A STUDY OF SEASONAL VARIATION OF PHYTOPLANKTON IN RELATION TO VARIATION IN WATER QUALITY IN LEGE DADI RESERVOIR

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ABSTRACT

The quality of water in Lege Dadi reservoir was assessed in terms of its physical, chemical and biological characterstics for a period of one year from June 1982 - May 1983.

Physical and chemical characterstics of the water assessed include temperature, pH, odour,taste,colour, suspended solids,turbidity,hardness,alkalinity,carbon dioxide, oxygen, nitrate, nitrite, ammonia, phosphate, silicate, fluoride, iron, manganese, copper and conductivity. The data obtained were compared with WHO (ref. Cox, 1964) standard values for source water. It is found that almost all measurements fall within the maximum allowable values given by WHO (ref. Cox, 1964) and prove that Lege Dadi reservoir is a good source of water for the public.

Biological method of water quality assessment was performed using algae as indicator. Biomass estimate, periodicity and species composition of phytoplankton were investigated. Periodicity of various taxonomic divisions such as Chlorophyceae, Cyanophyceae, Bacillariophyceae and Dinophyceae was found to be related with some

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physico-chemical parameters of the ecosystem. Factors like rainfall, nutrients and algicide ($CuSO_4$) application were observed to have an impact on the periodicity of the phytoplankton. Taxonomic analysis of phytoplankton resulted in the identification of 13 algal forms.

The present status of the quality of the water of Lege Dadi reservoir has been discussed on the basis of the results obtained. Possible sources of pollution have been stated and suggestions pertaining to control methods have been forwarded.

INTRODUCTION

Water is one of the necessities of man. It is generally accepted that the health of a community depends to a large measure on the ample provision of a wholesome water supply. The sources of water, which include rivers, wells, lakes, ponds and reservoirs have effects on the health of the public. Diseases of varied characters, from minor ailments to serious epidemics can be and are transmitted to man by water. The causal agents conveyed by the water may be poisonous chemicals, pathogenic microorganisms or parasites.

To improve and maintain the protection of the public from water-borne diseases, man has been using different methods of assessing water quality and of treatment techniques to make water suitable for drinking. Water which is used for drinking purposes can be designated as pure and wholesome if it is free from visible suspended matter, odour and taste, colour, from all objectionable bacteria and other disease producing organisms indicative of the presence of disease and contains no dissolved matter of inorganic or organic origin which in quality or quantity would render it dangerous to health (Holden, 1970).

Water pollution is defined as any impairment of the suitability of water for any of its beneficial uses, actual or potential, by man-caused changes in the quality of water (Hynes, 1966). These dhanges in water quality are contributed by man through activities like industralization and agriculture; residues from these activities which include fertilizers and pesticides together with other waste matter are discharged into the environment resulting in pollution of freshwater bodies. Besides these substances, the biotic communities of freshwater bodies which are mainly composed of algal populations are among the major pollutants, and have been reported as a cause for the change of odour and taste of drinking water in many reservoirs of the world (Neel, 1967; Stanely & Alpers, 1975).

Here in Addis Ababa, seasonal occurrence of algal blooms has resulted in odour and taste of water in Lege Dadi reservoir. This problem of algal bloom has been reported as the cause for the change of water quality in Lege Dadi reservoir for the last three years (Report, Addis Ababa Water and Sewerage Authority Plant Division, 1981 - 82). However, there is no scientific work done on this reservoir to study the effects brought about by algal growth. Morever, recommendations pertaining to proper treatment methods to combat the problem are non-existent.

The object of this study is to assess the variation in type and abundance of algae in relation to water quality and from this perhaps determine the best time, location and effective type of treatment necessary to control the problem.

2. LITERATURE REVIEW

2.1 Sources of Water

Water is one of the most important minerals which is vital for all life. It is necessary for drinking, for animal husbandry, for irrigation, for industrial uses, for cooling processes and for power generation. Based on WHO's classification (1973,1977), water sources of the world are divided into ground water, rain water and surface water.

Of all these sources, surface water is most prone to contamination and it is the main source of drinking water for the world at large. Surface water sources such as rivers, ponds and reservoirs are usually polluted by sewage and industrial effluents and residues from agriculture (FAO, 1971; WHO, 1977).

Waterborne diseases are commonly found in many countries, particularly in the tropics, where the diseases related to water supplies are more numerous, more important and more diverse than in temperate lands. Water which is used for domestic purposes in most of the less developed African countries contains pollutants of organic and inorganic forms which are believed to be the causes for most of the health hazards that occur in communities. Water-borne diseases that affect the health of the rural and urban population in Ethiopia are typhoid fever, paratyphoid fever, cholera, amoebic dysenetry, bacillary dysenetry, infective hepatitis, dracontiasis and bilharziasis (Gebre-Emanuel Teka, 1977).

Although ground water sources, wells and springs are less liable to pollution than other sources, there are reports of ground water pollution from many parts of the world (Environmental Quality Reports, 1976, 1979).

Ground water quality deteriorates through natural influences and human disturbances. The former refers to pollution that comes as a result of ground water movement through rocks. As it moves through mineral bearing rocks containing fluoride, for instance, it can accumulate fluoride in excess of concentrations established in drinking water standards. This kind of ground water pollution is reported from Metehara (Ethiopia) and in the surrounding drinking water sources of the community (Bekele Desta, 1981). Contamination from agriculture, such as infiltration of nitrate resulting from the application of fertilizer and contamination from surface and subsurface waste disposal and storage are among pollutions of ground water contributed by man.

In localities where other sources of water are inadequate or their qualities are unsuitable for domestic purposes, rain water serves as a satisfactory source of water for the public (WHO, 1973). Rain water is contaminated as it passes through the atmosphere and contains bacterial and fungal spores in the first part of precipitation. Wind blown dust in thatched roofs, paints on roof surfaces, leaves and bird droppings in gutters and generally the nature and degree of maintenance of the collecting surface, affect the quality of rain water.

It is a fact that water has played an important part in the well - being and development of our society. To achieve optimal utilization of water, man requires a proper and sound knowledge of the quantity and quality of available water and also requires to have standard methods of evaluating quality of water for drinking and other purposes. In other words, for efficient utilization of water, we would require to have a sound knowledge of all physical, chemical and biological characterstics of the water and evaluate the effects of these variables on aquatic orgnisms and man.

2.2 Water Quality Assessment

The principle of water quality control involves a study of physical, chemical and biological characterstics of water (Boyd, 1979; Degremont, 1979). Those parameters are given standard values in relation to their suitability for drinking, industrial or other related purposes. According to Holden (1970) and Ministry of the Environment, Ontario (1980), the physical characterstics of water which are largely used to measure its quality are turbidity, odour, taste, colour, temperature, hydrogen ion concentration and electrical conductivity.

Chemical methods of assessment on the other hand give information on the level of organic and inorganic substances that may or may not be hazardous to life at certain concentrations. Chemicals that are analysed in water for assessment of water quality are iron, manganese, copper, zinc, magnesium, nitrate, fluoride, phenolic substances, arsenic, cadmium, chromium, cyanide, lead, selenium in addition to other factors such acidity, alkalinity, hardness, concentration of gases like O_2, CO_2, H_2S and radioactivity (Holden, 1970). It is usually recommended that analysis of chemical constituents of source water be made at least twice a year or more if the water is suspected of containing undesirable materials (Ministry of the Environment, Ontario, 1980).

Biological methods for the assessment of water quality include the collection, counting and identification of aquatic organisms, biomass measurements and measurements of bioaccumulation and toxicity (Am. Publ. Hlth. Assoc., 1980). Biological methods of assessment of water quality are found to be advantageous over other methods of assessment applied (Patrick, 1977; Boyd, 1979). It is found to be less time consuming.

A single series of samples can reveal the status of the animal and plant communities which themselves represent the results of the summation of the prevailing conditions. The nature and condition of aquatic communities act as indicators of the quality of water. Bacteria are found to be important in the assessment of water quality. The coliform indicator test has proved to be a useful indicator of organic pollution. Other biotic communities such as invertebrates and fish are also used to assess water quality (Gaufin, 1973; Stephan and Mount, 1973). Algae can also be used as indicators of aquatic pollution. According to Patrick (1977), there are two ways of applying algae in the assessment of water quality. One approach is to observe and analyze natural communities with shifts in species composition and abundance as expressed by the effects of pollutants. The second approach is the study of a single or a few species in culture in the laboratory involving the determination of physiological and morphological changes as a function of changes in the concentration of a given chemical or physical factor.

Water quality standards have been established by WHO (Ref. Cox, 1964). These standards include the maximum allowable limits of certain substances beyond which potability is seriously impaired (See table 1).

Water quality standard and assessment together with the treatment applied varies for different water sources of the world (Cox, 1964). Due to variabilities of chemicals that exist among sources of water of the world, it remains difficult to establish rigid water quality standards. However, with all variable factors in existence, it has been stressed by Cox (1964) that WHO's water quality requirement should be adopted with some changes made in relation to technological capabilities of the nation concerned for pollution control.

2.3 Problems of Water Pollution

By definition, environmental pollution is the unfavourable alteration of our surroundings, wholely or largely as a by-product of man's activities through direct or indirect effects of changes in energy patterns, radiation levels, chemical and physical constituents and abundance of organisms. These changes may affect man directly through his supplies of water and of agricultural and other biological products. Accordingly, water pollution in particular is defined by Hynes (1966) as any impairment of the suitability of water for any of its beneficial uses, actual or potential, by man-caused changes in the quality of the water.

According to Mellanby (1972) and Bradley (1977), impurities resulting from human activities are wastes of animal or human origins which contain bacteria and sometimes viruses, run-off from farms, domestic sullage, industrial wastes and oil pollution such as that resulting from discarding engine oil into seas and oceans. It has been shown by WHO (1973) that in less developed countries of Africa and Asia where there is lack of sewerage systems, sewage treatment plants and other facilities, wastes of animal and human origins are dumped into streams and rivers and, as a result, have caused death of aquatic organisms and man. Deaths of thousands of people have been repeatedly reported from Bangladesh due to infection caused by cholera (Bradley, 1977). Faecal pollution has been reported as the major public health problem in Ethiopia (Gebre-Emanuel Teka, 1976).

Amha Belay and Bekele Desta (1978) have reviewed sources of aquatic pollution in Ethiopia in relation to protection of living resources in tributaries of the Awash River, and reported that pollution mainly from domestic wastes has resulted in fish kills in the Awash River, in death of livestock watering in Little Akaki, and clogging of water filters by aquatic growth in the Awash hydroelectric power plant.

According to Environmental Quality Reports (1975, 1979), domestic wastes (waste waters which have been used for bathing, washing clothes and cooking utensils) were found to contain high contents of food wastes, synthetic detergents and large amounts of phosphates, the latter, have been reported as one of the most notorious pollutants of freshwater bodies. These urban pollution discharges have contributed to eutrophication of water bodies. The process of eutrophication favours the growth of algae and macrophytes and results in fish kills by depleting dissolved oxygen and rendering the water unfit for recreation (Vollenweider, 1981).
By definition, eutrophication is the process of aging of freshwater bodies that usually begins with increased

plant production (Vollenweider, 1981). It has been established that phosphorus is a limiting nutrient for growth of algae and other plants in water bodies. According to Environmental Quality Report (1979), at present, high levels of phosphorus enter water bodies of the world through municipal sewage, seepage from sewers and septic tank systems, industrial discharges, run-off from agricultural areas and atmospheric deposition. These wastes result in sudden growth or bloom of algae in water sources. The subsequent decomposition of the blooms can reduce the dissolved oxygen content of the water to a level at which fish and other organisms could be killed. It has been reported (Ryder, 1981) that algae produce objectionable odour and taste in water sources, cause dermatitis, asthma, other allergic responses and low grade chronic toxicity in man and other animals. This accelerated natural biological process in water sources due to human activities, is recognized as cultural eutrophication and has been reported as a global problem in water quality control (Edmondson, 1970; Vollenweider 1981). Arumugam and Furtado (1980) have reported mass fish and zooplankton mortality due to algal blooms in a Malaysian reservoir, where the source of nutrients for the blooms

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has been found to be mainly effluents from oil palm and rubber factories that discharge waste water into the reservoir. Munro (1966) has reported eutrophication in Lake McIlwaine in Zimbabwe caused by effluents from sewage disposal works that entered the lake.
Marshal and Falcnor (1973a, 1973b) have reported algal blooms of blue greens predominantly Microcystis aeruginosa & Anabaena flos - aquae in lake McIlwaine and this eutrophication has resulted in the fish-kill that occurred in the lake in 1971 - 1972.

Very little is known of algal blooms in fresh-water bodies of Ethiopia. However, Belay and Wood (1982) have reported massive growth of Microcystis aeruginosa in Lake Chamo, and also the deaths of livestock and wild animals which drank water containing those dense algal blooms. The bloom was attributed to the general productivity of the lake. It was found that high level of nutrients together with other factors such as stratification and optical properties of the lake have resulted in massive growth of these organisms. Toxic blooms of different algal forms have been reported from many parts of the world. Parnas (1963) has reported a toxic bloom of *Prymnesium parvum* in lake Kinneret in Israel, which caused fish mortality in the lake. Certain forms of blue green algae such as *Anabaena* were implicated in contact type dermatitis, whereas *Microcystis aeruginosa* and *Lyngbya conerata* were reported as causing hay fever in the United States, and reports of death of livestock which drank water containing dense algal bloom of *Microcystis* have been made (Shilo, 1967; Fogg, *et al.*, 1973; Suess, 1981; Belay and Wood, 1982). The toxin must be released from the algae by decomposition if it is to be effective or the bloom must be concentrated in the body of the organism to a lethal dose to cause death in organisms (Fogg, *et al.*, 1973).

Massive growths of algae are at present the most challenging aquatic pollutants, particularly in water supplies where they cause objectionable odour and taste, shortened filter runs, change in pH and result in corrosion of steel tanks (Am. Publ. Hlth. Assoc., 1980). It is because of the above mentioned facts that different measures have been applied to water sources, particularly in reservoirs, to control the growth of algal population.

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2.4 Control of Water Pollution

It remains one of the major tasks of the world at present to control environmental pollution in general and aquatic pollution in particular and to prevent the harmful effects of pollution on man.

It has been observed in many freshwater bodies of the world that the source of pollution can be attributed to improper utilization of the environment by man. Water borne diseases that affect human health are the result of poor sanitation practices by the community. The problem of global eutrophication of freshwater bodies is largely attributed to improper handling of domestic and industrial wastes.

Since water pollution is a result of the unconscious activities of man ways and means of control primarly involve education, on the nature, prevention and control of pollution, of the public at large and of various

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agencies dealing with health, land and water management. There are two methods suggested by biologists for dealing with pollution.

These are :-

1. to disperse the contaminants over a wide area and hence decrease their effects.

2. increase the magnitude of the re-use and recycling loop and possibly erect other loops.

In some cases dilution of the polluting substance below the level at which it is recognized as poisonous solves the problem of water pollution. Hence, dilution and dispersal are satisfactory means of controlling the majority of the non-persistant or bio-degradable pollutants (Simmon, 1977; Dehadrai and Ghosh, 1978; Soegiarto, 1978).

The problem of eutrophication of freshwater bodies in many places has been solved by diverting nutrient sources such as sewage and sewage treatment plant effluents and industrial effluents from water sources (Edmondson, 1970).

The treatment of domestic sewage before discharging into water bodies has been used in slowing the rate of eutrophication. It has been reported by Jayangoudar and Ganapati (1965b) that solar sewage drying beds have been introduced to treat domestic wastes. The drying beds accomplish a very high degree of purification or rather stabilization of organic matter at practically no cost, by means of biological oxidation. In this method, two processes take place simultaneously in day light in solar drying beds. These are :-

1. synthesis of fresh organic matter in the form of millions of blue green algae making use of the fertilizing elements found in the sewage, and

2. the concomittant release of oxygen which is used for stabilizing the decomposing organic matter by bacterial action resulting in the formation of substances such as carbon dioxide ammonia and phosphates. The beds do not have effluents, but dispose of the water by seepage and evaporation.

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By doing so, substances that are released in the process could be used as fertilizers.

The problems caused by algal blooms in water works are solved using different means of treatment. According to Jayangoudar and Ganapati (1965a) and Campbell, _et al_. (1975), algal blooms, which are responsible for the cause of odour and taste in a lake or a reservoir, can be prevented either by reducing the available nutrient substances forming the food of algae, or changing its chemical composition so that it will not support large growth of plankton. These can be effected by physical, chemical and biological methods. Jayangoudar and Ganapati (1965a) and Campbell, _et al_. (1975) have stated that physical methods of control of algal blooms in new reservoirs include the removal of organic matter from the catchment area, including the clearing of swamps and vegetation and the removal of the top layer of the soil to reduce the availability of

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nutrients for the algae. Another method which is practised is known as "the carbon black-out method" which consists of spraying powdered activated carbon, which is very cheap, on the surface of a reservoir where algal troubles are anticipated. A thin layer of carbon shuts off light and photosynthesis and algal development are minimized.

It has also been stated (Lund, 1954a, 1955; Meyer, 1971; Klapper, 1980) that a knowledge of the periodicity, seasonal succession and vertical distribution of algae in reservoirs could serve in controlling the effects of algal blooms. From such studies it is possible to know the vertical distribution of algae and the depth at which the greatest concentration of algae occur. Water can then be drawn from the depth with the least concentration of algae.

Nevertheless physical methods of control cannot prevent the occasional out-burst of algae, so, for full algal control in water supplies, chemical methods of control are required. These include the use of algicides such as copper sulphate, chlorine, cupric chloro-amine and panacide. It has been reported that application of copper sulphate above 1ppm in reservoirs can kill algal blooms (Crance, 1963; McIntosh, 1974; Round, 1975).

Physico-chemical processes, like flocculation, that concentrate particles in the raw water into larger clumps, are applied to remove algae from raw water by subsequent filtration. In this method, chemicals such as aluminium sulphate and sodium silicate are used as flocculants (Ministry of the Environment, Ontario, 1980).

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Of all control measures, however, biological control has been recommended as an effective measure in managing water supplies particularly in warm climates. Biological methods of control of algae in part include the rearing of fish and their periodical croppings (Jayangoudar and Ganapati, 1965; Lawrence, 1966; Boyd, 1979; Harris, 1980; Fernando, 1983). Herbivorous fish can thus control the growth of algae in water sources. Another biological method of controlling algal growth is by infecting them with fungal parasites (Canter and Lund, 1951). However Canter and Lund (1951) have stated that this method is not found to be effective, because such epidemics as do take place, rarely last more than about three weeks and if other things remain the same, the algae may once more increase when the epidemics end.

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3. DESCRIPTION OF STUDY AREA

Lege Dadi reservoir is one of two main sources of water supplies for Addis Ababa. It is located some 30km. to the east of the city (9^{o} 20'N, 38^{o} 45'E, 2450m) and was completed and brought into operation in 1970. The Lege Dadi facilities include a dam and impounding reservoir with a useable capacity of 47 million m^3 and treatment facilities designed for a rated capacity of 50,000m^3 per day. The Lege Dadi catchment covers a total of 225 Km^2 and is drained by two rivers, Sekoru and Sendafa, on which is built the existing Lege Dadi dam (Belete Muluneh, 1981). The main catchment area of the reservoir is characterized by basaltic rock. The soil is reddish in colour, containing iron compounds from the bed rock (Elias Altaye, et al., 1980). The catchment area almost totally falls within cultivated lands. Lege Dadi reservoir has a maximum depth of 20 meters. Fig. 1 shows a map of Lege Dadi reservoir and the sampling sites.

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LEGE DADI DAM

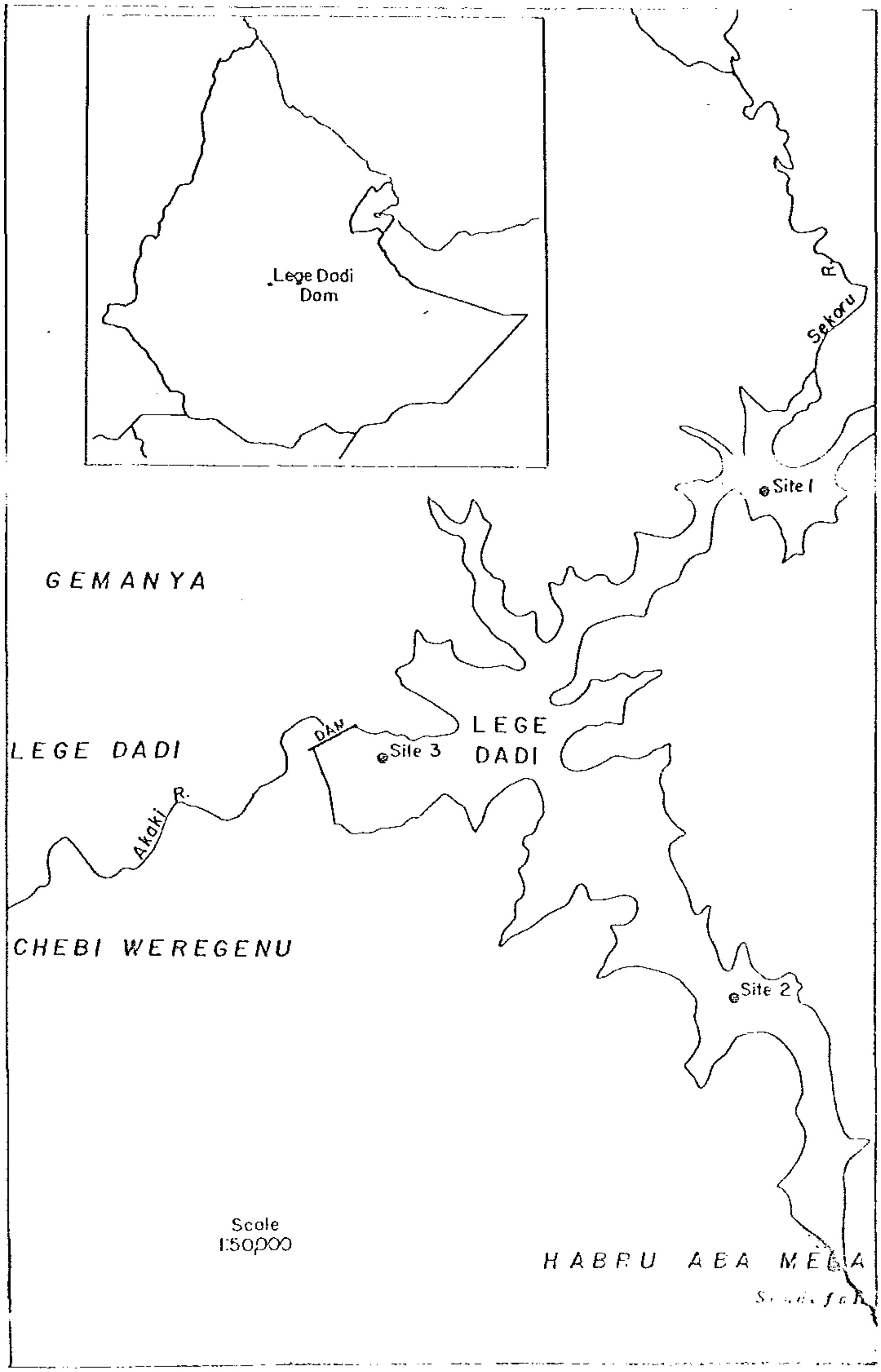

Fig. 1. Lege Dadi Reservoir.

4. MATERIALS AND METHODS

4.1 Physico-chemical Analysis

Samples (500 ml) for physical and chemical analysis were collected by boat from the water near the intake and were brought to the laboratory. Temperatures of surface water were measured near the intake on each sampling date. Conductivity and pH of the samples were measured in the laboratory immediately after collection with a conductivity meter and pH meter respectively. Odour and taste of the water was sensed on the spot. Data on rainfall and water level of the reservoir were recorded every day by a meteorological station established near the intake. The following physical and chemical characterstics were analysed using Hach Dr. EL/4 Direct Reading Engineer's Laboratory Kit (Hatch Chemical Co. Ames, Iowa) following the instructions of the manufacturer.

Physical and Chemical Characterstics Measured

1. Colour (Platinum Cobalt Units)

2. pH

3. Suspended solids (mg/l)

4. Conductivity (μ mho/cm)

5. Turbidity (mg/l)

6. Alkalinity as $HC\overline{O}_3$ (meq/l)

7. Total hardness as $CaCO_3$ (mg/l)

8. Dissolved carbon dioxide as CO_2 (mg/l)

9. Oxygen dissolved (mg/l)

10. Nitrate as N (mg/l)

11. Nitrite as N (mg/l)

12. Ammonia as N (mg/l)

13. Iron as Fe (mg/l)

14. Manganese as Mn (mg/l)

15. Copper as Cu (mg/l)

16. Fluoride as F (mg/l)

17. Silicate as SiO_2 (mg/l)

18. Phosphate as $PO_4^{=}$ (mg/l)

4.2 Biological Analysis

Three sampling sites were chosen. Site 1 (s-1) near the mouth of Sekoru river with a depth of 8 meters, Site 2 (s-2) near the mouth of

Sendafa river with a depth of 9 meters and Site 3 (s-3) near the dam with a depth of 20 meters.

Surface samples of phytoplankton were collected at two-weekly intervals from June 1982 to May 1983. Samples were collected from the surface using open plastic bottles (Vollenweider, 1969). Convenient time of sample collection was set between 1 pm and 2 pm. 4 litres of samples from every station were collected and brought to the laboratory for taxonomic work and estimation of the biomass of phytoplankton. 1 litre of sample from every station was preserved using modified Lugol's solution (Vollenweider, 1969) in a cylinder and was kept in the dark for 24 hours for sedimentation. The supernatant was siphoned off and the desired final volume, 100 ml concentrated samples, was stored in closed lablled glass vials in a refrigerator at $0^{o}C$.

Since counting of algae is one way of estimating algal biomass, the algae in the preserved samples were enumerated using Thoma counting chamber at 1000 X magnification (Am. Publ. Hlth. Assoc., 1980). Each sample was counted 5 times and the average value was taken as a final count for a given sample. These values, obtained from all sites, were then added and the average value for the reservoir was calculated. 1 litre of sample from all sites was examined fresh for identification of live organisms using relevant keys in Needham and Needham (1951), Edmondson (1959), Prescott (1970) and Am. Publ. Hlth. Assoc. (1980). The remaining 2 litres of sample from every site were used for chlorophyll "a" analysis for algal biomass estimate (Am. Publ. Hlth. Assoc., 1980). The method adopted for chlorophyll "a" analysis was that of Talling and Driver (1963), with 90% acetone as the extracting solvent.

5. RESULTS

I. Physico-chemical conditions

Data obtained on some physical and chemical characterstics of the water are compared with water quality standards established by W.H.O. (ref. Cox, 1964) (Table 1).

Table 1.

Comparison of data on some physical and chemical characterstics of raw water of the reservoir with W.H.O. standard (ref. Cox, 1964).

Physical and chemical characterstics	W.H.O. standard maximum allowable	Raw water of Lege Dadi Reservoir. Maximum value
Colour	300 (Platimum Cobalt Unit)	450 (Plt.Co.Unit)
Total solids	1500 mg/l	110 mg/l
Taste	Acceptable (normal)	Acceptable
Odour	Acceptable (normal)	Acceptable(Abnormal only in September)
Hardness	500 mg/l	60 mg/l
Iron	50 mg/l	0.7 mg/l
Manganese	5 mg/l	0.4 mg/l
Copper	1.5 mg/l	0.45mg/l
Fluoride	1.5 mg/l	1 mg/l
Nitrogen as NO_3^-	45 mg/l	8 mg/l
Silicate	20 mg/l	8 mg/l

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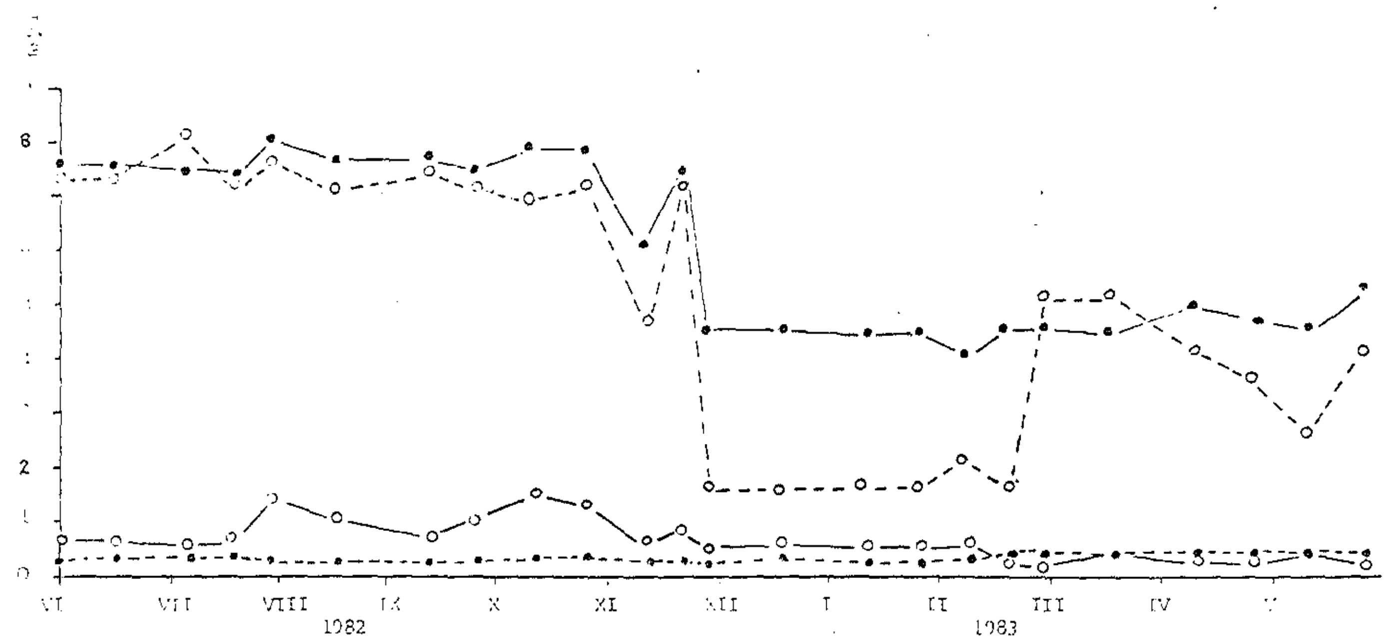

Fig.2.

Seasonal variation in concentrations of ammonia, nitrate, silicate and phosphate. Ammonia (—o—), nitrate (- - o - - -), silicate (—•—), phosphate (- - • - - -).

Fig.3.

Seasonal changes in turbidity, suspended solids and colour. Turbidity in F.T.U. (—•—), suspended solids in mg/l (—o—), colour in platinum cobalt unit (---•---).

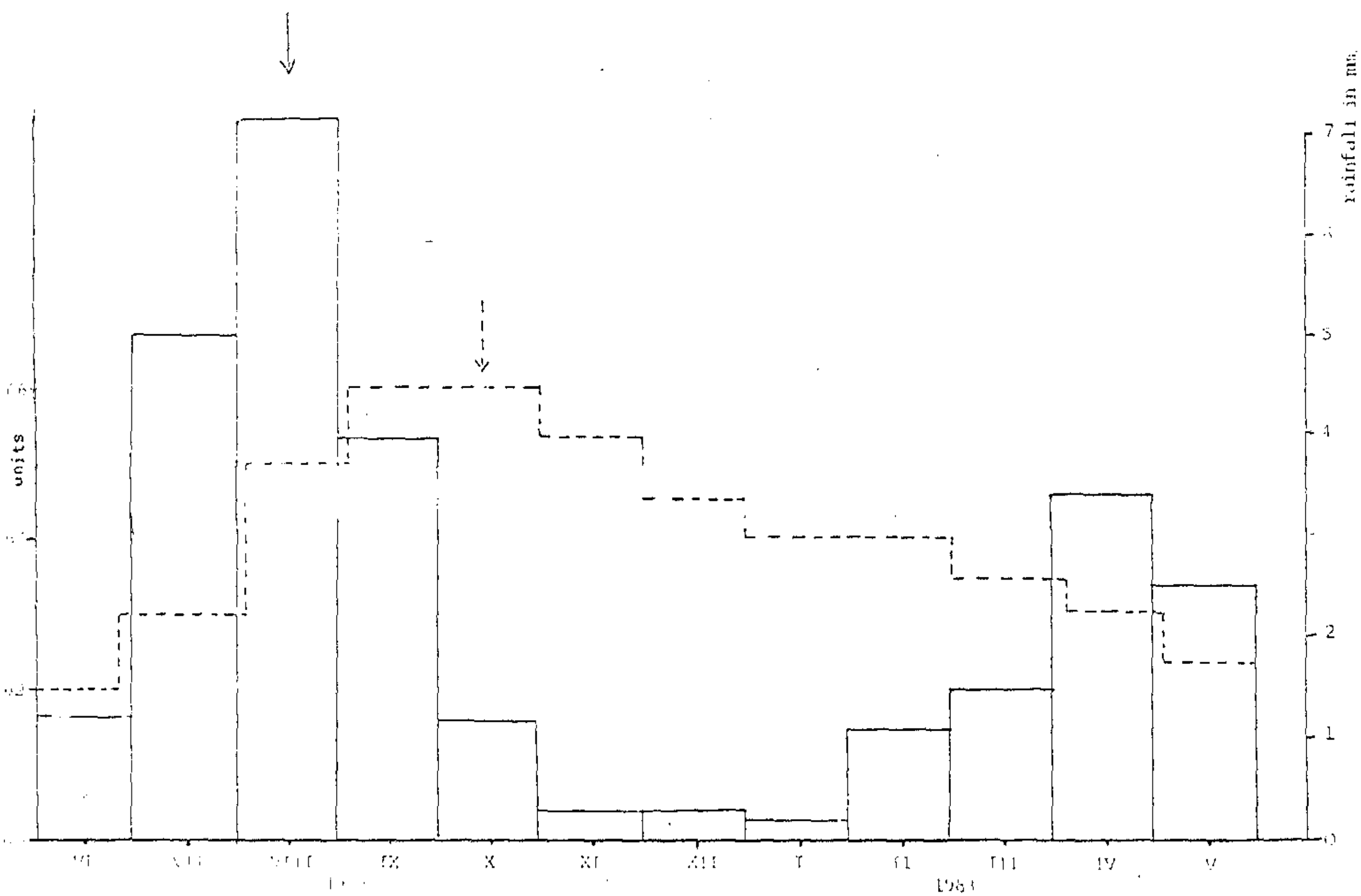

Fig.4.

Seasonal changes in monthly rainfall and water level. Rainfall (↓), water level (⇣).

It was found that some of the physical and chemical variables measured during the study period were affected by factors such as rainfall and biotic communities. Concentrations of nitrate and silicate were high between June and October, decreased between November and January and increased again between February and May (Fig. 2). The level of phosphate was more or less constant throughout the year (Fig. 2). Similar trends to that of silicate and nitrate were seen for turbidity and suspended solids (fig. 3). It is also noticed that water level of the reservoir started increasing in July, with the highest peaks recorded in the months of August, September and October (fig. 4).

The level of substances like iron, manganese, copper and fluoride showed variations at different times of the year (Fig. 5, 6). Concentrations of iron and manganese were high in June and September and were more or less constant for the other parts of the year. The peaks of copper ion indicated by the arrows in figure 6 were in samples collected just after the water was treated with copper sulphate. The relatively higher concentration of copper ion in June, July and August could probably be due

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to the release of copper ion from the sediment as a result of disturbances brought about by rain.

It is observed that fluoride ion increased between October and December. It increased again between January and February. It was relatively constant for the rest of the year (Fig. 6).

Measurements of alkalinity (as bicarbonate ion) and hardness of the water indicate a fairly high concentration of calcium and magnesium ions like other rivers and reservoirs. The conductivity of the water was relatively constant for the year (Fig. 7).

Seasonal changes in concerntrations of carbon dioxide and oxygen in surface water were measured (Fig. 8). The concentration of dissolved carbon dioxide was relatively high between the months of June and October ; it is possible that the disturbance of the water during the long rainy period could have contributed to the peaks recorded in these months. The concentration of dissolved oxygen was relatively constant during the study period (Fig. 8).

Surface temperature and pH were relatively constant throughout the study period (fig. 8).

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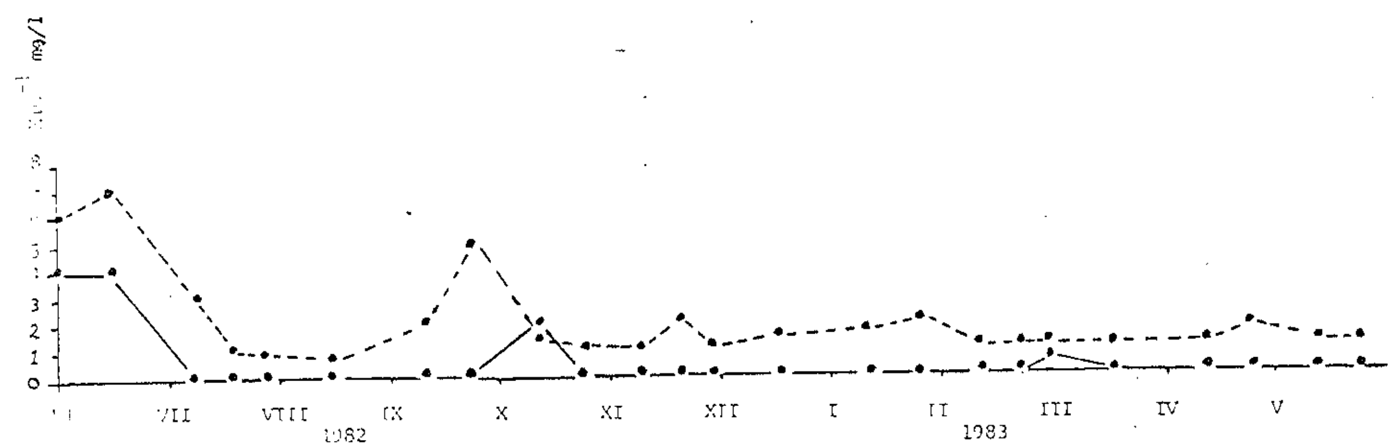

Fig.5.

Seasonal changes in concentrations of iron and manganese ions. Iron (--•---), manganese (—•—).

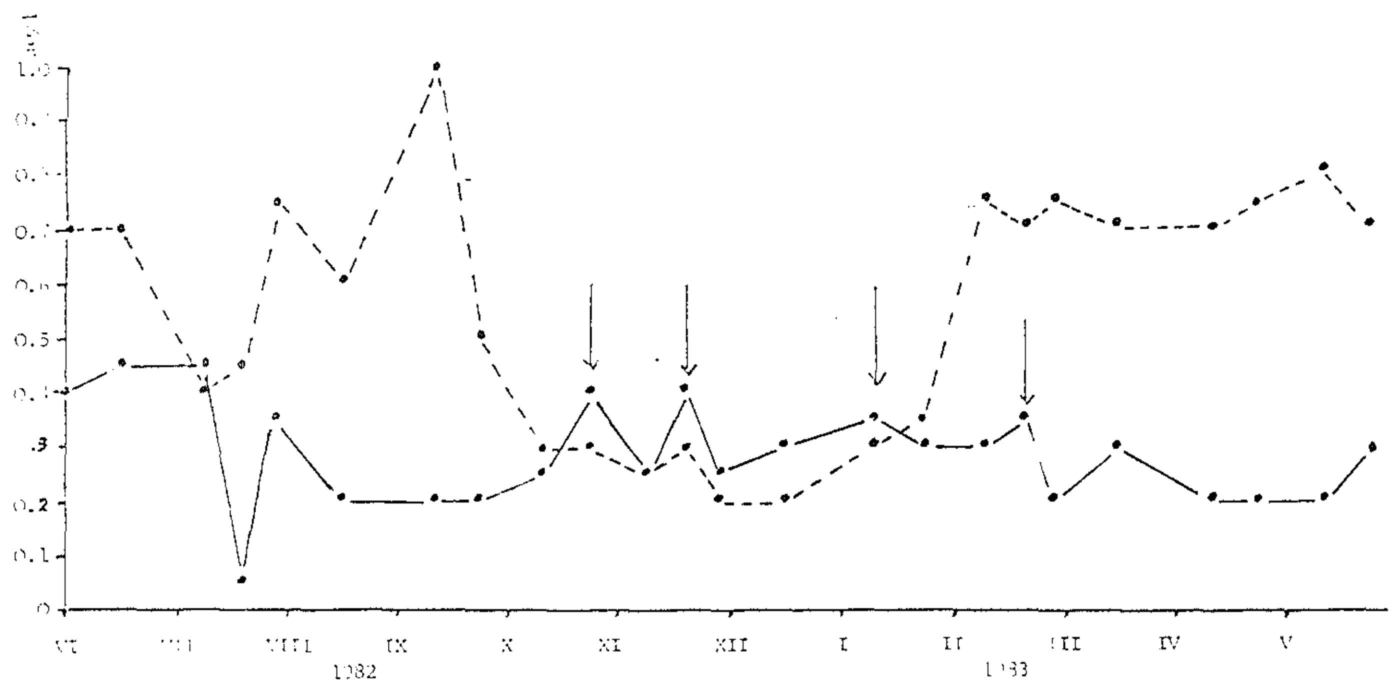

Fig.6.

Seasonal changes in concentrations of copper and fluoride ions. Copper (—●—), fluoride (---●---). Samples collected on the day of treatment with $CuSO_4$ (↓).

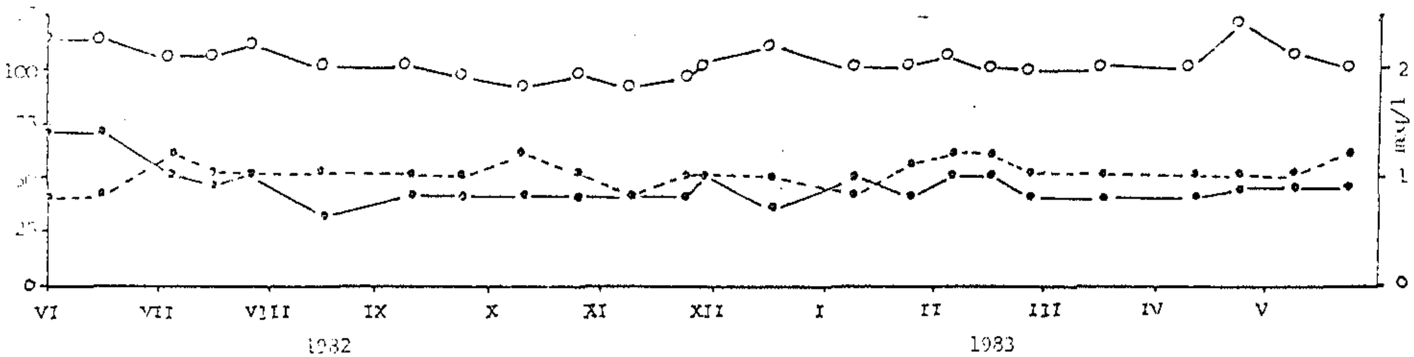

Fig.7.

Seasonal variation in hardness, alkalinity and conductivity. Conductivity in µ mho/cm (—o—), hardness in mg l (---•---), alkalinity as HCO_3^- in meq/l (—•—).

II. Biological Conditions

In this section seasonal variations in the phytoplankton are related, as far as possible, to the physical and chemical variables.

The phytoplankton was abundant in June, decreased between July and September and increased again between October and February. It then levelled off till May (Fig. 9, 10). The relative decrease in phytoplankton density between July and September is due to the heavy rains during these months. During this time the volume of the inflow exceeds the reservoir's holding capacity and normal drawdawn and overflows have been recorded in these months. It is possible that some algae may have passed out with the water that escapes. During this period the turbulence of the water could mix algae to all depths leading to low concentration on the surface of the water. It was observed that during the long rainy period (June - September) suspended solids and turbidity of the water were high (Fig. 4). These could possibly decrease the depth of light penetration and result in poor growth of algae during this period. There was a relative increase in phytoplankton density between September and February (Fig. 9, 10). There seems to exist an inverse correlation between the abundance of phytoplankton at a given time and the concentration of the nutrient substances at that time, for the latter are used when algae proliferate. The quantitative results show that the level of nutrients such as nitrate and phytoplankton abundance have a significant inverse relationship during the study period ($r = -.11$). The greater abundance of phytoplankton during the dry season (September - February) is probably associated with the increased photosynthetic activity during that time, resulting from increased insolation. It is also observed that plant nutrients such as nitrate and silicate decrease during the dry period (September - February) (Fig. 2). Phytoplankton peaks recorded in June could be attributed to the small rains (March - May) which may have resulted in some nutrient input for algal growth.

Lege Dadi reservoir is shallow (the maximum depth is 20 meters near the dam only) and is exposed to the force of wind from all directions. There is thus, the possibility of stirring and mixing of the whole water column and this phenomenon has an important effect on phytoplankton density. On most sampling dates the wind was observed to blow from the north,

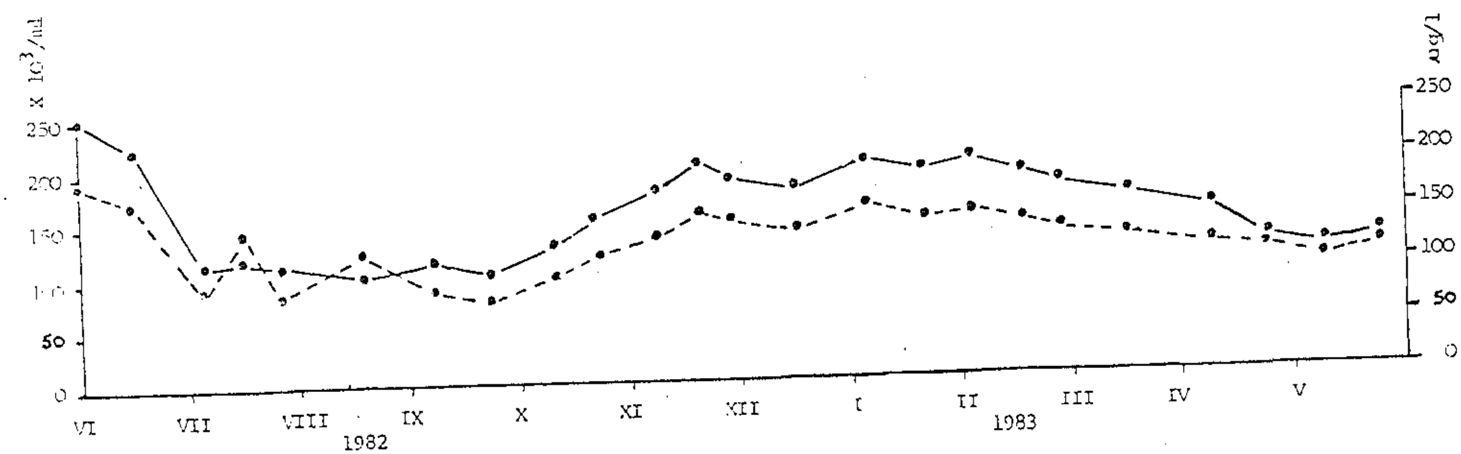

Fig.9.

Seasonal variation in total abundance of phytoplankton and chlorophyll "a" concentration. Chlorophyll "a" (—•—), number of algal cells (--•--).

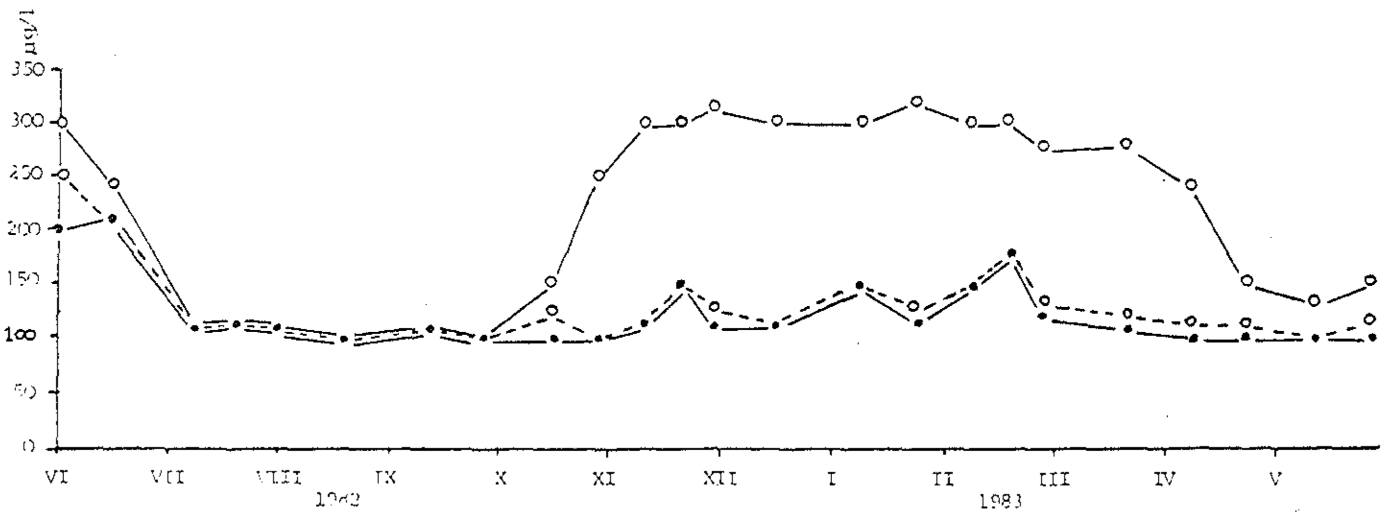

Fig.10.

Seasonal variation in concentration of chlorophyll "a" at sampling sites. Site-1 (—•—), Site-2 (--o--), Site-3 (—o—).

which is also the direction of the inflow. It is possible that these two factors could bring about the concentration of phytoplankton at the southern side of the reservoir. The observed variations in chlorophyll "a" concentration at the three sites point to the possible effect of the above factors. The phytoplankton concentration at Site 3 (southern side) was significantly higher than at the other two sites (Fig. 10).

The blue green algae were most abundant between June and September with lesser concentrations of green algae, dinoflagellates and diatoms. Green algae were dominant between September and December followed by blue green algae and diatoms. The months between February and May were dominated by diatoms followed by blue green algae (Fig. 11). In short, the blue green maximum was followed by predominance of green algae, which were succeeded in dominance by diatoms. It was observed that just after the long rainy period (September), the water had been treated with copper sulphate to avoid the odour produced by algae (Fig. 6). It is possible that the abundance of green algae, the decrease in blue greens and the disappearance of dinoflagellates could be attributed to the copper sulphate treatment given between the months of September and February (Fig. 11).

Taxonomic identification was made during the study period. 13 genera of algae were identified (Table 2).

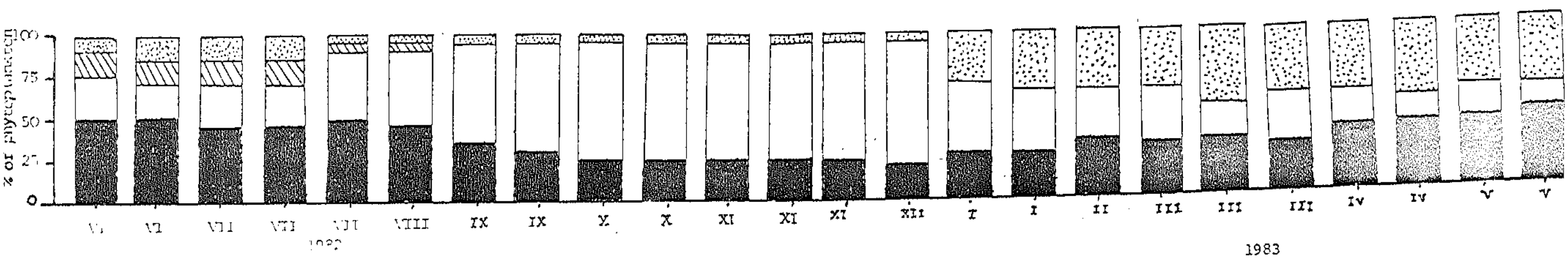

Fig. 11.

Seasonal variation in the proportions of phytoplankton communities of different taxonomic divisions. Dinophyceae ( ), Chlorophyceae ( ), Bacillariophyceae ( ), Cyanophyceae ( ).

Table 2.

List of algae identified during the study period

Division	Cyanophyceae	Chlorophyceae	Dinophyceae	Bacillario-phyceae
List of algae	Microcystis sp.	Chlorogonium sp.	Peridinium sp.	Navicula sp.
	Anabaena sp.	Tetraspora sp.	Ceratium sp.	Cymbella sp.
	Phormidium sp.	Chlorella sp.		
	Gloeocystis sp.	Protococcus sp.		
		Mougeotia sp.		

The relative abundance of each genus is shown in figure 12. Except for Protococcus sp. and Tetraspora sp., the rest are planktonic forms (Prescott, 1971). A strong wave action generated by wind has been observed at Site 3. It is possible that the action of such waves could remove these two algae from the wall of the reservoir and mix them with water.

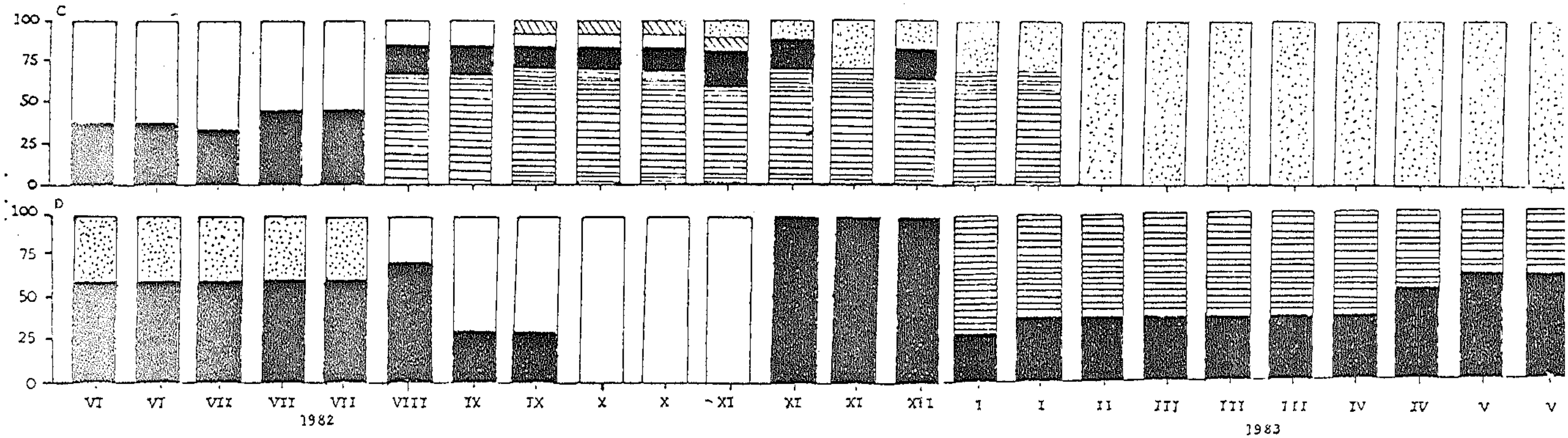

Fig. 12. Continued.

C: Chlorophyceae; Chlorella sp. ( ), Mougeotia sp. ( ), Tetraspora sp. ( ), Protococcus sp. ( ), Chlorogonium sp. ( ),
D: Cyanophyceae; Microcytis sp. ( ), Anabaena sp. ( ), Phormidium sp. ( ), Gloeocystis sp. ( ).

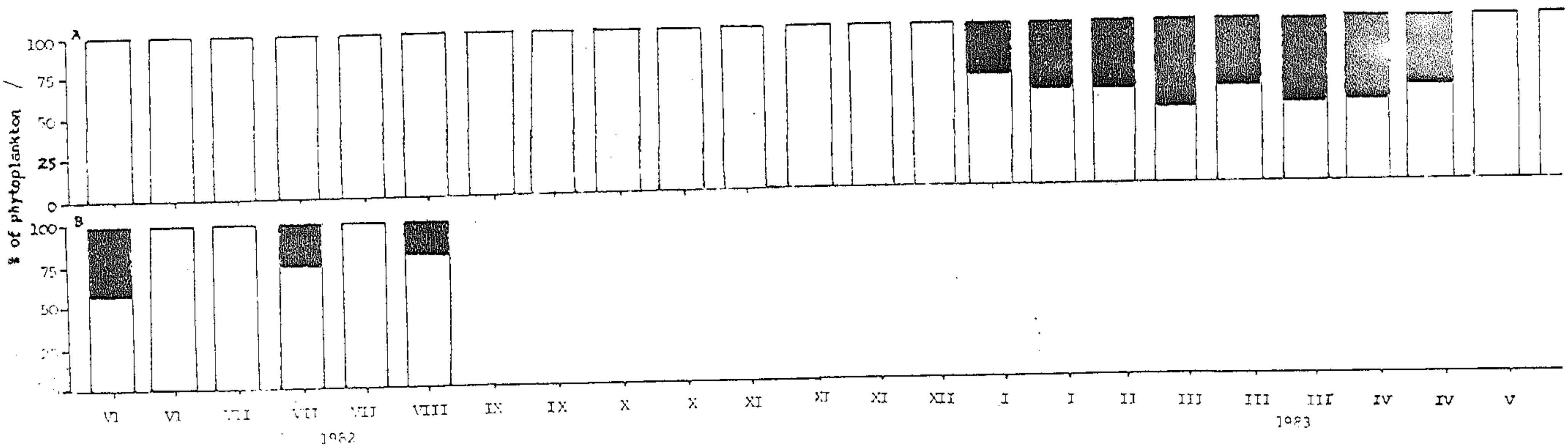

Fig. 12.

Seasonal variation in the generic composition of phytoplankton.
A: Bacillariophyceae: *Cymbella* sp. (■), *Navicula* sp. (□).
B: Dinophyceae: *Peridinium* sp. (□), *Ceratium* sp. (■).

6. DISCUSSION

I. Physico - chemical conditions

Man made lakes are peculiar ecosystems since they partake of the characterstics of the lacustrine and riverine environments. Though they do not represent strictly lotic environments because of damming, the fact that they are also provided with inflow - outflow arrangements would seem to show that they are also not strictly lentic environments. Conversion of a part of a river basin into a lake is likely to lead to instability in their conditions of existence (Hutchinson, 1975). It has been observed that most of the physical and chemical characterstics of the water are affected by rainfall. There are two wet periods in the study area; the short rains between March and May, and the long rains between June and September. These are followed by a dry season from October to March (Daniel Gemetchu, 1977). Rainfall increases the inflow bringing with it chemicals released from rocks and soil into the reservoir and bringing about changes in the quality of the water.

The rise in silicate and nitrate levels between June and October is probably due to run-off from the catchment area and allochthonous materials brought in by the two rivers that drain into the reservoir.

The drop in silicate and nitrate between November and February is probably associated with biological activity. The peaks in phytoplankton population recorded between October and February occured probably because these months happened to be dry with maximum sunshine hours (Daniel Gemetchu, 1977), and have resulted in the reduction of nitrate and silicate concentrations through photosynthetic activity.

It has been found that iron can only exist as the ferrous form in solution when the water contains not more than 0.5 mg/l of oxygen and pH around neutrality. If the oxygen content is higher or the water is alkaline, $Fe(OH)_3$ is precipitated. At low pH values, it is possible to find detectable amounts of iron in waters even when they are saturated with oxygen. Manganese also has a behavior very similar to that of iron (Ruttner, 1970; Hutchinson, 1975). However variation in concentration of these two substances in the reservoir is not the effect of pH. It has been reported that biotic communities use these substances for metabolic activities and could remove certain part of the substances from the water (Goldman, 1960 ; Lund, 1964; Boney, 1975).

Copper and fluoride ions are found in natural waters. Copper ion is required as a nutrient for algal growth (Round, 1975). However, at higher concentrations it is found to be toxic to algae. Because of this it is largely used as an algicide in many countries to control algal blooms. It is reported that the concentration of copper ion suddenly increases in water just after treatment with copper sulphate, then decreases in a week's time (McIntosh, 1974). McIntosh (1974) further reported that copper ion could be released from sediments through cation exchange mechanisms, or it may increase in surface water when the sediment is disturbed. It is observed that the peaks of copper ion recorded during the study period coincide with the time of treatment and with the pattern of rainfall (Fig. 4, 6).

It has been reported that concentration of fluoride ion up to 1.5 mg/l is permissable for water sources used for drinking purposes (Cox, 1964). Thus, the values of fluoride ion attained in this study could not be considered as abnormal, since they fall within the normal range. However, the reasons for the occurrence of the peaks of fluoride ions in August and September could be due to the rainfall (Fig. 6). During this period the ion could be washed from the surrounding rocks and brought into the reservoir.

It has been observed that water with high alkalinity has a greater complement of most ions than water of low alkalinity (Moyle, 1946). In most reservoirs and rivers hardness and alkalinity are closely related, and total hardness is referred sometimes as total alkalinity (Mairs, 1966). It is possible that alkalinity and hardness values roughly indicate the level of ions like calcium and magnesium in natural waters. It is designated that natural waters which contain 40 mg/liter or more alkalinity are considered for biological purposes as hard waters (Mairs, 1966; Boyd, 1979). Therefore the values of alkalinity and hardness obtained in the study period probably indicate fairly high levels of calcium and magnesium ions.

II. Biological Conditions

Phytoplankton communities are known to change with time both in composition and number. They are dynamic and their abundance at any given time depends on various factors such as climatic conditions, topography, rate of reproduction, death, herbivore grazing, water movements and other physico-chemical conditions of the water (Lund, 1965; Round, 1975; Venkataraman, et al., 1974). It has been observed that small temperate and tropical lakes and reservoirs, which have smaller volumes in relation to inflow respond to droughts and floods in the feeder streams. As a result, the phytoplankton picture is strongly influenced by the annual flood which causes algal washout (Brook and Woodward, 1956; Talling and Rzoska, 1967). It is possible that the above factors could have contributed to the seasonal variation and abundance of phytoplankton communities recorded during the study period.

The assessment of water quality in lakes and reservoirs is most often concerned with measurements of plankton particularly in tropics where high light intensity and high temperature favour primary production (Zafar, 1964, 1967; Munawar, 1974; Sreenivasan 1976; Beadle, 1981). There is little work done on the study of seasonal variation and species composition of phytoplankton in tropical lakes and reservoirs. (Seenayya, 1972; Munawar, 1974; Rao, 1977 a,b). It has been established that the waters favouring green algae are chemically distinct from those harbouring diatoms and blue greens in water bodies (Rao, 1955; Zafar, 1964, 1967; Munawar 1974; Rao, 1977 a,b). It is found that high temperature, large amount of carbon dioxide, nitrate and low oxygen content promote the production of blue greens (Rao, 1955; Seenayya, 1972; Munawar, 1974). Diatoms occur when the waters are rich in nitrate, phosphate and silicate. Pigmented flagellates are reported to be more numerous in acidic than in alkaline ponds. Nevertheless, much remains to be discovered about physico-chemical conditions favouring the growth of different forms of algae in water bodies (Lund, 1954 a,b, 1955, 1964; Seenayya, 1972; Rao, 1977 a, b).

The dominance of blue green algae during the rainy season (June to September) (Fig. 11) can be attributed to high nitrate values during these months (Fig. 2). Also the bouyancy of blue green algae, resulting from the presence of gas vacuoles in the cells could have assisted them to remain suspended on the water surface in spite of the distrubing effects of heavy rainfall (Fogg, et al., 1973; Shapiro, 1973; Reynolds and Rogers, 1976). In temperate climates, periodicity is usually related to the annual turnover which follows the end of the warm season; this breaks the thermal stratification of the lakes and brings to the surface nutrients released from the mud during the period of deoxygenation. Compared to temperate regions there is little variation of temperature in tropical water bodies (Fig. 8).

As a result, the tropical pattern of seasonal variation of phytoplankton in the study of ponds and reservoirs are typical and different from those observed in temperate regions (Seenayya, 1972; Munawar, 1974).

It has been found that different requirements of different species for nutrients can result in natural succession. Unlike other forms of algae, most blue greens are nitrogen fixers and are able to grow at very low concentrations of inorganic nutrients. (Fogg, 1965; Brylinsky and Mann, 1973). In a reservoir treated with copper sulphate an artificial succession can be produced; according to Pearsall, et al. (1946), Palmer (1962) and Jackson (1974) many algae are known to exhibit marked resistance to copper especially after an initial treatment. These include many species of green algae. It is possible that variations in physico-chemical condition of the water together with the treatment applied at different times would have contributed to the succession pattern of algal community observed in this reservoir (Fig. 11, 12).

Aging processes in a reservoir may result in a production of troublesome algal growth (Rodhe, 1964; Neel, 1967; Biswas, 1972). Algal genera commonly forming water blooms, which also can be a nuisance in water supplies, are Microcystis, Anabaena, Aphanizomenon, *Oscillatoria* (Cyanophyceae), *Synedra*, *Cymbella*, *Cyclotella* (Bacillariophyceae) and *Euglena* (Euglenophyceae) (Am. Publ. Hlth. Assoc., 1980). It is also noticed that in some water supplies odour and taste is caused by stagnation in the mains or by disturbances of sedimentary matter caused by alternation in flow (Holden, 1970). Algal forms identified (Fig. 12) during the study period, and the period of disturbance of the sediment by floods especially during the long rainy period, (July-September) probably contributed to the odour produced in the month of September.

With regard to horizontal distribution of phytoplankton, it has been observed that algae were relatively concentrated at Site - 3 (Fig. 3). Many workers have shown that the appearance of high concentration of algae at the surface of a lake is not necessarily the result of unusually large growth but more often a localized phenomenon caused by meteorological conditions, wind especially being a factor that concentrates algae towards one side (Margalef, 1964; Reynolds and Rogers, 1976; Belay and Wood, 1982). It is possible that the highest algal biomass recorded at Site 3 could be attributed to wind effect.

7. CONCLUSION AND RECOMMENDATION

Whenever water is provided for low income people of less developed countries, there should be the minimum possible treatment, and the best supply is one which needs no treatment at all. Construction of impoundments for water supply in many countries is being practised to solve shortage of potable water. However, along with this action, several problems have arisen in reservoir managements (Baxter, 1977; Obeng, 1978; Vollenweider, 1981). Water-borne diseases that have resulted from environmental pollution together with cultural eutrophication caused by discharges of domestic wastes and agricultural run-offs from catchement areas are some of the problems associated with water sources.

Like other tropical water sources at large, this reservoir is polluted by animal wastes from the surrounding. The catchment area which covers around 225 Km^2 (Belete Muluneh, 1981) is being used for agriculture with fertilizer applied in some of the farms. Domestic wastes from the present growing settlement around Lege Dadi reservoir could possibly affect the quality of the water. Algal blooms in Lege Dadi reservoir reported since 1979 are probably a result of nutrient enrichment due to the above causes.

To control the blooms, the Water and Sewerage Authority Plant Division of Addis Ababa has been treating the water with $CuSO_4$ for the last three years. However, this action could serve only as a short term solution for the problem., Treatment of water with $CuSO_4$ cannot give a long term solution as seen in other water sources. Continuous treatment with $CuSO_4$ might increase the concentration of copper ion beyond the standard level of drinking water and it might even be toxic to other organisms like fish, if the reservoir is designed for fish breeding like other reservoirs (Jackson, 1974 ; Boyd, 1979).

Based on the results obtained during the study period, the following recommendations can be made concerning the existing practices of $CuSO_4$ treatment so as to minimize the amount of $CuSO_4$ added to the reservoir.

(1) It has been observed that the amount of $CuSO_4$ presently applied, the method of application and the site of application are not based on a scientific study. Since the ion is toxic to all organisms at high concentration, the present trend of treatment should be corrected and a proper study should be made on the amount and method of application of copper sulphate.

(2) The results of the present study suggest that the algal population starts to build up in the month of September. It is therefore advisable to apply the $CuSO_4$ during this period so as to suppress the growing population instead of applying the $CuSO_4$ at the peak of growth of the algae as is currently practiced.

(3) It appears from the present findings that the algal population develops at Site 1 and 2 and is concentrated at Site 3 by wind. It is therefore advisable to apply the $CuSO_4$ preferably at Site 1 and 2 instead of Site 3 as it is practiced now.

(4) It is not advisable to use chemical methods to control algal blooms in reservoirs that mainly serve for drinking purpose. Experiences attained in reservoir managements of tropical water bodies should be adopted and other physical or biological method should be applied to control the effect of algal blooms.

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It should be stressed that the present study on problems associated with algal blooms in the reservoir is the first of its kind. Any recommendation based on this preliminary study should therefore be verified by further studies. The present study should therefore serves as a stepping stone to further more detailed studies that would reveal the state of the problem more clearly. The concerned authorities should therefore take all the necessary steps towards such detailed studies and at control measures.

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9. APPENDIX

Table - III Chlorophyll "a" concentration µg/l in Lege Dadi reservoir between June 1982 - May 1983

	1982														1983									
Month	Jun		Jul			Aug	Sept		Oct		Nov			Dec	Jan		Feb			Mar	Apr		May	
Date	3	15	2	15	28	17	6	20	7	18	3	18	29	15	3	18	1	14	28	15	5	5	2	16
Site 1	200	210	110	115	110	100	110	100	100	100	110	150	110	110	150	115	150	125	120	110	100	100	100	100
Site 2	250	210	110	115	110	100	110	100	125	100	115	150	130	115	150	125	150	130	130	115	110	110	100	110
Site 3	300	240	110	115	110	100	110	100	150	250	300	300	325	300	300	320	300	300	275	280	240	150	130	150
Average	250	220	110	115	110	100	110	100	125	150	175	200	185	175	200	190	200	185	175	165	150	120	110	120

Table IV The relative abundance of algae in Lege Dadi reservoir between JUNE 1982 - MAY 1983

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
June 3/82	Cyanophyceae	Microcystis sp.	57×10^3	95×10^3	60%	50%
		Anabaena sp.	38×10^3		40%	
	Chlorophyceae	Chlorella sp.	19×10^3	48×10^3	40%	25%
		Mougeotia sp.	29×10^3		60%	
	Bacillariophyceae	Navicula sp.	19×10^3	19×10^3	100%	10%
	Dinophyceae	Peridinium sp.	17×10^3	28×10^3	60%	
		Ceratium sp.	11×10^3		40%	15%
Total number of Algae				190×10^3		100%
June 15/82	Cyanophyceae	Microcystis sp.	51×10^3		60%	
		Anabaena sp.	34×10^3	85×10^3	40%	50%
	Chlorophyceae	Chlorella sp.	14×10^3	34×10^3	40%	
		Mougeotia sp.	20×10^3		60%	20%
	Bacillariophyceae	Navicula sp.	26×10^3	26×10^3	100%	15%
	Dinophyceae	Peridinium sp.	26×10^3	26×10^3	100%	15%
Total number of Algae				171×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
July 2/82	Cyanophyceae	Microcystis sp.	22×10^3	37×10^3	60%	45%
		Anabaena sp.	15×10^3		40%	
	Chlorophyceae	Chlorella sp.	6×10^3	21×10^3	30%	25%
		Mougeotia sp.	15×10^3		70%	
	Bacillariophyceae	Navicula sp.	12×10^3	12×10^3	100%	15%
	Dinophyceae	Peridinium sp.	13×10^3	13×10^3	100%	15%
Total Number of Algae				83×10^3		100%
July 15/82	Cyanophyceae	Microcystis sp.	39×10^3	63×10^3	60%	45%
		Anabaena sp.	24×10^3		40%	
	Chlorophyceae	Chlorella sp.	16×10^3	35×10^3	45%	
		Mougeotia sp.	19×10^3		55%	25%
	Bacillariophyceae	Navicula sp.	21×10^3	21×10^3	100%	15%
	Dinophyceae	Peridinium sp.	16×10^3	21×10^3	100%	15%
Total Number of Algae				140×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
July 28/82	Cyanophyceae	Microcystis sp.	24×10^3	40×10^3	60%	
		Anabaena sp.	16×10^3		40%	50%
	Chlorophyceae	Chlorella sp.	14×10^3	32×10^3	45%	
		Mougeotia sp.	18×10^3		55%	40%
	Bacillariophyceae	Navicula sp.	4×10^3	4×10^3	100%	5%
	Dinophyceae	Peridinium sp.	4×10^3	4×10^3	100%	5%
Total number of Algae				80×10^3		100%
August 17/82	Cyanophyceae	Microcystis sp.	38×10^3	54×10^3	70%	45%
		Phormidium sp.	16×10^3		30%	
	Chlorophyceae	Tetraspora sp.	32×10^3		60%	
		Mougeotia sp.	11×10^3	54×10^3	20%	
		Chlorella sp.	11×10^3		20%	45%
	Bacillariophyceae	Navicula sp.	6×10^3	6×10^3	100%	5%
	Dinophyceae	Peridinium sp.	5×10^3	6×10^3	80%	
		Ceratium sp.	1×10^3		20%	5%
Total number of Algae				120×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
Sept. 6/82	Cyanophyceae	Microcystis sp.	9×10^3	30×10^3	30%	35%
		Phormidium sp.	21×10^3		70%	
	Chlorophyceae	Tetraspora sp.	31×10^3		60%	
		Chlorogonium sp.	10×10^3	51×10^3	20%	60%
		Chlorella sp.	10×10^3		20%	
	Bacillariophyceae	Navicula sp.	4×10^3	4×10^3	100%	5%
Total number of Algae				85×10^3		100%
Sept. 20/82	Cyanophyceae	Phormidium sp.	16×10^3	23×10^3	70%	
		Microcystis sp.	7×10^3		30%	30%
	Chlorophyceae	Tetraspora sp.	34×10^3		70%	
		Chlorogonium sp.	5×10^3	49×10^3	10%	65%
		Chlorella sp.	5×10^3		10%	
		Protococcus sp.	5×10^3		10%	
	Bacillariophyceae	Navicula sp.	3×10^3	3×10^3	100%	5%
Total number of Algae				75×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
Oct. 7/82	Chlorophyceae	Tetraspora sp.	47×10^3		70%	70%
		Chlorogonium sp.	7×10^3	68×10^3	10%	
		Chlorella sp.	7×10^3		10%	
		Protococcus sp.	7×10^3		10%	
	Cyanophyceae	Phormidium sp.	23×10^3	23×10^3	100%	25%
	Bacillariophyceae	Navicula sp.	4×10^3	4×10^3	100%	5%
Total number of Algae				95×10^3		100%
Oct. 18/82	Chlorophyceae	Tetraspora sp.	57×10^3		70%	
		Chlorogonium sp.	8×10^3	81×10^3	10%	70%
		Chlorella sp.	8×10^3		10%	
		Protococcus sp.	8×10^3		10%	
	Cyanophyceae	Phormidium sp.	29×10^3	29×10^3	100%	25%
	Bacillariophyceae	Navicula sp.	5×10^3	5×10^3	100%	5%
Total number of Algae				115×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
Nov. 3/82	Chlorophyceae	Tetraspora sp.	55×10^3	91×10^3	60%	70%
		Chlorella sp.	18×10^3		20%	
		Chlorogonium sp.	9×10^3		10%	
		Protococcus sp.	9×10^3		10%	
	Cyanophyceae	Phormidium sp.	33×10^3	33×10^3	100%	25%
	Bacillariophyceae	Navicula sp.	6×10^3	6×10^3	100%	5%
Total number of Algae				130×10^3		100%
Nov. 18/82	Chlorophyceae	Tetraspora sp.	76×10^3	109×10^3	70%	70%
		Chlorogonium sp.	16×10^3		15%	
		Chlorella sp.	17×10^3		15%	
	Cyanophyceae	Phormidium sp.	38×10^3	38×10^3	100%	25%
	Bacillariophyceae	Navicula sp.	7×10^3	7×10^3	100%	5%
Total number of Algae				155×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage compostion of algal groups
Nov. 29/82	Chlorophyceae	Tetraspora sp.	71×10^3		70%	70%
		Chlorogonium sp.	31×10^3	102×10^3	30%	
	Cyanophyceae	Phormidium sp.	36×10^3	36×10^3	100%	25%
	Bacillariophyceae	Navicula sp.	7×10^3	7×10^3	100%	5%
Total number of Algae				145×10^3		100%
Dec. 15/82	Chlorophyceae	Tetraspora sp.	66×10^3		65%	
		Chlorogonium sp.	20×10^3	101×10^3	20%	75%
		Chlorella sp.	15×10^3		15%	
	Cyanophyceae	Phormidium sp.	27×10^3	27×10^3	100%	20%
	Bacillariophyceae	Navicula sp.	7×10^3	7×10^3	100%	5%
Total number of Algae				135×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
Jan. 3/83	Bacillariophyceae	Cymbella sp.	14×10^3	46×10^3	30%	
		Navicula sp.	32×10^3		70%	30%
	Chlorophyceae	Tetraspora sp.	42×10^3		70%	39%
		Chlorogonium sp.	18×10^3	60×10^3	30%	
	Cyanophyceae	Gloeocystis sp.	34×10^3	48×10^3	70%	
		Microcystis sp.	14×10^3		30%	31%
Total number of Algae				154×10^3		100%
Jan. 18/83	Bacillariophyceae	Cymbella sp.	20×10^3	50×10^3	40%	34%
		Navicula sp.	30×10^3		60%	
	Chlorophyceae	Tetraspora sp.	33×10^3		70%	
		Chlorogonium sp.	14×10^3	47×10^3	30%	33%
	Cyanophyceae	Gloeocystis sp.	28×10^3	47×10^3	60%	
		Microcystis sp.	19×10^3		40%	33%
Total number of Algae				144×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
Feb. 1/83	Bacillariophyceae	Navicula sp.	34×10^3	56×10^3	60%	37%
		Cymbella sp.	22×10^3		40%	
	Chlorophyceae	Chlorogonium sp.	44×10^3	44×10^3	100%	29%
	Cyanophyceae	Gloeocystis sp.	30×10^3	50×10^3	60%	34%
		Microcystis sp.	20×10^3		40%	
Total number of Algae				150×10^3		
Feb. 14/83	Bacillariophyceae	Navicula sp.	24×10^3	48×10^3	50%	34%
		Cymbella sp.	24×10^3		50%	
	Chlorophyceae	Chlorogonium sp.	46×10^3	46×10^3	100%	33%
	Cyanophyceae	Gloeocystis sp.	28×10^3		60%	
		Microcystis sp.	18×10^3	46×10^3	40%	33%
Total number of Algae				140×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
Feb. 28/83	Bacillariophyceae	Navicula sp.	33×10^3	55×10^3	60%	42%
		Cymbella sp.	22×10^3		40%	
	Cyanophyceae	Gloeocystis sp.	27×10^3	44×10^3	60%	34%
		Microcystis sp.	17×10^3		40%	
	Chlorophyceae	Chlorogonium sp.	31×10^3		100%	24%
Total number of Algae				130×10^3		100%
Mach 15/83	Bacillariophyceae	Navicula sp.	28×10^3	56×10^3	50%	45%
		Cymbella sp.	28×10^3		50%	
	Cyanophyceae	Gloeocystis sp.	23×10^3	38×10^3	60%	
		Microcystis sp.	15×10^3		40%	30%
	Chlorophyceae	Chlorogonium sp.	31×10^3	31×10^3	100%	25%
Total number of Algae				125×10^3		100%
April 5/83	Bacillariophyceae	Navicula sp.	23×10^3	46×10^3	50%	
		Cymbella sp.	23×10^3		50%	40%
	Cyanophyceae	Gloeocystis sp.	27×10^3		60%	
		Microcystis sp.	18×10^3	45×10^3	40%	39%
	Chlorophyceae	Chlorogonium sp.	24×10^3	24×10^3	100%	21%
Total number of Algae				115×10^3		100%

Table IV continued

Date	Group	Algal genera	Number of each genus per ml	Total number of algae in a group per ml	Percentage composition of genera	Percentage composition of algal groups
April 17/83	Bacillariophyceae	Navicula sp.	29×10^3	49×10^3	60%	45%
		Cymbella sp.	20×10^3		40%	
	Cyanophyceae	Microcystis sp.	22×10^3	44×10^3	50%	40%
		Gloeocystis sp.	22×10^3		50%	
	Chlorophyceae	Chlorogonium sp.	17×10^3	17×10^3	100%	15%
Total number of Algae				110×10^3		100%
May 2/83	Bacillariophyceae	Navicula sp.	40×10^3	40×10^3	100%	40%
	Cyanophyceae	Microcystis sp.	24×10^3	40×10^3	60%	40%
		Gloeocystis sp.	16×10^3		40%	
	Chlorophyceae	Chlorogonium sp.	20×10^3	20×10^3	100%	20%
Total number of Algae				100×10^3		100%
May 16/83	Bacillariophyceae	Navicula sp.	44×10^3	44×10^3	100%	40%
	Cyanophyceae	Microcystis sp.	29×10^3	49×10^3	60%	
		Gloeocystis sp.	20×10^3		40%	45%
	Chlorophyceae	Chlorogonium sp.	16×10^3	16×10^3	100%	15%
Total number of Algae				109×10^3		100%

Table V Data on physical and chemical characteristics of the water between June 1982 - May 1983.

Year	1982														1983									
Month	June		July			Aug.	Sept.		Oct.		Nov.			Dec.	Jan.		Feb.			Mar.	Apr.		May	
Date	3	15	2	15	28	17	6	20	7	18	3	18	29	15	3	18	1	14	28	15	5	17	2	16
Physical and chemical characterstics																								
Temperature (°C)	20	20	19	19	19	19	22	20	20	20	20	20	21	21	20	22	19	22	20	22	23	20	19	21
Turbidity (F.T.U.)	52	51	40	38	28	90	180	100	110	120	120	119	60	60	80	55	50	45	62	45	38	40	35	30
Colour (Pt. Co. Units)	110	110	90	90	80	280	350	300	450	350	230	300	180	250	300	200	200	180	250	175	150	150	150	100
Odour	V	V	V	V	V	V	X	X	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
Taste	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
Suspended solids (mg/l)	19	20	20	25	30	30	100	110	75	80	85	60	30	50	60	40	45	30	60	30	20	15	30	20
Alkalinity as HCO_3^- meq/l	1.4	1.4	1.0	0.9	1	0.6	0.8	0.8	0.8	0.8	0.84	0.8	1.0	0.7	1.0	0.8	1.0	1.0	0.8	0.8	0.8	0.9	0.9	0.9
Total Hardness as $CaCO_3$ (mg/l)	40	40	60	50	50	50	50	50	60	50	40	50	60	50	40	55	60	60	50	50	50	50	50	60
Carbon dioxide dissolved as CO_2 (mg/l)	20	18	24	10	28	16	22	12	24	12	13	14	20	20	16	16	20	20	16	20	20	20	12	16

V - Acceptable X - Unacceptable

Table V continued

Year	1982														1983							
Month	June		July			Aug.	Sept.		Oct.		Nov.			Dec.	Jan.		Feb.			Mar.	April		
Date	3	15	2	15	28	17	6	20	7	18	3	18	29	15	3	18	1	14	28	15	5	1[illegible]	
hysical and hemical haracter-tics																							
xygen issolved mg/l)	7	8	7	8	8	6	8	8	7	9	9	9	8	8	8	10	8	8	9	9	9	8	
itrate as (mg/l)	7.4	7.4	8.0	7.0	7.5	7.0	7.32	7.0	6.9	7.0	4.5	7.0	1.5	1.5	1.5	1.5	2.0	1.5	5.0	5.0	4.0	3.5	
itrite as (mg/l)	0.01	0.01	0.01	0.01	0.01	0	0.02	0	0.01	0.01	0.01	0.01	0.05	0.05	0.5	0.01	0.01	0.02	0.02	0.02	0.02	0.0[illegible]	
mmonia as (mg/l)	0.59	0.62	0.50	0.49	1.49	1.0	0.68	1.0	1.50	1.49	0.50	0.80	0.35	0.40	0.40	0.40	0.40	0.20	0	0.40	0.30	0.2[illegible]	
ron as Fe (mg/l)	0.60	0.70	0.30	0.10	0.08	0.07	0.20	0.50	0.25	0.10	0.10	0.20	0.10	0.15	0.15	0.20	0.10	0.10	0.10	0.10	0.15	0.1[illegible]	
anganese s Mn(mg/l	0.40	0.40	0	0	0	0	0	0	0.20	0	0	0	0	0	0	0	0	0	0.05	0	0	0	
luoride s F(mg/l)	0.70	0.70	0.40	0.45	0.75	0.60	1.0	0.50	0.30	0.30	0.30	0.40	0.70	0.70	0.70	0.75	0.75	0.70	0.75	0.70	0.70	0.75	
hosphate s $PO_4^=$ g/l)	0.20	0.30	0.30	0.30	0.20	0.20	0.20	0.20	0.30	0.30	0.25	0.30	0.20	0.20	0.30	0.35	0.30	0.25	0.35	0.35	0.40	0.35	
opper as (mg/l)	0.40	0.45	0.45	0.05	0.35	0.20	0.30	0.20	0.25	0.40	0.25	0.40	0.25	0.30	0.35	0.30	0.30	0.35	0.20	0.30	0.20	0.20	
ilicate s SiO_2 g/l)	7.5	7.4	7.4	7.3	8.0	7.7	7.7	7.5	7.8	7.8	6.0	7.9	4.6	4.4	4.4	4.4	4.0	4.4	4.4	4.4	4.8	2.3	
onduct-ivity mho/cm)	114	115	111	104	109	102	100	96	90	94	90	95	100	114	100	101	103	97	97	100	100	120	
pH	7.3	7.4	7.0	7.32	6.9	7.1	7.0	6.97	6.89	7.0	6.81	6.85	6.85	6.9	7.0	7.1	6.9	7.6	6.7	7.2	6.8	6.5	7