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IMPACT OF SEWAGE DISCHARGE ON THE WATER QUALITY OF THE EASTERN HARBOUR OF ALEXANDRIA. II- OXYGEN STUDIES.

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ABSTRACT

Dissolved oxygen, biochemical oxygen demand and permenganate values have been used as pollution indices in a heavily polluted basin, the Eastern Harbour of Alexandria, suffering from sewage discharge. The spatial and seasonal variation as well as the factors affecting the distribution of these variables were studied. Anoxia rarely appeared near the bottom layer. The population equivalent for the effluent water was 6.33. With regards to the continuous increase in the quantity of sewage, this value is expected to be tripled between now and year 2000. The BOD/PV ratio of the Harbour water indicated that most of the sewage reaching the Harbour is biodegradable.

INTRODUCTION

Dissolved oxygen is a fundamental requirement of life for aquatic plant and animal populations. Their survival depends on the ability of water to maintain certain minimal levels of this vital gas. It is needed by aquatic animals in various degrees of which fishes require the highest levels. For a diversified warm-water biota, the optimum concentration should be at least 5 mg/l while for a cold-water biota, concentrations at or near saturation (not lower than 6 mg/l) are desirable for healthy growth (Grundy,1971 and Arin,1974).

Dissolved oxygen is also considered as one of the most important and useful parameters for the identification of different water masses and in assessing the degree of pollution in the marine environment. Sewage pollution which is regarded mainly as an organic pollution, adversly affects fish and other aquatic life principally through oxygen depletion.

THE STUDY AREA

The Eastern Harbour of Alexandria is a semiclosed basin, situated between longitudes $29^{\circ}53'$ to $29^{\circ}54'$E and latitudes $31^{\circ}12'$ to $31^{\circ}13'$N(Fig. 1). The exchange between the Harbour water and the neritic Mediterranean waters takes place through two main openings, the western known as El-Boughaz and the eastern known as El-Silsila. The Harbour's area is about 2.53 x $10^6 m^2$ with an average depth of 6 m.

The bottom of the Harbour is muddy in most of its parts. In the southern part, the bottom sediments are composed of 80% black mud which smells H_2S at certain times of the year, while the central area is covered with a mixture of mud, sand and shell remains (El-Sayed et al., 1980). The northern area near El-Boughaz is mainly sand including few broken shells (Al-Handhal, 1979). In some places the Harbour is covered with extensive algal population mostly **Caulerpa** spp. and Eel grasses **Posidonia** spp. (El-Sayed et al., 1980).

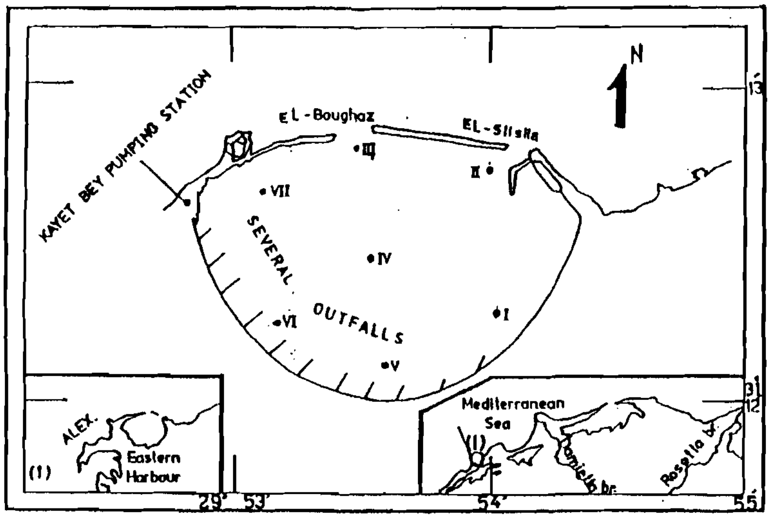

Fig. (1)
Sampled stations in the Eastern Harbour during the period 1985-1986.

The Harbour water is affected by the sewage disposal of central part of Alexandria city which is pumped into the Mediterranean Sea. Inside the Harbour, several small sewage openings (11 outlets) discharge on the average 15,000 m^3/day and 10,000 m^3/day of unprocessed sewage directly to the Harbour in winter and summer, respectively (Anon., 1978). According to the information given by the 'General Authority of Waste Water and Municipal Sewage (GASWWMS)'; the waste water is pumped through the outfalls 3 hrs/day. Hence the total amount of sewage and waste water discharged annually to the Harbour is about 35.18 x $10^6 m^3$. This volume is about 2.3 times the volme of the Harbour water, thus the flushing rate of the Harbour would be about 5 month.

SAMPLING AND ANALYTICAL METHODS

Sampling was carried out at regular bimonthy intervals throughout the period from May 1985 to May 1986. Seven stations were chosen to cover adequately the different ecological areas of the Harbour (Fig.1). At each station, water samples were collected from two or more depths according to the station maximum depth, representing surface, subsurface and bottom water layers. Samples were collected using 5 liter Niskin bottle provided with a reversing thermometer.

Samples for determination of dissolved oxygen and hydrogen sulphide (when present) were treated and analysed according to the methods described by Strickland and Parsons (1972) and Anon. (1969).

For determination of biochemical oxygen demand (BOD), samples were filled from each depth and incubated at 20° C for 5 days. As a precaution against introducing air into the bottles during incubation, a water seal is recommended by adding water to the flared mouth of the BOD bottles, (Anon., 1980). BOD was computed from the difference between initial and final dissolved oxygen.

Samples for determination of oxidizable organic matter (Permenganate value) were taken in special acid cleaned glass bottles and the permenganate number or value (PV) was determined according to the method described by Carlberg (1972).

RESULTS

Table 1 shows the annual average concentration of dissolved oxygen, BOD and PV at the different stations sampled in the Eastern Harbour.

The absolute surface values for dissolved oxygen fluctuated between 4.4 and 14.7 mg/l. The corresponding saturation values were 64.5 and 238.5%, respectively. In the bottom layer, dissolved oxygen (D.O.) was much lower varying between complete depletion and a maximum of 8.0 mg/l, corresponding to 106% saturation.

The distribution of D.O. in the Harbour showed remarkably high levels in the southern part. The annual averages were 8.70, 7.39 and 6.91 mg/l at station I, V and VI, respectively (Table 1). Station VII also showed high surface values, its annual average being 7.34 mg/l.

Vertical variation showed a decrease of D.O. with depth with high magnitude of vertical differences specially during warm months. However, the vertical gradient during winter was comparatively lower due to vertical mixing. It is interesting to note that, based on average values, the oxygen content of the bottom water of the E.H. is progressively decreasing in the last few years (Table 2). This may be attributed mainly to the continuous increase of the organic load discharged into the Harbour through the increased quantities of sewage disposed into it. However, during the study period oxygen levels were comparable or sometimes slightly lower than those observed by several authors in the area (Table 2).

The pattern of D.O. distribution at fifferent stations varied in different months (Fig. 2) and is probably affected by the quantity and quality of discharged sewage and waste water as well as the exchange with coastal Mediterranean waters.

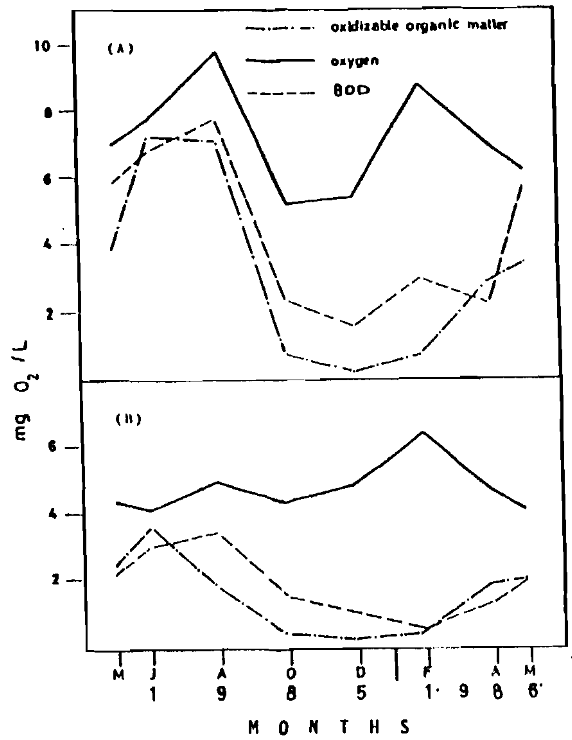

Fig. (2)

Monthly variations of dissolved oxygen, oxidizable organic matter and BOD in both (A) surface and (B) bottom waters in the Eastern Harbour during 1985 - 86.

During the period of study, the values of BOD recorded in the Harbour water were relatively high. The absolute surface values fluctuated between 0.45 and 11.56 mg O_2/l with the annual average being 3.86 $\pm$ 3.32 mg/l. Values tend to decrease with depth at all stations with higher gradients reaching sometimes 10 mg/l at station I. Monthly BOD variation in surface and bottom waters followed those of D.O. with higher averages in August i.e. 7.74 and 3.35 mg/l in surface and bottom layers, respectively (Fig. 2). BOD values were highest in surface water of southern stations (I, V and VI) with the maximum average i.e. 5.01 mg/l at station V (Table 1) which also recorded the maximum average for the bottom water layer.

TABLE 1

Annual average concentrations of D.O., B.O.D. and P.V. for the different stations of the Eastern Harbour during 1985-1986.

St. No.	Depth (m)	Sample depth	D.O. (mg/l)	D.O.Sat (%)	B.O.D. (mg/l)	P.V. (mg/l)	B.O.D./DO (%)
I	4.0	S	8.70	126	4.46	4.43	51.3
		B	4.34	61	1.25	1.55	28.8
II	5.5	S	7.09	101	3.10	2.91	43.7
		B	6.07	88	2.20	1.34	36.2
III	9.0	S	3.59	95	2.75	3.17	41.7
		M	5.67	80	1.88	1.28	33.2
		B	4.91	69	0.69	0.95	14.1
IV	6.5	S	7.14	101	3.25	3.16	45.5
		M	5.33	76	1.57	0.98	29.5
		B	4.04	56	0.74	0.96	18.3
V	4.0	S	7.39	108	5.01	3.69	94.0
		B	5.33	77	3.17	1.35	59.5
VI	2.5	S	6.91	99	4.12	2.51	59.6
		B	5.34	77	3.10	2.03	58.1
VII	5.5	S	7.34	105	4.32	2.17	58.9
		B	4.29	61	1.38	1.33	32.2
Average		S	7.27	105	3.86	3.15	51.3
			±1.81	±31	±3.32	±3.17	±26
(± S.D.)		B	4.89	69	1.76	1.34	37.3
			±0.83	±10	±1.10	±1.27	±23

TABLE 2

The mean and range of dissolved oxygen (ml O_2/l) in the E.H. and other Egyptian inshore areas.

Location		Mean	Range	References
E.H.	S	5.09	2.96-10.52	Present Study
	B	3.42	0.00- 5.71	
E.H.	S	4.95	2.66- 8.21	Shriadach (1982)
	B	4.89	2.70- 7.60	
E.H.	S	6.79	3.46-11.07	El-Nady (1981)
	B	5.75	1.51-10.83	
In front of El-Boughaz	S	4.52	1.30- 8.42	Mahmoud (1985)
	B	5.86	3.24- 7.78	
Abu-Qir Bay	S	4.39	3.43- 5.17	El-Deeb (1977)
	B	4.48	3.46- 5.95	
Western Harbour		3.32	0.20- 9.80	Hemeda (1982)
In front of Alexandria		-	4.30- 5.39	Sultan (1975)
Egyptian coasts		-	4.39- 5.96	Emara (1969)
Off Alexandria		-	4.11- 5.36	El-Rayis (1973)

The lowest BOD values were recorded at station III located at the main entrance of the Harbour.

The concentrations of the oxidizable organic matter in the E.H. were remarkably low. The overall annual surface and bottom averages were 3.15 $\pm$ 3.17 and 1.34 $\pm$ 1.27 mg/l, respectively (Table 1). PV concentrations were slightly during warm months with the maximum in June while the minimum occurred in the cold season with the lowest average in December (Fig. 2).

DISCUSSION

Dissolved oxygen and its related parameters 'BOD and PV' have long been used as basic water quality criteria to assess sewage pollution. Redfield (1942) mentiond that the oxygen content can be an indicator of organic loading, nutrient input and biological activity. The importance of oxygen to quatic organisms is directly connected with their biological processes and indirectly with the oxidation of organic matter in water and sediments followed by regenerating the cycle of nutrients in the water.

Except on rare occasions, the water of the E.H. was well oxygenated (annual average for water column 6.00 $\pm$ 1.81 mg O_2/l corresponding to 87.2 $\pm$ 29% saturation). However, the surface layer is over-saturated (105%) while the bottom is undersaturated (69%) with oxygen. Referring to the work of Grundy (1971) and Arin (1974) (vide supra) concerning the D.O. requirements of warm-water organisms, the surface water layer of the Harbour is still suitable for all marine life while the conditions in the bottom water is a border line suitable for some invertbrates and bacteria. The continuous increased disposal of raw sewage into the Harbour would result in the nearest future of converting the Harbour water into a place unsuitable for marine life.

The bottom water of the E.H. is sometimes completely deoxygenated. This dangerous phenomena occurred in May 1985 (this work) and June 1987 (Unpublished data) following a high sewage discharge load, an elevation of air and water temperatures accompanied by dense phytoplankton bloom developed at the surface. The whole water column of the eastern side of the Harbour was sometimes temporarily deoxygenated where H_2S levels reached 12.7 ml/l in June 1987. The primary cause of water deoxygenation in the presence of substances called oxygen-demanding wastes, easily broken down or decayed aerobically or anaerobically through bacterial activity. Although, some inorganic substances are found in this category, most of these wastes are organic.

The D.O budget in the Harbour is a balance between the high rate of photosynthetic activity (annual production 584 g C/m^2, c.f. Halim et al., 1980) leading to the production of large amounts of D.O. and the high load of organic matter discharged that consume large amounts of D.O. Both processes occurred simultaneously in the Harbour water. This condition was clearly demonstrated at stations I and V located in front of sewage outfalls specially in summer when the activity of decomposing bacteria

is maximum. Motahashi and Matsudaira (1969) stated that the decrease in D.O. near the bottom layer is mainly due to respiration and biochemical decomposition of organic matter. The complete depletion of oxygen and appearance of H_2S recoded once near the bottom of station I in May 1985 (i.e. 5.00 ml H_2S/l) affected the high organic load of bottom at this station as observed by Aboul-Kassim (1987).

The concentration of dissolved oxygen in a water body is a function of salinity and temperature. The effect of salinity on the concentration of D.O. in the Harbour water was significant. A statistically significant negative correlation was observed between both variables ($r = -0.4927$, $p \leq 0.001$). However, during the study period an inverse relation between oxygen concentrations and water temperature was only significant in the bottom water layer of the Harbour ($r = -0.2613$, $P \leq 0.001$). The insignificant surface correlation was due to the presence of high chlorophyll a biomass during summer despite its high surface water temperature. Thus comparatively high surface D.O. values recroded in summer season (Fig.2) are mostly due to increased rate of oxygen production by phytoplankton crop developed in the Harbour (average 18.2 mg chl a/m^3; Aboul-Kassim, 1987). The low temperature recorded in February may decrease the rate of bacterial decomposition and supress the activity of many animals thus decreasing the rate of oxygen consumption (Welch, 1952).

Because oxygen demanding wastes rapidly deplete the D.O. of water, so it is important to estimate the amount of these pollutants in a given water body. Since it was first brought to general usage, the 5 days BOD is still a very widely used measure of organic pollution. It is the quantity related to the amount of wastes present, indicating the amount of molecular oxygen required by aeropic biochemical action to oxidize these wastes present in water. It is a real measure of the polluting capacity of an effluent due to the dissolved oxygen taken up by micro-organisms in decomposing organic matter it contains.

A BOD of 1 ppm is characteristic of nearly pure water. Water is considered fairly pure with a BOD of 3 ppm and of doubtful purity when the BOD value reaches 5 ppm (Anon., 1975). A comparison between these levels and those observed in the present study showed that the average BOD of the surface waters of the E.H. (i.e. 3.86 ± 3.32 mg/l) is comparatively higher than those of standard values indicating the presence of a high load of sewage continuously discharging into the Harbour. Table 3 showed that the BOD in the E.H. is lower than that recorded for the inshore waters west of Alexandria region (Mahmoud, 1985). The high results are attributed to sampling infront of the main sewage pipe of Kayet Bey pumping station and subsidary outfalls located west to the Harbour. However, despite the elevation in the absolute BOD values of the present work, average concentrations are comparable to those mentioned by Shridah (1982) for the Harbour water (Table 3).

A comparison of the BOD_5 levels of sewage discharging into the Harbour with the range of values characterizing of the different sources given in the following table (c.f. Halim, 1983) indicated that BOD_5 levels are still

TABLE 3
Mean and range of BOD (mg O_2/l) in the area of the E.H. and in other Egyptian areas.

Location		Mean	Range	References
E.H.	S	3.86	0.45-11.56	Present study
	B	1.76	0.11- 8.00	
E.H.	S	3.83	0.13- 9.41	Shriadach (1982)
	B	1.98	0.14- 6.11	
In front of El-Boughaz	S	12.40	9.66-17.04	Mahmoud (1985)
	B	8.82	4.07-13.70	

far from seriousness of severe sewage pollution (Table 4) and are within the typical BOD_5 values for domestic sewage i.e. 250 - 350 g/m^3 (Anon., 1975). However, clean water normally has BOD_5 values of 3 g/m^3 or less and very polluted streams might have a BOD_5 around 10 g/m^3. The 1963 WHO minimum limit of BOD_5 recommended for raw waters to be used after treatment as drainage water was 6 g/m^3 (Anon., 1975).

It is interesting to mention that the comparatively low BOD_5 in the E.H. (average 3.86 mg/l) irrespective of the discharge of large amounts of untreated sewage discharged is mostly due to the effective exchange between fresh Mediterranean neritic water and the Harbour water as well as the short flushing time of the Harbour water i.e. 5 months.

An attempt was made to estimate the biotic oxygen consumption in the area of investigation, calculated as percent of the original D.O. content [O_2 consumption = BOD_5 (mg O_2/l) x 100]. Values represented in Table 1 define the possible oxygen consumption caused by mineralization of organic substances (carbon step). This part of degradation process is certainly very important when judging the effect of pollution load. However, other oxygen consumption processes are always in action, e.g. oxygen consumption caused by nitrogen present in a dissolved state such as ammonia (nitrifcation process) which is present in appreciable quantities in the Harbour (average 3.34 $\pm$ 1.3 µg at/l).

The high surface D.O. consumption (annual average 51.3 $\pm$ 26%) of the available D.O. is related to the sewage water of lower density discharging with its high content of organic matter and bacteria. The maximum average BOD /D.O. percent i.e. 94% was recorded at the surface of station V while

TABLE 4
Average and range of BOD levels (ppm) characteristic for different sources (c.f. Halim, 1983).

Source	Average BOD_5 (ppm)	BOD_5 (range) (ppm)
Untreated municipal sewage of Alexandria	500	420-750
El-Max slaughters house	9900	-
Tannaries	2050	-
Food processing wastes	-	100- 10,000
Sewage discharged to E.H. (Present study)	-	220-380
Typical domestic Sewage values (ECPH, 1975)		250-350

the minimum occurred at stations II, III and IV (41 - 45%). The BOD /D.O. (%) values for the bottom layer were fairly lower than those observed for the surface. The average ratio reached 14% (overall average of 37.3%) (Table 1). Low bottom values may be attributed to the presence of detrital (dead) micro- organisms in the bottom water layer, not able to perform aerobic biochemical oxidation of wastes specially in presence of low oxygen concentrations. Station to station variations depend mainly on their degree of suffering from sewage discharge.

An interesting way to point out the magnitued of the oxygen-demanding waste problem is to equate the BOD_5 of total daily nationwide wastes from specific source to the number of humans required to produce daily waste with an equivalent BOD_5. Ech individual contributes to urban sewage an average BOD_5 value of about 60 gm/ day (Anon., 1975). Based on daily sewage discharge to the Harbour (effluents having a maximum BOD_5 of 380 mg/l) the population equivalent of this effluent water will be 6.33. Table 5 indicates the population equivalent for various wastes in comparison to those discharged into the Harbour.

Based on data from the General Authority of Municipal Waste Water, the expected population equivalents during the years 1990 and 2000 will be 10.08 and 13.67, respectively. However, it is clear from this data that the total waste water pollution loads (BOD_5) are projected to be approximately triple between now and the year 2000.

However, although the BOD test is still the mostly useful method in estimating the amount of biodegradable organic matter present in the aquatic

TABLE 5

Population equivalent for various BOD sources* in comparison to those discharged into the harbour.

Source of waste	Population equivalent (Millions)
Tannaries	8.0
Meat slaughtering	13.7
Cotton precessing	5.1
Paper and pulp processing	216.0
Domestic animal wastes	1,900.0
Sewage discharged to E.H. (Present study)	6.33

* Data selected from U.S. Dept. of Agriculture, Wastes in Relation to Agriculture and Forestry, pp41, 46.

environment, it suffers from some drawbacks because it depends on living organisms of unconsistant behaviour. A combination of biological and chemical tests allows more identification for the problem.

Another way to assess the degree of sewage pollution in the Harbour was to neasure the organic matter present. In conjunction with BOD values, the measure of the oxygen equivalent to the amount of material oxidized by a strong oxidizing agent ($KMnO_4$) gives a convinient characterization for the water quality of the Harbour. This test is usually called PV test or oxidizability of organic matter. This test do not measure the biodegradable matter in the sample. Since the carbon and hydrogen, but not the nitrogen in organic matter can be readily oxidized by $KMnO_4$, the oxygen consumed indicates only the carbonaceous organic matter present (Carlberg, 1972). The COD test which emplys $K_2Cr_2O_7$ instead of permenganate affects a more complete oxidation of organic matter than PV test does. Despite this, it was not used for the Harbour samples due to lack of some expensive chemicals.

In comparison with other Egyptian inshore and offshore waters, the PV of the Harbour water (average water column, 2.24 mg/l) was insignificantly low (Table 6). According to El-Awady (1972), the low values in the Western Harbour were due to the high capacity of its water for selfpurification, i.e. partial oxidation of organic matter takes place even at short distances from the outfalls.

The increase in PV values with depth recorded at some stations i.e. I, V, and VI during April, October and May 1986, respectively was due to the oxygen concentrations which were low enough to oxidize any organic matter present. Ketchum (1957) and Vinogradov (1962) stated that vertically migrating organisms which may feed in surface water and then migrate to the deep water may excrete undigested organic matter or the organisms themselves are eaten and add to the organic content of the bottom water.

TABLE 6
Mean and range of oxidizable organic matter (mg O_2/l) in the E.H. and other Egyptian areas.

Location		Mean	Range	References
E.H.	S	3.15	0.12-12.32	Present study
	B	1.34	0.08- 4.76	
Abu-Qir Bay	S	11.50	0.00-27.20	El-Deeb (1977)
	B	13.10	0.00-34.4	
Alexandria coastas		3.23	-	Mahmoud (1979)
Western Harbour		-	1.00- 5.00	El-Awady (1972)
S.E. Mediterranean		-	0.11- 1.13	Emara (1969)
El-Max		17.0	-	Abdel-Moneim (1977)
Lake Mariut		22.5	6.50- 8.00	Abdel-Moneim (1977)

An excellent way to determine the type of waste watyer discharge, to know if it is or not biodegradable, is by calculationg its BOD_5/PV ratio. A BOD_5/PV ratio of 1:1 is characteristic of purified water. The ratio of 2:1 - 4:1 is specific to crude domestic sewage, while carbohydrates and proteins rich wastes (food processing wastes) have ratios equal to or greater than those of sewage (Anon., 1975). During the study period, the average values of BOD/PV ratio in the E.H. varied between 0.87 to 2.00 and 0.73 to 2.35 for surface and bottom waters. Higher ratios were observed at stations directly affected by sewage discharge. The western area of the Harbour, affected by wastes discharged from sporting clubs and fishing boats (food processing wastes), represented by station VII showed always ratios > 2:1. Generally data may indicate that most of the sewage reaching the Harbour is of biodegradable character.

Statistically high positive correlations were found between PV and dissolved organic carbon ($r = 0.4065$ and $r = 0.3975$, $P \leq 0.001$ for surface and bottom waters, respectively) and PV and particulate organic matter ($r = 0.6399$. $P \leq 0.001$ at the surface and insignificant near the bottom). Both DOC and POM where determined simultaneously during this study (Aboul-Kassim, 1987). These correlations indicate the increase of PV with increasing organic load.

As expected high significant correlation also existed between PV value and BOD in the Harbour water, ($r = 0.7336$, $P \leq 0.001$). The scatter diagram (Fig. 3) and the empirical regression equation relating both variables:

$$PV = 0.1522 + 0.7389\ BOD$$

underscored the important role of micro-organisms in the decomposition of organic matter and showed that inspite of its drawback, the PV method is still a convinient indicator of sewage pollution.

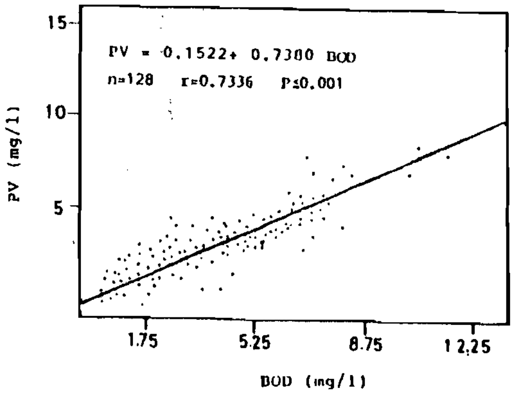

Fig. (3)
Scatterplot relating both Permenganate Value (PV) and BOD in the waters of the Eastern Harbour during 1985 - 86.

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