OCEANOGRAPHIC INVESTIGATIONS ON THE RED SEA WATERS IN FRONT OF AL-GHARDAQA I. HYDROGRAPHY

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VIE MILIEU, 1987, 37 (3/4) : 229-236

OCEANOGRAPHIC INVESTIGATIONS ON THE RED SEA WATERS IN FRONT OF AL-GHARDAQA
I. HYDROGRAPHY

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HYDROGRAPHIE
MER ROUGE
AL-GHARDAQA

RÉSUMÉ - Les variations saisonnières des conditions hydrographiques des eaux côtières de la Mer Rouge, face à Al-Ghardaqa, ont été étudiées. La température de l'eau de surface est influencée principalement par la température de l'air, les deux montrant des variations locales. Les plus basses moyennes des températures de l'air et de l'eau ont été relevées en janvier, et les plus élevées en juillet. Une tendance à l'élévation de la température de surface du nord au sud et de l'est à l'Ouest a été observée. La valeur moyenne élevée de la salinité en juillet est attribuée à un accroissement du taux d'évaporation dû à l'augmentation de la température. L'augmentation de la salinité avec la profondeur coïncide avec l'enfoncement par densité de l'eau la plus saline qui se forme en surface par évaporation. La valeur moyenne élevée de la salinité calculée pour l'aire étudiée (40,41 ‰), reflète le caractère original de la Mer Rouge connue comme l'étendue d'eau de salinité la plus élevée du monde. Le pH de la zone d'étude est toujours alcalin, avec une valeur moyenne de 8,24. L'oxygène dissous (DO) présente une concentration relativement haute, avec une moyenne de 5,81 $mg.l^{-1}$. La distribution horizontale du pH et de l'oxygène dissous à la surface est influencée par les conditions locales. Les variations verticales irrégulières de pH et de DO sont attribuées principalement au processus de mélanges verticaux et aux effets des vagues. La baisse du pH et de la DO avec la profondeur résulte surtout de la décomposition des déchets organiques qui se déposent. Les moyennes minimales saisonnières de pH et de DO en juillet coïncident avec l'accroissement du taux de décomposition des déchets organiques due à l'élévation de la température.

HYDROGRAPHY
READ SEA
AL-GHARDAQA

ABSTRACT - Seasonal variations of the hydrographic conditions in the coastal Red Sea waters in front of Al-Ghardaqa were studied. The surface water temperature was mostly influenced by air temperature and both showed local variations. The lowest average air and water temperatures were recorded in January and the highest in July. A tendency of increasing surface temperature from north to south and west to east was observed. The maximum seasonal average salinity value in July is attributed to the increase in the rate of evaporation brought about by elevation of temperature. The increase in salinity with depth occurs with sinking of the denser mass of more saline water, formed near the sea surface by evaporation. The high average salinity value calculated for the area of study (40.41 ‰) reflects the unique character of the Red Sea as the most saline body of water in the world oceans. The pH of the study area was always on the alkaline side, giving an average value of 8.24. Dissolved oxygen (DO) in this area gave relatively high concentrations, with an average value of 5.81 mg/l. The horizontal distribution of pH and DO in the surface water is generally influenced by certain local conditions. The irregular vertical variations of pH and DO are attributed mainly to the vertical mixing processes and the tidal effects. The decrease in pH and DO values with depth resulted in the main from decomposition of the descending organic remains. The minimum seasonal averages of pH and DO in July coincided principally with the increase in the rate of decomposition of organic remains by elevation of temperature.

INTRODUCTION

The Red Sea is considered one of the least explored areas. This landlocked semi-enclosed sea, located in an arid zone where evaporation is far in excess of precipitation and run-off, has a unique ecosystem in the tropical region. The environment of the Red Sea, particularly the coastal areas, is threatened, mainly from oil pollution as well as the discharge of sewage and industrial wastes into the coastal waters (Anon, 1976). One of the coastal areas of special interest is that in front of Al-Ghardaqa (Hurgada) on the western side of the Red Sea. According to the available literatures, there are no chemical measurements in the coastal Egyptian Red Sea waters, especially at Al-Ghardaqa. However, Morcos (1960), Morcos and Riley (1966) and El-Sabh (1968) investigated some physical properties of the Suez Canal water. Also, Morcos (1968) determined the chemical composition of this water. Although the Red Sea area at Al-Ghardaqa has received intensive biological studies since 1932 (Beltagy, 1975), it still lacks the physico-chemical investigations. Consequently, this coastal water was chosen for a research programme dealing with the hydrography and nutrients presented in Parts I and II, respectively. The main purpose of this project is to determine the status of the environmental and nutrient parameters in the different regions of the study area during the four seasons of the year. Knowledge of the vertical variations of the investigated parameters seems to be essential for understanding the biological changes, mainly phytoplankton populations, in the study area. Also, the data obtained are expected to provide the essential basic oceanographic information to serve as a reference for evaluation of possible environmental variations, which may occur in the future by different developments in this area.

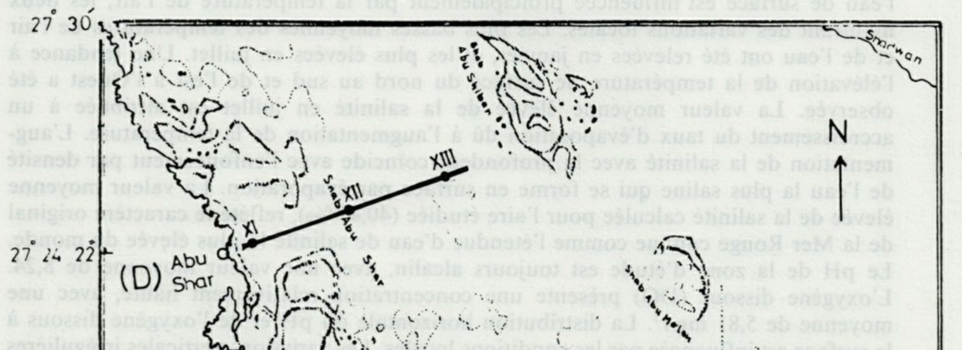

Fig. 1. — Map fo the study area showing the position of stations.

STUDY AREA

The study area, the coastal sea water in front of Al-Ghardaqa occupies the northwestern part of the Egyptian coast of the Red Sea around Al-Ghardaqa between latitude 27° 05' N and 27° 30' N and longitude 33° 37' E and 34° 0' E. This area extends from Magawish in the south to Abu-Shar in the north and from Al-Ghardaqa shore to near Shadwan Island (Fig. 1). The area of investigation is situated near the southernend of the remarkable maze of reefs and Islands, which occupy the northwestern corner of the Red Sea. All forms of reef are mostly found in this area.

The maze of reefs on the western side of the entrance to the Gulf of Suez , according to Crossland (1939), gives way to a slightly simpler system at Al-Ghardaqa comprising; a) the shore fringing reef, 100-150 m wide; b) a series of small lagoon reefs enclosed by a barrier. Along the shore and inside the 100 m line, the reefs extend to few meters in width and are clearly visible near the water surface. In addition to these coastal reefs, the area includes other reefs varying in size that are not uniformly distributed. Most reefs have local names mentioned in the chart. The bottom topography of the area is irregular. The area includes a number of islands of different heights, reaching up to 900 feet, as Shadwan Island.

The climatic conditions in this region in the northwestern part of the Red Sea favour a high rate of evaporation. The rainfall is very small. Water movements are due to three causes; tides, winds and changes of density. The winds blow from the N.N.W. and remain almost unchanged, except on a few days, all the year round.

MATERIAL AND METHODS

Four sections perpendicular to the coast were selected to cover the study area. They were from south to north; A - Magawish; B - Fanadir; C - Marine Biological Station, and D - Abu-Shar. Each section included three stations, except section C which included stations VII, VIII, IX and X (Fig. 1). This section was chosen to describe the vertical distribution of each of the investigated parameters, due to the more or less consistent similarity with other parts of the study area and the fact that it was the longest and deepest section (about 10 km long and 100 m in depth). Sampling was carried out seasonally in April (spring), July (summer), October 1980 (autumn) and January 1981 (winter). Each cruise was completed in two successive days, starting from the southern part of the study area, except in January when three successive days were required, due to poor weather conditions. Vertical water samples were collected, using reversing Nansen water sampler, at different depths (surface, 5, 10, 15, 25, 50 and 100 m) at the deepest station, and as many as the depth allowed at the shallower ones.

The air and water temperatures were recorded at the time of sampling. The air temperature was measured with an ordinary thermometer and the water temperature with standard reversing protected thermometers. The hydrogen ion concentration was determined *in situ*, using a portable glass electrode pH-meter accurate to 0.01 unit. The salinity of water samples, collected in special hard glass salinity bottles, was determined immediately on return to the laboratory, using an inductive salinometer. Determination of dissolved oxygen was carried out with the classical Winkler method modified by Strickland and Parson (1968). The oxygen bottles were filled with water samples and fixation was performed immediately in order to prevent loss of dissolved oxygen by elevation of temperature and to prevent any reduction due to the plankton content (Strickland and Parsons, 1968).

RESULTS

Temperature measurements

The values of air temperature fluctuated between 16.5°C at station VII in January and 33.3°C at station IX in July. The surface water temperatures ranged from 18.24°C at station VII in January to 29.0°C at station I in July. The seasonal average values of air temperature varied from 18.1 to 31.2°C and those of surface water temperature from 19.70 to 28.84°C in January and July, respectively (Fig. 2).

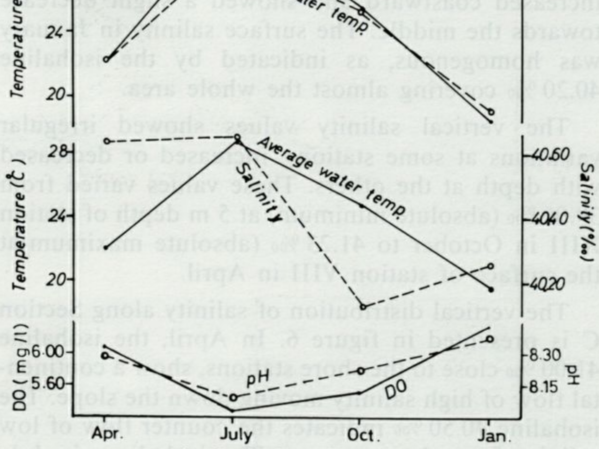

Fig. 2. — Variations of the seasonal average values of air and water temperatures, and of salinity, dissolved oxygen (DO) and pH in the study area during 1980-1981.

The horizontal distribution of surface water temperature is shown in figure 3. In April, October and January, the isotherms run almost parallel to the coast line, showing a general increase seaward. However, this condition did not exist in July when the surface temperature decreased towards the open sea. An increase in the surface temperature towards the south was generally observed.

Although the water temperature decreased with depth at the majority of stations, slight irregular vertical temperature variations appeared at some locations. The readings ranged from an absolute minimum of 18.23° C at station VII (5 m of depth) in January to an absolute maximum of 29.00 °C at station I (surface and 5 m of depth) in July.

The vertical distribution of temperature along section C is presented in figure 4. In April, the isotherms 20, 21 and 22°C cover the shore area. The seasonal thermocline was observed in July and October. The isotherm 28.8°C covers the upper 15 m depth in July, indicating a homogenity of this layer. The isotherm 24.0°C shows in October a continental flow at station IX. A continental flow of cold water (less than 19.0°C) moved down the slope in January. The seasonal average values (averages of all stations in each season) fluctuated markedly between 19.60°C in January and 28.65°C in July (Fig. 2).

Salinity

The surface horizontal distribution of salinity is shown in figure 5. In April, the salinity values exhibited a horizontal distribution pattern different from that for the surface temperature. The isohaline of this month run almost parallel to the coast line in most regions. The surface salinity in July was higher than that in the other seasons. In general, the surface salinity in April and July increased northward and coastward. In October, the surface salinity increased coastward and showed a slight decrease towards the middle. The surface salinity in January was homogenous, as indicated by the isohaline 40.20 ‰ covering almost the whole area.

The vertical salinity values showed irregular variations at some stations, increased or decreased with depth at the others. These values varied from 39.06 ‰ (absolute minimum) at 5 m depth of station XIII in October to 41.23 ‰ (absolute maximum)at the surface of station VIII in April.

The vertical distribution of salinity along Section C is presented in figure 6. In April, the isohaline 41.00 ‰ close to the shore stations, show a continental flow of high salinity moving down the slope. The isohaline 40.50 ‰ indicates the counter flow of low salinity from the open sea. The isohalines in July indicate slight stratification. The surface water layer that month showed higher salinity than the subsurface layer, whereas the deep layers had the highest

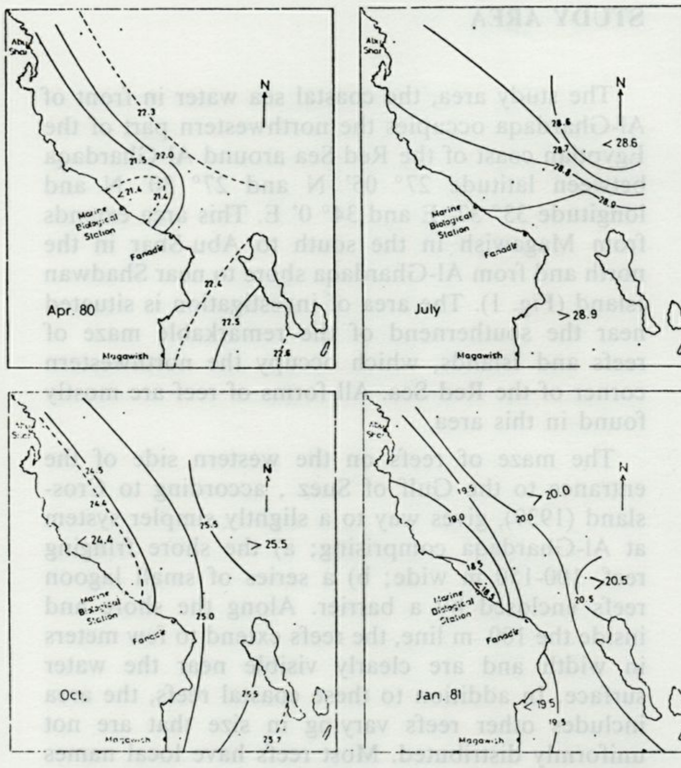

Fig. 3. — Horizontal distribution of surface water temperature (°C) in the study area during 1980-1981.

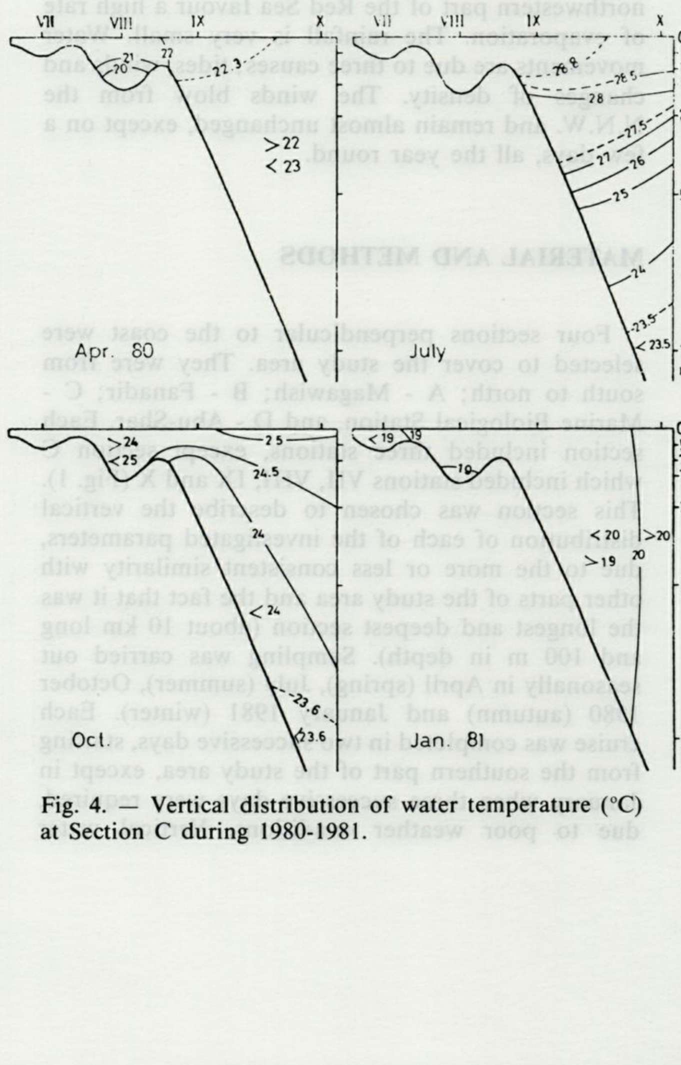

Fig. 4. — Vertical distribution of water temperature (°C) at Section C during 1980-1981.

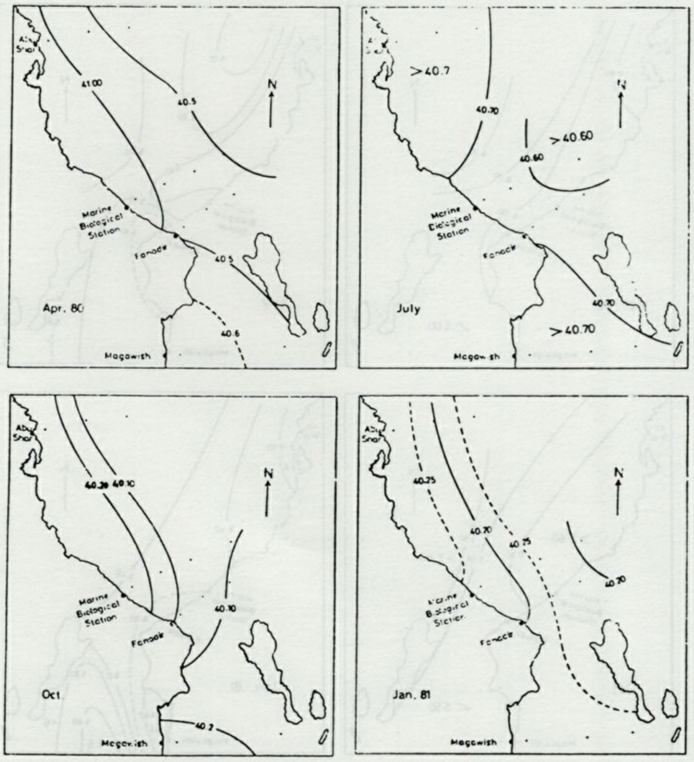

Fig. 5. — Horizontal distribution of surface salinity (‰) in the study area during 1980-1981.

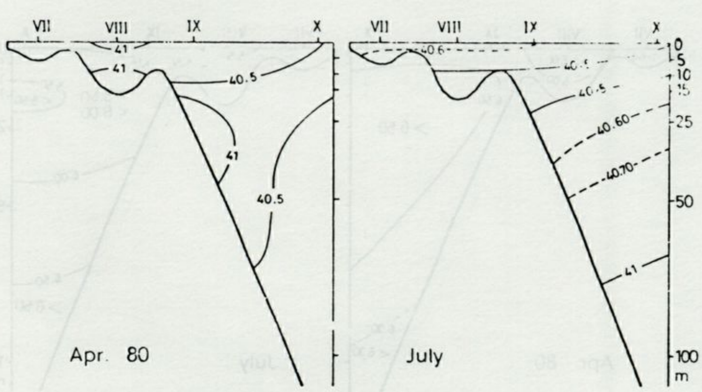

Fig. 6. — Vertical distribution of salinity (‰) at Section C during 1980-1981.

values. In October, the isohalines show a relative increase in salinity towards the coast and the bottom. The isohalines in January illustrate irregular distribution. The seasonal average salinity values fluctuated slightly between 40.12 ‰ in October and 40.65 ‰ in July (Fig. 2).

Hydrogen ion concentration

The surface horizontal distribution of pH is presented in figure 7. The pH isolines show in April the same distribution as in January. They are irregular in July, with a decrease in pH values from north to the middle. The surface pH exhibited in October a decrease seaward and an increase southward. The isolines run parallel to the coast during this month. In January, the isolines also run parallel to the coast, except in the middle region, and show a decrease from north to the middle and increase to the south.

The vertical pH values showed irregular variations, both decreases and increases with depth. These values ranged from an absolute minimum of 7.80 at the surface of station VII and the bottom of station VIII in July to an absolute maximum of 8.78 at the bottom of station XII in January.

The vertical distribution of pH along Section C (Fig. 8) shows an increase seaward in April and coastward in October, as well as a general decrease seaward in January. At this section, the pH values exhibited a decrease downward during the study, except in April. The seasonal average values of pH varied slightly from 8.08 in July to 8.37 in January (Fig. 2).

Dissolved oxygen (DO)

The surface horizontal distribution of DO is shown in figure 9. In April, there was an increase in DO concentrations seaward and northward. The whole study area in July generally indicated irregularity in the surface DO distribution. A slight increase coastward and northward was observed in October. The DO isolines in January show a decrease southward and seawards.

The DO concentrations gave irregular vertical variations and decreased or increased with depth. They fluctuated between 4.30 mg/l (absolute minimum) at the bottom of station II in July and 6.71 mg/l (absolute maximum) at the surface of station I in January.

The vertical distribution of DO along Section C is presented in figure 10. In April, the isoline 6.50 mg/l covers the subsurface layer. The coastal and surface waters in July showed lowest DO values, whereas the highest were observed in the subsurface and bottom waters. In October, the isoline 5.50 mg/l covers the upper layer and that of 6.00 mg/l the bottom layer. The vertical distribution of DO in

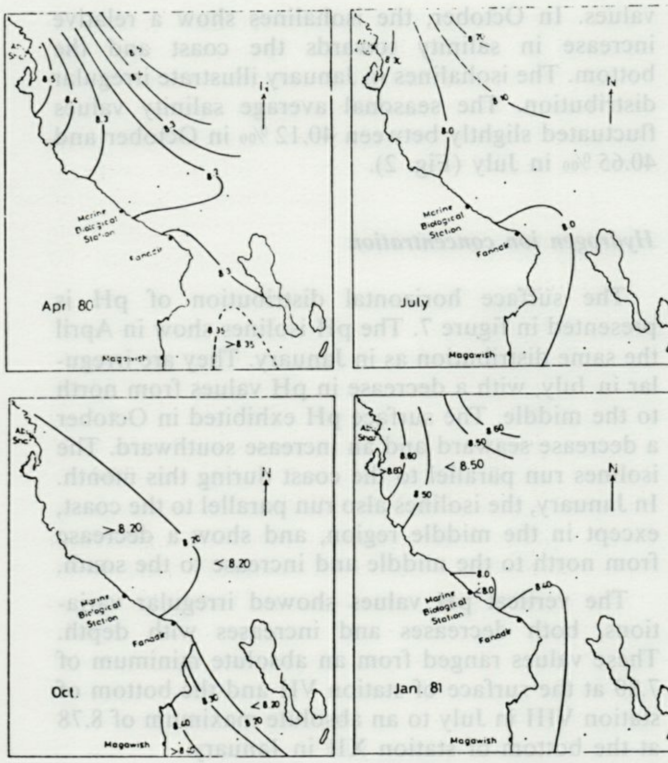

Fig. 7. — Horizontal distribution of surface pH in the study area during 1980-1981.

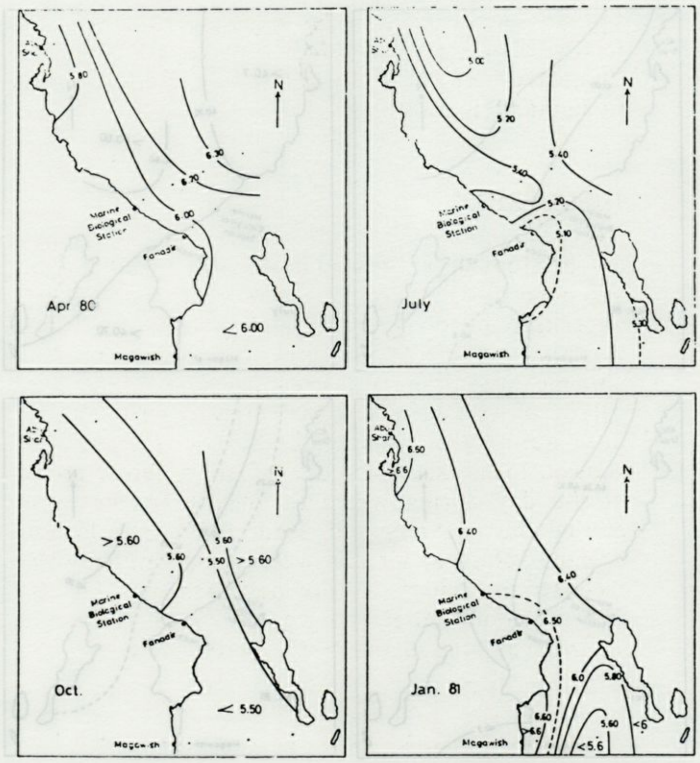

Fig. 9. — Horizontal distribution of surface DO (mg/l) in the study area during 1980-1981.

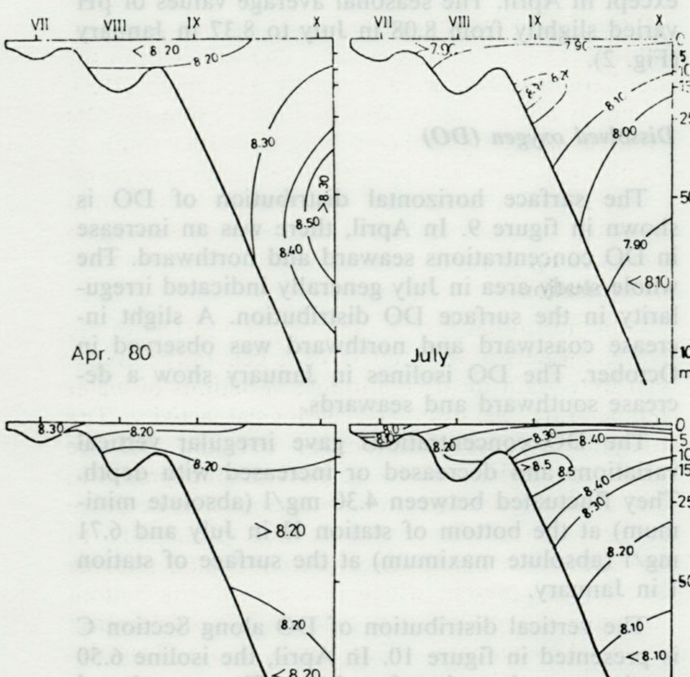

Fig. 8. — Vertical distribution of pH at Section C during 1980-1981.

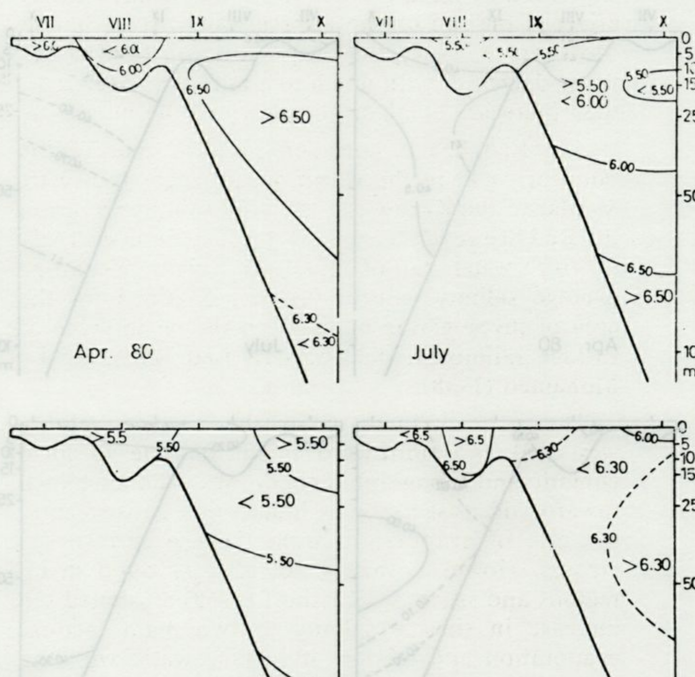

Fig. 10. — Vertical distribution of DO (mg/l) at Section C during 1980-1981.

January shows the effect of winter convection and mixing of waters. The seasonal average DO values fluctuated between 5.28 mg/l in July and 6.36 mg/l in January (Fig. 2).

DISCUSSION

The study area, situated in the arid zone between two great deserts, receives a very limited amount of water through precipitation and run-off. Accordingly, this shallow water area is affected by the climatic conditions, and irregular topography. The values of surface water temperature were mostly influenced by air temperature. Both temperatures showed local variations, due to the different times of the day during which the measurements were carried out (Behairy and Saad, 1984). The lowest average values of air and water temperatures were recorded in January and the highest in July (Fig. 2). The variations reflect the conditions of the warm subtropical zone of the northern Red Sea.

A tendency of increasing surface temperature from north to south and from west to east was observed. Mohamed (1938) gave different explanations for this west-east distribution, based on the effect of the northwestern winds blowing from land over the northern Red Sea. This was only for spring, autumn, and winter seasons.

The decrease in water temperature with depth was explained by Saad (1978b) to be due to the heating effect of the sun on the surface water. According to Mohammed (1938), the temperature of the Red Sea water decreases with depth to a minimum of 21.5°C, then increases adiabatically down to the bottom.

The Red Sea is considered as the most saline body of water in the world oceans (Morcos, 1970). Similar to the Arab Gulf, the high salinity values in the Red Sea result from the extremely limited supply of fresh-water run-off (Dubach, 1964). The high average salinity value (40.41 ‰) obtained for the area of investigation agrees with the mean value of surface salinity in the northern Red Sea given by Mohamed (1938).

The general increase in the surface salinity westward and northward might be due to local climatic and topographic conditions. The air blown towards the east becomes humid and consequently the rate of evaporation from the sea surface decreases. However, this is not always found in all regions and seasons. Grasshoff (1969) attributed the increase in surface salinity to two main factors; evaporation and mixing of surface water with the more saline deep water through turbulence. This author pointed out that the surface currents become weaker and consequently the effect of evaporation increases. The salinity gradient becomes weaker and irregular in the northward direction and this creates favourable conditions for vertical mixing.

The increase in salinity with depth is a general characteristic of the Red Sea. This could be related to sinking of the denser more saline water, which was formed near the surface by water evaporation. The stratification of salinity observed in July along Section C could be attributed to the high evaporation rate. However, the irregular vertical distribution of salinity generally found in the other seasons is possibly related to the vertical mixing processes and land effect.

The maximum seasonal average salinity value in July (Fig. 2) is attributed to the increase in the rate of evaporation brought about by elevation of temperature (Behairy and Saad, 1984). Shaikh (1981) related the high salinity values during summer months in the coastal Red sea waters north of Jeddah to excessive evaporation.

The pH is a reflection of many biological and chemical processes occuring in natural waters (Saad, 1978a). According to Atkins and Harris (1924), the photosynthetic activity exceeds the respiratory activity of the biota when the pH of the surface water is higher than 8.10. The pH in the present study was always on the alkaline side, with an average value of 8.24 for the whole area. This was also found by Behairy and Saad (1984) in the coastal Red Sea water in front of Jeddah and by Al-Saadi *et al*, (1977) in the North-West Arab Gulf.

The concentrations of DO at any time represent a momental balance between the rates of supply and consumption (Wahby *et al.*, 1972). Our knowledge of the DO content in the Red Sea was acquired relatively late. The first modern DO values from the northern Red Sea were given by Mohamed (1938, 1940). It was noted by Van Riel (1932) that the DO content of the upper layer increased from south to north. In general, DO gave relatively high concentrations in all seasons and has never been found depleted in the study area. The average DO value obtained for this area was 5.81 mg/l (more than 80 % of saturation).

The horizontal distribution of pH and DO in the surface waters of the study area is generally influenced by certain local conditions; variations of water temperature, aeration and biological activity. The irregular vertical variations of pH and DO are attributed mainly to the vertical mixing processes and the tidal effects in the study area. The decrease in pH values with depth is due principally to decomposition of the descending plankton remains and organic matter, which increases in the bottom waters (Juday, 1924; Saad, 1976), and to the decrease in DO (Wattenberg, 1933; Smith, 1952). This decrease in oxygen content towards the bottom resulted mainly from this decomposition process (El-Wakeel and Wahby, 1970).

The minimum seasonal average pH and DO values in July (summer) occurred in relation mainly with elevation of water temperature (Fig. 2), and consequently with the increase in the rate of decomposition of detrital material and organic remains. However, the maximum seasonal average pH and DO values in January (winter) could be related to the decrease of water temperature (Fig. 2) and the vertical mixing processes. The relatively high seasonal average pH and DO values in April are mostly attributed to the relative increase in the photosynthetic activity in spring. Juday *et al.* (1924), Philip (1927) and Hutchinson (1957) showed that the increase in the rate of photosynthetic activity raises the pH values, as a result of the consumption of CO_2 and the increase in oxygen values in the water.

BIBLIOGRAPHIE

AL-SAADI H.A., M.A.H. SAAD, R.A. HADI & N.A. HUSSAIN, 1977. Further investigations on some environmental characteristics of North-West Arab Gulf. *Proc. Ind. nat. Sci. Acad.*, 43 : 183-192.

ANON, 1976. Marine science programme for the Red Sea. *Unesco tech. Pap. mar. Sci.*, 25 : 21 p.

ATKINS W.R.G., & G.T. HARRIS, 1924. Seasonal changes in the water and heleoplankton of fresh-water ponds. *Sci. Proc. Roy. Dub. Soc.*, 18 : 1-21.

BEHAIRY A.K.A. & M.A.H. SAAD, 1984. Effect of pollution on the coastal waters of the Red Sea in front of Jeddah, Saudi Arabia. 1. Environmental conditions. *Tethys*, 11 : 111-117.

BELTAGY A.I., 1975. A bibliograhy of the Red Sea and Gulf of Aden, ALECSO, Cairo, 217 p.

CROSSLAND C., 1939. Report on the preliminary expedition for the exploration of the Red Sea in the R. Rs. Mabahiss. *Publ. Mar. Biol. St. Al-Ghardaqa* (Red Sea) 1 : 3-11.

DUBACH H.W., 1964. A summary of temperature - salinity characteristics of the Persian Gulf. Nat. Geogr. Data Center. NODC General series Publ., G-4, 223.

EL-SABH M.I., 1968. Effect of the Aswan High Dam on the distribution of salinity in the Suez Canal. *Nature*, 218 : 758-760.

EL-WAKEEL S.K. & S.D. WAHBY,1970. The hydrography and chemistry of Lake Manzalah, Egypt. *Arch. Hydrobiol.*, 67 : 173-200.

GRASSHOFF K., 1969. Zu chemischen Beobachtungen von F.S. « Meteor » während der Indischen Ozean Expedition 1964-65. « Meteor » Forschungsergeb. Reihe 805 (Bornträger).

HUTCHINSON G.E., 1957. A treatise on limnology. Vol. I., Geography, Physics and Chemistry. New York and London, John Wiley and Sons Inc., 1015 p.

JUDAY C., 1924. Summary of quantitative investigations on Green Lakes, Wisconsin. *Int. Rev. ges. Hydrobiol. Hydrogr.*, 12 : 2-12.

JUDAY C., E.B. FRED & F.C. WILSON, 1924. The hydrogen ion concentration of certain Wisconsin lake waters. *Trans. Amer. Micros. Soc.*, 43 : 177-190.

MOHAMED A.F., 1938. Ph.D. Thesis, Liverpool Univ., 213 p.

MOHAMED A.F., 1940. The Egyptian exploration of the Red Sea. *Proc. Roy. Soc. London*, Ser. B, No 852, 128 : 306-316.

MORCOS S.A., 1960. Die Verteilung des Salzgehaltes im Suez- Kanal. *Kieler Meeresforsch.*, 16 : 133-154.

MORCOS S.A., 1968. The chemical composition of sea water from the Suez Canal region. Major Cations. *Kieler Meeresforsch.*, 24 : 66-84.

MORCOS S.A., 1970. Physical and chemical oceanography of the Red Sea. *Oceanogr. Mar. Biol. Annu. Rev.*, 8 : 73-202.

MORCOS S.A. & J.P. RILEY, 1966. Chlorinity, salinity, density and conductivity of sea water from the Suez Canal region. *Deep Sea Res.*, 13 : 741-749.

PHILIP C.B., 1927. Diurnal fluctuation in the hydrogen ion activity of a Minnessota Lake. *J. Ecology*, 8 : 73-89.

SAAD M.A.H., 1976. Some limnological investigations of Lake Edku, Egypt. *Arch. Hydrobiol.*, 77 : 411-430.

SAAD M.A.H., 1978 a. Seasonal variations of some physico-chemical conditions of Shatt Al-Arab Estuary, Iraq. *Est. Coast. Mar. Sci.*, 6 : 503-513.

SAAD M.A.H., 1978 b. Distribution of phosphate, nitrite and silicate in Lake Edku, Egypt. *Verh. Internat. Verein. Limnol.*, 20 : 1124-1130.

SHAIKH E.A., 1981. Phytoplankton ecology and production of the Red Sea off Jeddah, Saudi Arabia. Open Univ., Ph.D. Thesis.

SMITH M.W., 1952. Limnology and trout angling in Charlotte County Lakes, New Brunswick. *J. Fish. Res. Bd. Canada*, 8 : 383 p.

STRICKLAND J.D.H. & T.R. PARSONS, 1968. A practical handbook of sea water analysis. *Bull. Fish. Res. Bd. Canada*, 167 : 1-311.

VAN RIEL P.M., 1932. Einige ozeanographische Beobachtungen im Roten Meer, Golf von Aden und Indischen Ozean. *Ann. Hydrogr. USW*, 60 : 401-407.

WAHBY S.D., S.F. YOUSSEF & N.F. BISHARA, 1972. Further studies on the hydrography and chemistry of Lake Manzalah. *Bull. Inst. Oceanogr. Fisch.*, 2 : 399-422.

WATTENBERG H., 1933. Ueber die Titrations-Alkalinität und Calcium Carbonat-Gehalt des Meerwassers. Deutsche Atlantische Exped. Meteor 1925-27, Wiss. Erg., 8 : 122-231.

Reçu le 2 juin 1986; received June 2, 1986
Accepté le 26 mars 1987; accepted March 26, 1987