

# Studies on the Phytoplankton of the River Ganges, Varanasi, India\*

by

J. S. S. LAKSHMINARAYANA

Central Public Health Engineering Research Institute, Nagpur.  
(with 10 figs.)

## Part I

### “The Physico-Chemical Characteristics of River Ganges”

#### INTRODUCTION

Studies on fresh waters have thrown much light on the life of biota and its interrelationships with habitat factors (cf. BLUM, 1956; LUND & TALLING, 1957). BLUM (1956) has pointed out that most of the information pertaining to the periodicity of algae in streams have been obtained from investigations in Europe and North America. The streams of India have been scantily investigated. ROY (1949, 1955) and IYYENGAR & VENKATA RAMAN (1951) have investigated the estuaries, like the Hooghly near Calcutta and Cooum at Madras respectively. DUTTA et al. (1954) have also worked on the Hooghly estuary. The present paper embodies the results of observations taken on the Physico-chemical aspects on the river Ganges at Varanasi, India, during March 1957 to March 1958.

Detailed information on the geography and hydrology of the river Ganges is readily available (WADIA, 1953; KRISHNAN, 1956). The river Ganges proper is formed of two tributaries called the Bhagirathi and Alkananda, although traditionally the former is accepted as the original Ganges. Alkananda joins Bhagirathi at Deva Prayag, to the

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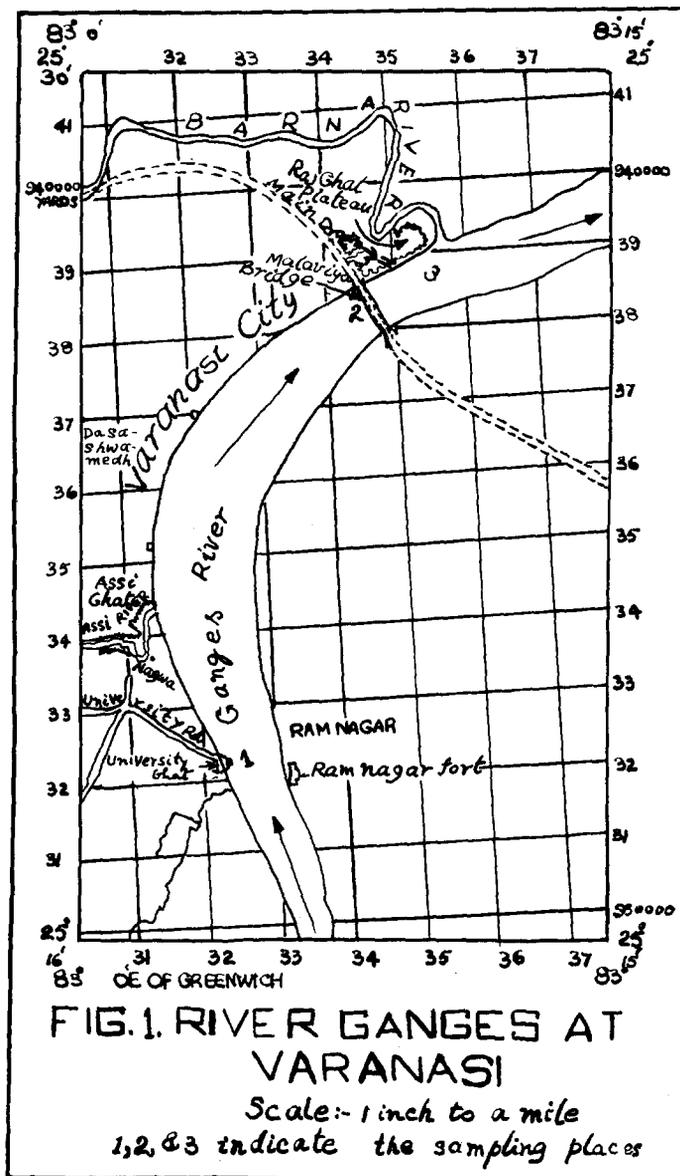


Fig. 1. River Ganges at Varanasi; scale: 1 inch to a mile. 1, 2 3 indicates the sampling places.

north of Missoorie hills, which the river crosses before passing into the Siwalik ranges of Dehra Dun and Hardwar. The river Ganges enters the plains near Hardwar and passes through Kanpur, an industrial city, and Allahabad. At the latter place the river Yamuna joins the river Ganges at the holy 'Sangam' or 'Triveni'. After this confluence, the river flows down to Varanasi, thence through Bihar and West Bengal, and finally joins the Bay of Bengal near Calcutta in the form of river Hooghly, which is an estuary formed of its three feeders: the Bhagirathi, Jalangi and Mathabhanga. The total length of the Ganges from its source at Gangotri to the mouth of Bay of Bengal is 1557 miles (KRISHNAN, 1956).

The river Ganges at Varanasi (cf. Fig. 1), lies at Lat. 25° 18' N and Long. 83° 1' E, in the middle of Gangetic Plain region. The river makes a deep turn from east to west and again reverts to east. For the present investigation, the water-sheet between 'University Ghat' and 'Raj Ghat', the distance being nearly six miles, was selected.

Embracing the curve of the river Ganges, on the western side, all along its course, the city, Varanasi, lies on a 'Kankar' ridge for about four miles. On either side of the city, two rivers, Assi (South) and Barna (North) join the river Ganges. The 'Kankar' ridge is extended almost continuously from near the confluence of the Barna with the Ganges to that of Assi. This course is lined by great flights of steps, the bathing 'Ghats'. The land gradually drops down towards the interior of the city from the 'Kankar' ridge which is quite above normal flood-level. 'Raj Ghat' plateau, hemmed between the Ganges and Barna, is situated towards the north-east of the city. Barna formed a north-easterly loop, just before its confluence with the Ganges. From 'Assi' to 'University Ghat' the bank is not uniform in height and generally lower than the rest of the western bank. On the eastern bank of the river, excepting near the fort of Ramnagar, the land is low-lying and is susceptible to frequent inundations during floods. The 'Ramnagar Fort' is situated on a 'Kankar' ridge, and the huge flights of steps being confined to the base of the fort facing the river Ganges. On the whole, most of the eastern bank, beyond 'Ramnagar Fort' and area below 'Assi' (South) on the western bank contributes to the cultivable lands, where generally 'Rabi' cereals are cultivated. For the present, the river 'Assi' is represented by a small stream.

Before entering the city of Varanasi, the river Ganges dashes against the 'Ramnagar Fort', and turns to the west and again strikes the 'Assi Ghat' and finally takes its course towards the east. In recent years, the peak floods occurred in 1948, when the water-level reached 244 feet, while during the present investigation the water-level varied between 187 and 228.9 feet, the latter was registered in

July, 1957. Depending upon the season, the width of the river will be changing from 1/8th of a mile to one and a half mile.

In general, the river Ganges is a fast flowing river with consequent high currents. Rains and floods bring about fluctuating changes in the water-levels, which cause tremendous variations in current velocity. In summer at Varanasi, the river is generally split up into two streams as a consequence of the exposure of part of its bed in the middle. A small stream slowly flows towards the city side, which is generally confined to the 'University Ghat' and joins the main stream after a distance, while the main one follows the normal course. As a result of this, there is a vigorous growth of macrophytes like *Najas*, *Hydrilla*, *Chara*, *Nitella*, species etc. Although such an exposure of the river bed is a common feature in summer months, during the period of investigation it was not observed, possibly due to high floods and late rains.

The river receives sewage throughout the year by means of (I) the main sewer situated below the Malaviya Bridge; (II) the old underground drainage system at places like 'Trilochan Ghat', 'Shiwala Ghat' and 'Harischandra Ghat', etc., and (III) the entry of Barna river which also carries a part of city's sewage. Besides, there are several places in between 'University Ghat' and 'Raj Ghat', where a part of city's wastes are also discharged. The drained water from the surrounding agricultural fields, during rains and floods, may further add to the pollution of the river.

The steps of the 'Ghats' and bottom of the boats show abundant growth of attached algae like species of *Cladophora*, *Stigeoclonium*, *Phormidium*, etc.

## METHODS

The water samples were collected at fortnightly intervals from three arbitrarily selected places (Fig. 1), both in the littoral and pelagic regions. Samples were always taken at one and a half feet to two feet depth from the surface of the water. The time of collection varied between 6.00 A.M. and 3.00 P.M. according to seasons. The samples were brought upto the surface with the minimum disturbance. Hard-glass, narrow-necked, ground-glass stoppered one litre bottles were used for this purpose. Chemical analysis of the samples was performed soon after their transport to the laboratory. Sometimes the analyses had to be continued for forty to sixty hours from the time of collection. During floods it became necessary to filter the water samples before analysis.

For the determination of dissolved oxygen and total sulphides,

narrow-necked stoppered bottles of 275 ml capacity were used. Soon after the bottles were brought to the water surface, the samples were winklered and acidified. To those intended for the estimation of sulphides, 1 ml of zinc acetate solution was added in order to stop oxidation and volatilization of sulphides. These determinations were completed immediately after reaching the laboratory.

A centigrade thermometer was used, and the temperatures were noted at about 8 inches below the surface of water, during the hours of collection. Outside temperatures were simultaneously recorded. Hydrogen-ion concentration was determined with B.D.H. wide and narrow range Universal indicator papers and solutions. Transparency was determined with a standard Secchi disc of 20 cm diameter.

Chemical analyses carried out by standard methods described by the American Public Health Association (1946), American Society of Testing Materials-19 (1949) and Limnological Methods by WELCH (1948) included Ammonia (direct Nesslerization), nitrate (Phenol-disulphonic acid method), Nitrite method (Sulfanilic - alpha - naphthylamine acetate method), Albuminoid nitrogen (alkaline potassium permanganate method), Organic Nitrogen (Kjeldahl method), Silicon (Molybdate and reduction with Amino Naphthol sulphonic acid - this estimation was performed immediately after the collection), chlorides (titration with silver nitrate), sulphides (evolution method), dissolved oxygen (Rideal-Stewart modification of Winkler method), carbon dioxide (titration using phenolphthalein and N/44 sodium hydroxide-determined at the time of collection), alkalinity (volumetric) and manganese (periodate method). Sulphate was estimated volumetrically after precipitating with barium chloride (cf. SCOTT & FURMAN, 1952, p. 2096). Calcium (Bersworth Chemical Co., 1954) and magnesium (BANKS, 1952) were estimated by Versenate titration with ammonium purpurate and Eriochrome Black T as indicators. Total iron was measured colorimetrically using aminonaphthol sulfonic acid method of FISKE & SUBBAROW (1929). Carbonate and bicarbonate were estimated indirectly from Alkalinity. Total hardness of water was calculated from calcium, magnesium and iron indirectly. Total nitrogen was estimated by adding all the respective values of nitrogen fractions. All the analyses estimated refer to the surface water.

#### PHYSICO-CHEMICAL FACTORS AND THEIR SEASONAL VARIATIONS

The periodic changes of the physical and chemical factors and their interrelationships are discussed in the following account. Seasonal variations of the factors during the period of investigation are shown in figures 2 to 7.

## Water-levels and water-movements

The water depth is liable to great fluctuations with sudden rises after heavy rains, and consequent heavy spates with incredible wave action. The velocity of the river is invariably high during floods. There are surface currents, under-currents etc., due to which whirlpools are very common all the year round.

The water-level was observed to fluctuate between 228.9 feet to 187 feet, the former towards the end of July, 1957 and the latter in the second half of January and March, 1958 (Fig. 2).

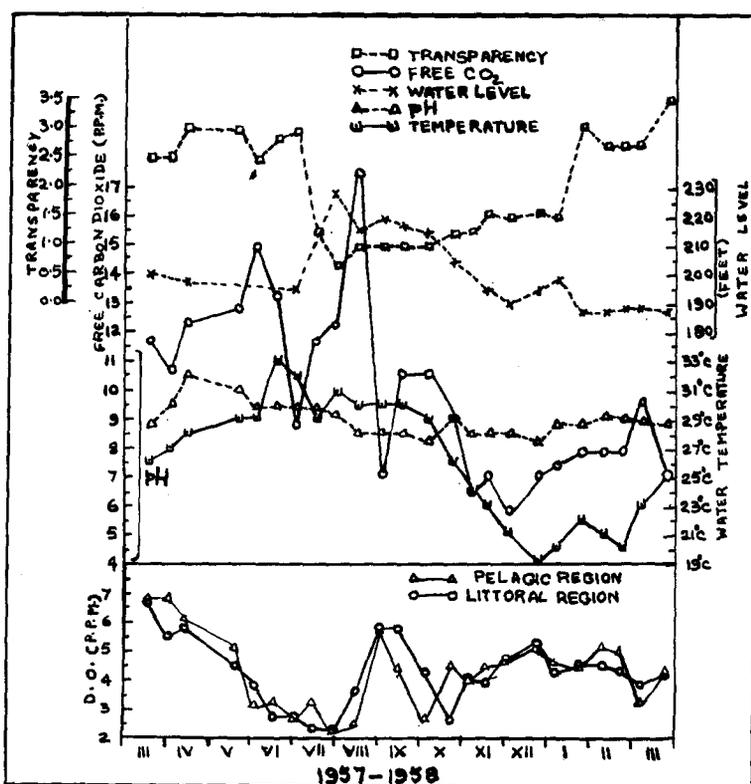


Fig. 2. Seasonal Variations in Transparency, Free Carbon dioxide, Water level, pH, Temperature and Dissolved Oxygen contents of the River Ganges during March 1957 to March 1958.

## Temperature

The temperature variations of the water are shown in figure 2. The maximum 33°C was recorded in the latter half of June, while the

minimum 19°C in December. The atmospheric temperatures, over the surface of the water, were observed to follow closely the water temperatures. In December, 1957 and January and February, 1958, the air temperature over the river were generally lower during the morning hours. On 22.12.57, the water temperature remained at 19°C throughout the day, while the air temperature was 16°C. This might be explained as follows: In general, during the day, when it advances, the surface waters of the river become heated owing to the insolation from the sun. This continues till the end of the day, whence cooling of the water begins. As the surface water cools, it becomes denser than the water below it and therefore sinks. Ultimately this cycle of sinking of cold water and rising up of lower waters towards the surface due to convection currents brings about mixing of these waters. These changes in the layers of the waters, coupled with the cold nights of the winter, would result in maintaining low temperatures, and this might continue even during the day time, on cold days like 22.12.57, when the air temperatures were lower than the water temperatures.

When the water-levels, current velocity, and turbidity of the river in rains were high, the water temperatures were comparatively low. This can be explained on the basis of frequent clouds and high humidities. During summer, however, the water temperatures increased due to the low water-levels, clear atmosphere and greater insolation from the sun.

### **Light and Transparency**

A close indirect association of transparency (Fig. 2) with the turbidity of the surface waters was observed. When waters were highly turbid the extent of transparency, i.e., light penetration, was found to be less. As would be expected the transparencies were less during the flood period, i.e., from July to September, in view of extreme turbidity of the flood water.

### **Dissolved Oxygen**

The maximum values of dissolved oxygen attained in both littoral and pelagic regions are 6.7 and 6.8 ppm respectively, the minimum values being 2.1 ppm in pelagic and 2.2 ppm in littoral (Fig. 2). These two regions adopted an almost equal course, with minor fluctuations, in various seasons (Fig. 2), and attained their respective maximum values in March, 1957. These maxima were followed, from April onwards, by pronounced falls with slight variations till the middle of July, when they registered their lowest values. Through most of winter and rainy seasons the dissolved oxygen content showed relatively high values.

A comparison of the dissolved oxygen content of the Ganges water with those of other physical and chemical components of the water revealed the following relationships. Periods of high temperatures nearly coincided with those of low oxygen content (Fig. 2), a feature observed by NEEL (1951) in the hard water limestone stream. RUTTNER (1953) stated that temperature is one of the factors which affects the quantity levels of oxygen. The attainment of maximum levels of dissolved oxygen, during March, 1957, in the river Ganges might be due to relatively low temperatures of the waters as evident from figure 2. The sudden falls in the dissolved oxygen levels, from about April, 1957 to the end of June 57, were followed by gradual rises in temperature.

In general, with high water-levels, the dissolved oxygen content maintained high levels, except by the end of July, 1957, when the water recorded the highest level. This deviation can be attributed to the inflow of more drainage from the 'Assi', which may be less in oxygen content. The reduction of oxygen levels by the entry of drainage waters was stressed by WELCH (1952), RUTTNER (1953), and BLUM (1956). TALLING (1957) also observed a similar feature, in the case of White Nile.

The oxygen content of the water showed an almost inverse correlation with free carbon dioxide content.

The hydrogen-ion concentration, silica, nitrogen fractions, phosphate and others were found to be independent of oxygen concentration.

### **Free Carbon dioxide**

The free carbon dioxide varied from a minimum of 5.8 ppm on 1st December, 1957 to 17.6 ppm in the middle of August, 1957 (Fig. 2). In summer the carbon dioxide values were high and on the onset of rainy season there was a sudden fall and a gradual rise by the middle of August, again followed by a steep fall in the beginning of September. Later, although the values rose slightly, relatively low values of free carbon dioxide were maintained all through the year culminating in the lowest value of 5.8 ppm by the beginning of December. From figure 2, a clear maximum by the middle of August and a sub-maximum at the beginning of June are seen. The higher values of carbon dioxide recorded in summer might have been due to deoxygenation, a feature observed also by TALLING (1957) while investigating the White Nile.

The over-all picture indicates an inverse relationship between the oxygen consumption and carbon dioxide production, although the variations were not markedly periodic.

When the values of carbon dioxide concentration were compared with those of carbonate, bicarbonate (Fig. 3) and pH (Fig. 2) no precise relationship was evident. However, the rise in temperature (Fig. 2) could be correlated with the increase in the carbon dioxide levels (cf. also TALLING, 1957). The same relationship was observed with reference to floods, water-level and transparency of the river, i.e., whenever there was a rise in these factors there was a corresponding increase in carbon dioxide concentration.

## **pH**

Except in April, 1957, when the maximum of 10.5 was registered, the pH values varied between 10 and 8.2. The pH generally maintained a high buffering capacity for most of the period of investigation (Fig. 2).

ROY (1955) observed the pH of the river Hooghly to be more or less stable within the range of 8.3 to 8.4 which is another example of high buffering capacity.

BLUM (1956) observed that removal of carbon dioxide was also affected by photosynthesis and may result in an annual variation of pH as in the river Thames (cf. RICE, 1938), where the pH attained a value of 8.5 in spring at the time of phytoplankton maximum, and was relatively low in summer, fall and winter. Similarly, in the case of river Ganges, the waters maintained relatively high values of pH in summer and winter, when the phytoplankton was generally high. In the rainy season, low values of pH were recorded. This may be due to the river's enormous size and constant water movements, which are expected to bring changes in the levels of carbon dioxide and carbonates and hence a fall in the pH values.

## **Alkalinity**

Bicarbonate and carbonate alkalinities are present in the water while hydroxide alkalinity is absent.

The bicarbonate alkalinity (Fig. 3) varied from a maximum of 130 ppm in July to a minimum of 44 ppm in the middle of August and September. After reaching the highest value in July, there was a sudden drop to the minimum with a gradual and steady rise thereafter through the rainy and winter seasons.

The values for the carbonate alkalinity (Fig. 3) are comparatively lower than those of bicarbonate alkalinity. The lowest value of 2 ppm was recorded in July and September and the highest value of 18 ppm in February. Mostly there seems to be an inverse relationship between carbonate and bicarbonate alkalinities, particularly in July

when carbonate alkalinity reached a minimum of 2 ppm. The curve (Fig. 3) reveals high values of carbonate throughout winter and most of the summer.

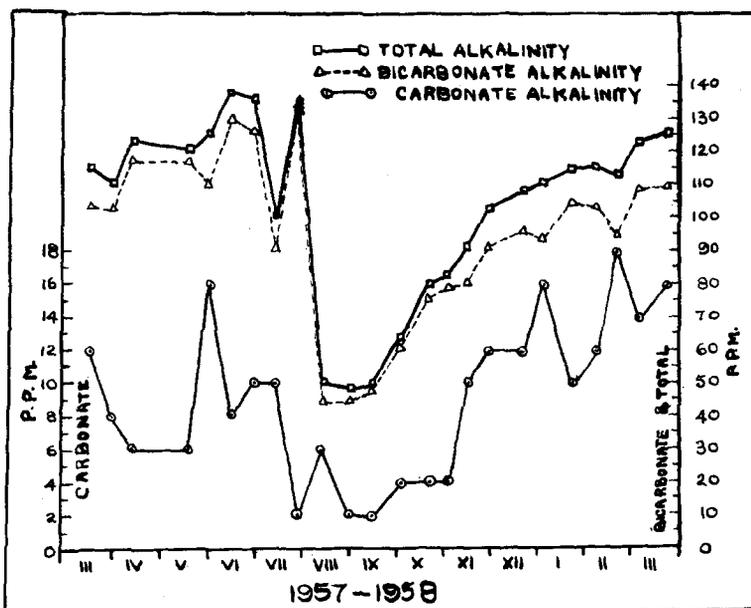


Fig. 3. Seasonal variations in Bicarbonate, Carbonate and total Alkalinity contents of the River Ganges during March 1957 to March 1958.

The total alkalinity curve (Fig. 3) almost travels quite parallel to that of bicarbonate alkalinity in all the three seasons. This may be due to the predominating contribution of bicarbonate alkalinity towards total alkalinity. Just like bicarbonate alkalinity, the total alkalinity shows a minimum in September (46 to 49 ppm) and a maximum (138 ppm) in June.

### Calcium and Magnesium

In general, the values of magnesium (Fig. 4) were comparatively higher than those of calcium (Fig. 4). The highest value recorded was 167 ppm during March, 1957, the lowest, 24 ppm, in the middle of September. In the case of calcium the maximum concentration was 100 ppm during March, 1957, the minimum being 26 ppm during October, 1957. Although, in both cases maxima were present in winter and summer, the latter ones were always the highest.

The calcium and magnesium values followed the magnesium curve and were higher in summer and winter months.

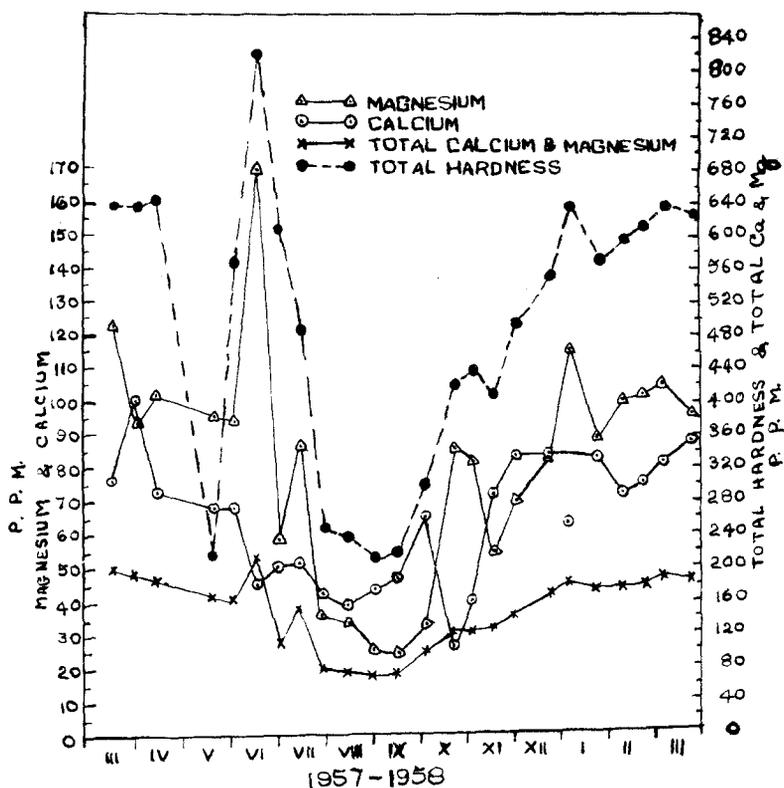


Fig. 4. Seasonal variations in Magnesium, Calcium, total Calcium and Magnesium and total Hardness contents of the River Ganges during March 1957 to March 1958.

### Total Hardness

The concentration of total hardness (Fig. 4) attained a maximum of 815 ppm in the middle of June, and the minimum value of 213 ppm was recorded during May. In summer and winter, the values of total hardness were high and during the rainy season they were low.

A marked resemblance was observed between total calcium and magnesium curve (Fig. 4) and total hardness (Fig. 4). No clear-cut correlation was present between free carbon dioxide content and total hardness concentration.

### Total Nitrogen

Five forms of nitrogen were estimated. They were nitrate, nitrite,

ammonia, organic and albuminoid nitrogens. The total of the values of all these types of nitrogen was considered as the total nitrogen of the waters. In general, the ammonia nitrogen, albuminoid nitrogen and organic nitrogen contents contributed much to the total nitrogen values when compared to nitrate and nitrite nitrogen contents. The total nitrogen (Fig. 5) varied from a maximum of 1.86 ppm during September to a minimum of 0.11 ppm in February. The curve of total nitrogen registered abrupt rises during August, October and December; while sudden falls were seen in September and December.

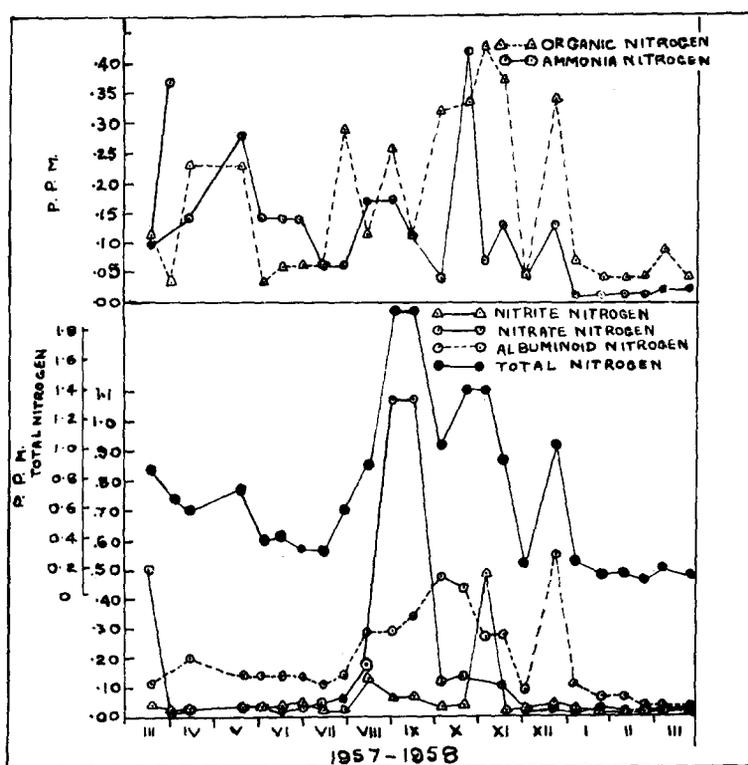


Fig. 5. Seasonal variations in Organic, Ammonia, Nitrite, Nitrate, Albuminoid and total Nitrogen contents of the River Ganges during March 1957 to March 1958.

### Nitrate Nitrogen

From a value of 0.5 ppm in March, 1957, the nitrate nitrogen (Fig. 5) curve suddenly dropped and remained at a very low level till the

end of July when it increased slightly and suddenly in the middle of August, when the maximum value of 1.08 ppm was recorded. The latter continued for a short time, followed by an abrupt fall and finally maintained very low values of 0.01 ppm throughout winter. Although low values are met with during winter and summer, the values of the latter are higher than the former. The highest values of nitrate nitrogen followed periods of rainfall and floods when one can expect waters to be very rich in nitrates (cf. WELCH, 1952; RUTTNER, 1953; BLUM, 1956). The addition of nitrates in the form of run off water and organic pollution due to the entry of sewage etc.; to the river Ganges is considered to be a function of fertilization and enrichment, a characteristic feature of rivers as pointed out by BLUM (1956). Nitrate depletion in winter and summer may be due to the photosynthetic activity of the algal phytoplankton or may be due to oxidation of organic compounds (cf. BLUM, 1956).

### **Nitrite Nitrogen**

In general, the nitrite nitrogen maintained very low levels. Its highest value recorded in the beginning of November was 0.48 ppm, the lowest being 0.01 ppm in January and February, 1958. The curve (Fig. 5) showed a well-defined sub-maximum during August.

### **Ammonia Nitrogen**

The curve of ammonia nitrogen (Fig. 5) showed an abrupt sub-maximum of 0.37 ppm in the beginning of summer, 1957. Thereafter it followed abrupt falls and rises, concentrations of a moderate nature reached at the end of rainy season, i.e., in October, the maximum being 0.44 ppm. During the winter it showed very low concentrations and ended in the lowest value of 0.01 ppm. The lowest values of winter may be due to the utilization of ammonia nitrogen by the phytoplankton.

In general, the values of ammonia nitrogen were higher when compared with nitrate or nitrite nitrogen.

### **Organic Nitrogen**

Organic nitrogen varied from a maximum of 0.43 ppm in November to a minimum of 0.03 ppm in May and June. The values fluctuated very much, particularly during the rainy season, and remained low through most of the winter. The maximum and sub-maximum were attained during the early winter i.e., November and December (Fig. 5).

## Albuminoid Nitrogen

In general, the albuminoid nitrogen (Fig. 5) recorded low values throughout summer and through half of the winter. It varied from a maximum of 0.55 ppm in December to a minimum of 0.04 ppm during February and March, 1958. There was only one well-defined maximum and that was in December. No sub-maximum was clearly marked.

## Silica

The curve of the silica content (Fig. 6) shows well-defined maximum of 80.5 ppm. and minimum of 0.6 ppm in September and at the end of June respectively. The values on the whole continued to be low, except during rains, and floods. This shows a direct correlation of silica content with high water-levels.

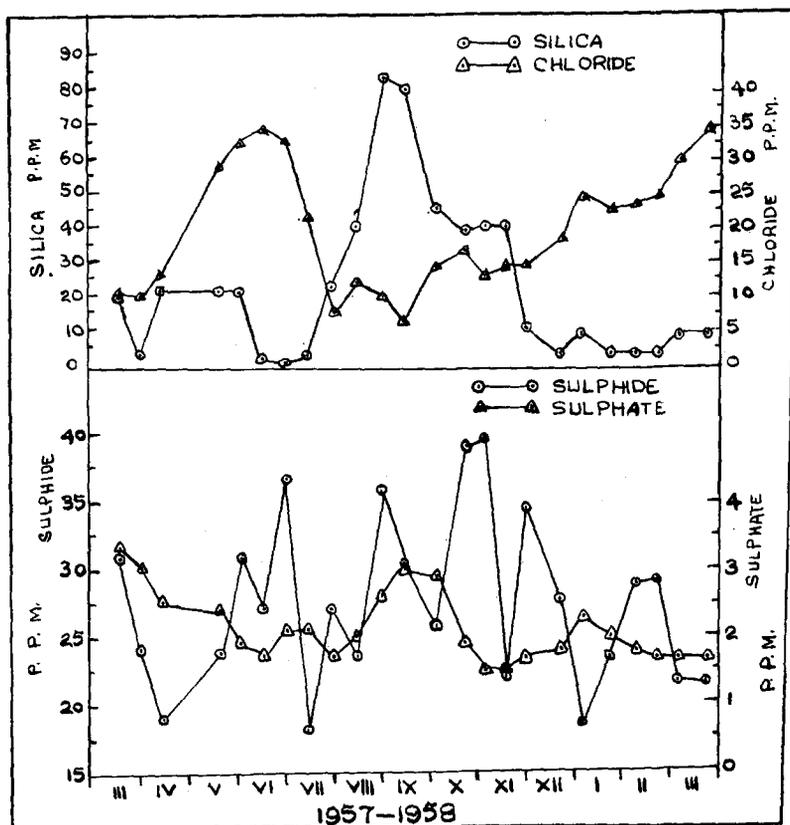


Fig. 6. Seasonal variations in Silica, Chloride, Sulphide and Sulphate contents of the River Ganges during March 1957 to March 1958.

## Phosphate

The phosphate content (Fig. 7) attained the lowest values of 0.06 to 0.08 ppm in the beginning of summer of 1958. The highest values of 2.0 to 2.02 ppm were recorded during September to December which formed the maxima. Throughout the whole of summer, 1957, the waters maintained moderate values of 1.6 ppm. and these formed the big prolonged sub-maxima. The high values of phosphate can be attributed to the formation or accumulation of inorganic phosphates and also to the substantial addition of phosphates through agricultural drainage and sewage from the surrounding areas (cf. BLUM, 1956). During the latter part of the winter and the former part of the rainy season, the phosphate content remained low. This might be due to photosynthesis of the algal phytoplankton and also delayed rains and

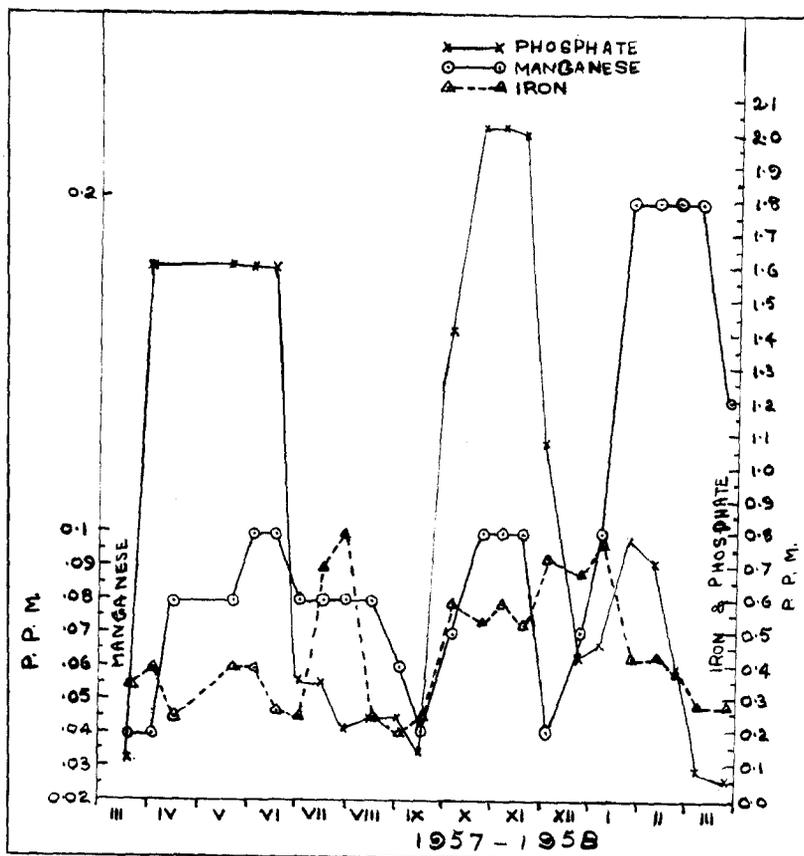


Fig. 7. Seasonal variations in Phosphate, Manganese and Iron of the River Ganges during March 1957 to March 1958.

floods carrying depleted phosphate matter (cf. ATKINS, 1923, 1926; PEARSALL, 1930). It is noteworthy that the values do not show sudden fluctuations within a given period.

### **Iron**

All the iron present in the water was in ferric form, since the waters were highly alkaline, when the solubility of iron is very low. That was how the ferrous iron could not be detected. The absence of ferrous iron, according to RUTTNER (1953), can be attributed to (a) the presence of dissolved oxygen, (b) the lack of adequate amounts of carbon dioxide, (c) the high pH of the water and, lastly (d) the absence of organic substances arising from decomposition which can reduce ferric hydroxide.

The total iron content (ferric) (Fig. 7) of the water, while being low throughout the year, varied from a maximum of 0.8 ppm in July, 1957 to a minimum of 0.2 ppm in September, 1957. The iron content in the waters attained highest maxima in the rainy season and a sub-maxima during the winter season. The highest value in July was followed by a steep fall. The values of iron remained very low throughout the year when compared with those of manganese.

### **Manganese**

This varied from a highest value of 0.2 ppm mostly in winter season to a lowest value of 0.04 ppm twice during March, 1957 and once each in September and December, 1957 (Fig. 7). It showed a prolonged maximum in the winter and two equal sub-maxima, each in summer and rainy seasons of 1957. The maximum in winter continued to persist till the earliest part of March, 1958. The total manganese contents of the waters, on the whole, remained very low all through the period of investigation.

### **Chloride**

The chloride content showed the highest value of 34.6 ppm in June, 1957 and March, 1958, and lowest value of 6.4 ppm in September, 1957. The curve (Fig. 6) indicated that during summer the values of chloride concentrations were very high whereas in the rainy season they remained low. All through the winter there was a gradual rise in the chloride content and on the onset of summer, 1958, the maximum was again reached. The sub-maximum was not very pronounced and an equivalent was obtained during January.

The chlorides registered greater values when the silica content

of the water remained low. Silica attained maximum values during the rainy season, whereas chlorides in June, 1957 and March, 1958.

### **Total Sulphides**

These include all dissolved sulphides and also acid soluble metallic sulphides present as suspended matter.

The curve of the total sulphides (Fig. 6) of the waters showed frequent fluctuations in their concentrations and there are apparently no marked seasonal variations excepting low values during summer. During the rest of the two seasons they varied markedly.

The maximum of 39.8 ppm and the minimum of 18.0 ppm of total sulphides were attained during November and July respectively.

### **Sulphates**

The sulphate concentrations varied from a maximum of 3.3 ppm in March, 1957 to a minimum of 1.5 ppm in November. On the whole, the curve (Fig. 6) suggests that the sulphate content was small during winter, more in rainy season, and moderate during summer.

When compared to the sulphide concentration curve (Fig. 6) the sulphates are very low and no correlation was found between them.

## **DISCUSSION**

The various physical and chemical characteristics of the river Ganges described in earlier pages are in relation to their periodic changes and their interrelationships or interdependence. Their modifications with particular reference to the river Ganges are summarized below:

Of the physical factors, changes in the water movements by rate of flow and consequent currents predominantly influenced the river. Fluctuations in the water level of the river, with consequent changes in the transparency and light penetrability of the water affected the growth of phytoplankton (LAKSHMINARAYANA, 1965). Diurnal variations in temperatures of the river waters was clearly indicated. There was a close indirect correlation of light with turbidity of the waters.

The highest dissolved oxygen concentrations were associated with the summer and winter maxima of the phytoplankton (LAKSHMINARAYANA, 1965). The Ganges waters were always alkaline and generally maintained a high buffering capacity and the little changes in pH were gradual. During floods and rainy season the pH values

TABLE I

Concentrations (ppm) of nitrogen, phosphate and silica contents of natural fresh-waters (from various sources as compiled by CHU, 1942) and the river Ganges at Varanasi.

Name of the river	Nitrogen	Phosphate	Silica
Nile	Trace to 0.098	Trace to 0.023	10.3 to 26.7
Mississippi	0.05 to 0.91	Trace to 0.065	11 to 24
Wharfe	Trace to 1.58	0.0 to 0.022	0.5 to 14.9
Illinois	0.023 to 2.82	—	12 to 31.6
	or 9.52 to 11.3		
Thames at Slough	3.5	—	—
Thames at Stains	8.7	—	—
River Ganges	0.11 to 1.86	0.06 to 2.02	0.6 to 83.7

are somewhat low and this may be due to the enormous size, constant water movements and presence of sparse phytoplankton. Mostly there was an inverse relationship between carbonate and bicarbonate alkalinities. The total hardness of the waters (213 ppm to 815 ppm) was highly pronounced. A comparison of nitrogen, phosphate and silica contents with those of the other rivers (Table I) revealed that the Ganges waters were very rich in phosphates and silicates, while the nitrogen content was moderate. In general, the chlorides were more in abundance when the Silica content was comparatively less and *vice versa*. The total sulphide content of the waters was also found to be higher. The chlorides also were high, although the variations were not markedly periodic. This might be due to the river getting highly polluted by natural drainage and sewage. In short, the physical and chemical characteristics of the river Ganges showed great richness of the major inorganic plant nutrients.

#### SUMMARY

The physico-chemical aspects on the river Ganges at Varanasi, India, during March, 1957 to March, 1958, were described and discussed in relation to their periodic changes and their inter-relationships.

#### ACKNOWLEDGEMENT

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