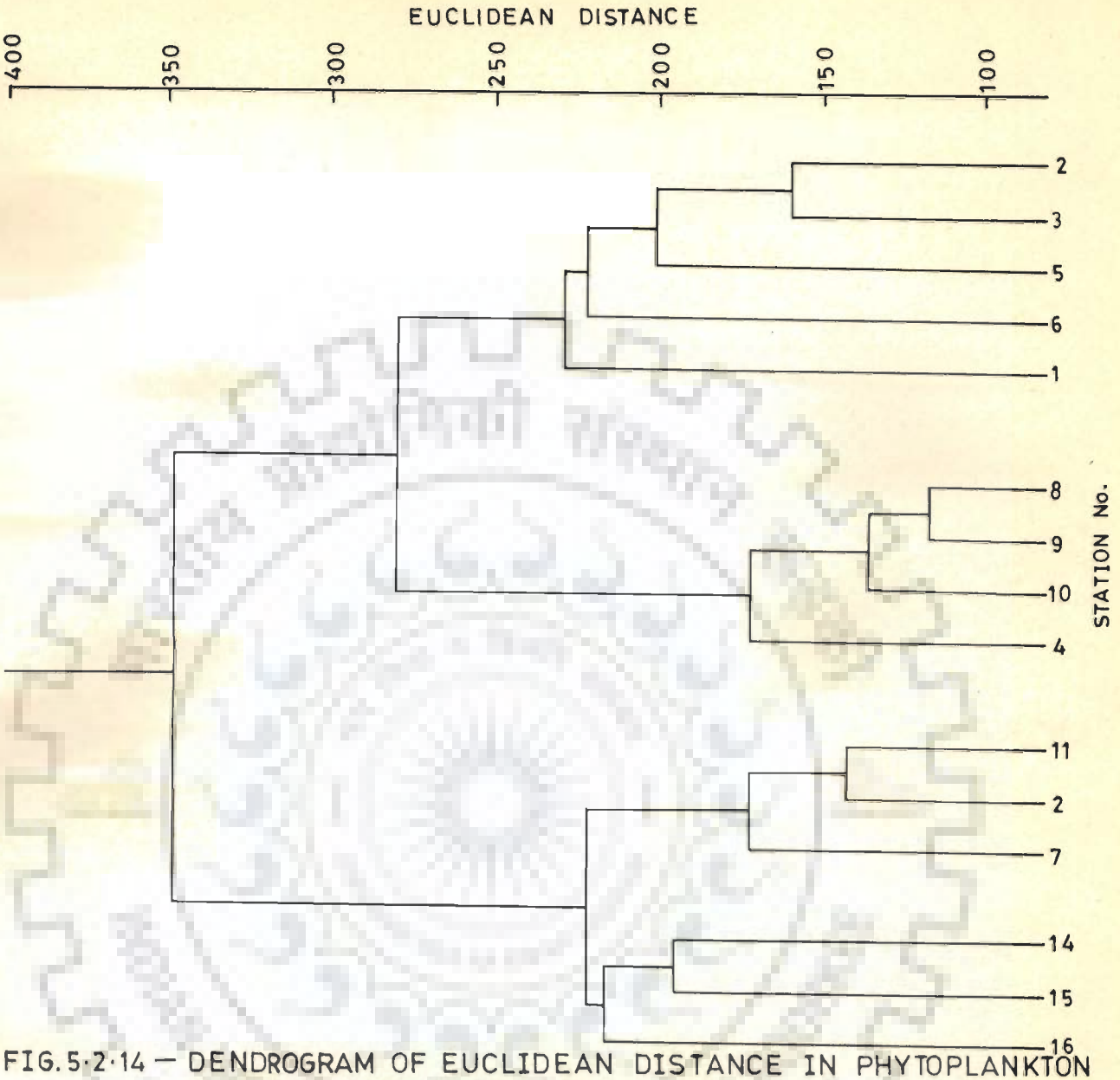


FIG. 5·2·14 — DENDROGRAM OF EUCLIDEAN DISTANCE IN PHYTOPLANKTON COMPOSITION OF DIFFERENT STATIONS

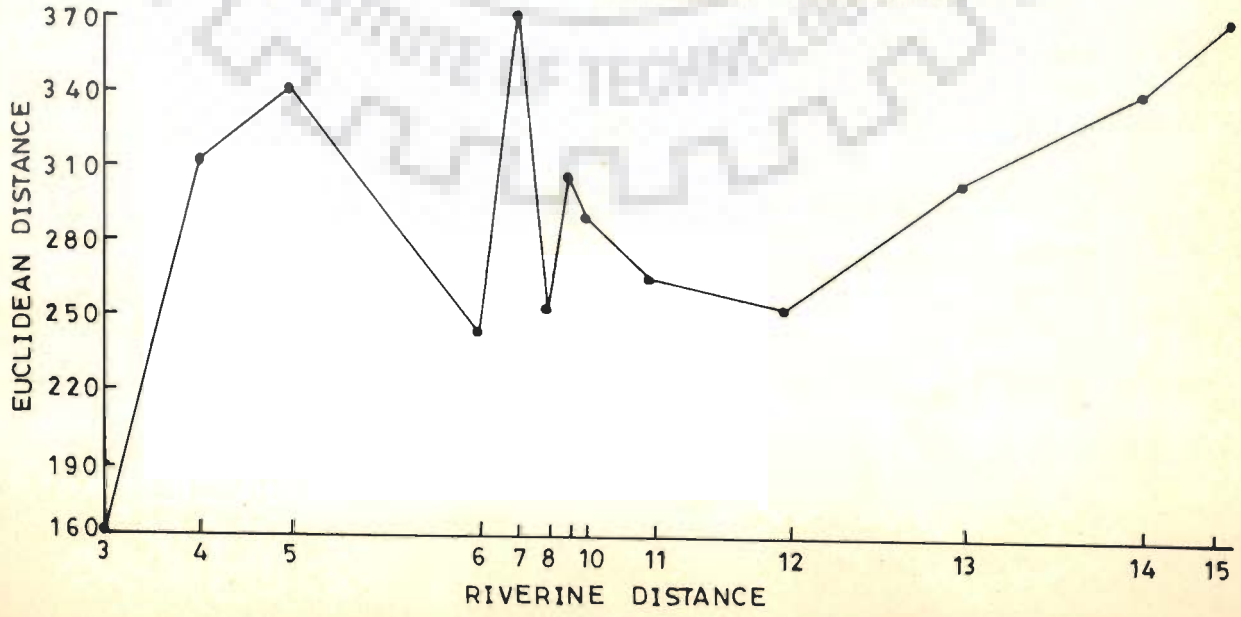


FIG. 5·2·15 - EUCLIDEAN DISTANCE IN PHYTOPLANKTON WITH REFERENCE TO NANDPRAYAG

the Satyanarayana in the second cluster of foothills. The latter joined Balawali and Bijnor and merged in the cluster of plains. The degree of dissimilarity between these clusters as measured by this index was significant.

As in pollution studies, severe effects tend to alter dominance relationship, and if the balance of taxa is nearly identical then the communities may be functionally the same. Thus PSC may judge the structural changes in the community better than Euclidean distance.

Another approach of the similarity or dissimilarity was to compare various sampling stations with a pristine water area such as Nandprayag. Similarity (PSC and Pinkham-Pearson's) with Nandprayag decreased gradually from Rudraprayag to Narora (Fig. 5.2.11 and 5.2.13). This decrease in similarity or increase in dissimilarity was an indication of the relative magnitude of impact of stress on the community. The Euclidean distance attained the maximum dissimilarity at Satyanarayana, which show an abrupt increase and then decrease in the dissimilarity (Fig. 5.2.15). Bijnor downstream the dissimilarity increased gradually to attain its maximum at Narora again. This also indicated that overall changes in the communities were in agreement with the changes in the community structure (PSC).

However, it was not possible to grade the community comparison indices, as they differ in responsiveness to various changes in the community structure. Euclidean distance measure the overall changes in the communities, whereas PSC may better pointout structural changes in the community. Pinkham-Pearson's index is sensitive to rare taxa changes. All the three indices together might reflect the actual community response.

5.3 Variability of Bacterial Indicators

The concentration of indicator bacteria in upper Ganga water was subjected to very wide variations, both temporally and spatially. These variations were induced by several variables like rate of discharge of bacteria, degree of dilution the sewage receives before reaching the sampling station and proportion of bacteria which die or multiply on way in relation to the time of transit.

The MPN values are stated as 'skew estimates' of 'true values'. Therefore, log MPNs, which are more symmetric estimates were referred to be applied in any kind of computation (Bonde 1963; Gameson 1980). Thus the log MPNs were regarded as approximately normally distributed and for groups of these a standard deviation was computed. The analysis of variance and t-statistics were performed between groups of such log-transformed values.

5.3.1 Coliform

The MPN coliform data for the entire study period at each station was summarised in Table 5.3.1, which includes mean, maximum and minimum values encountered, standard deviation, coefficient of variation & variance. Also shown are the F and t statistics. The mean values showed a gradual increase from Badrinath to Narora due to increasing activities. At few stations the mean values show a remarkable increase over the upstream and downstream stations i.e. Srinagar, Satyanarayana. The coefficient of variation at 15 stations provide a measure of variations of coliform input relative to the mean over the entire study duration. A comparatively high variability at Badrinath is expected in that the bacterial input varies greatly in accordance with the floating population at this station. The low number of observations at Badrinath also effected the standard deviation comparatively.

Table 5.3.1 Statistical Evaluation of MPN Coliform Values at Different Sampling Stations in Upper Ganga

Stations	n	x min	x max	$\bar{x}$	SD	COV	S^2	F-statistic		t-statistic	
								With Nandp.	With up-stream Station	With Nandp.	With up-stream Station
Badrinath	03	1.954	2.875	2.403	0.461	0.192	0.212	1.493	-	1.496	-
Nandprayag	13	2.041	3.322	2.806	0.377	0.134	0.142	-	1.493	-	1.496
Rudraprayag	12	2.041	3.663	2.831	0.493	0.174	0.243	1.711	1.711	0.142	0.142
Srinagar	13	3.079	4.041	3.598	0.320	0.089	0.102	1.392	2.382	5.781*	4.613*
Devprayag	12	2.176	3.663	3.057	0.417	0.136	0.174	1.255	1.706	1.577	3.638*
Rishikesh	14	2.591	4.041	3.215	0.382	0.119	0.146	1.028	1.192	2.798*	1.004
Satyanarayana	13	3.041	4.380	3.881	0.427	0.110	0.182	1.282	1.247	6.809*	4.270*
Hari ki Pauri U/S	12	2.969	4.041	3.495	0.356	0.102	0.127	1.118	1.433	4.693*	2.453*
Hari ki Pauri D/S	13	3.041	4.380	3.600	0.380	0.106	0.144	1.014	1.134	5.353*	0.713
Kankhal	13	3.176	4.041	3.748	0.321	0.086	0.103	1.379	1.398	6.862*	1.074
Balawali	13	3.079	4.041	3.606	0.437	0.121	0.191	1.345	1.854	4.999*	0.944
Bijnor	13	2.968	4.041	3.430	0.359	0.105	0.129	1.101	1.481	4.322*	1.122
Garhmukteshwar	14	3.322	4.380	3.938	0.288	0.073	0.083	1.711	1.554	0.762*	4.051*
Anupshahar	15	3.322	4.380	3.979	0.337	0.085	0.113	1.257	1.362	6.024*	0.352
Narora	14	3.380	4.380	4.000	0.263	0.066	0.069	2.058	1.638	9.544*	0.187

* values indicate significant difference between the stations considered at 0.05 level.

To confirm the equality of variance the F - statistics was performed between the values of two adjacent stations. In a second set Nandprayag was selected as comparatively less affected station with low mean and a reasonable COV and all the stations were compared with it for difference in variance. In no case the variance was found to differ significantly at 0.05 significance level. A common estimate of variance was then computed for insignificantly different variance and the equality of means was tested by t-test between the stations similar to F-test.

The t-statistics show that Nandprayag differ significantly from rest of the stations at 0.05 significance level, except three stations - Badrinath, Rudraprayag and Devprayag. Rishikesh was able to qualify at 0.001 significance level. The t-values computed between the adjacent stations show that input was significant between Rudraprayag-Srinagar, Rishikesh-Satyanarayana and Bijnor-Garhmukteshwar as the mean of downstream station was significantly higher from upstream station at 0.05 significance level. The dilution between Srinagar and Devprayag after Bhagirthi confluence and between Satyanarayana and Hari ki Pauri upstream (after the confluence of Chilla return water) was also found significant, which lowered the mean values significantly at 0.05 significance level in these two pairs of stations.

The trend of temporal variation differs from region to region. The minimum values in upper reaches from Nandprayag to Rishikesh were observed during winter months, whereas the highest values were recorded during summers and/or monsoon months. This trend could be attributed to follow a clear drift of floating population due to tourism. The trend was entirely different in the remaining stretch (except Kankhal), where the high values were found during winter month or lean flow period. The second highest value was recorded on the onset of rains, causing flushing of waste deposits or heaps in the catch-

ment area. The lowest values were recorded during monsoon and post-monsoon periods.

At Kankhal the maximum value was encountered frequently because of nearly constant flow throughout the year. At Hari ki Pauri downstream the second highest value were recorded during monsoon due tovigorous bathing activity during this period.

Thus pattern of temporal variation of coliform show a difference with heterotrophic bacteria in lower stretch. It shows a marginal dilution in high flow season, thus indicating a faecal input from the catchment area. The highest value 24000/100 ml was recorded at four stations i.e. Satyanarayana and last three stations during lean flow season whereas a lowest 90/100 ml was recorded at Badrinath once only. A second lowest 110/100 ml recorded at Nandprayag and Rudraprayag during winters was also during lean flow season. Only 20 samples out of 80 taken from Badrinath to Devprayag in the entire study period were < 500 MPN coliform/100 ml.

The percentile values calculated on the combined data of Nandprayag and Rudraprayag show that only 40% of the samples were able to quality the standard being less than 500 coliforms/100 ml. The 80 and 90 percentile values were found 1500 and 2400 respectively. It was evident, that no station was able to meet the recommendations of Indian water quality objectives for organised outdoor bathing.

Findings of this study seems to demand a fresh look at the criteria for the fixation of bacterial water quality standards for outdoor bathing. Similar views have also been expressed by Waite (1984), and Foster et.al. (1971), who felt that use of coliform standard may cause an undue restriction on recreational use and that total coliform standard are arbitrary and have no real epidemeological basis to claim their validity. In the absence of clear

epidemeological basis for setting bacteriological criteria for bathing waters, Wakefield in 1975 suggested to view bacteriological standards as determinants of aesthetic qualities rather than as public health requirements. Koblitz (1971) compared concentrations of coliform bacteria with visual observations on the aesthetic conditions and apparent cleanliness of the beaches of Rio de Janeiro and suggested that 10,000 coliform bacteria per 100 ml represented a reasonable level for the standard. Ludwig (1975) thought that such a standard might be suitable for developing nations with limited financial resources.

The normal habitat of Aerobacter aerogenes has also been suggested other than faecal matter. Their multiplication outside the gut of warm blooded animals decrease their significance as indicator bacteria (Mathur & Ramanathan 1966). As such then for a better indication of faecal contamination either faecal coliform and/or faecal streptococcus seem to be more appropriate choice at least for the reason of specificity of origin.

5.3.2 Faecal coliform

The spatial variation of faecal coliform (mean values) with standard deviation and coefficient of variation were presented in Fig. 5.3.1. The pattern was found in agreement with coliforms, giving peaks at Srinagar, Satyanarayana and Hari ki Pauri d/s. The general trend was in an increasing order with riverine distance. The greater COV were found for Badrinath, Devprayag and Rishikesh because the means were so low that large percentage of variations about them are inevitable. The counts were occasionally observed at these stations. The only sample showing faecal coliform count at Bardinath was taken on the onset of rain, which caused introduction of such matter into stream by the surface runoff washing the banks into the stream. The faecal coliform was not found in measurable range at Nandprayag and Rudraprayag.

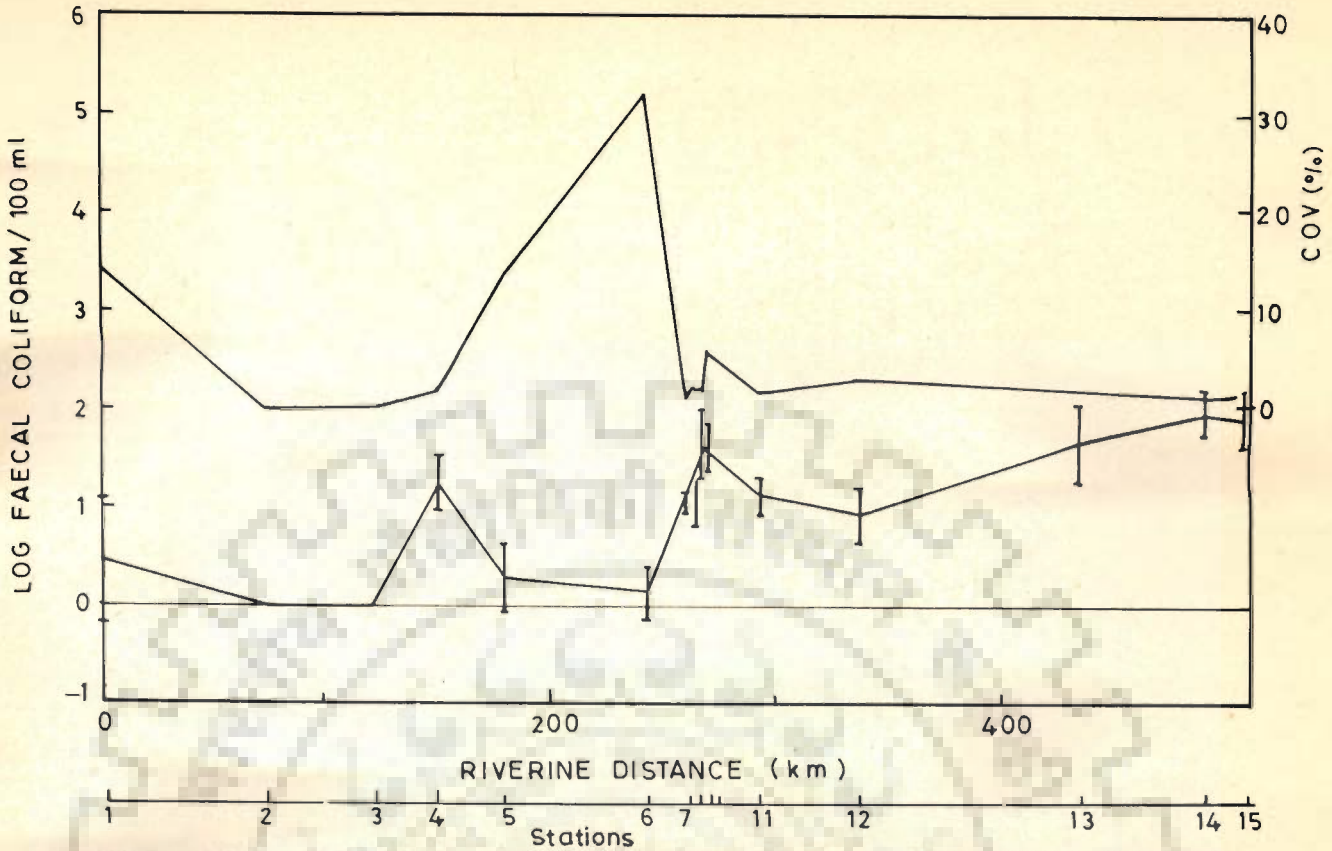


FIG. 5.3.1 - SPATIAL VARIATION OF FAECAL COLIFORM BACTERIA

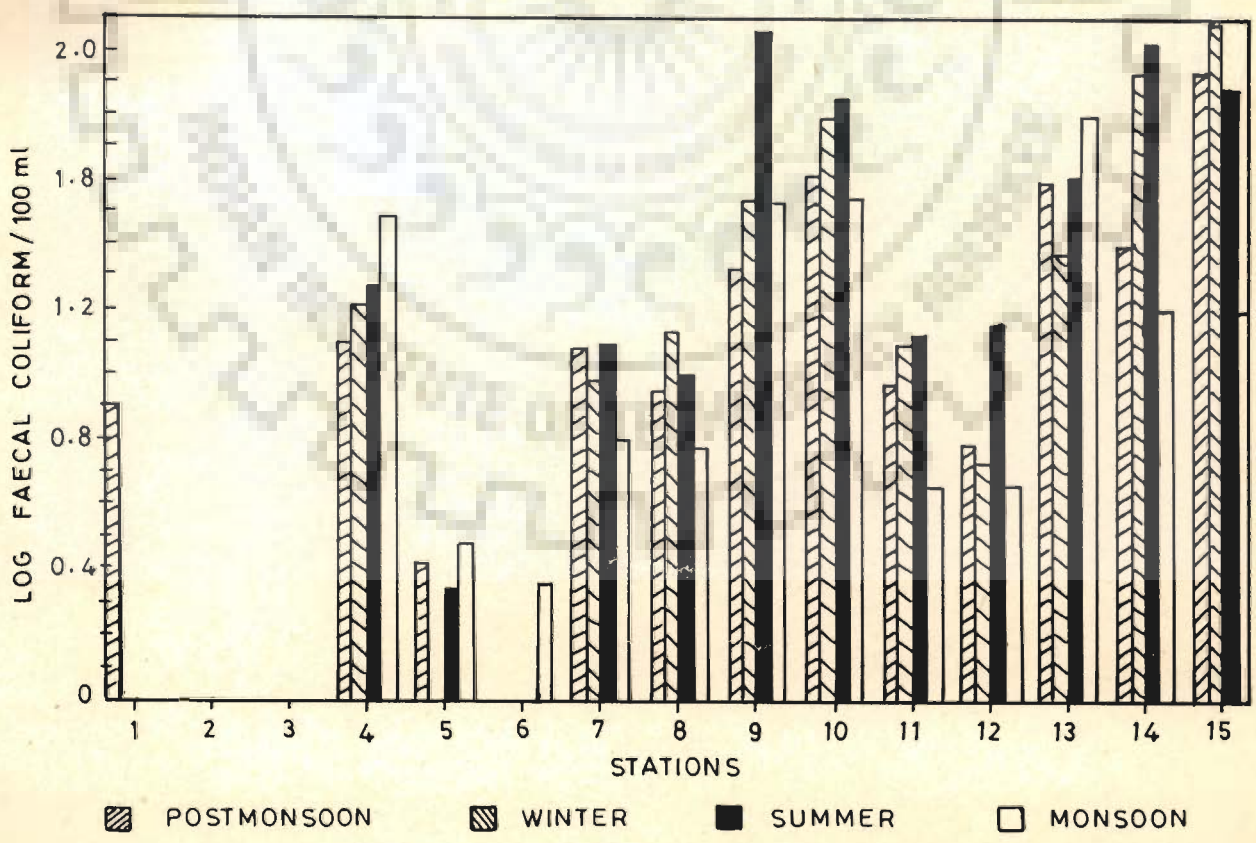


FIG. 5.3.2 - TEMPORAL VARIATION OF FAECAL COLIFORM AT DIFFERENT STATIONS

For the computation of log values, 1 faecal coliform $(100\ ml)^{-1}$ was used. Comparatively low COVs and high mean values were observed in the down-stream of Balawali indicating a significant increase in the faecal input.

The temporal variation of faecal coliform was presented in Fig. 5.3.2. The trend was almost similar to coliforms in hills but in plains the higher values were encountered during summers due to significant activities on the river banks.

Although overall low counts were observed, dilution during monsoon indicated the faecal discharge into the river in the plains, despite of the significant activities on the bank during monsoon season. The individual counts observed were always below 200/100 ml except at one occasion, it was observed 220/100 ml at Narora. Thus the values were found well within the limits suggested by Geldreich for recreational water (200/100 ml) throughout the stretch.

5.3.3 Faecal streptococcus

The faecal streptococcus was suggested of merit in water quality criteria as it occurs infrequently in the matter other than of faecal origin and generally do not multiply in water. In Table 5.3.2 the data of faecal streptococcus was summarized. Badrinath again encountered a high COV. Lowest range and mean value were observed for Rudraprayag. Hence the variance and mean for rest of the stations were compared considering Rudraprayag as control. The variance of all the stations except last three, were not found different from Rudraprayag at 0.05 significance level. The variance of the last three stations were not significantly different from that of Hari ki Pauri and Kankhal. The mean of the estimates at each station were also tested at 0.05 significance level. The mean value of Rudraprayag was not different from that of Rishikesh

Table 5.3.2 Statistical Evaluation of MPN Faecal Streptococcus Values at Different Sampling Stations in Upper Ganga

STATIONS	*n*	x min	x max	$\bar{x}$	SD	COV	S^2	F-statistic		t-statistic	
								With Rudrap.	With up-stream Station	With Rudrap.	With upstream Station
Badrinath	02	0.477	0.954	0.716	0.337	0.471	0.114	4.222	-	0.115	-
Nandprayag	07	0.477	0.845	0.635	0.197	0.310	0.037	1.370	3.081	0.178	0.368
Rudraprayag	07	0.477	0.845	0.618	0.165	0.267	0.027	-	1.370	-	0.178
Srinagar	07	0.845	1.380	1.046	0.214	0.205	0.046	1.704	1.704	4.191*	4.191*
Devprayag	07	0.477	0.954	0.771	0.207	0.269	0.043	1.593	1.070	1.417	2.439*
Rishikesh	09	0.477	0.845	0.763	0.162	0.212	0.026	1.038	1.654	1.768	0.086
Satyanarayana	08	0.954	1.591	1.309	0.187	0.143	0.035	1.296	1.346	7.583*	6.434*
Hari ki Pauri U/S	08	0.602	1.362	0.859	0.261	0.304	0.068	2.519	1.943	2.137	3.966*
Hari ki Pauri D/S	08	0.845	1.634	1.177	0.260	0.221	0.068	2.519	1.000	4.956*	2.439*
Kankhal	08	0.845	1.634	1.099	0.241	0.219	0.058	2.148	1.172	4.508*	0.622
Balawali	08	0.954	1.634	1.287	0.221	0.172	0.049	1.815	1.184	6.631*	1.626
Bijnor	08	0.845	1.362	1.210	0.175	0.145	0.031	1.148	1.581	6.717*	0.770
Garhmukteshwar	09	0.845	2.176	1.405	0.417	0.297	0.174	6.444*	5.613*	5.168*	1.254
Anupshahar	09	1.041	2.322	1.541	0.421	0.273	0.177	6.556*	1.017	6.018*	1.461
Narora	09	1.176	2.322	1.451	0.455	0.314	0.207	7.667*	1.170	5.083*	0.924

* values indicate significant difference between the stations considered at 0.05 level.

and Hari ki Pauri upstream which were encountered significantly different for total coliforms. The increase in mean values at Srinagar and Satyanarayana and dilution at downstream station was observed significant, similar to coliform. The addition of bacterial load in Hari ki Pauri zone was also found significant in this case, whereas in the downstream of Hari ki Pauri the values increased gradually. The spatial as well as temporal variations were observed more or less similar to faecal coliform bacteria. A lowest of 3 in upper reaches and highest of 210/100 ml faecal streptococcus at Narora were observed as two extremes for the entire stretch.

Most of the stations (except last three) were able to meet the limit of 100 faecal streptococcus per 100 ml which was felt by Geldreich (1970) too diffifult to establish. Geldreich has also reported the drawbacks associated with the use of faecal streptococcus due to the ubiquitious presence of S. faecalis var. liquifaciens. It has also been recommended that the use of FC and FS conjunctively can provide a substantially improved picture of the pollution of the water under examination (Dutka 1973; Faechem 1974, 1975).

5.3.4 FC : FS ratio

One of the principal advantages of the conjunctive use of FC and FS as pollution indicator is that it enables the FC:FS ratio to be calculated and this ratio has been proposed as a means of estimating whether the pollution originated from a human or nonhuman source (Geldreich 1966, 1970; Geldreich and Kenner 1969; Geldreich et.al. 1968). In Fig. 5.3.3 faecal coliform concentrations were plotted against the faecal streptococcus concentrations for each sample taken from river Ganga. Out of 114 samples, 24 from mountainous stretch produced the FC count below detective range, hence are not plotted in the figure. Of the total samples, 11 samples had FC:FS ratio greater than

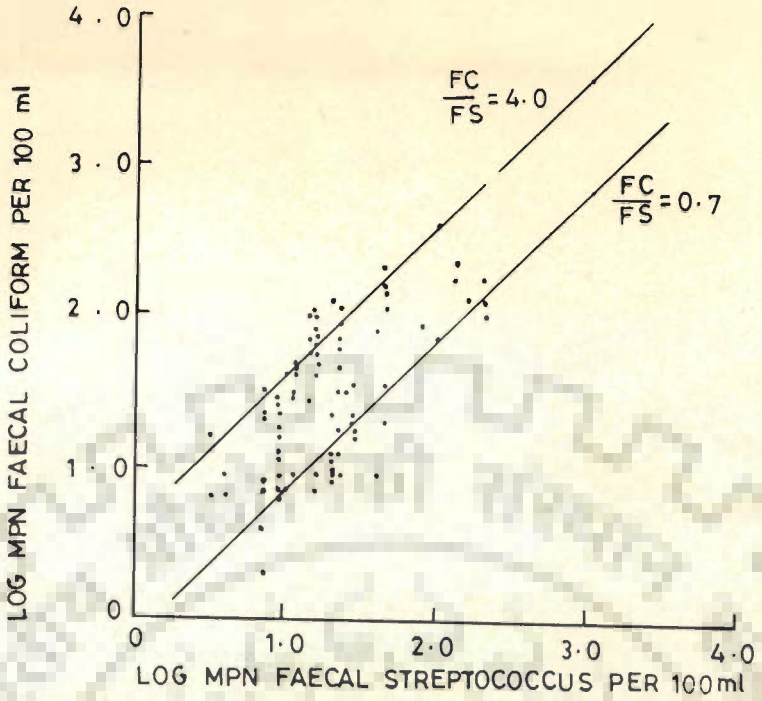


FIG. 5·3·3 – FAECAL COLIFORM CONCENTRATION COMPARED TO FAECAL STREPTOCOCCI CONCENTRATION IN UPPER GANGA

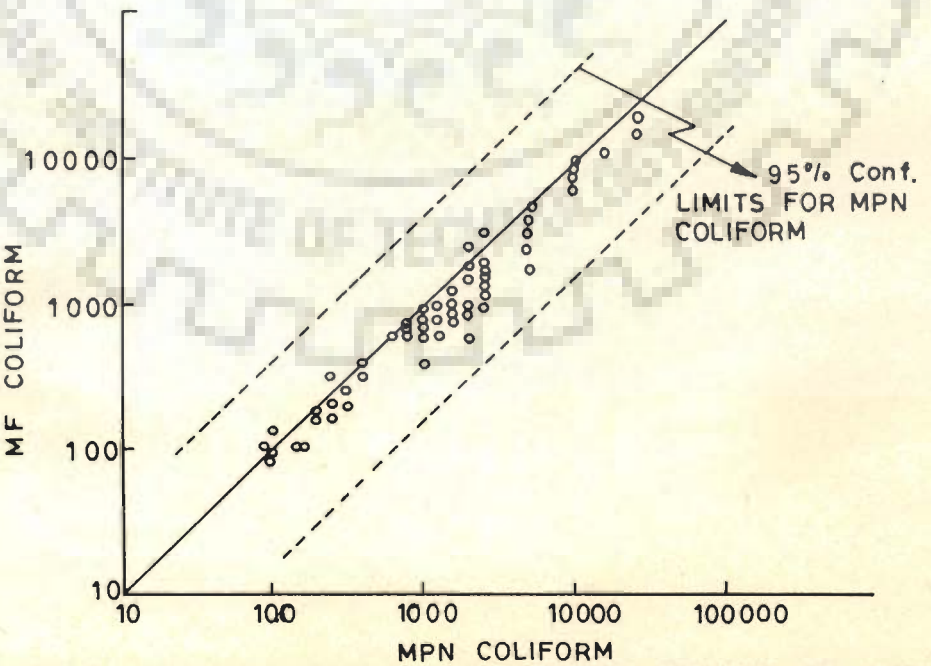


FIG. 5·3·4 – COMPARISON OF COLIFORM COUNTS OF GANGAS RIVER WATER OBTAINED WITH MPN & MF TECHNIQUE

4.0, characteristic of human source pollution. 19 were less than 0.70, the limit suggested by Geldreich and Kenner (1969) as pollution by animal waste. However, many of the samples (60 samples) exhibited ratios between these extremes, indicating a mixture of human and animal waste.

No station was found to have the source of pollution from human or animal origin alone on the above ground. The ratio more than 4 was observed occasionally at Srinagar, Hari ki Pauri d/s, Anupshahar and Narora. The ratio less than 0.70 was observed mostly in mountainous stretch except Srinagar, and at Balawali and Bijnor in few months. Thus a mixed nature of pollution at most of the stations was observed.

The major weakness of the approach is that unless the FC and FS die-away at identical rates, the ratio will gradually change and so will no longer reflect the original ratio in the fresh faecal matter. Geldreich and Kenner (1969) therefore, recommended that the ratio was only valid during the first 24 hrs immediately following the discharge of bacteria into the stream. However, it is not always possible to judge the age of pollution and, even if one can, one cannot always estimate the time between excretion and discharge into the river. This problem of differential die-away rates of FC and FS appeared therefore to make the FC : FS ratio an unreliable gauge of the source of pollution.

5.3.5 Comparison of MPN and MF results

The recovery efficiency of a particular bacteriological technique is the density of organisms recorded as a percentage of the actual density of these organisms. Unfortunately there is no way to quantify the actual density. Even in the absence of actual density, one gets satisfaction if several techniques of enumeration give essentially the same value. The coliform count obtained by

Multiple tube and MF techniques for upper Ganga river water were compared to provide much needed additional information.

139 samples of the 145 analysed were observed with acceptable counts on the membrane filter . The remaining 4% yielded less than 10 colonies on membrane, and were unacceptable statistically.

A scattergram of the density estimated by Multiple tube technique (X-axis) and MF technique (Y-axis) with a 45^{o} line through the origin provided an eyeball guidance of the comparative recovery efficiency of the two techniques (Fig. 5.3.4). It is apparent that Multiple tube technique more frequently gave a higher count than MF technique. The linear correlation between the estimates of the two techniques was found to be + 0.982. It was also found that all the MF counts were well within the 95% confidence intervals for MPN counts.

For statistical analysis the counts were transformed to logarithms in order to normalize the distribution of results. The pooled within sample variance for each set of replicate were computed from these transformed values. The equality of variance estimated by F-test at 0.05 significance level showed that within sample variance of each technique was not significantly different. The within sample standard deviation of MPN (0.653) and MF (0.657) counts were also similar. The calculated t-value (student's t-test) for these replicates was 1.560 and the critical t-value at 0.05 significance level was 1.965. Thus the technique 'means' were also not significantly different. It is therefore concluded that the estimates by the two techniques are homogenous and may very well be regarded as the results of the same sample.

5.4 Evaluation of Enteric Viruses

During the entrie study period the water from only five sampling station, showing enough incidences of faecal input into the system were tested for the presence of enteric viruses, in April, September and December. It was important to realize that there was only one sample to yield positive result, when inoculated in 10 day old embryonated hen's egg by the amniotic route as a routine practice. Thus the 14 samples concentrated from 25 lit. of river water showed the absence of enteric viruses. Hence it can be stated only that if the entric viruses were present at these occassion they probably occured at levels below as low as one virus particle per 25 lit. of water. The only positive sample resulted in the isolation of an Influenza virus type A strain, which was neutralized by the antisera raised in fowls against influenza/A/Pune/78(H1N1) similar to A/USSR/90177 (Prasad, Vijayan & Mathur 1985). This only strain was encountered at Kankhal in the month of December (lean flow).

In general isolation of influenza virus type A from river water has been rarely reported. Reports are available regarding the isolation from birds frequenting lakes and other water bodies (Hinslaw et.al. 1985).

The setting of virus standard for different kinds of water has been only tentatively attempted and the levels suggested are arbitrary and not based on considerations of risk of infection or disease. It is generally agreed that potable waters should contain no virus, but at present there is no agreement as to how this could be defined in terms of sample volumes and the sensitivity and accuracy of the method. WHO drinking water standards suggested less than one infectious virus unit per litre on the basis of examination of 10 litre samples.

5.5 Impact of Community Bathing

The town of Haridwar is one of the four venues which host the major religious bathing congregations every sixth year called Purna Kumbh. The unique event was observed on 13th and 14th April 1986, and considred to be the largest of all the previous ones held. A reported 6.5 million people gathered in this town to take bath in this river. Amidst the height of emotions, people often failed to understand the plight and agony of the river water, a small portion of which was made to accept a large load of several kinds of impurities resulting in the severe deterioration of its quality. Considering it a rare chance to assess the impact of community bathing on the state of the system, a comprehensive diurnal monitoring was undertaken. Crux of the bathing activity was localised at and in the immediate vicinity of Hari ki Pauri. Both sampling station, one representing Hari ki Pauri upstream at Bhimgoda and another 3000 m downstream were monitored (Fig. 2.1).

Samples were collected from 6th hrs of April 13 to 15th hour of April 14, at a regular interval of three hours. Samples were transported from the respective sites to the field laboratory for subsequent analysis. Time gap between the two sampling stations was fixed taking mean velocity and river distance between the two stations into account.

The parametric difference, with an increase or decrease in the values in the downstream were calculated and are given in Table 5.5.1. A decrease in the difference between upstream and downstream values upto about noon of April 13th with relatively high conductivity and coliform value occuring even upstream was noticed. Thereafter, the difference gained prominence showing a growing deficit in DO alongwith the increase in coliform, pH, ORP and conductivity upto about 6.00 pm in the evening afterwhich these differences

Table 5.5.1 Paired Difference for Parameters Between Up and Downstream Stations During Kumbh

Date	Time	Parameters							
		Water temp. ^{o}c	pH	Conduct.	ORP	DO	COD	Coliform	Faecal Coliform
13 April 1986	6.00	-0.3	+0.24	+3.06	+17.0	-0.22	0.0	+ 19400	+ 1320
	9.00	0.0	-0.03	-7.14	-10.0	-0.14	+1.6	+ 19400	-
	12.00	-0.1	+0.15	-10.88	- 5.67	-0.02	+3.0	+ 13000	+ 4248
	18.00	-0.5	+0.19	+ 1.02	+18.0	-0.14	+0.8	+ 99000	-
	24.00	+0.8	+0.11	+ 2.04	+10.0	0.0	-9.2	+108500	+10560
14 April 1986	3.00	-0.6	+0.05	+ 4.08	+ 4.0	-0.18	-6.8	+107900	-
	6.00	-1.1	+0.03	+ 3.06	+ 2.0	-0.32	+8.4	+107900	+23900
	9.00	+0.2	+0.15	+ 4.08	+ 9.0	-0.30	+2.8	+105400	-
	12.00	-0.3	+0.12	+11.67	+27.0	-0.09	-4.4	+105400	+16692
	15.00	+0.5	+0.19	+14.28	+ 9.0	-0.50	+0.8	+ 14070	-

+ = increase in values in downstream

- = decrease in values in downstream.

again faced a decline except for coliforms. On 14th April high DO deficits occured in the early hours of day and towards the evening. This trend was supported by high coliform values in the downstream.

Coliform values of Kumbh presented in Fig. 5.5.1 indicated a significant impact on the system. The high values of total coliform at upstream during 12th to 18th hrs of April 13th and 9th to 12th hrs of April 14th were due to unorganised bathing at Bhimgoda upstream possibly during day hours only. The coliform values at downstream were constantly very high. To get more insight in the difference of coliform populations between upstream and downstream locations, the data on the distribution of coliforms corresponding to various sources viz. faecal, intermediate and soil as obtained after conducting IMViC tests were plotted in Fig. 5.5.2. The t-statistics along with the associated statement of significance were presented in Table 5.5.2.

The comparison of upstream and downstream values of pH, ORP, DO and total coliform indicated a difference quite significant at 5% level showing bathing to have a prominent impact on these parameters. The difference in case of temperature, conductivity and COD did not appear to be significant. The significant increase in the downstream values of total coliforms was shown to include a significant increase in coliforms of faecal, intermediate as well as of soil origin.

Faecal streptococcus also exhibited a prominent increase downstream. The increase in the number of faecal coliforms was far greater in number, compared to that of faecal streptococcus and obviously confirmed the case of faecal pollution of human origin. Surprisingly 10 samples at three hourly interval composited to make four samples of 20 lit. each for virus estimation, showed negative results.

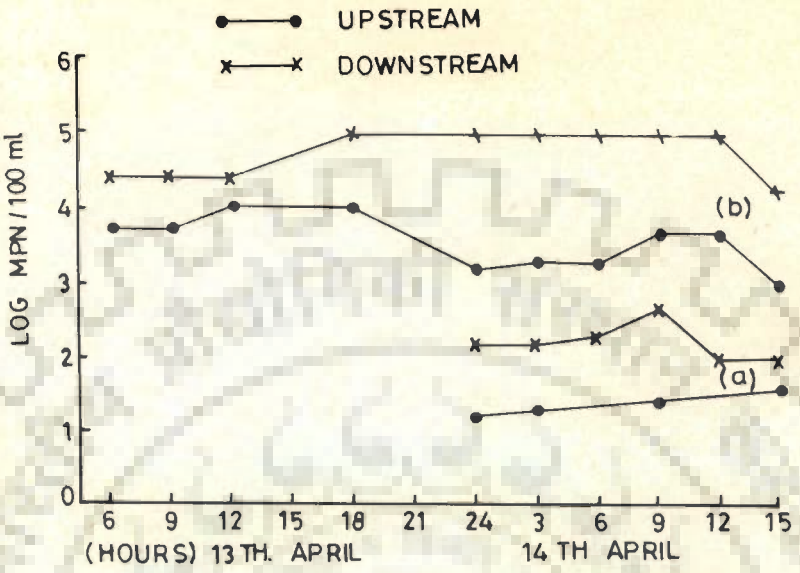


FIG. 5·5·1 — CONCENTRATION OF COLIFORM (b) AND FAECAL STREPTOCOCCUS (a) BACTERIA DURING KUMBH

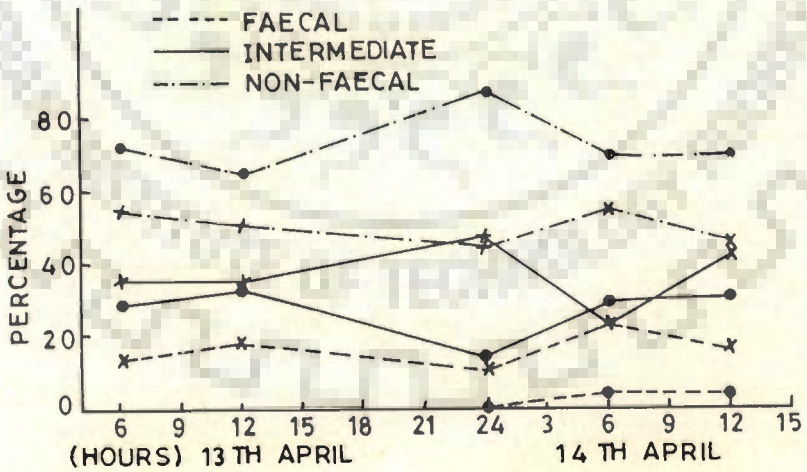


FIG. 5·5·2— PERCENT COMPOSITION OF COLIFORM BACTERIA DURING KUMBH

Table 5.5.2 Students-t Statistic and Corresponding Statement of Significance for Various Parameters During Kumbh

Parameter	n	t-statistic	Statement of significance (at 0.05 level)	
Water temperature	10	0.802	decrease	insignificant
pH	10	4.572	increase	significant
ORP	10	2.286	increase	significant
Conductivity	10	1.069	increase	insignificant
DO	10	4.188	decrease	significant
COD	10	0.248	decrease	insignificant
Total coliform	10	4.792	increase	significant
Faecal coliform*	5	3.00	increase	significant
Coliform of intermediate origin*	5	2.77	increase	significant
Coliform of soil* origin	5	3.02	increase	significant

(* Differentiation based on the classification, Suess 1982)

Out of the four parameters, considered in existing water quality standards to support the designated best use of organised outdoor bathing, BOD (range 3 mg/l or less) was not estimated during this study. Upstream pH values were seen to lie althrough in the permissible range (pH 6.5-8.5), whereas in the downstream only two values were more than 8.5.

All the upstream and downstream values of Dissolved Oxygen were comfortably placed within the permissible range (5 mg/l or more), with 7.93 being the 90 percentile value at both locations inspite of a general decrease downstream. Generally low COD values yielding averages 5.28 (COV = 70.6) and 4.88 (COV 65.2) mg/l for upstream and downstream locations, with statistically insignificant difference between both could support the assumption that BOD would not have created an alarming situation during this period.

Coliform data again appreared to be quite outstanding in that both upstream and downstream values exhibited extraordinarily large violations. The reference value of 500 no./100 ml was exceeded in all samples. The 90 percentile values were found to be much higher than permissible, i.e. 11000 for upstream and 110,000 for downstream as compared to the prescribed limit of 2000. Surprisingly absence of enteric viruses as well as no reported incidence of infection, even during such high concentration of coliform bacteria, questioned the validity of such standards.

5.6 Ecological Control of Microbial Imbalances in Ganga Water

5.6.1 Survival of enteric bacteria

The decrease of bacteria, especially those of faecal origin, as a function of flow distance or flow time in a river was expressed as bacterial self-purification by Phelps in 1944. Apparent mortality of micro-organisms in water is suspected to be caused by a variety of factors viz. sedimentation, adsorption, coagulation, flocculation, solar-radiation, lack of nutrients, predation, bacteriophages, algal toxins, bacterial toxins and physico-chemical factors. The relative significance and the extent of interaction of the different factors are yet to be established.

It has been established that microbial predators present in all aquatic systems play a key role in the restoration of biological equilibrium by consuming the foreign micro-organisms, if the latter entered in the eco-system (Mitchell 1972). The importance of indigeneous bacterial population as a factor involved in the destruction of entric bacteria (Escherichia coli) in marine water has been emphasised by Mitchell and Nevo (1965). They reported a direct proportionality between the size of native bacteria and the rate and extent of decline of the population of E. coli. McCambridge and McMeckin (1978) emphasised that the survival of E. coli was mainly dependent on the presence of protozoan predators and not on the presence of predacious bacteria in marine estuarine waters.

Although considerable information has accummulated on the survival of indicator bacteria in marine water and fresh water bodies of the world, there is much less data available on the survival characteristics of indicator bacteria in river water in India. In comparison with coliforms and E. coli,

very little work has been done on the survival of faecal streptococci. Sharma and Ghosh have reported the survival of E. coli and faecal streptococci in Ganga at Patna. They attributed the process of photolysis where zinc possibly acts as photocatalyst in oxidising processes to the mortality of these organisms in water. In order to give an insight into the importance of inter-microbial predators in the survival characteristics of indicator bacteria, comparative investigations on E. coli and faecal streptococci in Ganga waters were made.

5.6.1.1 Survival of E. coli : Following the introduction of E. coli cells into filtered sterilized river water a minimal decrease in the number was observed even after seven days (Fig. 5.6.1). However, these flasks containing natural river water showed a marked decrease in E. coli number from 1.41×10^4 to less than three E. coli per 100 ml after six days. In order to evaluate the effect of intermicrobial predators on E. coli survival, the flasks containing filter sterilized water were supplemented with indigenous bacterial population 2.8×10^4 per 100 ml. The subsequent destruction of E. coli in this sample was from 1.44×10^4 to 5.6×10^2 with T_{90} value, 116 hrs, which was more than in the filter sterilized sample (from 1.55×10^4 to 3.9×10^3 T_{90} 279 hrs). The survival of E. coli in the presence of indegenous protozoan population (50 per 100 ml) was affected (from 1.48×10^4 to 3.2×10^3 T_{90} 61 hrs), in comparison to the samples withoput protozoans. When E. coli were exposed to both protozoan and bacteria together in association they were found to affect the survival more than the bacteria but less than the protozoan do alone. These observations confirm the findings of Mitchell and Nevo (1965) regarding the predation of native bacterial population in fresh water as well.

Enzinger and Copper (1976) suggested that bacterial competition, antagonism and even bacterial predation were relatively un-important in removing coliforms from estuarine water and that indigenous protozoans were responsible.

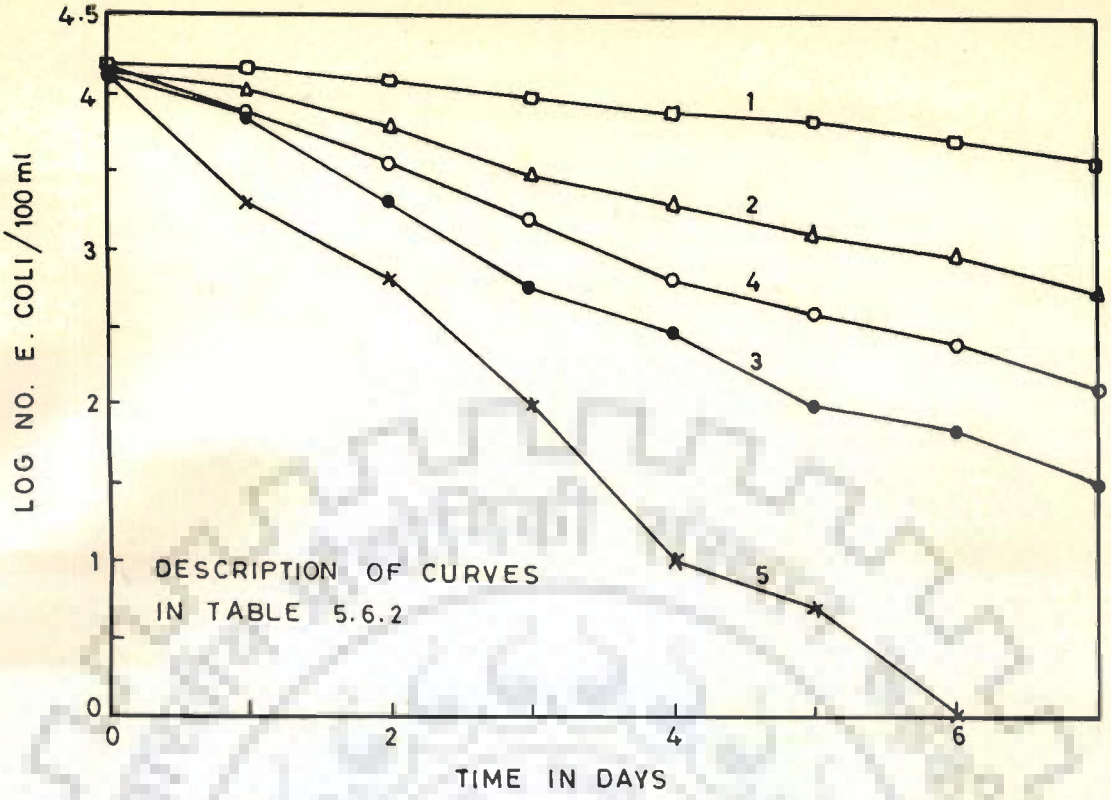


FIG. 5.6.1 – SURVIVAL OF ESCHERICHIA COLI IN DIFFERENT CONDITIONS IN GANGA WATER

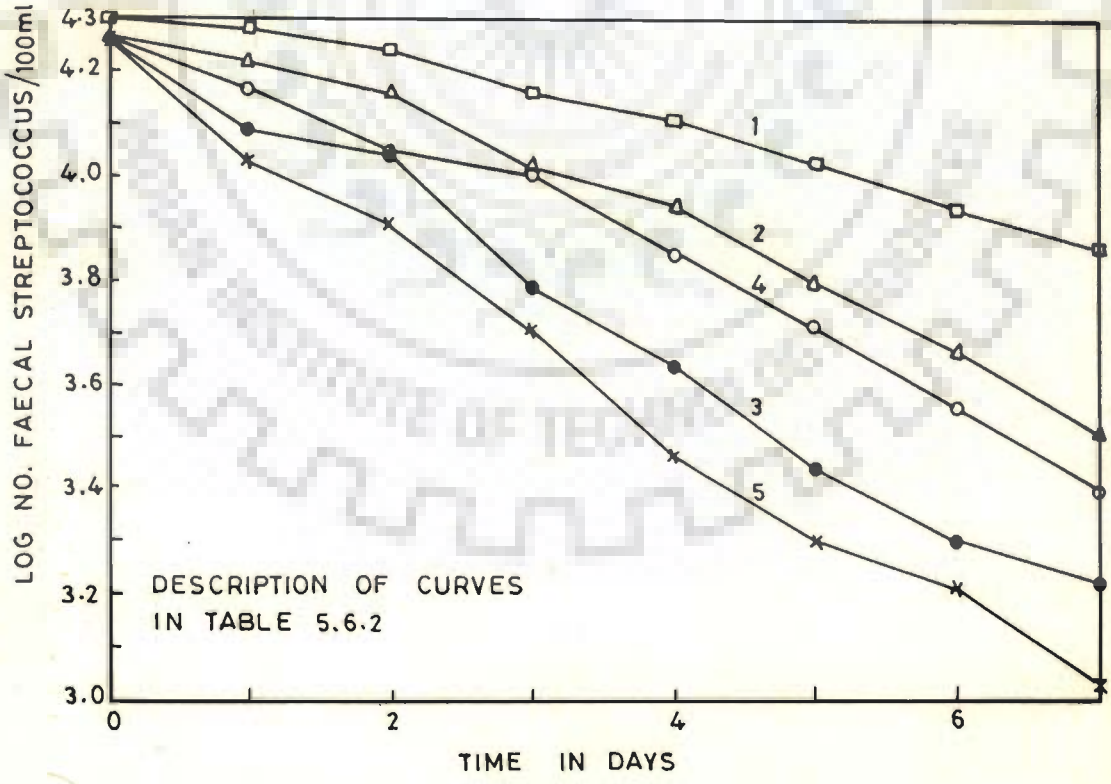


FIG. 5.6.2 – SURVIVAL OF FAECAL STREPTOCOCCUS IN DIFFERENT CONDITIONS IN GANGA WATER

The indigenous bacteria in the present case, however, show a significant difference in coliform destruction possibly due to the difference in the microbial population in the system. The protozoans in combination with the native bacteria resulted in less decline in E. coli numbers. The native bacteria serves as an alternative prey for the protozoans. Thus protozoans would also suppress the population of predaceous bacteria below numbers capable of causing significant reduction in E. coli population. In all the experiments where protozoans were observed, ciliates appeared to be the dominant species present. Some flagellates were also observed but in low number.

The marked bactericidal activity in natural water, which achieved the complete reduction of E. coli number in six days only, indicated that some factors mentioned earlier other than intermicrobial predators were involved in this activity.

Compared to the T_{90} values of E. coli in river waters of the world (Table 5.6.1), Ganga water could be placed among the rivers with reasonably short T_{90} values (32 hours at room temperature during winters).

5.6.1.2 Survival of faecal streptococcus : In all the experimental conditions faecal streptococci have a considerably longer T_{90} value than E. coli. Figure 5.6.2 showed typical characteristic with a T_{90} of 136 hrs for faecal streptococci compared with 32 hrs for E. coli in natural Ganga water. Although in all conditions the survival of faecal streptococci was better than E. coli, both bacteria followed a similar pattern for different experimental conditions. The T_{90} value for faecal streptococci in filter sterilized water was observed as long as 374 hours.

5.6.1.3 Rate equations : It may be seen that with the counts on the logarithmic scale the curves do not deviate greatly from regression lines. To develop

Table 5.6.1 T_{90} Values of E. coli Decay in the Water of Some Rivers of the World

Sl.No.	River	Season	T_{90} Hours
1.	Ohio River	Summer	47
		Winter	51
2.	Missouri River	Winter	115
3.	Tennessee River	Summer	53
4.	Sacramento River	Summer	32
5.	Cumberland River	Summer	10
6.	Glatt River (small shallow stream)	Summer/ Winter	2.1

Table 5.6.2 T_{90} and Decay Rate Constants for Faecal Bacteria in Ganga Water

Curve No.	Experimental Conditions	E. coli		Faecal Streptococci	
		T_{90}(hrs.)	k	T_{90}(hrs.)	k
1.	Filter sterilized water (FSW)	279	-0.086	374	-0.064
2.	FSW + Ind. Bacteria	116	-0.207	218	-0.110
3.	FSW + Protozoans	61	-0.393	154	-0.156
4.	FSW + Ind. Bacteria + Protozoans	82	-0.295	195	-0.123
5.	Natural Water	32	-0.713	136	-0.176

the rate equations for different sets of data on enteric bacterial death, the first order reaction was tried. This is expressed mathematically as

$$\frac{dN}{dt} = D_c N \qquad \text{(i)}$$

In integrated form

$$N_t = N_o e^{-kt} \qquad \text{(ii)}$$

Where N_o represents the number at time 0, N_t the number at time t and e the base of natural logarithms, k the constant rate of bacterial death.

($\log N_t - \log N_o$) values were plotted against time for all sets of data obtained for E. coli and faecal streptococci (Figs. 5.6.3 and 5.6.4). A statisfactory correlation (more than 0.98) was observed in each case.

$$\log N_t - \log N_o = -kt \qquad \text{(iii)}$$

The values of k were calculated for each curve from the slope obtained and compared. The value of k for natural water was found to be 8.3 times greater than filter sterilized water for E. coli (Table 5.6.2). Lower k values were obtained for faecal streptococci (Table 5.6.2).

The evidence from these lines of investigation, support the view that faecal streptococci survive longer than E. coli in Ganga water. More rapid reduction of E. coli than faecal streptococci occured in natural Ganga water. But these observations need confirmation under entirely natural conditions in field.

5.6.2 Predation by protozoans in Ganga water

Khanna et.al. (1971) reported some preliminary observations on the reduction of total bacterial flora in Ganga water. It took 7 days for the complete

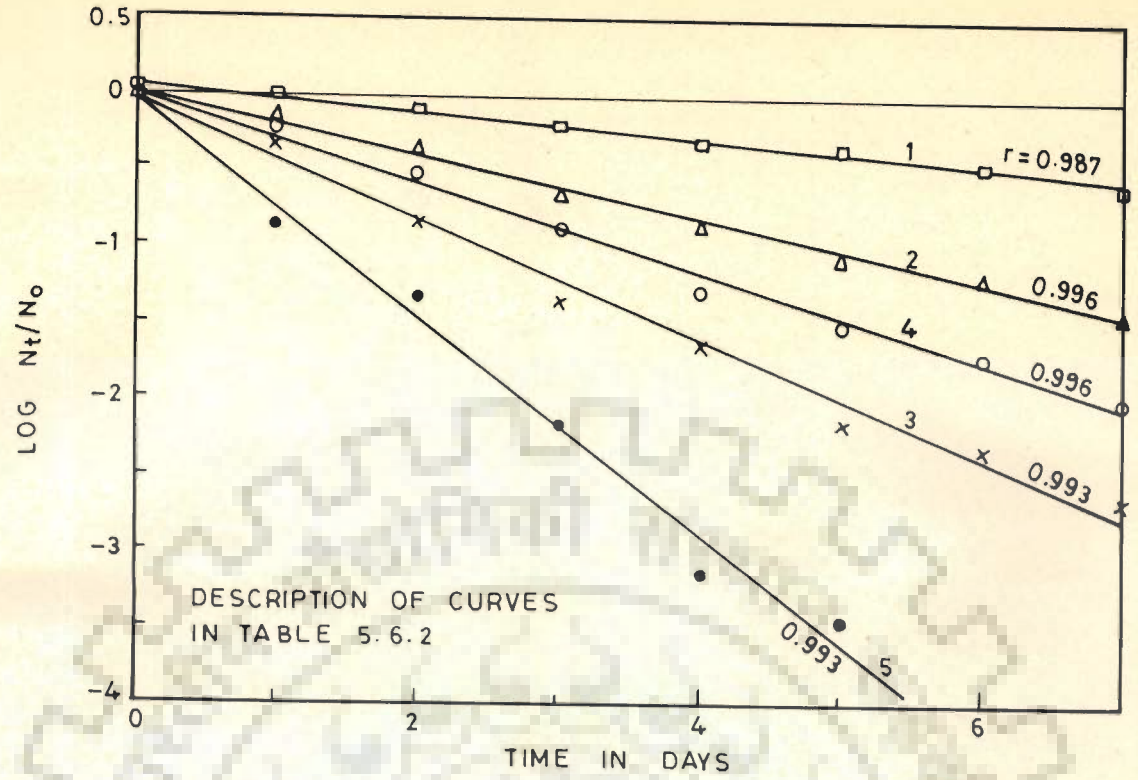


FIG. 5.6.3 - DEATH RATE OF E. COLI IN DIFFERENT CONDITIONS

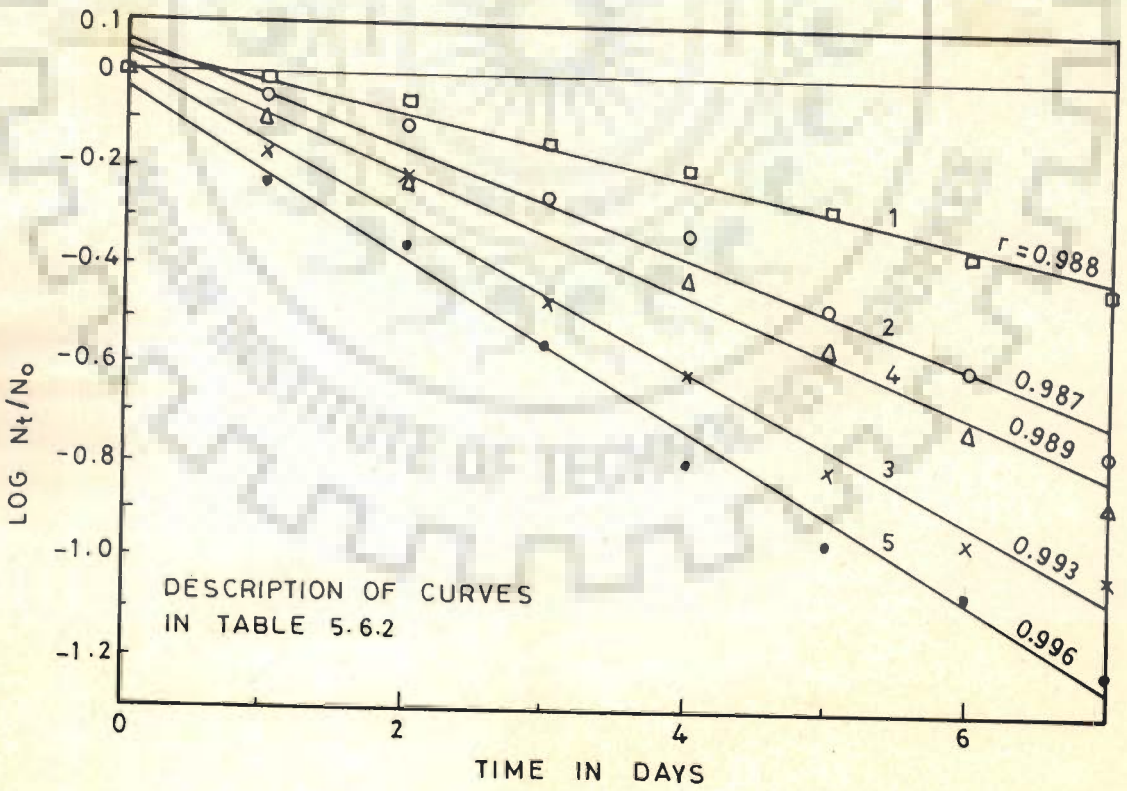


FIG. 5.6.4 - DEATH RATE OF FAECAL STREPTOCOCCUS IN DIFFERENT CONDITIONS

disappearance of bacteria from Ganga water sample (Rishikesh) compared to more than 15 days in the water sample of river Yamuna (India). This quality of Ganga was further investigated during the present study giving due weightage to the predation by acquatic microfauna.

In the absence of predaceous microfauna, the rate of reduction in bacterial number was observed according to the following equation developed from collected data.

$$N_t = N_o e^{-0.0926 \times t}$$

First, the bacterial number increased by 25% in fortyeight hours in response to the supplemented nutrients (50 ppm glucose) in the absence of microflora. Then, a gradual decrease in the number was noticed from 3.16×10^4 $(100\ ml)^{-1}$ to 1.31×10^3 $(100\ ml)^{-1}$, during the 16 days of experimentation. The bacterial number dropped significantly in the presence of predator (Fig. 5.6.5). For the complete removal of bacterial flora it took nearly fourteen days where the value of k was observed - 0.24009 which was 2.6 times greater than the value observed for without predacious microflora (Fig. 5.6.6).

The decrease in the number of bacteria was accompained by an increase in the number of protozoans present, which constitute more than 99% of the total microfauna. The number of protozoans increased from $<5 \times 10$ $(100\ ml)^{-1}$ to 9.9×10^3 $(100\ ml)^{-1}$ in 7 days. As the number of bacteria decreased, the protozoan population dropped markedly after 7th day in response to a level 1.0×10^2 $(100\ ml)^{-1}$ (Fig. 5.6.5). The ciliates appeared to be the dominant species as in the previous experiments.

The coefficient of predation computed by Sorokin and Kadota (1972) method was found to be 1225 bacterial cells $(100\ ml)^{-1}$ per day. The G (predation

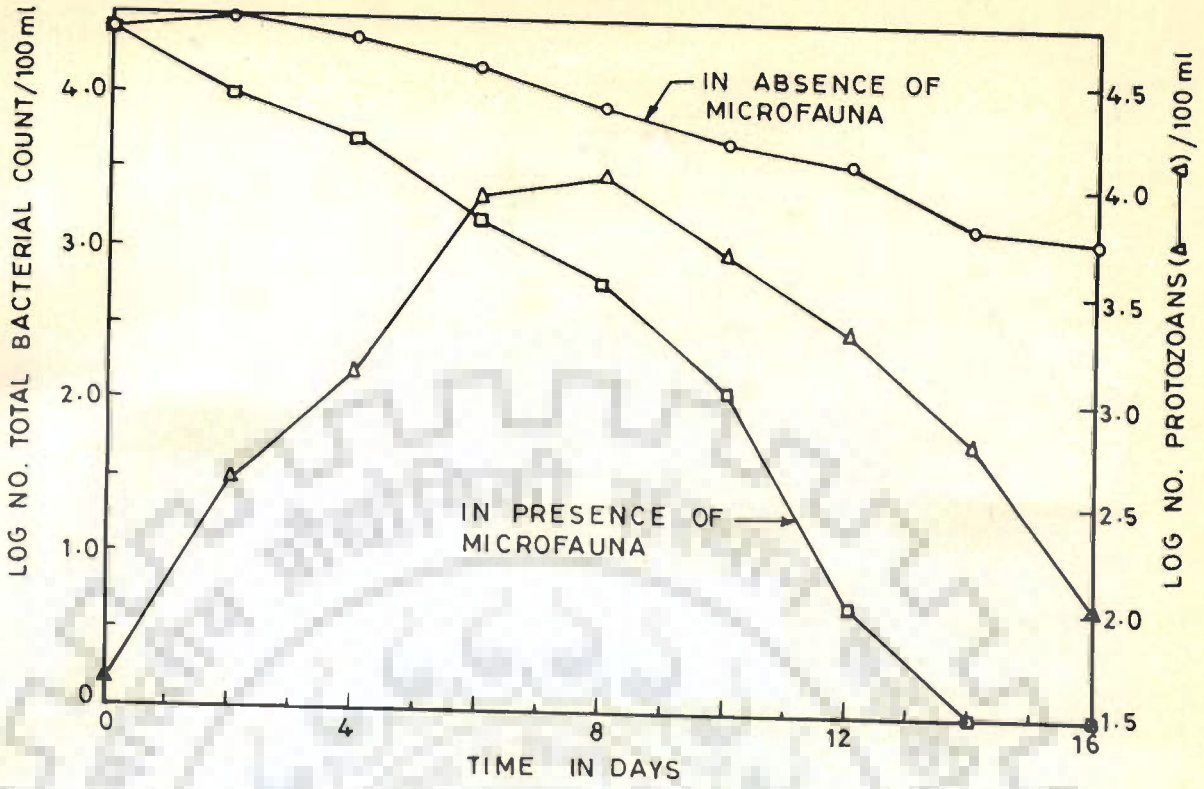


FIG. 5.6.5 – SURVIVAL OF HETEROTROPHIC BACTERIA IN PRESENCE AND ABSENCE OF MICROFAUNA IN GANGA WATER

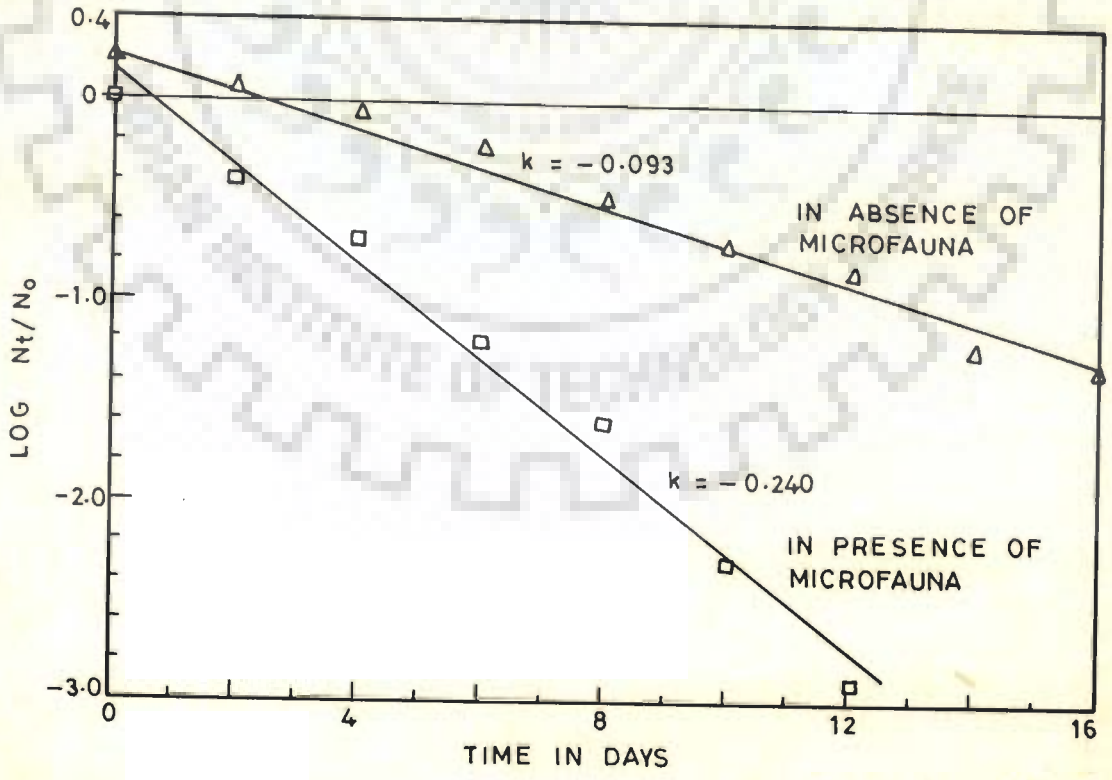


FIG. 5.6.6 – DEATH RATE OF HETEROTROPHIC BACTERIA IN GANGA WATER

number$(100\,ml)^{-1}day^{-1}$) was calculated for each set. The $\log N_t - \log N_o$ were plotted against time and the value of k per 100 ml per day were calculated.

Khanna et.al. (1971) ascribed this bacterial activity of Ganga water sample to the presence of bacteriophages in the water. Although the collection of complete possible reliable data is necessitated before arriving at a final conclusion, it may be deduced that microfaunal predation plays a key role in this activity. It is inferred that this quality of Ganga water has reduced tremendously from 1971 to 1987 as the complete reduction of bacterial number took 14 days in 1987 for river water sample at Haridwar compared to the time worked out by Khanna et.al. (7 days only) in 1971.

CHAPTER - VI

CONCLUSION

Based on the work done during the period December 1984 to December 1986 on 509 km stretch of upper Ganga river, following conclusions have been drawn. These are relevant to a zone where pollution is minimal and would need rectification for generalization.

1. Planktonic flora takes time to establish itself in the snow melt stream even though environmental conditions were suitable for growth and regeneration.

2. In general phytoplankton population was found to be more than zooplankton indicating healthy ecosystem. Members of bacillariophyceae dominated all the year round with predominance of pinnales. Zooplankton build up becomes apparent downstream.

3. Species composition of plankton varied both seasonally and spatially. Rainfall and surface run-off appeared as important factors in determining the seasonal fluctuations.

4. Organic pollution in general appeared to be of low order, with BOD and COD values not showing any alarming peaks. However, Satyanarayana and downstream of Kankhal presented a little concern. A comparable dependance also existed between organic waste and heterotrophic bacterial number. During monsoon the input of organic matter and corresponding increase of microorganisms was comparable to an unpolluted state where increase in number is concomitant with discharge.

5. Of the 8 diversity indices computed, Shannon's H', evenness (V&V'), Hurlbert's PIE, Keefe's TU and Simpson's D were found satisfactory to predict the fluctuation in ecosystem quality. Margalef and Gleason's index could also be used as an alternative for quick and simple evaluation.

Despite the lack of major change in species assemblage spatially, it is possible to classify the stretch into three zones on the basis of similarity indices viz. mountainous, foothills and plains. Although, Eucledian distance provided a picture of overall change in the community structure, it was not possible to grade the community comparison indices, as they differ in response to the dominant /rare species structure.

6. Although diversity indices are useful to define the community structure, together with evenness and community comparison, they could provide a promising approach to determine the state of community in a riverine system. Thus the indices which have a maximum and minimum diversity could be selected (e.g. H', PIE) for the same. An inter-conversion of the values is possible between the scales of some of the diversity indices.

7. Coliform load was high throughout the stretch with pronounced seasonal effects. No station satisfied the recommendations of water quality objectives (bacterial) for organized outdoor bathing. E. coli values were well within the limits and qualify as per suggestion of Geldreich. The faecal streptococcus crossed the limit of 100 MPN $(100\ ml)^{-1}$ at last three stations.

8. Out of several parameters studied, impact of bathing was noticed to be statistically significant on pH, ORP, DO and coliform.

9. Violation was noticed to be most prominent in existing coliform objectives, whose validity came under serious doubt as indicated by results of this study.

10. The survival of E. coli and faecal streptococcus was found to be influenced by predators. The role played by native bacteria was of secondary importance and their effect was only exerted when protozones were reduced

artificially. Factors other than predation were also found to be responsible for the decay of these bacteria. Faecal streptococcus servived longer than E. coli in Ganga water.

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RESEARCH PAPER FROM THIS THESIS

1. Paper accepted:

   Shishodia, S.K. and Mathur, R.P., Recovery of Coliform Bacteria from Fresh Waters-Comparison of Multiple Tube and Membrane Filter Techniques. (accepted in Environ. Tech. Lett., England).

2. Paper Communicated :

   Joshi, H., Kumar, S.N., Shishodia, S.K. and Mathur, R.P., Impact of Community Bathing on Ganga River, India : A Case Study. (communicated with Wat. Res.); Part of the paper is from this thesis.