Limnological Studies on Freshwater Ponds of Hyderabad-India

I. The Biotope*

by

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INTRODUCTION

A number of publications on the limnology of freshwaters of India have appeared since the beginning of the present century. Most of these contributions are based on the year round study of freshwater bodies of diverse dimensions. Invariably these studies are confined to the surface but a few observations such as those by SINGH (1960) and SREENIVASAN (1964) have been made at various strata. GANAPATI (1960) has studied the thermal stratification of certain reservoirs of South India. The thermal stratification in ponds and vertical movement of certain organisms has been studied in smaller bodies of water by MUNAWAR & ZAFAR (1967), while ZAFAR (1966) gives a detailed account of the morphometry and annual heat budget of a lake lying in the vicinity of Hyderabad. It is rather encouraging that most of the researchers, particularly those whose works appeared in this decade have given more attention to the physical and chemical factors operating in the waters, however their observations are not spread over a longer period.

Very little is known about the behaviour of basic elements in Indian waters. The only data available is by ZAFAR (1959, '64) who

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emphasizes the importance of PEARSALL's basic ratio (Na + K/Ca + Mg), not only in understanding the ecology of many groups of Algae but also in the classification of waters. Consequently it was felt that there is a need of investigation of Algal ecology in relation to PEARSALL's basic ratio (1932), in smaller bodies of freshwaters particularly the polluted ones.

It is surprising that N : P : K ratio, which has a significant role in the field of agriculture, has not so far been applied to Indian waters. The relationships existing between algal ecology and such important ratios like per cent Na (Na x 100/Ca + Mg + Na + K), per cent $Cl + NO_3$ $(Cl + NO_3) \times 100/(CO_3 + HCO_3 + SO_4 + Cl + NO_3)$ has not yet been explored. Very meagre information is available regarding the sulfur complex in Indian waters. The importance of all these factors in the ecology of polluted waters is too well known to be emphasized here. An attempt has been made for the first time to use per cent Na and per cent $Cl + NO_3$ as indices of pollution for the ponds studied and ecological behaviour of certain algae has also been correlated with fluctuations of these ratios. It was with these objectives that the present investigations were undertaken. The present paper includes discussions on various physico-chemical complexes of the waters studied where the elements of biological importance are discussed as components of ecological complexes and not as individual factors. This approach is probably more appropriate in view of the fact that many factors are interdependent and the variation of one, very often influences the other.

THE DESCRIPTION OF PONDS

Three freshwater ponds were selected for the investigation purposes. They lie in the vicinity of the city of Hyderabad (Andhra Pradesh) which is located between 12°40′ and 19°50′ North Latitude and 70°45′ and 84°40′ East Longitude. Andhra Pradesh lies in the Peninsular India with two principal geological formations, i.e. the Deccan traps and the Archaen rocks. The main soil groups found in the state are the laterite soils, the black soils and the alluvium.

Sewage Pond

This pond is situated north of the city of Hyderabad at a distance of approximately 10 kilometers. It is not very deep as the maximum depth rarely exceeds 3 meters. It is more or less 0.243 km^2 in surface area. It receives large amounts of sewage all the year round from the city through a canal which connects it to one of the sewage purification tanks of the Drainage Department. The pond remains practically covered with *Eichhornia crassipes* SOLMS. throughout the year and the decaying plants and the debris add to the already existing oxygen deficiency of water. During summer the anaerobic conditions of water reach their maximum and as a result large quantities of hydrogen sulphide are discharged in the atmosphere. The surrounding area becomes saturated with putrid smell especially after the dusk.

Garden Pond

This pond lies in the landscape garden of the Osmania University and is 0.0099 km^2 in surface area with overhanging thick plantation of *Casurina* and other trees. It has an artificial bund on one side and possesses a sandy basin. During the monsoon it swells up to a greater area and in the subsequent months develops an appreciable vegetation of water plants. The slopes of the basin possess luxuriant growth of *Chara* and *Nitella.*

Typha Pond

This pond is also situated in the campus of the Osmania University and has a surface area of 0.007 km^2. It does not exceed a meter in depth. The basin is rocky with very meagre deposition of silt. Its main source of water supply is a freshwater well which does not dry up in summer. The Angiospermic vegetation mainly consists of *Typha angustata* B. and Ch. *Eragrostis* sp. and *Fimbristylis* sp.

METHODS

Samples of surface water for chemical analysis were collected from each pond at the interval of about 30 days in pyrex flasks of 2 liters capacity which were tightly corked. Samples for the estimation of gases and silica were collected in thermos flasks and polythene bottles respectively. Great care was taken to guard these samples against undue shaking and exposure to the atmosphere during transport. Certain factors were immediately analysed, after they were brought to the laboratory. They were kept in a cold storage room throughout the period required for chemical analysis. In the chemical analysis of water, the following methods were adopted:

1. Carbonates (WILCOX & HATCHER, 1950), Page 15, para 16.
2. Bicarbonates (WILCOX & HATCHER, 1950), Page 15, para 16.
3. Freecarbon dioxide (DICKINSON, 1960), Pages 34–35.
4. Free ammonia (APHA, AWWA, WPCF, 1962), Pages 168–171 (Distillation Method).
5. Nitrites (MACKERETH, 1957), Pages 19–20. Modified Greiss Illosvoy Method.

6. Nitrates (Wilcox & Hatcher, 1950), Pages 16—17, paras 23 & 24 (Phenoldisulphonic acid Method) and comparisons were made in Nessler cylinders.
7. Albuminoid ammonia (APHA, AWWA, WPCF, 1962), Page 166 (Distillation Method).
8. Sulphates (Wilcox & Hatcher, 1950), Page 16, para 19. Precipitate was ignited and kept in a muffle furnace at 800°C for one hour. Platinum crucible was used.
9. Total sulphides (APHA, AWWA, WPCF, 1962), Page 331 (Titrimetric Method).
10. Phosphates (Wilcox & Hatcher, 1950), Pages 19 & 20, paras 31 & 32 (Chapman's Modification of Truog and Meyer Method). Nessler cylinders were used.
11. Silicates (Mackereth, 1957), Page 22 (Atkin's Modification of Dienert & Wandenbulcke's Method). Nessler cylinders were used.
12. Chlorides (Wilcox & Hatcher, 1950), Page 15, para 17.
13. Calcium (APHA—1947), Page 60 (Volumetric-oxalate Method).
14. Magnesium (Wilcox & Hatcher, 1950), Page 33, paras 54 & 55 (Gravimetric Method).
15. Sodium (APHA, AWWA, WPCF, 1962), Pages 232—234 (Gravimetric Method).
16. Potassium (Wilcox & Hatcher, 1950), Page 34, para 57. Gravimetric, trisodium-cobaltinitrite modified procedure.
17. Total Iron (Apha—1947), Pages 53—54 (Colorimetric-thiocyanate Method), employing Nessler cylinders.
18. Oxidizable organic matter. (Thresh, Beale & Suckling, 1944), Page 235. Estimations were made on 100 ml. aliquot kept for 4 hours at 40°C.
19. Dissolved oxygen (Mackereth, 1957), Page 1 (Winkler's Modified Method).
20. Total residue (Total solids), (APHA, AWWA, WPCF, 1962), Pages 213—214. Residue was not ignited. It was dried at 103—105°C for one hour.
21. pH. pH was measured with Lovibond Comparator.
22. Water temperature. The average of the surface temperatures taken in five different positions.

Derived factors

23. C/N = Oxidizable organic matter/Albuminoid ammonia.
24. % $Cl + NO_3 = (Cl + NO_3) \times 100/(CO_3 + HCO_3 + SO_4 + Cl + NO_2)$.
25. Inorganic nitrogen/Organic nitrogen =
    $(NO_3 - N) + (NO_2 - N) + (NH_3 - N)/(Alb\ NH_3 - N)$.
26. Basic ratio = Na + K/Ca + Mg.
27. % Na = Na × 100/Ca + Mg + Na + K.
28. N : P : K = Nitrogen : Phosphorus : Potassium.

A few meteorological factors have also been incorporated in the present data. The fortnightly averages of maximum, minimum air temperatures, rainfall, wind speed and hours of bright sunshine, were calculated from the data supplied by the Begumpet Meteorological Station, situated about 6 kilometers from the Osmania University campus.

The samples of water for chemical analysis were collected every month while the algal samples were taken fortnightly from each pond. A bottle of about 2 litres capacity was filled with surface water from several selected sampling stations of the ponds in an effort to obtain a representative sample. The filamentous masses of algae were avoided from entering into the sampling bottles by covering their mouths with cotton gauze. The plankton samples were preserved by adding sufficient quantity of formalin and wre sedimented as suggested by WELCH (1948) in glass columns of 25e mm diameter for 15 days. Later these samples were transferred and sedimented again in glass columns of 15 mm in diameter, to finally concentrate the phytoplankton population. Frequency of an algal form in a sedimented sample was calculated by counting its individuals occurring in 0.05 ml under the higher magnification of a microscope (REICHERT, 400-magnification). This formed the basis for enumeration of organisms per litre of the original sample. As the waters were found to be very rich in plankton it was decided to express the final results as "the numbers occurring in one ml of the original sample".

THE BIOTOPE

Temperature

The climate of Hyderabad city is more or less dry and consists of three distinct seasons, i.e. Summer, Monsoon and Winter. Summer commences from the last week of February and continues till the end of May and is characterised by high atmospheric temperature, bright sunshine and longer days. The Monsoon season starts from June and lasts till the first week of October. In these months sky is usually cloudy and atmosphere humid. The atomospheric temperature in rainy months is moderately high with frequent fast winds. October to January are the Winter months which record low temperature with cloudless sky. The air is comparatively dry and the sunshine is bright but its duration is reduced due to shorter days. Summer and winter seasons also experience some showers which are irregularly distributed and are brought by cyclones or by north-east winds.

Temperature in relation to various physico-chemical factors

In the present data water and air temperatures go more or less hand in hand (Figs. 1, 2, 3). Similar observations have been made by RICE (1938), RAO (1955) and ZAFAR (1955). Obviously this is due to the smaller masses of water involved in all these investigations. It is well known (WELCH, 1952) that the smaller the body of water the more quickly it reacts to the change in the atmospheric temperature.

One may expect a direct relationship between bright sunshine, its duration and air temperature in the tropical countries. The present data suggests such a relationship (Figs. 1, 2, 3). It is also evident that the duration of sunshine and temperature influence the percentage of soluble gases in water particularly that of carbon dioxide and oxygen. Possibly longer hours of sunshine provide an opportunity to the phytoplankton and the angiosperm population in ponds to photosynthesize for a longer duration. This will obviously help in the depletion of carbon dioxide in water. However, summer temperatures which are closely associated with the bright sunshine, accelerate the process of decay of organic matter and large quantities of carbon dioxide are added to it. Thus apparently over-all gain of carbon

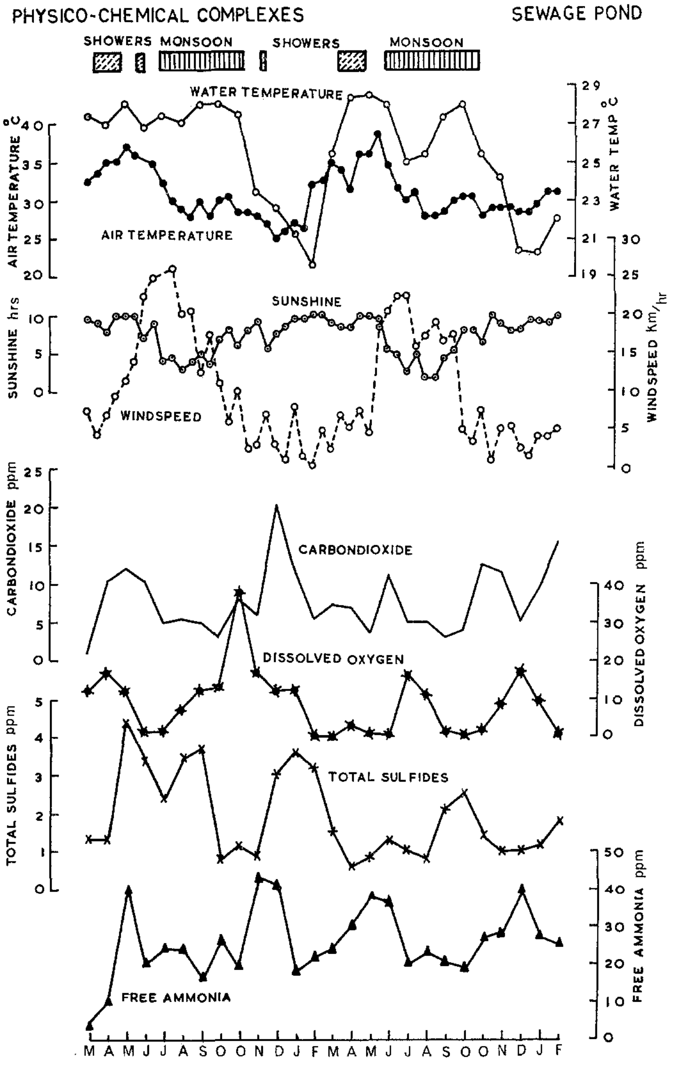

FIGURE I

dioxide is more than its loss in photosynthesis in these waters in summer. It is also interesting that even in winter months carbon dioxide accumulates in quite large quantities in these waters. These months are characterized by shorter periods of bright sunshine and the plankton population is thicker than that in summer. It may be that the shorter periods of sunshine result in the photosynthetic activity for shorter durations and even the thick plankton population does not remove all the carbon dioxide, which is added to the water by decaying organic matter. Therefore, the winter months also experience the

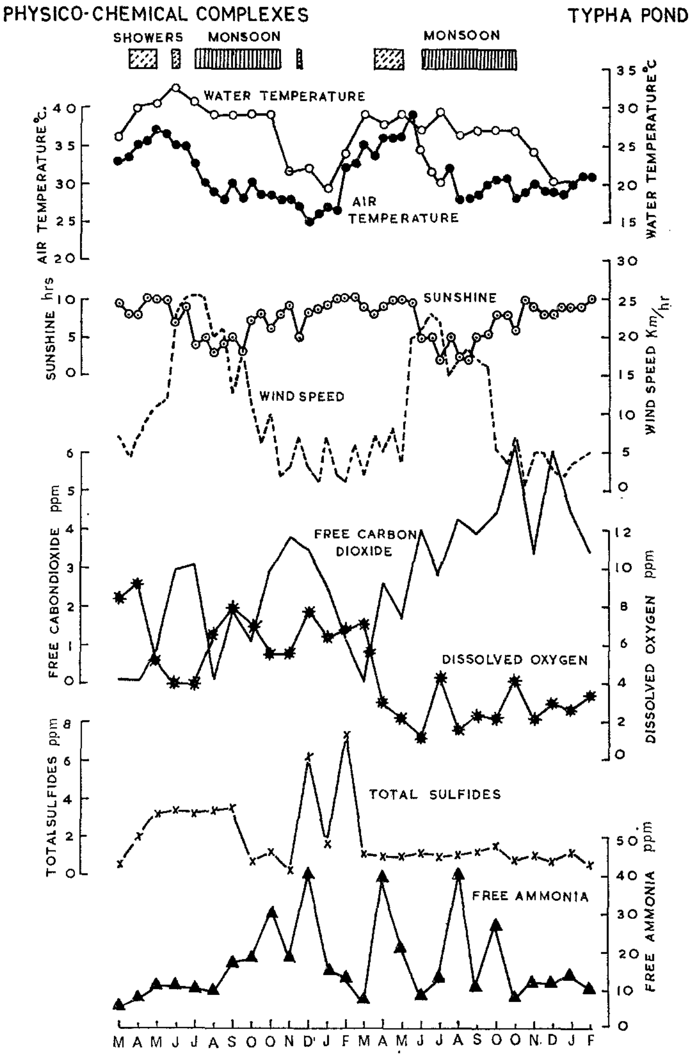

FIGURE 2

accumulation of carbon dioxide just as the summer months. (Figs. 1, 2, 3).

In the present ponds, liberation of carbon dioxide during the decomposition of bottom deposits, possibly results in the conversion of insoluble carbonate of calcium into soluble bicarbonate. This leads to the accumulation of larger quantities of calcium bicarbonate in water and the total inorganic carbon shows a distinct increase. This is more evident in summer (Figs. 4, 5, 6). Such a relationship has also been described by Ruttner (1953). Similarly longer duration of

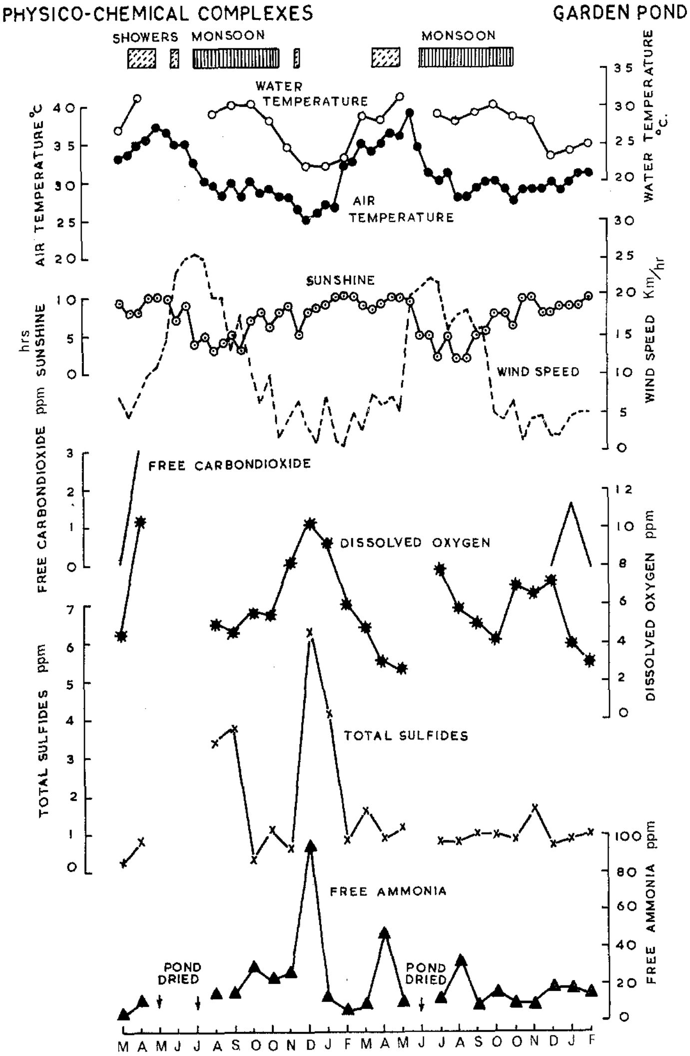

FIGURE 3

photosynthetic activities of plants in summer may bring into the water larger quantities of oxygen, a portion of which might be lost to the atmosphere as the water at higher temperature has a lesser capacity to hold it. It may also be that at higher temperatures the rate of oxidation of the organic matter in water increases and some quantity of oxygen is also used up in this process. This explains the fall of oxygen in summer in the present ponds.

In the Sewage Pond hydrogen sulphide which is reported in terms of total sulphides, accumulates in water in summer, early monsoon

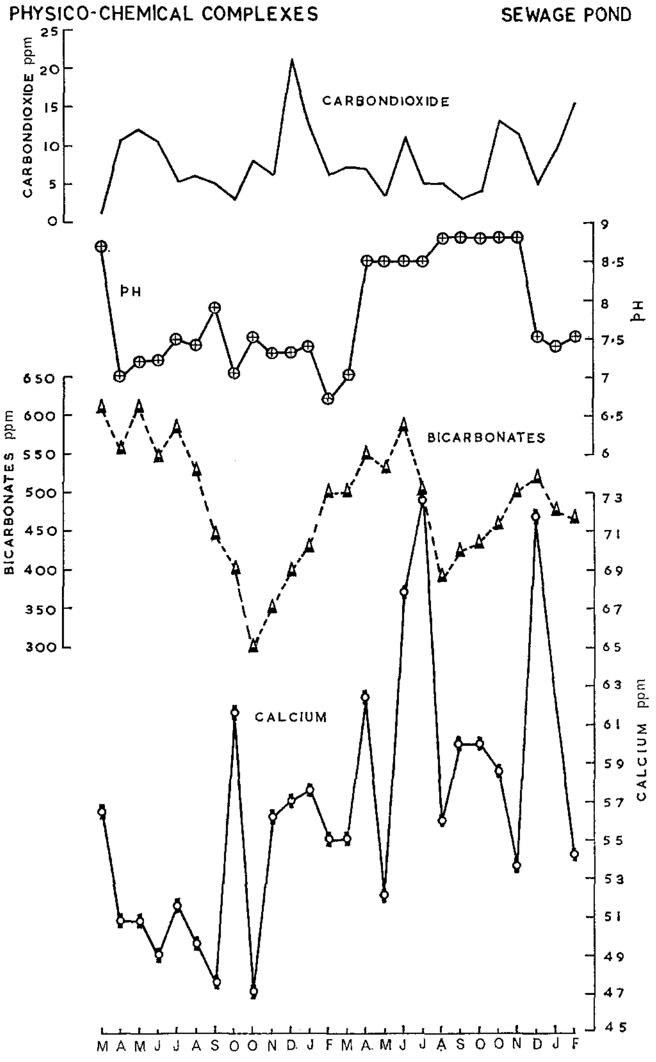

FIGURE 4

and in winter. In the Typha Pond it rises to considerable quantities in late winter and early summer whereas in the Garden Pond it is more in water soon after it gets inundated after remaining dry for about two months. Its percentage declines after the heavy showers but it increases again in winter (Figs. 1, 2, 3).

In all the ponds free ammonia is found to be more during the periods of bright sunshine and this could be attributed to the observed oxygen deficiency in water. Possibly the oxygen deficiency accelerates the activity of anaerobic bacteria which break the nitrogenous organic

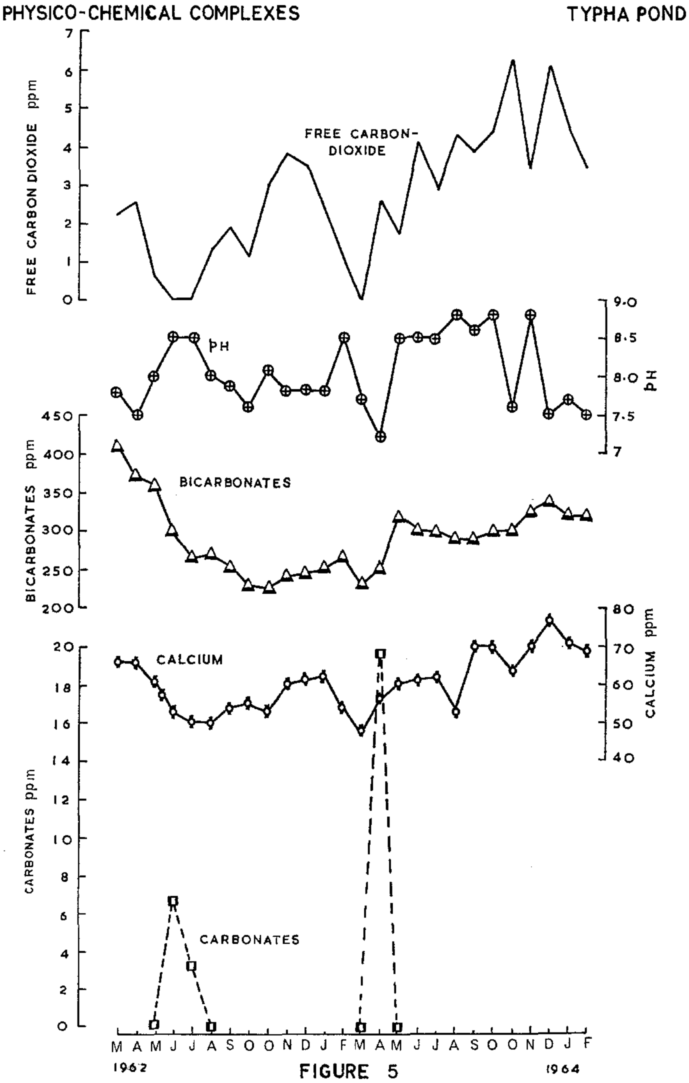

FIGURE 5

matter into ammonia. THRESH, BEALE & SUCKLING (1944) have clearly elucidated this point. PEARSALL (1923) has also recorded larger percentages of free ammonia in lake waters during the periods of low oxygen. This course of argument is further supported by the work of PIA (1933) which indicates that the denitrifying bacteria are more active at higher temperatures and, according to ATKINS (1933), the abundance of oxygen in tropical waters is detrimental to the activity of bacteria (Figs. 1, 2, 3).

In the present data percentages of oxygen, carbon dioxide, free

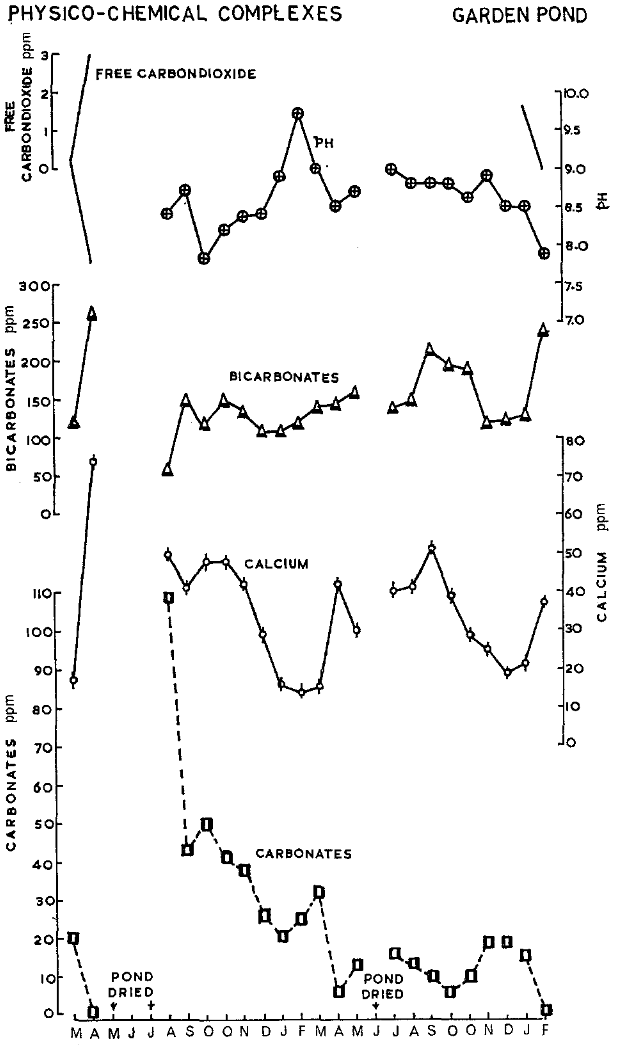

FIGURE 6

ammonia and total sulphides in water vary inversely with wind speed. It may be that the increased wind speed brings about intermixing of bottom and surface strata and this leads to the over all decrease in the percentages of gases in water.

Rainfall shows an inverse relationship to oxygen and free ammonia contents in the present data (Figs. 1, 2, 3). PEARSALL (1923) has however noted a higher oxygen content after rains in natural waters poor in plankton and organic matter. Similarly GONZALVES & JOSHI (1946) have correlated the higher percentages of oxygen with heavy rains. ZAFAR (1964) has observed an increase in the free ammonia content of pond water after rains. This indicates that the concentration of these gases in water may be due to many factors. No doubt rain water could be expected to be rich in oxygen and ammonia but their concentration in pond water will depend, apart from the physical factors, on the density of the population of various pigmented and non-pigmented organisms, rate of their photosynthesis and other metabolic processes in which these gases are directly or indirectly involved. The present data suggests a direct relationship amongst rainfall, free carbon dioxide and total sulphides. May be that with the heavy rainfall organic matter is washed in from the catchment area, the decomposition of which leads to the formation of these gases.

Oxygen and Carbon Dioxide

The inverse relationship between carbon dioxide and oxygen in freshwater bodies has been observed by WHIPPLE & PARKER (1902), BIRGE & JUDAY (1911), PEARSALL (1930), GANAPATI (1943), GONZALVES & JOSHI (1946), RAO (1955) and SAHA et al. (1959) but SINGH (1960) has observed a direct relationship between these two. However, a well marked inverse relationship could not be established in the present ponds. It may be that in deeper lakes where hypolimnion is not directly in contact with atmosphere, the existence of such a relationship is explainable, but in the shallow bodies of water, the concentration of these gases is possibly controlled by the physical laws of diffusion of gases into liquids and the rate of various metabolic activities of the biotic community. As these processes are influenced by temperature and light intensity, the concentration of the gases will be different in the same body of water at different times of the day. Hence it will be difficult to establish an indirect relationship between these gases in smaller bodies of freshwater.

Carbon Dioxide and the Buffer System

Carbon dioxide appears to be an important component of the buffer system of these waters. The concentration of carbonates, bicarbonates and calcium are influenced by the presence or absence of this gas and following generalisations hold true for ponds under discussion (Figs. 4, 5, 6).

1. Waters rich in carbon dioxide are comparatively less alkaline (Sewage and Typha ponds; pH 6.7 to 8.8) whereas waters deficient in this gas are more alkaline (Garden Pond; pH 7.8 to 9.7). Similar observations have been made by ATKINS (1926), PEARSALL (1930), HOWLAND (1931), PRINGSHEIM (1946), RAO (1955) and ZAFAR (1964). On the other hand, SINGH (1960) claims that the "high alkalinity of sheets of water is maintained and does not seem to be affected by either oxygen or carbon dioxide". However free carbon dioxide was present in Sewage and Typha ponds throughout the period of observation but it was detectable only twice in the Garden Pond. The pH of Sewage and Typha ponds fluctuated from 6.7 to 8.8 and 7.2 to 8.8 respectively whereas in the Garden Pond it is from 7.8 to 9.7. This indicates that the carbon dioxide influences the pH of water.

2. The bicarbonate content of water fluctuates directly with calcium and both of these vary more or less inversely with carbonates and pH (Figs. 4, 5, 6). The direct relationship between bicarbonates and calcium has been observed by PEARSALL (1930) and ZAFAR (1964) whereas the inverse relationship between bicarbonates and carbonates has been noted by GANAPATI (1940). ZAFAR (1964) has shown an inverse behaviour of bicarbonates towards carbonates and pH in certain fish ponds.

The above mentioned relationships between pH, carbonates, bicarbonates, calcium and carbon dioxide may be interpreted on the basis of dissociation of these into ionic state. Free carbon dioxide in water forms carbonic acid (H_2CO_3) which dissociates into H^+ and HCO_3^- ions. This brings a change in the pH of water (RUTTNER, 1953) as hydrogen ions are set free. HCO_3^- reacts with calcium to form calcium bicarbonate which is soluble in water. If at this stage free carbon dioxide is not available calcium bicarbonate gets converted into insoluble calcium carbonate and is lost to the water. However, if carbon dioxide is in surplus, calcium can be retained in solution in the form of calcium bicarbonate. That amount of carbon dioxide which inhibits the conversion of bicarbonates into carbonates is named 'equilibrium carbon dioxide' by RUTTNER (1953). This explains clearly that the concentration of carbon dioxide in water which depends on temperature to a great extent, controls the pH and concentrations of bicarbonates, carbonates and calcium.

Sodium and Chlorides

GONZALVES & JOSHI (1946) and SINGH (1960) have noted that chlorides increase in summer and decrease in winter. Similarly ZAFAR (1964) has recorded a marked rise in chloride content in summer in one of the fish ponds investigated. The present data confirms such an increase in summer in all the three ponds (Figs. 7, 8, 9).

It is interesting to note that the present ponds differ markedly in the yearly averages of the chloride content. Sewage pond records the highest values while the Garden Pond gives the lowest. Typha Pond occupies a middle position. THRESH, BEALE & SUCKLING (1944) suggest that higher chloride content of water is an index of pollution of animal origin and it may be therefore logical to assume that the Sewage Pond receives contamination of this type. This

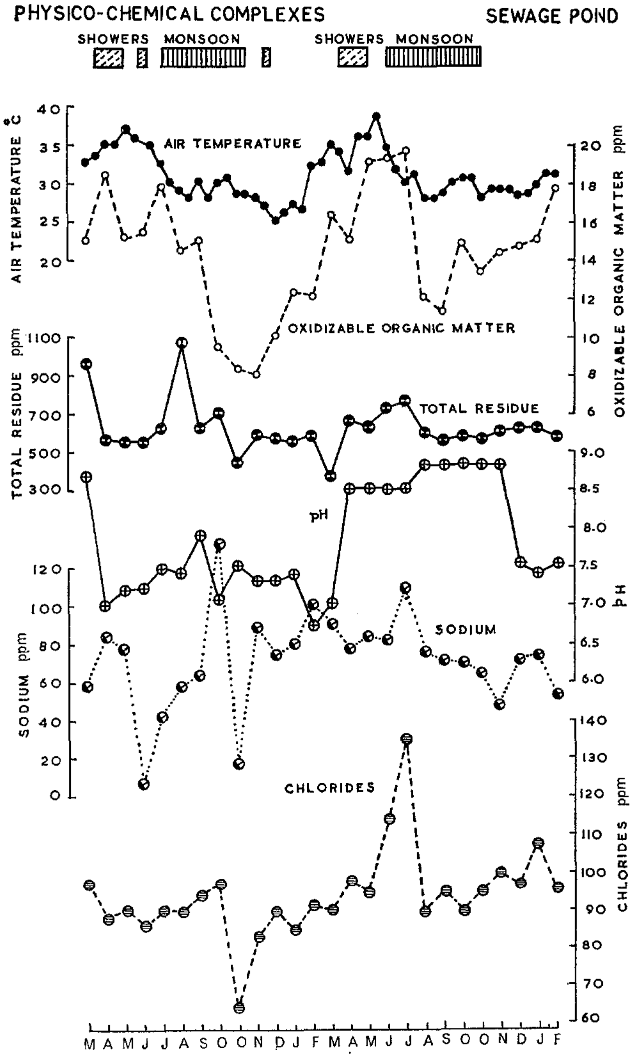

FIGURE 7

argument is further supported by the fact that this pond shows highest values of nitrates, nitrites, free ammonia and oxidizable organic matter which are generally associated with the pollution of animal origin (Table I). Furthermore, Sewage and Garden ponds are more or less similar in the percent sodium which is a ratio derived with the following formula:

$$\mathrm{Na} \times 100/\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na} + \mathrm{K}$$

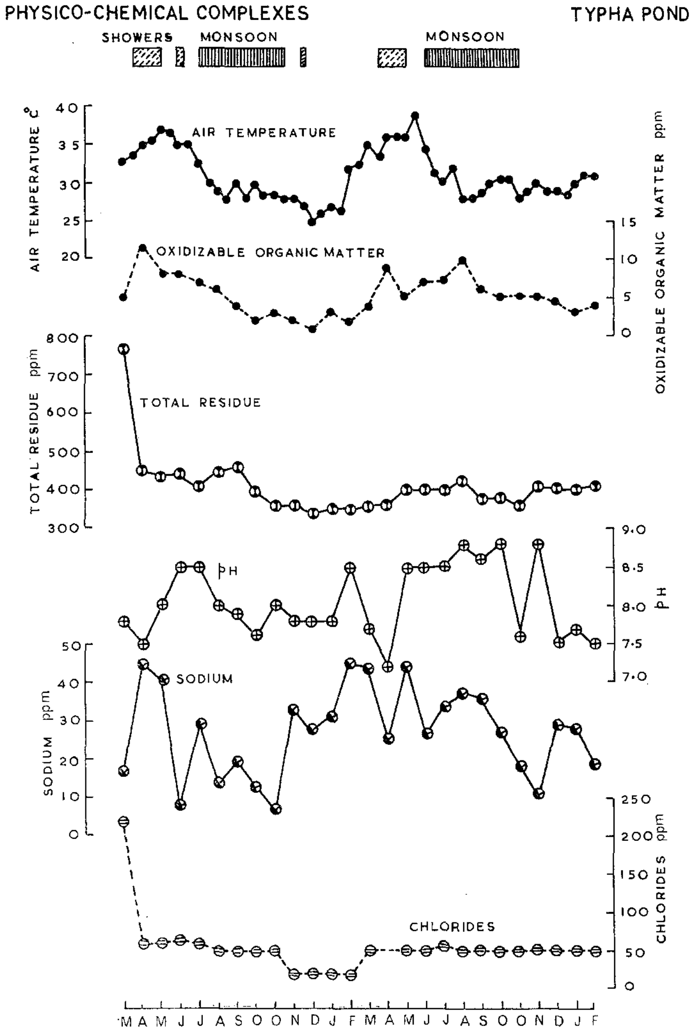

FIGURE 8

TABLE I

Averages of certain chemical factors in all the ponds.

Factors as ppm	Average for both the years		
	Sewage	Typha	Garden
Nitrates	1.26	0.54	0.64
Nitrites	0.019	0.0001	0.025
Free ammonia	26.11	15.31	20.34
Oxidizable organic matter	15.16	6.44	6.94

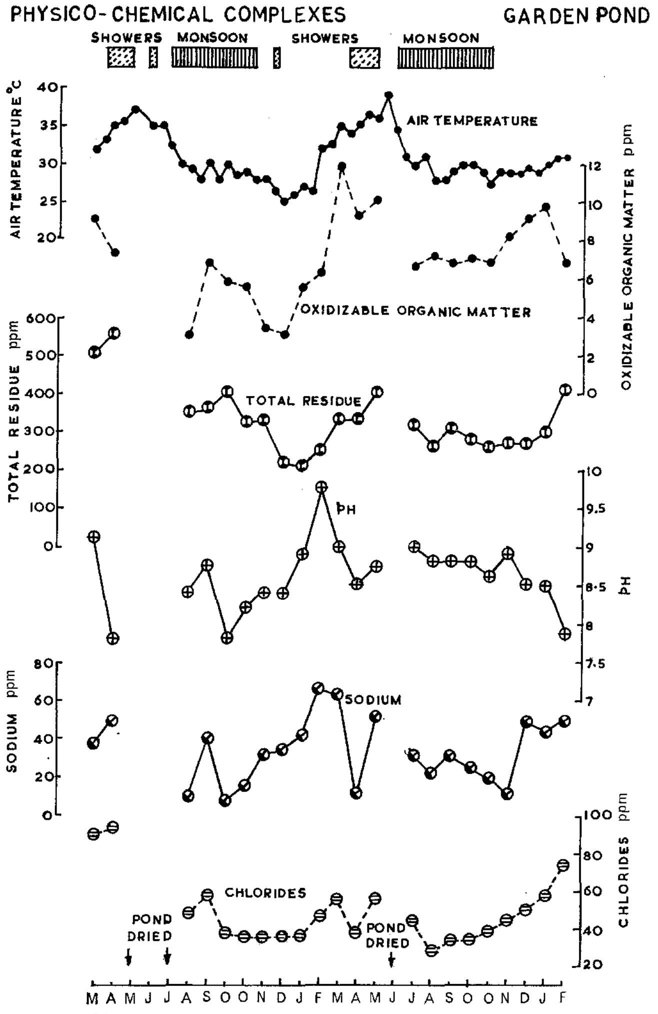

FIGURE 9

TABLE II

Averages of percent Na and percent Cl + NO_3 in all the ponds.

	Sewage		Typha		Garden		Average for both the years		
	1962–63	1963–64	1962–63	1963–64	1962–63	1963–64	Sewage	Typha	Garden
%Na	36.31	34.50	21.35	22.25	34.65	38.76	35.40	21.80	36.70
%Cl + NO_3	21.64	23.16	20.35	21.30	24.12	21.86	22.40	20.82	22.99

The averages for percent sodium of Typha Pond differ markedly from those of the other two (Table II). Therefore one may treat the value of this ratio as an index of organic pollution.

Another ratio i.e. percent Cl + NO_3 as calculated with the formula $(Cl + NO_3) \times 100/(CO_3 + HCO_3 + SO_4 + Cl + NO_3)$ appears to be a good index of organic pollution. The present ponds differ considerably in this respect and the monthly fluctuations of this ratio throw light on the ecology of certain classes of algae (Table II).

Sodium and chloride show a direct relationship in their monthly variations in all the ponds under present investigation (Figs. 7, 8, 9), which is in accordance with the findings of ZAFAR (1964).

Temperature and Other Solids

According to KRAUSE (1962), changes in temperature in any type of natural water can influence the speed and the course of decomposition of organic matter. GONZALVES & JOSHI (1946) also found warm and longer sunshine days more favourable for the concentration of oxidizable organic matter whereas ZAFAR (1964) records an increase in organic matter in summer in one of his ponds while after rains in another. RICE (1938) also found a direct relationship between flood rains and organic matter.

In the present data a direct relationship exists between air temperature and oxidizable organic matter. In Sewage Pond, it gradually increases with the rise of atmospheric temperature and attains a definite peak in summer. It falls to a minimum in winter. There are also indications that oxidizable organic matter increases after early showers and its percentage goes down when the heavy rains set in. It may be that with the early showers the surface run-off washes into the pond, organic matter from the catchment area but the subsequent showers dilute it.

More or less similar pattern of fluctuations with respect to the oxidizable organic matter are noted for Typha Pond but it is interesting that even heavy rains do not dilute its water. This may be be-

TABLE III

Seasonal fluctuations in total cations.

	Sewage		Typha		Garden	
Total cations ppm	1962–63	1963–64	1962–63	1963–64	1962–63	1963–64
Summer	782.53	1020.93	534.84	526.70	215.10*	344.07
Monsoon	644.35	659.06	321.05	449.43	293.38	304.75
Winter	688.92	691.05	422.31	431.24	316.97	318.41

*This is a departure from the expected values as the pond had dried up.

cause the catchment area is covered by a thick growth of angiospermic vegetation providing a continuous supply of organic matter all through the rainy season.

In Garden Pond the behaviour of oxidizable organic matter is essentially similar to that of the above discussed pond but its rise and fall are rather abrupt. This is possibly because it dries up in summer.

It is likely that the process of conversion of suspended organic matter into soluble form is accelerated with the rise of temperature. This results in the accumulation of large quantities of oxidizable organic matter in water. Consequently free carbon dioxide evolving during this process brings about all those changes in water which have been discussed earlier. One may accordingly expect higher values of total cations (Ca, Mg, Na, K) when the decomposition of organic matter is going on and the water temperature is high. The present data exhibits a marked rise in the values of total cations in water in summer (Table III).

ATKINS & HARRIS (1924), GANAPATI (1943) and ZAFAR (1946) observed an inverse relationship between total residue and pH while GANAPATI (1940) records them to vary directly. According to FRITSCH (1931) and RAO (1953) the alkaline ponds are richer in dissolved solids as compared with the acidic ones. In the present data less alkaline ponds have more total residue as compared to those which are highly alkaline. This is apparent both in their monthly fluctuations and the yearly averages (Table IV).

TABLE IV

Total averages of total residue in all the ponds.

	Average for both the years		
	Sewage	Typha	Garden
Total residue ppm.	625.30	409.80	335.70
pH	7.80	7.70	8.58

Organic Matter and Allied Factors

Oxidizable organic matter shows a direct relationship to magnesium and pH but is inversely related to oxygen, iron and albuminoid ammonia in these waters (Figs. 10, 11, 12). It is known that organic matter exists in soluble, insoluble and colloidal forms (James, 1941; Saunders, 1957). In temperate regions the particulate organic matter undergoes decomposition in summer when water temperature is more suitable for the bacterial activity. In tropics, however, one may expect the decomposition to continue throughout the year, although

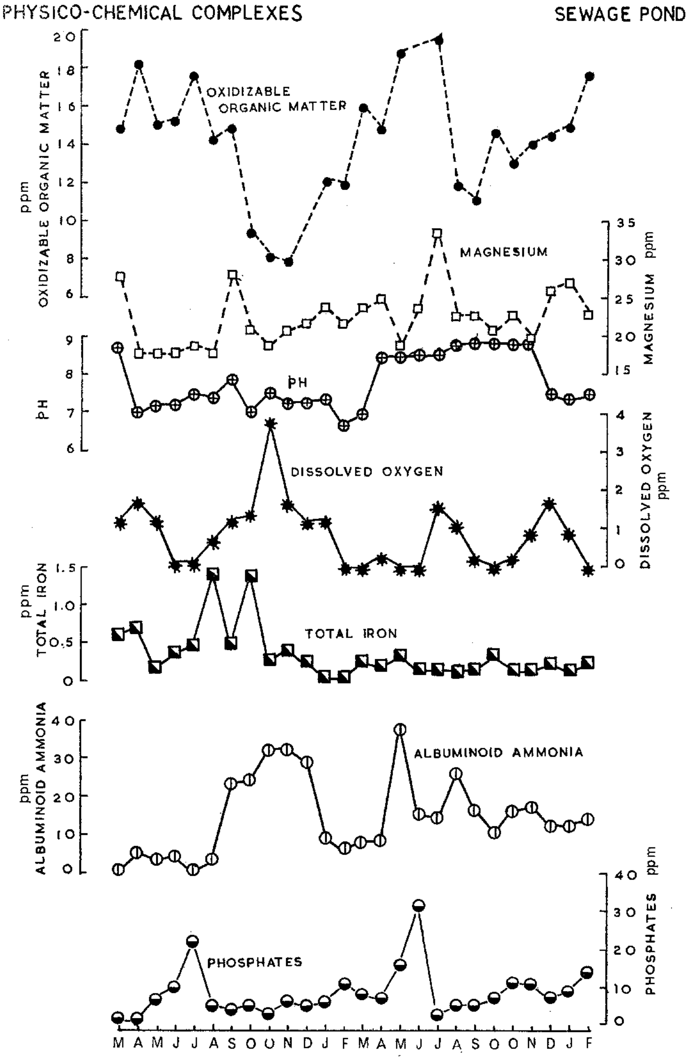

FIGURE 10

it may get accelerated in summer. Possibly this is the reason that these waters, exhibit higher concentrations of oxidizable organic matter throughout, reaching a peak in summer (Figs. 10, 11, 12).

In the present ponds a positive relationship exists between oxidizable organic matter and pH, similar to that observed by Zafar(1964). It can be interpreted on the basis of the accumulation and interaction of the products of decomposition of organic matter. According to Welch (1952) free carbon dioxide and hydrogen sulphide are produced during decomposition of organic matter and Foster (1951)

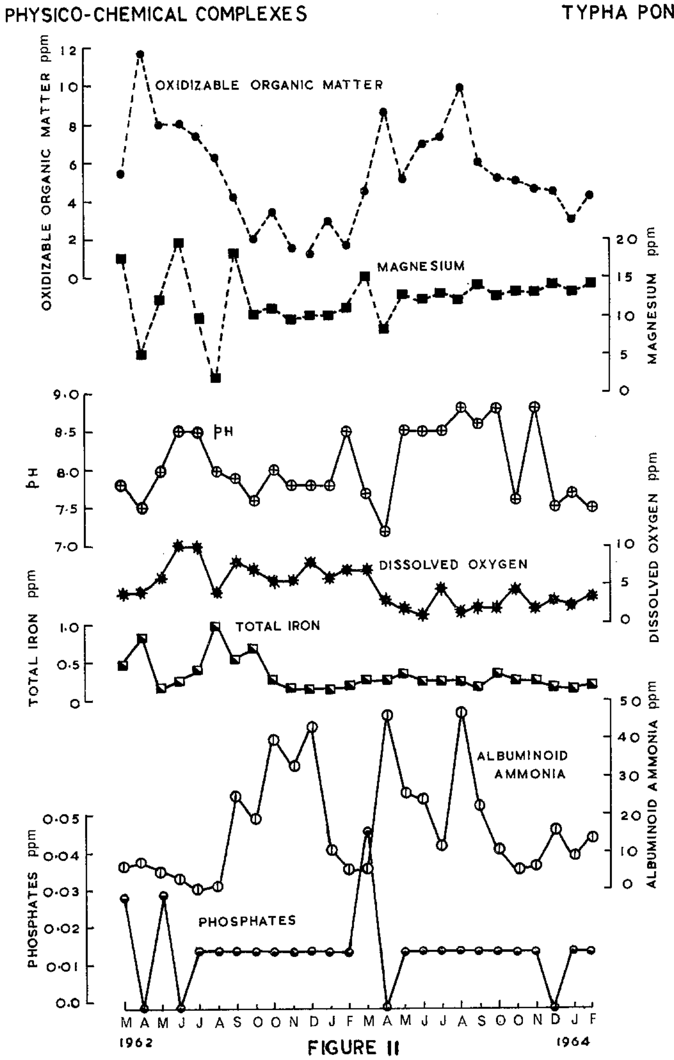

FIGURE 11

believes these to react in the presence of sulphur bacteria to produce sulphuric acid.

$$2CO_2 + H_2S + 2H_2O \text{ light } 2(CH_2O) + H_2SO_4$$

Even if one makes an allowance for a part of the acid to be neutralized by the calcium salts, the remaining will bring a change in the pH and will consequently be responsible for converting the insoluble organic matter into soluble. Conversely when active decomposition of dissolved organic matter is not going on, the pH of water may not change and remain high as in the present ponds. This explains to some

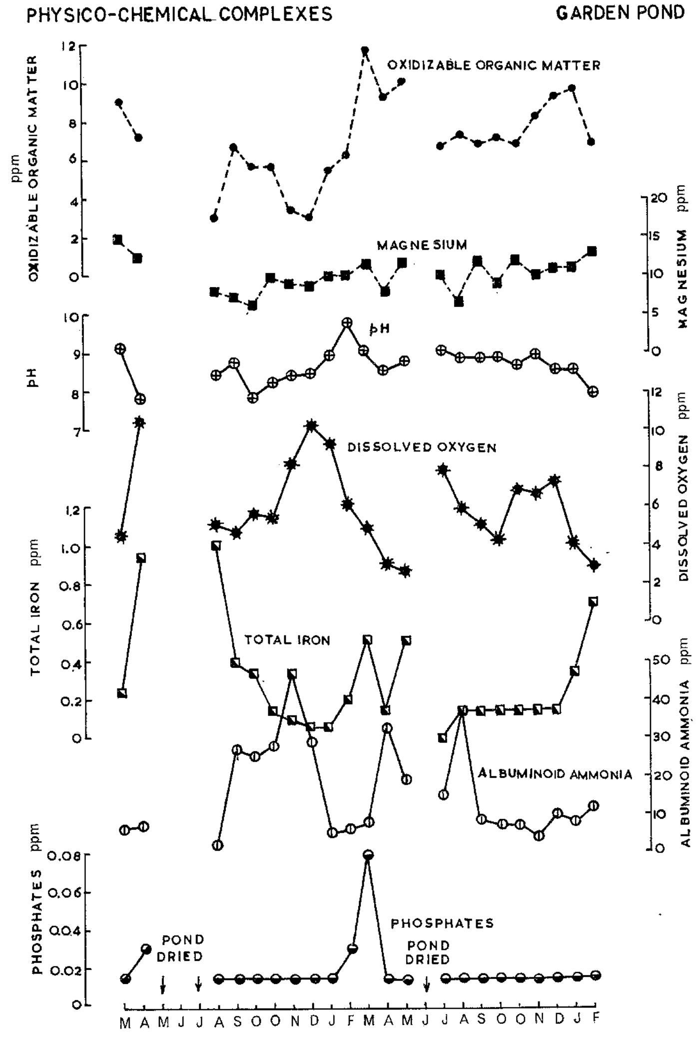

FIGURE 12

extent the observed direct relationship of pH and organic matter in these ponds.

The relationship of iron and organic matter in water has been discussed by a number of limnologists. Of particular interest are the works of OHLE (1935, 1937), IVLEV (1937), EINSELE (1936, 1937, 1938) and MORTIMER (1941—1942). It has been established that iron and organic matter are interrelated. An inverse relationship exists between oxidizable organic matter and iron in the present data. It is likely that as the organic matter is decomposed the waters become more acidic due to the liberation of carbon dioxide and this fall in pH brings in more soluble iron. This is in accordance with the views of USPENSKY (1927) who has established that the acidic waters are capable of holding a greater quantity of iron.

ZAFAR (1964) has noted a direct relationship between magnesium oxidizable organic matter which is also evident from the present data. As discussed earlier, waters become less alkaline when more quantities of carbon dioxide are produced during the decay of organic matter which is expected to convert both calcium and magnesium carbonates into soluble bicarbonates. The present data show that as compared to magnesium the percentage of calcium is markedly high in all the ponds. It may be that carbon dioxide reacts more readily with calcium salts than with the magnesium salts and converts larger quantities of calcium into soluble bicarbonates. This preferential behaviour of carbon dioxide is possibly responsible for comparatively low percentages of magnesium in alkaline waters (Table V).

TABLE V

Total averages of calcium and magnesium.

	Average for both the years		
	Sewage	Typha	Garden
Calcium ppm	56.56	59.96	35.15
Magnesium ppm	22.76	11.99	10.10

Several workers have correlated dissolved oxygen and oxidizable organic matter in fresh waters. GANAPATI (1943) observed the paucity of oxygen in waters when organic matter undergoes decomposition. SINGH (1960) has also noted an inverse relationship between oxygen and organic matter. Such a correlation is present in all the three ponds under present observation, both in monthly fluctuations and the yearly averages. Thus the interpretation that oxygen is utilized in the oxidation of organic matter, completely fits into the present data.

The relationship between organic matter and albuminoid ammonia has been discussed by various workers. DREW (1914) finds a direct relationship between the two whereas GONZALVES & JOSHI (1946) and RAO (1949) correlate them during the summer months only. ZAFAR (1964) has noted an inverse relationship between these two, and the present data confirms it. As pointed out by ZAFAR (1964), albuminoid ammonia is a measure of readily available nitrogenous organic matter in water, the character and concentration of which influences the rate of bacterial activity. TAYLOR (1949) concludes that "supply of readily available organic matter is the factor which controls primarily the activity of bacteria in lake waters". It may be that albuminoid ammonia increases the activity of bacteria which simultaneously decompose the dissolved organic matter releasing more carbon dioxide in these ponds. Therefore when albuminoid ammonia increases, the rate of decomposition of organic matter gets accelerated to such an extent that the concentration of organic matter in pond water decreases. Consequently such conditions deflect the pH towards acidity and a direct relationship between pH and dissolved organic matter, as discussed earlier, confirms this relationship.

Phosphates

WELCH (1952) and RUTTNER (1953) have reported smaller amounts of phosphorus in waters free of contaminating effluents. HUTCHINSON (1957) also reports the increase of phosphorus as a result of sewage contamination. In the present data, Typha and Garden Ponds which are comparatively free of any contamination show lower concentration of phosphates but the Sewage Pond has larger quantities of phosphates (Figs. 10, 11, 12).

In the present data an interesting correlation exists amongst phosphates, iron and dissolved oxygen. Monthly fluctuations in phosphates are almost identical to those of iron in the Sewage Pond (Fig. 10). EINSELE (1936) has observed similar relationship between phosphorus and iron in certain eutrophic lakes. He states that ferrous iron and phosphates react together in the presence of oxygen in alkaline medium and form ferric phosphate, which is insoluble in water. Furthermore, if ferrous iron is still in excess, ferric hydroxide is formed, which is also insoluble in water. Both these compounds are deposited in the sediments of the lakes, thus carrying the phosphates of lake water to its bottom. On the other hand when there is a lack of oxygen in the sediment, the iron is reduced from the ferric to the ferrous state releasing phosphorus into water. One can expect this behaviour of phosphorus and iron more pronounced in contaminated waters with sewage or agricultural effluents because they are low in oxygen. Therefore during oxygen deficiency of the present pond, phosphorus is expected to be released in water from the bottom mud. Sewage pond exhibits this phenomenon quite clearly.

Sulphur Complex

Sulphates and sulphides increase considerably in pond water after the rains (Figs. 13, 14, 15). This may be because the surface run-off brings into the pond more suspended solids along with organic matter and soluble salts from the catchment area. Possibly some portion of sulphates is reduced to sulphides which dissociate in water

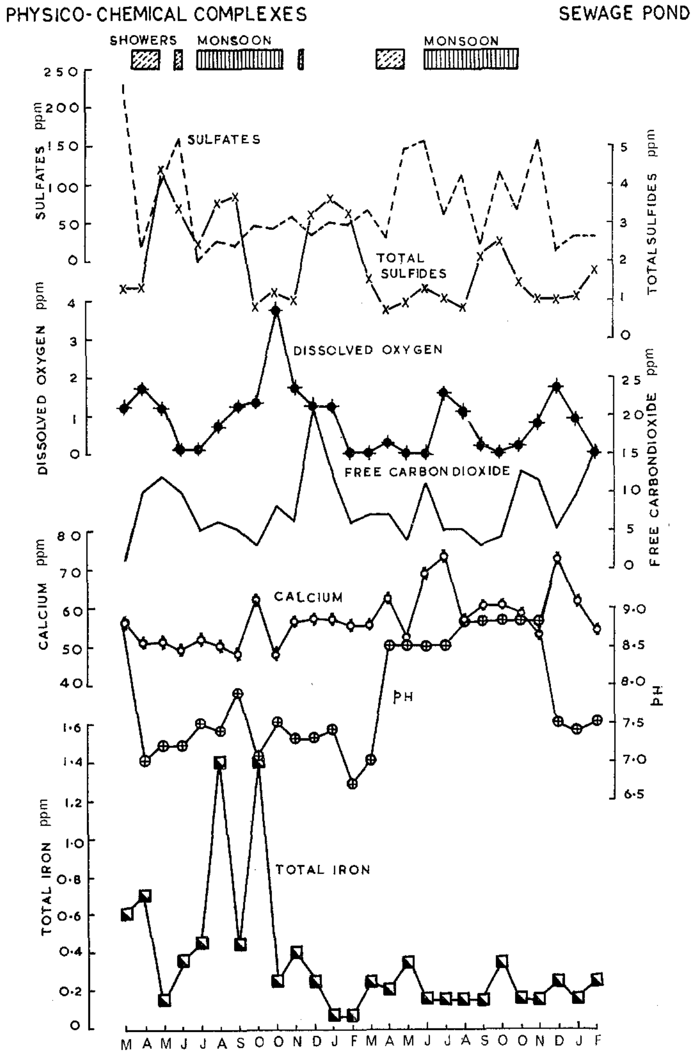

FIGURE 13

gradually. This explanation is more understandable in the light of RUTTNER's (1953) statement that a large amount of hydrogen sulphide is produced due to the reduction of sulphates in freshwaters. VAMOS (1964) also thinks that besides the protein decomposition, reduction of sulphates also results in the production of hydrogen sulphide.

It seems that oxygen, carbon dioxide and total sulphides are interrelated in these ponds (Figs. 13, 14, 15). Whenever oxygen deficiency prevails, carbon dioxide and total sulphides increase. There is every possibility that during oxygen deficiency anaerobic bacteria

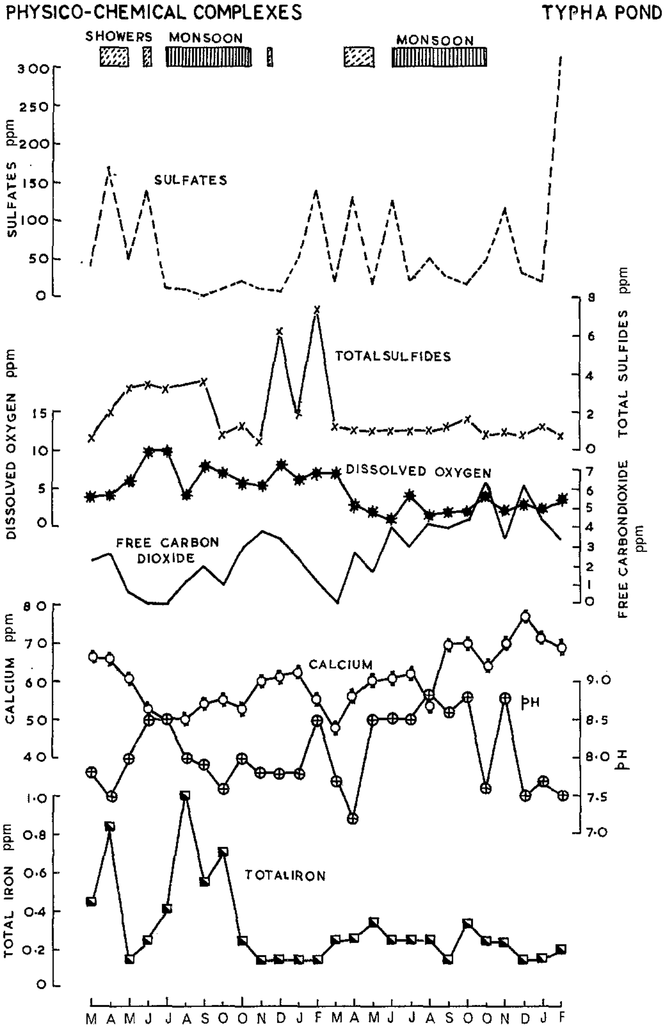

FIGURE 14

become more active in the decomposition of organic matter. Carbon dioxide and hydrogen sulphide thus released at the bottom get diffused in the entire mass of water. This is supported by the observation of WELCH (1952) who concludes that hydrogen sulphide first appears at the bottom due to the prevailing anaerobic conditions there and it is a product of anaerobic decomposition of water containing sulphur. HUTCHINSON (1957) has made similar remarks.

Sulphates and sulphides do not show uniform behaviour in all the ponds. They vary more or less inversely in Sewage and Typha ponds

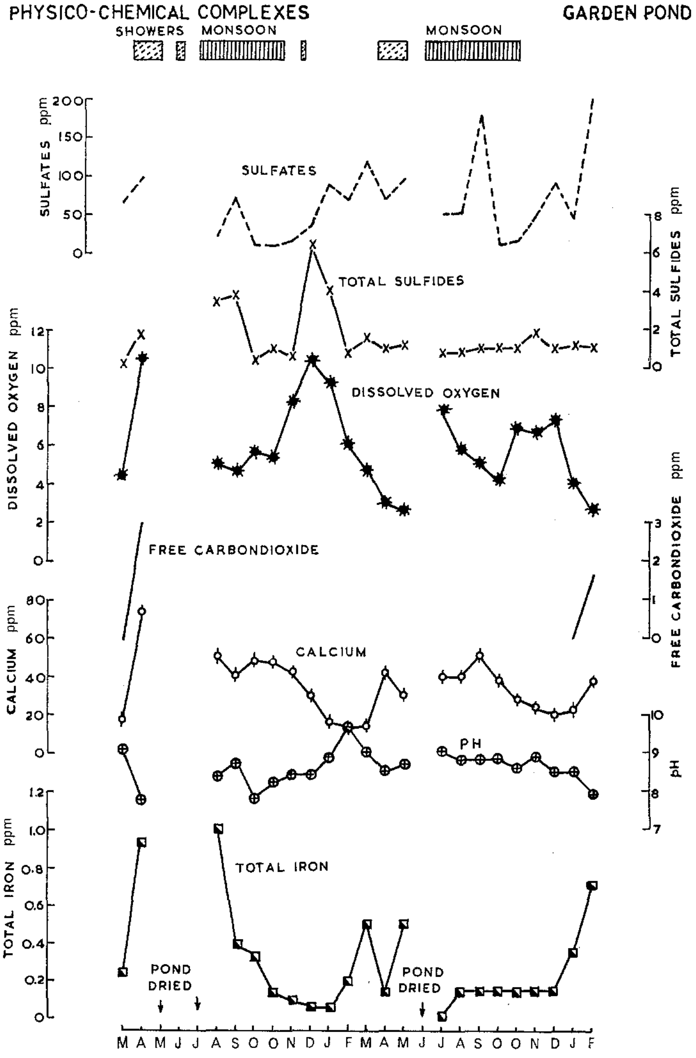

FIGURE 15

(Figs. 13 & 14), while in the Garden, their fluctuations are almost identical (Fig. 15). This disparity is expected in the light of various reactions involved in the conversion of sulphates to sulphides and vice versa which are reversible and brought about by bacteria. Furthermore, as suggested by HUTCHINSON (1957), reduction of sulphates may be direct or indirect. In the direct course sulphate is utilized as a hydrogen accepter by anaerobic and heterotrophic bacteria in the metabolic oxidation. In the indirect process sulphates are absorbed by autotrophic and heterotrophic bacteria and are utilized to form amino acids such as cystine, methionin etc. containing - SH group. It is reduced during assimilation and the heterotrophic bacteria ultimately liberate it in the medium in the form of hydrogen sulphide. It may also be interesting to note that *Chromatium okenii* was present in this pond which is one of the microbes that oxidize hydrogen sulphide. Thus sulphides and sulphates in water may be regarded as components of a complex and fluctuate in relation to the activity of autotrophic and heterotrophic bacteria. It is also known that the phytoplankton draws sulphur from the medium for the production of protein but the quantities involved in this process are probably very small.

It is also interesting that sulphates exhibit more or less inverse relationship with calcium, pH and iron (Figs. 13, 14, 15). This indicates that the sulphur content is dependable to some extent on the buffer system of water. Since free carbon dioxide controls the buffer system, it is likeley that the entry of sulphur into water partly depends on the concentrations of free CO_2. This interpretation becomes more important in view that the entry of iron in water is also linked with the free carbon dioxide content. Therefore iron and carbon dioxide exhibit a somewhat similar behaviour towards sulphur. VAMOS (1964) has shown that hydrogen sulphide in water-logged soils forms ferrous sulphide. But in the presence of free carbon dioxide in water some of the ferrous sulphide may get converted into ferrous bicarbonate which is soluble. Such a probability has been discussed by RUTTNER (1953) and HUTCHINSON (1957) for lake waters. Consequently one may expect diurnal fluctuations of these elements in surface waters depending upon the presence or absence of free carbon dioxide.

Silicates

ATKINS (1926) concludes that the silica content of freshwaters is influenced by temperature and evaporation. In the present ponds a direct relationship exists between silica and atmospheric temperature (Figs. 16, 17, 18). It might be that silica accumulates in water in summer partly because the diatoms, which are the main consumers of this element, are comparatively less in the summer plankton whereas in winter the demand for silica increases manifold due to the increase in the diatom population. RUTTNER (1953) refers to a major decrease in dissolved SIO_2 in the epilimnion after a bloom of Diatoms. These data also suggest an inverse correlation between silica and carbon dioxide. Possibly, as silicic acid is more weakly dissociated than carbon dioxide, it is removed from its strongly hydrolyzed compounds – the silicates, in the presence of carbon dioxide or bicarbonates and is then held in the water as free silicic acid in a dissolved or colloidal form (RUTTNER, 1953). Thus when free carbon dioxide increases silica decreases. ATKINS (1926) has observed the increase in alkalinity accompanied by higher silicate concentration.

Nitrogen Complex

The nitrogen complex in these ponds shows some interesting features. Sewage Pond is the richest amongst these in the total nitrogen content. It also exhibits a high percentage of organic matter. This indicates that the level of the concentration of organic matter in water is an index of nitrogen budget of a freshwater body. THRESH, BEALE & SUCKLING (1944) have attributed the nitrogen richness of a freshwater body to the pollution of animal origin. Sewage Pond may thus fall under this category in contrast to the other two which are protected against the free access of cattle.

Free and albuminoid ammonia fluctuate identically in these waters. This has also been observed by RAO (1949) and ZAFAR (1964), (Figs. 16, 17, 18), but fluctuations in nitrite are somewhat irregular. Nitrites are often present in Sewage Pond and generally increase when albuminoid ammonia is low. It is fairly established that nitrite is an unstable product of either nitrification of free ammonia or denitrification of nitrates. As both these processes depend largely on the nitrifying and denitrifying bacteria, the concentration of nitrite in water will depend on the relative abundance of these organisms and their activity. If the conditions for the activity of nitrifying bacteria are more favourable than for the denitrifying bacteria the nitrification will supersede denitrification and vice versa. It is likely that the activity of the microbes is controlled by certain physical or chemical factors and one of these may be the albuminoid ammonia. This point has been emphasized by investigators like ZOBELL (1940) and TAYLOR (1949).

The relationship between nitrate and albuminoid ammonia is rather interesting in the present data. An inverse relationship exists between these factors in all the three ponds (Figs. 16, 17, 18). Similar relationship has been observed by TRESSLER & DOMOGALLA (1931) and SINGH (1960) whereas ZAFAR (1964) reported a direct relationship between the two and argues that albuminoid ammonia is but a laboratory product which gives an indication of the nitrogenous organic matter present in water. He believes that nitrogenous organic matter may be regarded as an intermediate stage between the dissolved organic matter and nitrates and the absorption of the latter results in the formation of simple proteins and then finally, the complex protein molecules are formed inside the organisms themselves. ZAFAR (1964) also observes that when the dead organic matter decomposes in water, complex proteins are converted into "nitrogenous

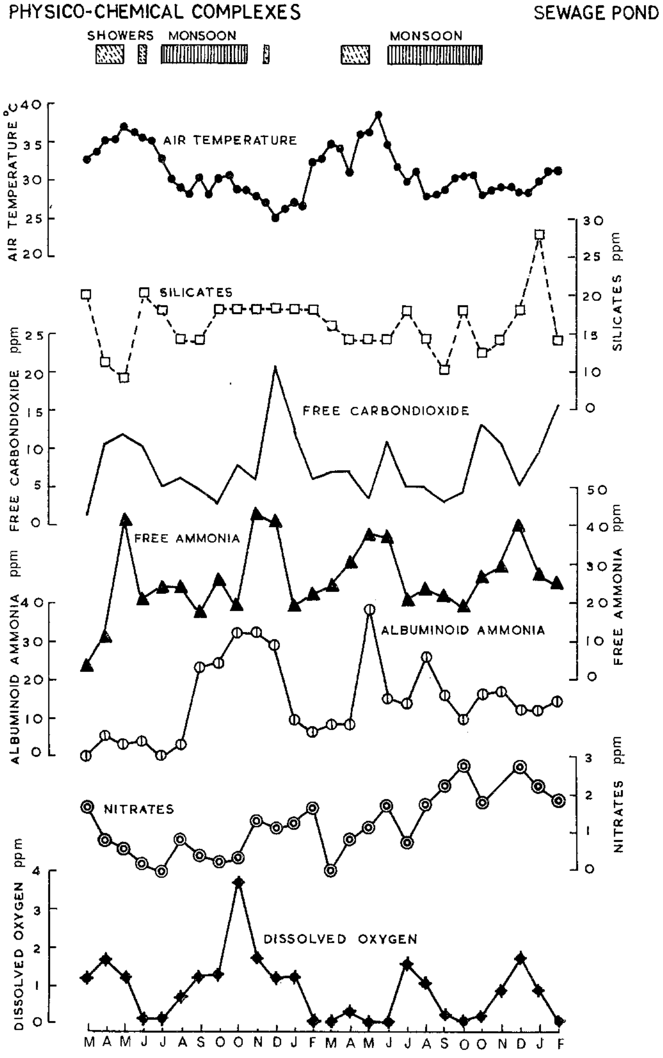

FIGURE 16

organic matter" and finally into nitrates, by the bacterial activity. Accordingly when albuminoid ammonia and nitrates go hand in hand and show an inverse relationship to the dissolved organic matter, it may indicate that the main source of nitrogenous organic matter is the dissolved organic matter which is undergoing decomposition whereas, on the other hand, if the albuminoid ammonia fluctuates inversely with the nitrate, it may be assumed that the plankton organisms are living at the expense of nitrates in water and they themselves are the main source of nitrogenous organic matter.

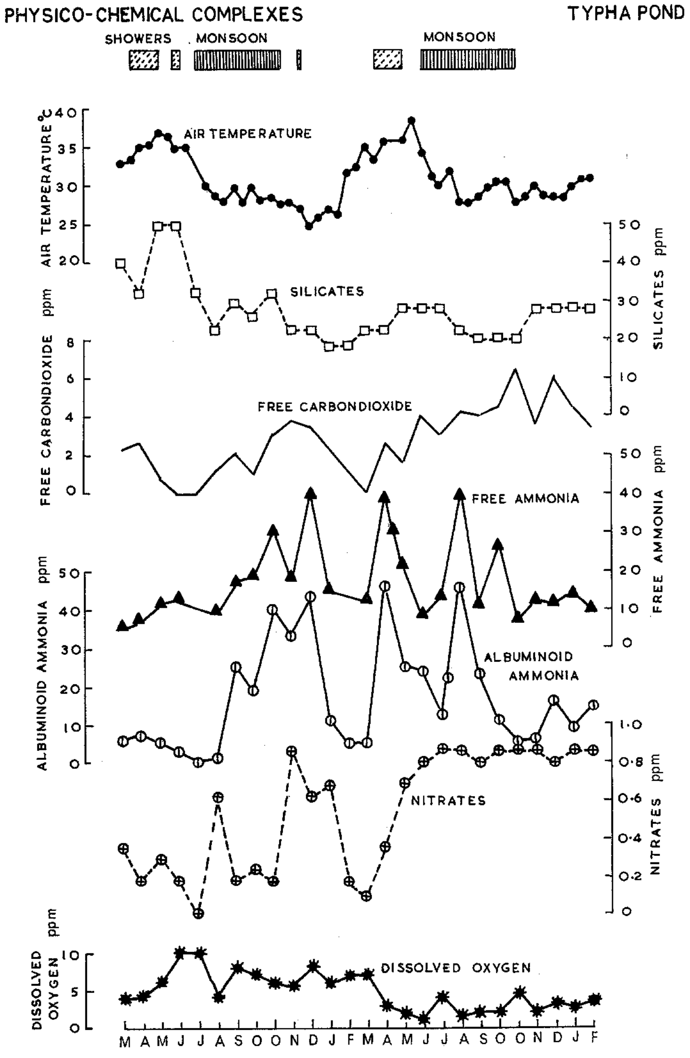

FIGURE 17

It seems that atmospheric temperature has a profound effect on the nitrate content of water in the present ponds. An inverse correlation is evident between these two factors (Figs. 16, 17, 18). This is explainable in view of the fact that temperature accelerates the activity of denitrifying bacteria in the presence of organic matter. The process of reduction of nitrates may stop with the production of nitrite, which is sometimes accompanied by hydroxylamine, or it may proceed to the formation of molecular nitrogen or perhaps to N_2O or to ammonia (Hutchinson, 1957). This accounts for the observed depletion of nitrates at higher temperatures.

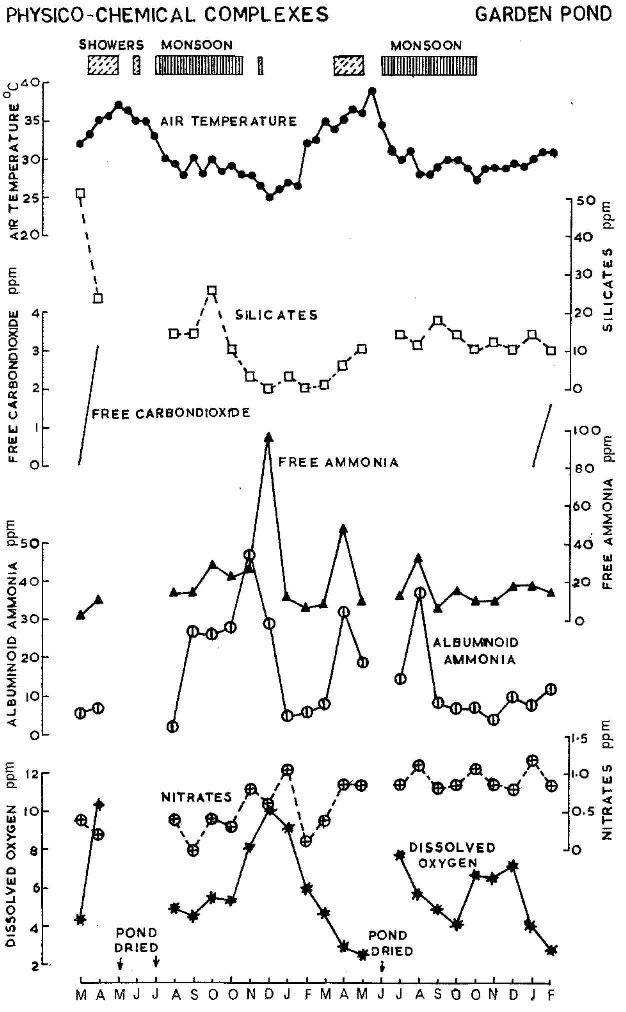

FIGURE 18

Rainfall is supposed to be responsible for increasing nitrates in water by PEARSALL (1923, 1924, 1930), RICE (1938), LIND (1938, 1943, 1945), MATSUDAIRA & KATO (1943), GONZALVES & JOSHI (1946), RAO (1955) and SINGH (1960). In the present data nitrates increase invariably after heavy rains and sometimes during winter (Figs. 16, 17, 18).

The relationship between nitrate and dissolved oxygen is quite interesting. They fluctuate inversely in the present data (Figs. 16, 17, 18). However, a positive correlation has been reported by GANAPATI (1943) and ZAFAR (1964). SINGH (1960) assumes that nitrate is independent of oxygen and does not vary inversely with it. It may be emphasized here that the conversion of nitrogenous organic matter to nitrites and nitrates is brought about by anaerobic bacteria which are more active in the waters low in oxygen. The works of LEES & QUASTEL (1946) and QUASTEL & SCHOLEFIELD (1951), suggest that the oxidation of ammonia takes place only in association with the surface of fine particles which possibly form foci for the activity of the microbes. Therefore, the quantity of particulate organic matter and the suspended soil particles will certainly influence the activity of these in water and the conversion of ammonia to nitrites and nitrates will in a way depend on their presence. Thus, if such foci are present in abundance, the conversion process will be accelerated leading to the utilization of very large quantities of oxygen. This will not only increase the percentage of nitrate in water but will simultaneously make the pond deficient in oxygen. This explains to some extent the contrasting data available on the nitrates and nitrite content of tropical waters (c.f. RUTTNER, 1953, GANAPATI, 1960 and ZAFAR, 1964). In spite of the nonpolluted nature of the Typha and Garden ponds, they exhibit appreciable quantities of nitrates (0.093—0.868 ppm and 0.0—1,24 ppm). One may thus conclude that waters rich in particulate organic matter and suspended soil particles are likely to be rich in nitrates even though they may not be the recipients of sewage.

SUMMARY

The limnology of three freshwater ponds, polluted and unpolluted was studied over a period of two years. The ponds studied, differed substantially in the degree of organic pollution. Physico-chemical complexes occurring in the ponds were analysed which exhibit interesting interrelationships. The investigation indicated certain important complexes operating in the ecosystem. The paper includes discussion on the interrelationships of the following sets of factors:

1. Temperature and other physico-chemical factors.

2. Oxygen and carbon dioxide.
3. Carbon dioxide and the buffer system.
4. Sodium and Chlorides.
5. Temperature and other solids.
6. Organic Matter and allied factors.
7. Phosphates.
8. Sulfur complex.
9. Silicates.
10. Nitrogen complex.

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