J.K.A.U. Mar. Sci., Vol. 1, pp. 27-38 (1410 A.H./1990 A.D.

Model of the Dispersion of Fresh Water and Other Sewage Materials in the Coastal Red Sea Water in Front of Jeddah

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ABSTRACT. The distribution pattern of the fresh water percentage and other sewage materials, viz. phosphate, suspended matter and manganese, in the surface water of the Red Sea coast in front of Jeddah was studied at different times of the year. It was found that the pollutants discharged into the Bankalah region were dispersed mainly to the southeastern side of the coastal area to an extent entirely controlled by the surface water movement induced by prevailing winds. An empirical dispersion model has been applied to one of the pollutants (phosphate) and this showed that there were other two significant sources of phosphate to the area.

Introduction

The levels of some chemical pollutants in the coastal area off Jeddah (Fig. 1) have been shown to originate from discharge of domestic sewage at its southeastern side, in the Bankalah area (El-Rayis *et al.* 1982, and Behairy and Saad 1984a,b). However, these authors did not show whether there was more than one source of sewage for the area, and what are the factors that control the pattern of the dispersion of these pollutants in the surface water. The present paper is an attempt to fill these gaps in our knowledge and to give, in the same time, data for the level and distributions of suspended matter, water transparency and the percentage of fresh water, as well as the chemical pollutants, dissolved reactive phosphate and manganese in this water. The conservative, or non-conservative, behaviour of one of the chemical pollutants (phosphate) during the mixing process of the water effluent with the surface coastal Red Sea water was also investigated.

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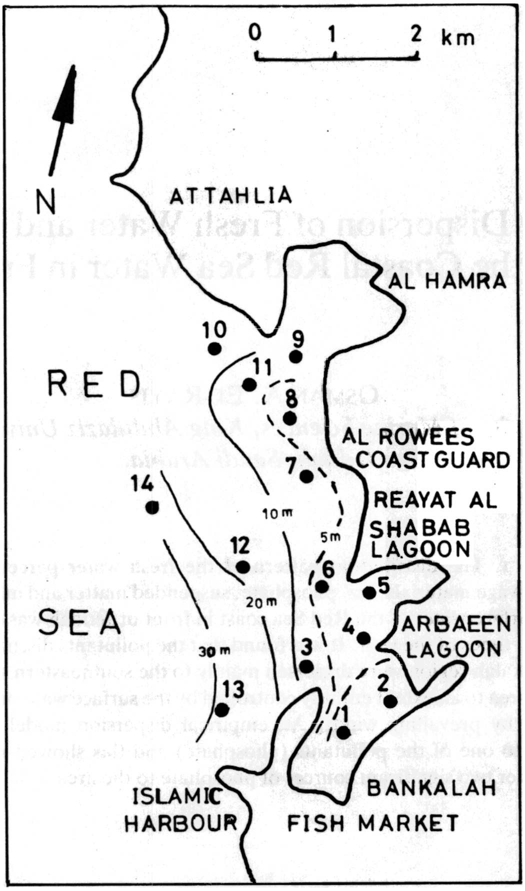


Jeddah coast (between Attahlia and the Islamic Harbour) bathymetry and locations of the sampling stations.

Material and Methods

Surface water samples were collected at fourteen stations shown in Fig. 1, during six cruises in the period between October 1981 and May 1982. Subsurface water samples were collected once in January 1982 from stations 1, 3, 12 and 14, that form a section extending at right angles seawards from the Bankalah coast.

In situ measurements for Secchi Disc depths were taken. Determinations of salinity, dissolved oxygen or hydrogen sulphide, total suspended matter and dissolved phosphate and manganese were made, for the first four successive cruise. For the last two cruises only salinity and dissolved oxygen or hydrogen sulphide were measured. All the determinations were carried out according to the methods described previously by El-Rayis *et al.* (1982 and 1985).

Results and Discussion

The results of the studied elements in the surface water of Jeddah coast are presented in the form of distributions shown in Fig. 2, 5-8.

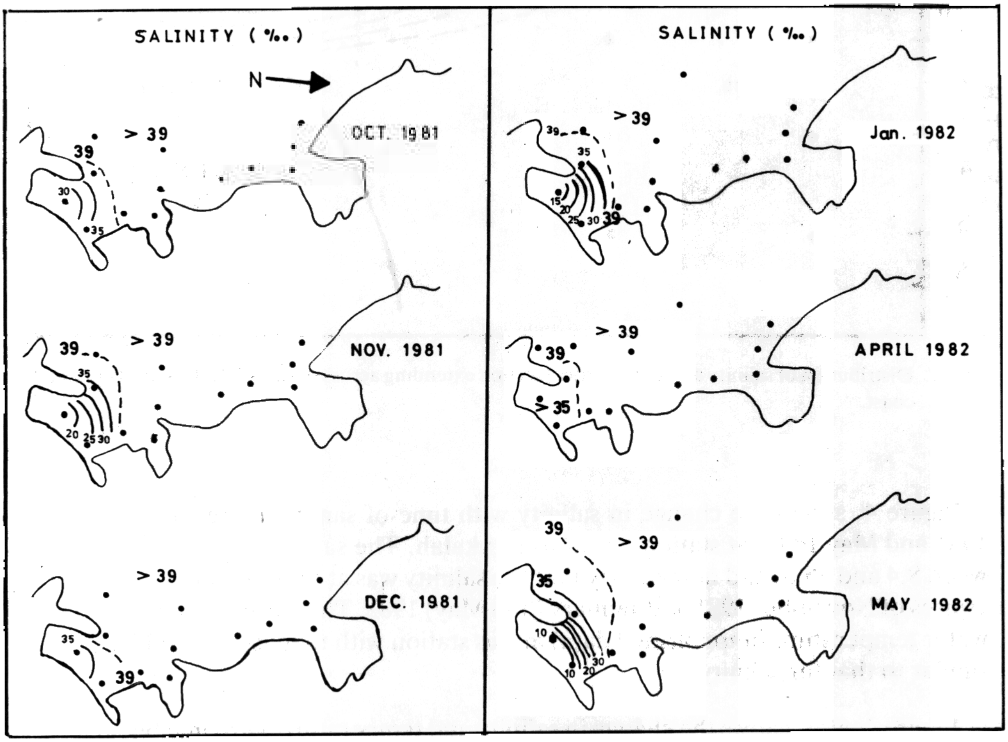


FIG. 2. Distribution of salinity in the surface water of the Red Sea coast in front of Jeddah.

Figure 2 shows the surface distribution of salinity. Figure 3 shows the vertical distribution of salinity along the section extended from Bankalah seaward. From these figures, it is easy to define the place of the discharge of the fresh water (that accompanied the effluent of the domestic sewage), which is at Bankalah area at the southeastern side of the studied area, where salinity values less than 39.0, minimum 8.4, were found. The minimum salinity was always found at station 1 near to Bankalah. Whereas the rest of Jeddah coast were characterized by salinity values greater than 39.0, maximum 39.6. From Fig. 2, it can be seen that the isohalines of values < 39.0 were close to one another near the entrance of Bankalah zone indicating that the rate of mixing during the inflowing of the discharged waste water with the Red Sea water was greater there. But the isohalines were changing their positions back and forth (or in and out) of Bankalah zone from one cruise to another. For example, they were out during the November 1981 and January 1982 (and May 1982) cruises and were in, during the cruises of October and December 1981 (and April 1982).

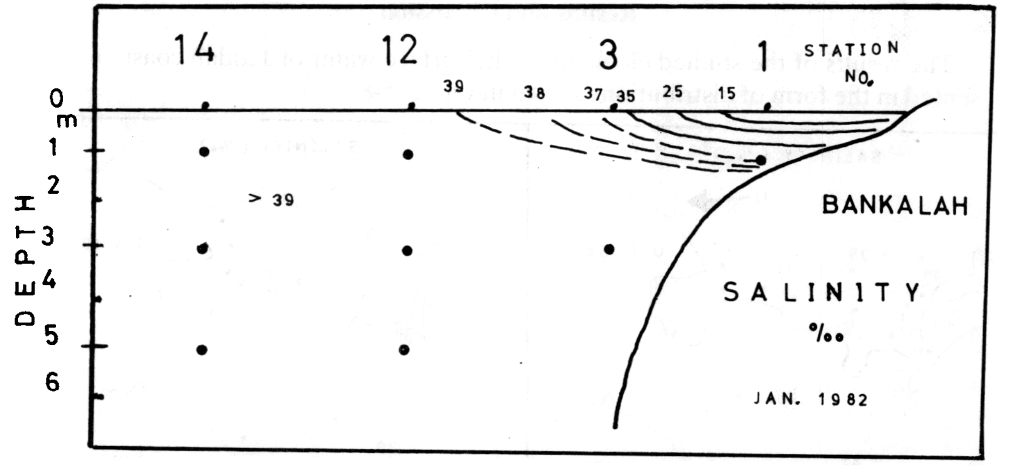


FIG. 3. Distribution of salinity along the vertical section extending across stations 1, 3, 12 and 14 in Jeddah coast.

Figure 4, shows the change in salinity with time of sampling (between October 1981 and May 1981) at station 1 near to Bankalah. The salinity was fluctuating between 8.4 and 35.8, and noteworthy that the salinity was at its minimum values in the cruises of November 1981 and January (and May) 1982. The pattern of change of the water temperature (unpublished data) at this station with time, shown in Fig. 4, was similar to that for salinity.

Figure 4, also, shows the change in salinity and temperature with time but at a station lying outside the Bankalah zone (station 10), *i.e.*, in the main coastal area. It shows there is very little change in the salinity (39.3 ± 0.3), unlike the water temperature, which was at a minimum in the winter (January 1982) and at a maximum in the (summer and) autumn, October 1981. This is related to the scarcity of the precipitation, in this arid zone and agrees well with the climatic changes reported for the Red Sea region by Morcos (1970).

The change in the minimum salinity observed near Bankalah (*i.e.*, near to the discharge site of the sewage effluent) during these cruises would be expected to depend mainly on the rate of the discharge of the fresh water accompanied the waste effluents and on the hydrographic conditions that prevails during these times in the coastal area. The first is expected not to be altered much at least during the months of the cold season, November 1981 to January 1982. In addition, the Water and Wastewater Authorities in Jeddah (personal communication) confirmed the stability of the rate (~ 32,000 m^3/day) of the discharge of the waste effluents at least during these months. Therefore, the minimum salinity observed during November 1981 and January 1982 cruises must be due to the other factor, the hydrographic conditions, *e.g.* water currents generated by the prevailing winds.

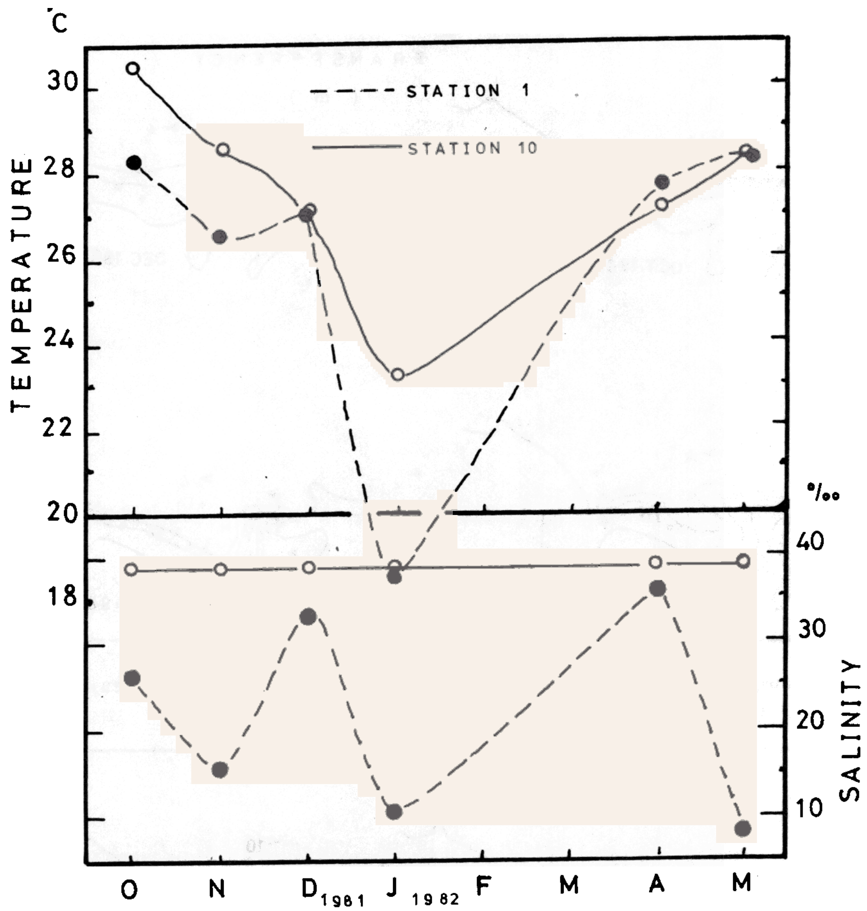
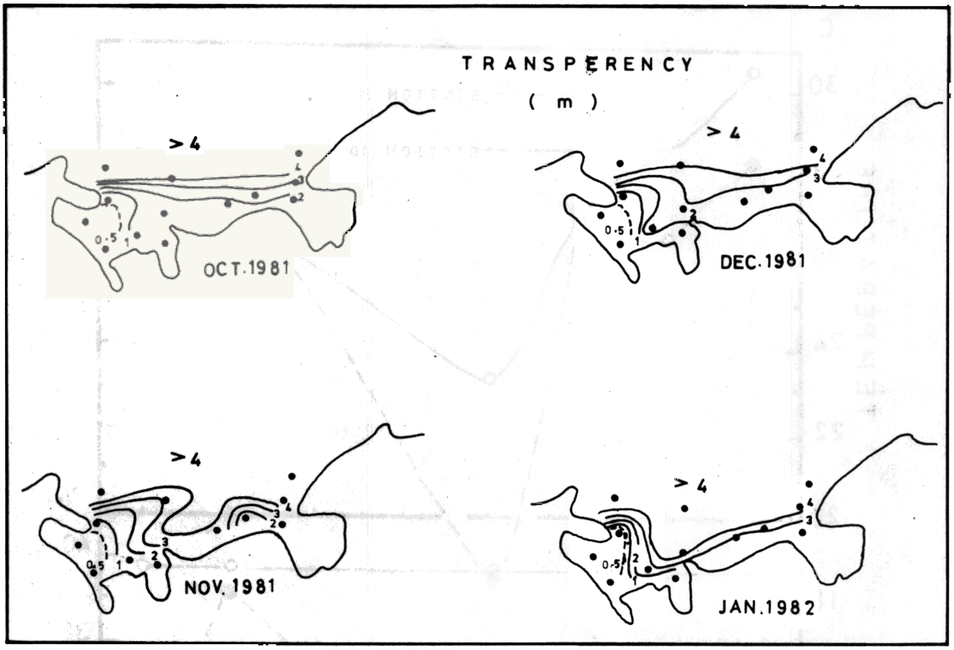


FIG. 4. Change of temperature and salinity of the surface waters at station 1 in Bankalah zone and at station 10 in the main coastal area of Jeddah at six different cruises.

As mentioned before, and from Fig. 2, the shift of the isohalines of salinity values < 39.0, during the November 1981 and January (and May 1982) cruises, were more seaward, outside the entrance of Bankalah zone, the shift was also more in the western side relative to the eastern side of the isohalines, *i.e.* the outflowing water was more towards the Islamic Harbour (Fig. 1).

The water flow from Bankalah zone during the November 1981 and January 1982 cruises was also confirmed from study the distribution pattern of transparency of the water (Fig. 5). Where an expansion of the turbid water from Bankalah zone towards the sea has occurred. This has been reflected also on distribution of the total suspended matter (TSM) in the surface water of Jeddah coast (Fig. 6). The isolines, *e.g.* of value 25 mg TSM/1, has been expended outside Bankalah area towards the sea during the November 1981 and January 1982 cruises relative to that in the respective ex-cruises, October and December 1981.



Transparency (Secchi Disc depth, in meter) for the coastal area of the Red Sea in front of Jeddah at four different cruises.

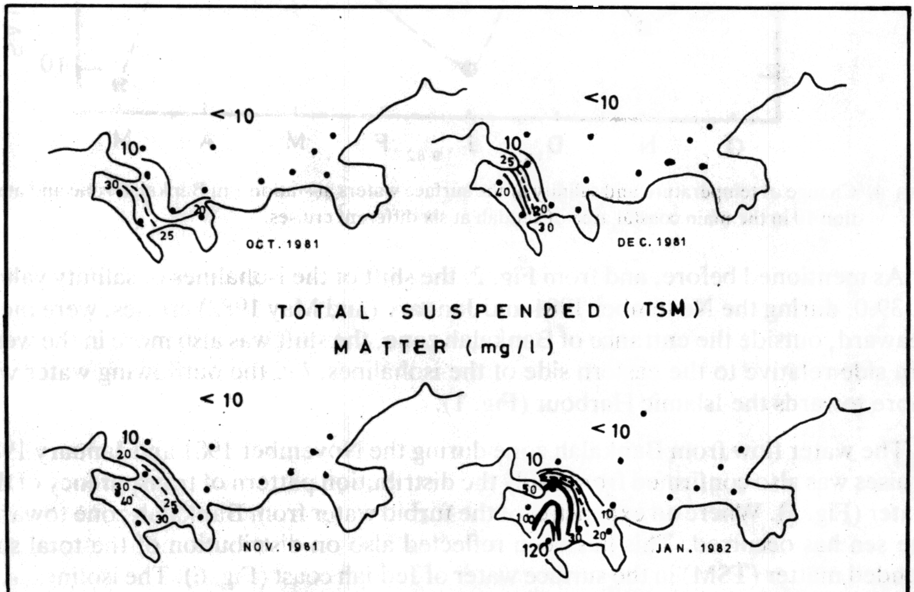


FIG. 6. Distribution of total suspended matter (mg/l) in the surface water of the Red Sea coast off Jeddal at four different times.

The distribution pattern of the other chemical elements, dissolved oxygen or hydrogen sulphide, phosphate and manganese during the period between October 1981 and January 1982 were quite similar to that mentioned above and all show that the flowing of the Bankalah water towards the sea was more pronounced during the cruises of November 1981 and January 1982. The level of concentration and distribution for these chemical elements in the surface water of Jeddah coast, represented by the January 1982 cruise, are shown in Fig. 7 and 8a.

The wind direction observed during the present study was northerly to northerly-west during the October and December 1981 cruises, whereas during the cruises of November 1981 and January 1982 the winds were ranging between calm and light breeze. During the northerly to NW winds, it seems likely that a water movement in the same wind direction, *i.e.* towards south-southeast in the study area towards Bankalah zone), has happened and caused two effects. The first was the restriction or accumulation of the mixed water there, inside the Bankalah area. The second was the increase of the proportion of the sea water volume relative to that of the discharged waste water, indicated from the rise in the salinity of the Bankalah water, especially near the discharge site, station 1, to reach values > 25.0.

When the sea was calm, the chance became greater for the surplus water inside Bankalah zone to spread out towards the sea as a surface layer of low salinity lying over more saline waters, Fig. 3. The spread of the surplus water is expected to be much greater if the wind direction turned to south to southeast. According to Morcos (1970) the prevailing winds in this area of the Red Sea are from the north to north-west and the tidal range of the latitude of Jeddah is at its minimum; less than 30 cm.

Model of Dispersion of the Chemical Pollutants (Phosphate)

According to Ketchum and Keen (1955), in estuaries or coastal areas, when fresh water flows into the sea, a mixture develops that represents a salinity ratio between the two extremes. The amount of fresh water in the mixture can be estimated by measuring the salinity of the mixture (S) and the salinity of the open sea water (S_o) neighbouring the estuary or the coastal area. The percentage of fresh water (F) is equal to,

$$F\,\% = (S_o - S) / S_o \qquad (1)$$

The concentration of any element discharged with the fresh water obviously will follow the fresh water-sea water distribution, if this element is a conservative one, *i.e.* its concentration would not be altered, *e.g.* by biological activity, *en route* down stream towards the sea. In this case, the observed concentration of this element at any location *en route* would be :

$$C_i = F\,\% \cdot C_o / 100 \qquad (2)$$

where C_i, the concentration at some point down stream from the fresh water source and C_o the concentration of the conservative pollutant in the fresh water source. $F\,\%$ is obtained from equation (1).

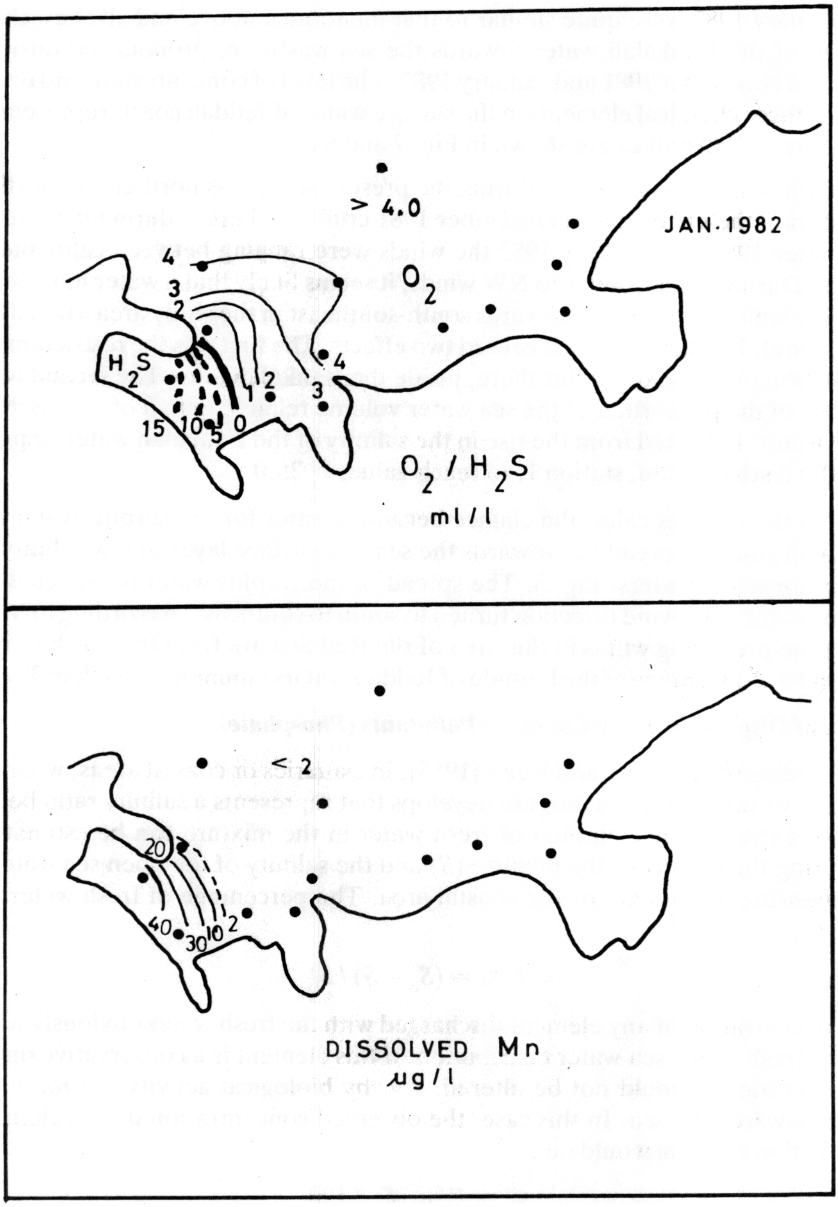


FIG. 7. Distribution of dissolved oxygen or hydrogen sulphide and manganese in the surface water of the Red Sea coast in front of Jeddah.

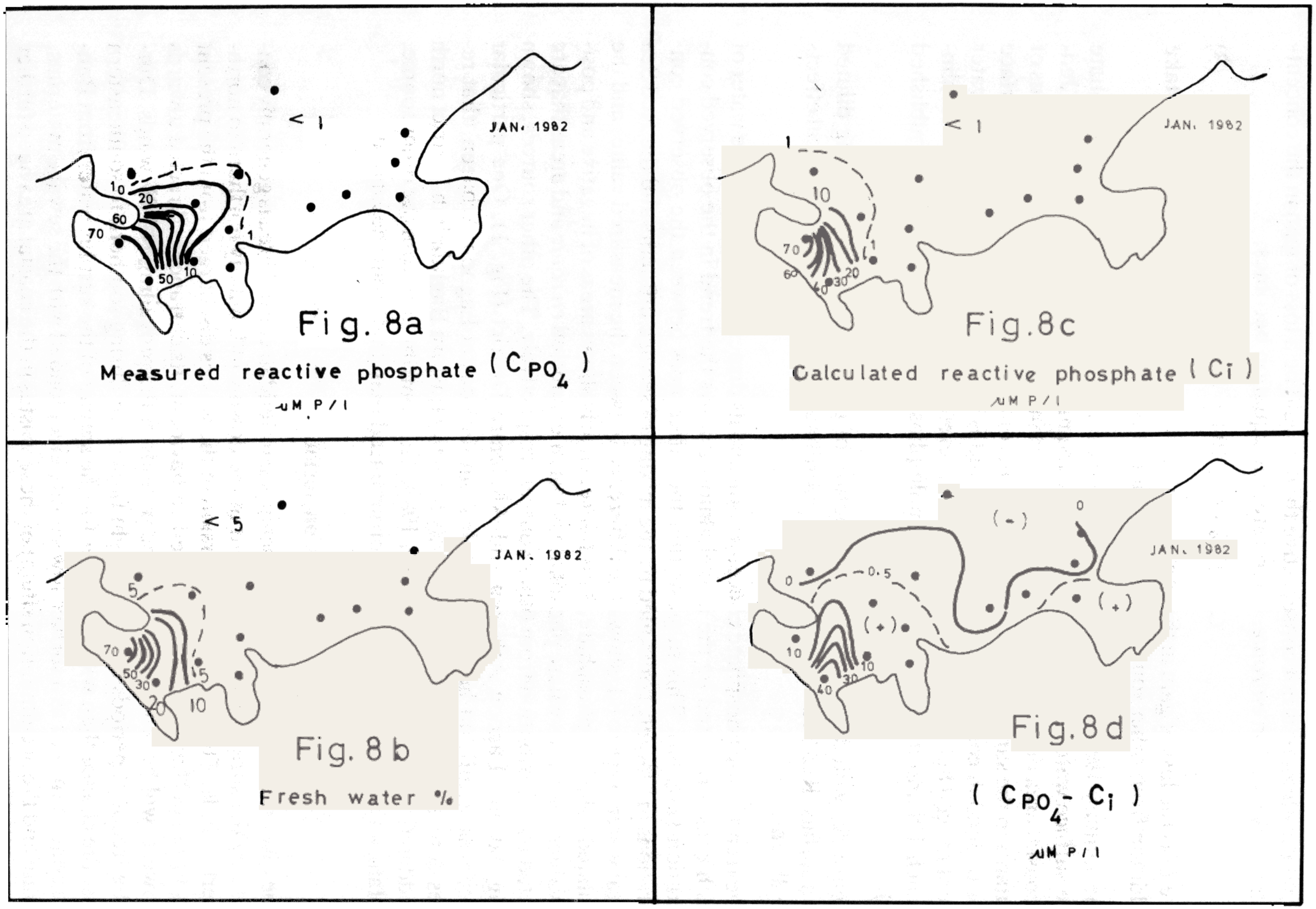


FIG. 8. Distribution of (a) dissolved phosphate $C_{PO_{4,\,measured}}$, (b) fresh water percentage, (c) calculated reactive phosphate (C_i), and (d) the difference between the measured and calculated phosphate in the surface water of the Red Sea coast in front of Jeddah.

But if the element is not conservative there would be a loss or gain in the concentration at any location *en route*. Therefore, the equation becomes,

$$C_i = F\% \cdot C_o / 100 \pm U_s \quad (3)$$

where U_s is the loss or gain in the concentration *en route* due to, *e.g.* biological uptake or addition from other source(s) in the region, respectively.

The January 1982 cruise was chosen for investigating the dispersion of phosphate in the surface water of Jeddah coast. It was assumed that vertical mixing in the Jeddah coastal area during this cruise was unimportant in deciding the concentrations of pollutants in the surface water. The percentage of fresh water throughout the surface water of Jeddah coast has been calculated and is shown in Fig. 8b. The fresh water content ranged between 0.5 and 74.8%. The reference source of fresh water of salinity reach 1.8 and it contained 105.6 μ mole phosphate-P/l (El-Rayis, unpublished data).

Figure 8c, would describe the distribution of phosphate if it were being diluted with a surface Red Sea source having no phosphate and from which biological effects were absent.

The trend in the phosphate concentration and its dispersion in the surface water of Jeddah coast predicted by the model almost follows the trend in the observed concentration (Fig. 8a). This suggests that the differences between the observed concentrations are largely controlled by the mixing of sewage effluents and the Red Sea coastal water. Figure 8d, shows the difference between the measured values and the calculated values of phosphate. This figure, clearly shows areas of negative and positive values, *i.e.* areas where phosphate is lost or exhausted *en route* and areas that are affected by contribution from other sources, respectively. The other sources, shown in Fig. 8d, are Lagoon Arbaeen and Al-Hamra District (Fig. 1). One particular source was significant here, the runoff from the coastal Lagoon Arbaeen, that receives domestic sewage effluents mainly from the Eastern Baghdadiah District north of Jeddah City Center, El-Rayis *et al.* 1988. The contribution from the other source, Al-Hamra District, seems to be less pronounced than that from the lagoon.

Conclusion

The dispersion of the pollutants discharged in Jeddah coastal area is generally controlled by the surface water movement in the down wind; mainly northern to northwesterly winds. Therefore, the dispersion of the wastes discharged from the present two sources in Bankalah semi-enclosed embayment, its entrance is directed towards northwest, will be hindered during the periods of the prevailing N-NW winds. During the frequent periods of calm or light breeze, or during southern to southeastern winds, the chance then will be greater for the spread of the surplus water from Bankalah zone to the sea as a surface low salinity layer loaded with the sewage materials. The fate and the accumulation site(s) of these wastes in the coastal area need further investigation.

Acknowledgement

The author wishes to thank Prof. Dr. J.P. Riley, Head of the Oceanography Department, Liverpool University, for critical reading of the manuscript.

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نموذج انتشار المياه العذبة ومواد المجارى الأخرى فى المياه الشاطئية للبحر الأحمر أمام جدة

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مستخلص

لقد تم دراسة توزيع نسبة المياه العذبة ومواد المجارى الأخرى فى المياه السطحية لشاطىء البحر الأحمر أمام جدة عند أوقات مختلفة من العام ، تم فيها الكشف عن أن المُلوِّثات تصب أساسا فى منطقة البنقلة ، وأن تشتت هذه الملوثات كان أكثر انتشارا فى الجانب الجنوبى الشرقى للمنطقة الساحلية المدروسة ، وأن التشتت كان محكوما أساسا بحركة المياه السطحية المتأثرة بالرياح السائدة .

تم تطبيق نموذج أولى للانتشار على أحد الملوثات (الفوسفات) واتضح أن هناك مصدرين آخرين هامين لإضافة المُلوثات للمنطقة المدروسة .

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