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WATER COLUMN CONTAMINATION FROM DISCHARGE OF WASTEWATER TREATMENT PLANT IN SOUTH BEIRUT, LEBANON

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The main functional wastewater treatment plant in Lebanon is suspected to be the major polluter for south Beirut marine areas from a depth of 60 m to the surface. To evaluate the state of the environment of the water column in relation to seasonal stratification, five profiles were executed between 2007 and 2009 at the location of the outfall of the main pipe of discharge. The selected quality parameters were water temperature, salinity, nitrite, nitrate, phosphate, chlorophyll-a, pheopigments, fecal coliforms and fecal streptococci. The results showed that the seasonal thermocline did not under any circumstances constitute a natural barrier preventing treated water loaded with contaminants to reach the surface of the water. The factors responsible for the upwelling of contaminants through the water column were identified to be the shallow depth, the hydrodynamism of the area, and the flow intensity of discharged waters.

INTRODUCTION

In Lebanon coastal water is subjected to multiple sources of pollution threatening its coastal, pelagic and benthic ecosystems (MoE/ECODIT, 2005). In addition to the chemical contaminants and the solid wastes, more than 249 Mm^3 of sewage water loaded with microbial pathogenic agents, hazardous chemical and organic compounds are discharged into sea water without any prior treatment (MoE/LEDO/ECODIT, 2001) and represent a marginal problem for the marine environment. The discharge of untreated wastewater into shallow coastal water may affect greatly water and sediments characteristics (Martinez and Adarraga, 2003) and may influence the biological communities (Terlizzi et al., 2005)

The problem arises mainly from the lack of sewage treatment plants, the shortage in sewage channels networks and the absence of rural and urban planning. A main solution for the mitigation of the domestic pollution is the installation of appropriate functional wastewater treatment plants (Sorsa & Leiviskä, 2007) that are able to perform at least the three main stages: primary (solid wastes removal), secondary (oxygenation) and tertiary (chemical) treatments (Parr et al., 1999) with the aim of producing a disposable effluent without causing harm to the surrounding environment. The main outflow pipe of such waste treatment plant should be installed offshore at appropriate distance taking into consideration the depth, the bottom type, the generated currents, the prevailing winds and the hydrodynamism of the area.

In Lebanon, Al-Ghadir wastewater treatment plant, located 5 km to the south of the capital Beirut, was rehabilitated and put back in service since 1997. This plant, capable of performing only primary treatment, was theoretically designed to receive the wastewater of 400000 citizens of the southern suburbs of Greater Beirut but in fact it is serving more than one million habitants. The surplus of received untreated water is evacuated through a coastal outfall situated at 200 m offshore and at 4 m depth, while the treated water is pumped out offshore through a principle outfall pipe located at 2.6 Km offshore to the west of the plant and at 60 m depth.

In order to have an overview on the state of contamination of water column in Ghadir off-shore marine area, vertical profiles were executed in different seasons just above the end point of the main pipe of evacuation. These profiles aim to define the possibility for water column to become polluted under different seasonal conditions and in relation with seasonal thermocline by measuring the variation of physico-chemical and biological characteristics of water column.

MATERIAL AND METHODS

In relation to seasonal change, five vertical profiles were executed, in October 2007 (G1), November 2007 (G2), October 2008 (G3), April 2009 (G4), August 2009 (G5) just above the terminal discharge outfall of the pipe of evacuation located at 60 m depth and at 2.5 km offshore at a fixed geographic point (N33°48.901' & E35°27.213') (Figure 1).

Each profile consists of lowering a Niskin reversible bottle at 4 consecutive depths 0, 20, 40 and 60 m in the aim to take water samples for further analyses of chemical (phosphate, nitrite & nitrate), biological (chlorophyll-a and pheopigments) and microbiological (fecal coliforms and fecal streptococci) parameters. An STD probe is used for temperature and salinity measurements every 5 m. Nitrite ($N\text{-}NO_2$) and nitrate ($N\text{-}NO_3$) levels were determined according to Bendschneider & Robinson (1952) method by the measurement of nitrite ions (NO_2^-) after reduction of nitrate ions (NO_3^-) by the passage of water sample through a cadmium column treated with copper (Wood

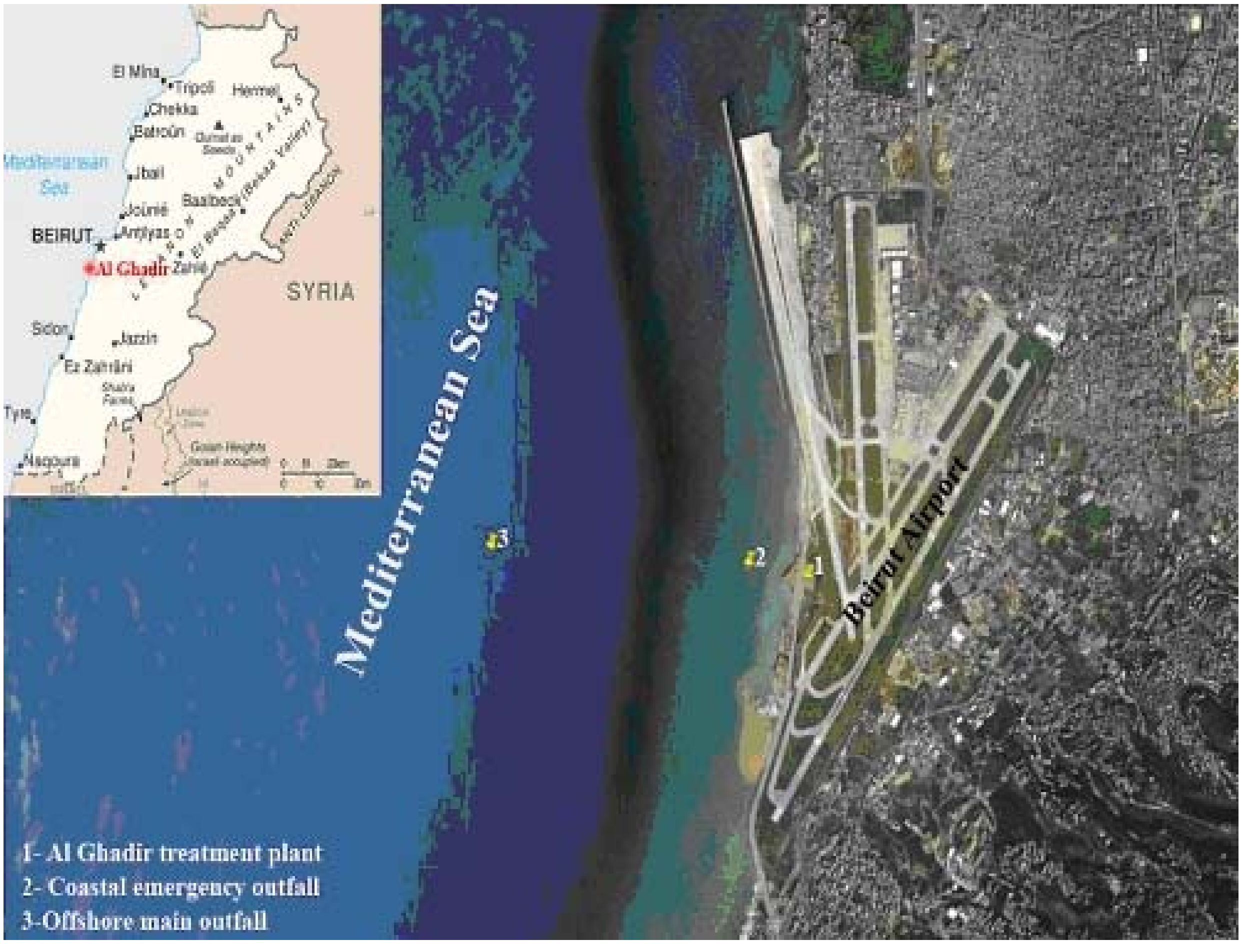

Figure 1. Location of Al-Ghadir wastewater treatment plant (1) and its outfalls (2 & 3), South of Beirut - Lebanon.

et al., 1967), whereas the phosphate was analyzed by the colorimetric method of Murphy & Riley (1962). The extraction and analyses of chlorophyll-a and pheopigments were done according to fluoromerty method described by Arar & Collins (1997). Fecal coliforms and fecal streptococci densities in water where measured according to the filtration on membrane method (OMS – PNUE, 1995).

The obtained results during the 5 profiles up to 60 m depth are illustrated in: Figure 2 for temperature and salinity, Figure 3 for nutrients (nitrite, nitrate and phosphate), Figure 4 for chlorophyll-α and pheopigments and Figure 5 for fecal coliforms and fecal streptococci.

RESULTS

Profile of October 2007 (G1)

The temperature decreased gradually between surface (25.72 ºC) and 35 m depth (24.36 ºC). A sharp decrease was observed at 40 m (22.21 ºC) where a minimum of 20.7 ºC was measured at 60 m depth. Salinity's values followed almost the same trend. They fluctuated tightly between 38.67 and 38.61 from surface down till 35 m. A decrease of salinity was observed at 40 m (38.48) till reaching a minimum value of 38.33 at 60 m depth. At surface the concentrations of nitrite, nitrate and phosphate were lower (0.004, 0.099, 0.12 $\mu mol.L^{-1}$ respectively) if compared with the

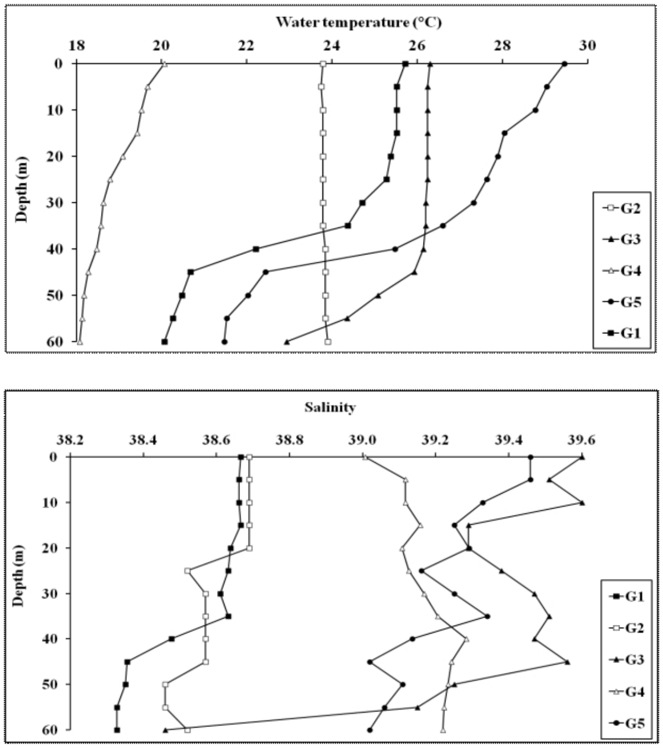

Figure 2. Variation of water temperature and salinity during different profiles.

values obtained at 60 m depth (0.143, 0.179, 0.178 µmol.L^{-1} respectively). The concentration of chlorophyll-α was low in the whole water column and decreased from 0.05 µg.L^{-1} at surface till 0.02 µg.L^{-1} at 60 m while that of pheopigments was 0.01 µg.L^{-1} at surface and 0.02 µg.L^{-1} at 60 m. The densities of fecal coliforms and fecal streptococci showed minimum values at water surface (16 and 30 CFU/100 mL respectively) and maximum values at 60 m (30 and 42 CFU/100 mL respectively).

Profile of November 2007 (G2)

During this profile, the water temperature was almost stable where it increased tightly from 23.79 at surface till 23.90 at 60 m depth. The salinity decreased slowly from 38.69 at surface till reaching a minimum of 38.52 at 60 m. For nutrients the concentrations of nitrite were low in the whole water column whereas the concentrations of nitrate fluctuated between a minimum of 0.11 µmol.L^{-1} at 40 m and a maximum of 0.25 µmol.L^{-1} at surface. Phosphate concentrations were also low and they varied tightly between a minimum of 0.12 µmol.L^{-1} at 60 m and a maximum of 0.15 µmol.L^{-1} at 20 m depth. The concentrations of chlorophyll-α and pheopigments were extremely low with a maximum of 0.1 and 0.04µg.L^{-1} at surface for chlorophyll-a and pheopigments respectively. The bacteriological analysis showed the presence of limited number of colonies through the water column where the maximum of colonies was recorded at 60 m for fecal coliforms and streptococci (5 and 8 CFU/100 mL respectively).

Profile of October 2008 (G3)

In the mission of October 2008 the temperature values didn't vary much between surface (26.29 °C) and 45 m depth (25.93 °C). A sudden decrease in water temperature was detected at 50 m (25.07°C) and it reached a minimum value of 22.93 at 60 m depth. The salinity slightly changed between surface (39.60) and 45 m (39.56) then it dropped quickly (39.24) at 50 m and reached

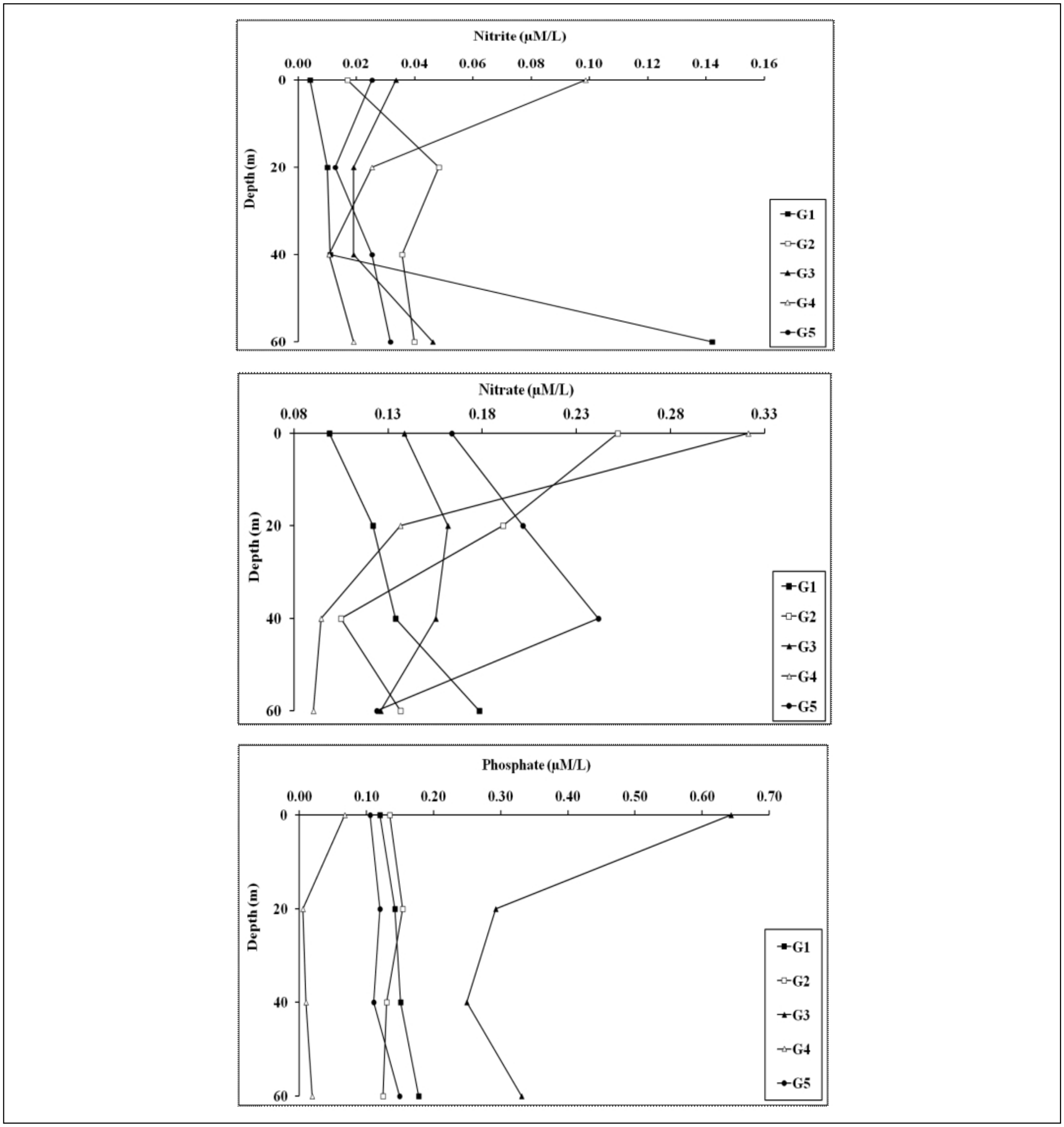

Figure 3. Variation of nitrite, nitrate, and phosphate during different profiles.

minimum value of 38.46 at 60 m. The concentrations of nitrite were low between 0.02 and 0.05 μmol.L^{-1}. The nitrate concentrations didn't vary much, they fluctuated between 0.13 and 0.16 μmol.L^{-1}. The concentrations of orthophosphate were high; the maximum of 0.64 μmol.L^{-1} was measured at surface and the minimum of 0.25 μmol.L^{-1} at 40 m. At 60 m the concentration was 0.33 μmol.L^{-1}. The whole water column was poor in chlorophyll-α (between 0.01 and 0.07 μg.L^{-1}) and its derivative the pheopigments (between 0 and 0.03 μg.L^{-1}). The densities of fecal coliforms (F.C) and fecal were maximum at surface, 1000 CFU/100 mL for F.C and 2000 CFU/100 mL for F.S. At 20 m and 40 m the densities were extremely low. At 60 m they were 200 CFU/100 mL for both types of bacteria.

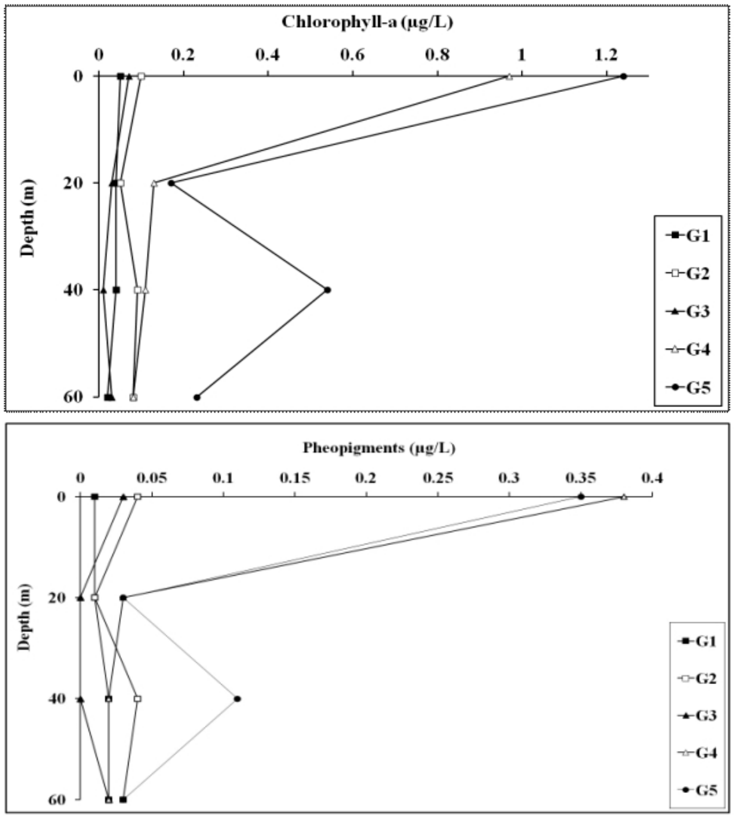

Figure 4. Variation of chlorophyll-α and pheopigments during different profiles.

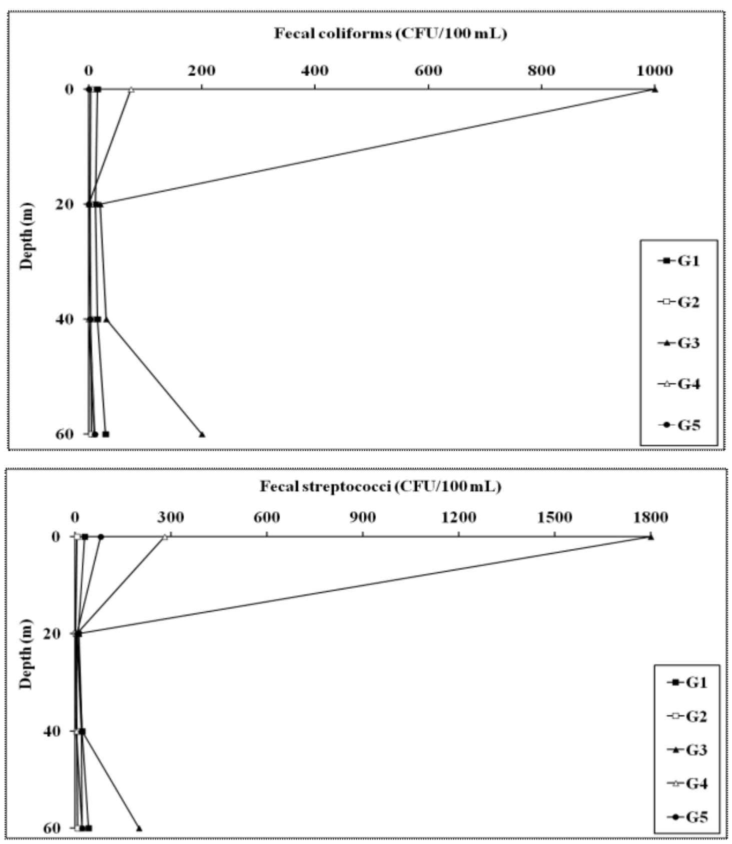

Figure 5. Variation of fecal coliforms and fecal streptococci during different profiles.

Profile of April 2009 (G4)

In April 2009, the temperature declined gradually from surface (20.07 °C) till 60 m (18.08 °C), while the values of salinity showed arbitrary and tight fluctuations between surface and 60 m where the minimum value was measured at surface (39.01) and the maximum value at 40 m (39.28). The concentrations of nitrate varied between a minimum of 0.02 μmol.L^{-1} at 60 m and a maximum of 0.1 μmol.L^{-1} at surface. The same situation was marked for nitrate with a minimum of 0.09 μmol.L^{-1}at 60 m and a maximum of 0.32μmol.L^{-1} at surface. The concentrations of orthophosphate were, in general, low. A maximum of 0.067 μmol.L^{-1} was registered at surface, and then it dropped to a minimum value of 0.005 μmol.L^{-1} at 20 m depth. At 40 and 60 m depth, the concentrations increased slightly to 0.010 and 0.019 vmol.L^{-1} respectively. The maximum concentrations for both biological parameters, chlorophyll-α (1 mg.L^{-1}) and pheopigments (0.4 μg.L^{-1}), were recorded in surface water. The deeper levels were much poorer where minimum values were measured at 40 m, 0.1 μg.L^{-1} for chlorophyll-α and 0.02 μg.L^{-1} for pheopigments. The ratio chlorophyll/pheopigments at surface was 2.5, which is lower than the one found at 20 m (4.3), at 40 m (5.5) and at 60 m (4.0) respectively. In reference to Figure 4, the contamination of water column with F.C was null at both depth 20 and 40 m. At surface the density of F.C was maximum (74 CFU/100 mL) and at 60 m it was 10 CFU/100mL. The maximum density of F.S was detected at surface (280 CFU/100 mL) while at 20, 40 and 60 m, the densities were low of 6, 4 and 21 CFU/ 100 mL respectively.

Profile of August 2009 (G5)

During the profile of August 2009, the temperature dropped gradually from surface (29.44 °C) till 40 m (25.47 °C). At 45 m there was a sharp decrease in water temperature (22.43 °C) till reaching a value of 21.47 °C at 60 m. The salinity fluctuated arbitrary between a minimum of 39.02 at 45 m and a maximum of 39.34 at 35 m. The concentrations of nitrite were low, they fluctuated between 0.01 and 0.03 μmol.L^{-1}. The nitrate concentrations increased from 0.16 μmol.L^{-1} at surface till 0.24 μmol.L^{-1} at 40 m depth. A minimum of 0.12 μmol.L^{-1} was measured at 60 m. The minimum concentration of orthophosphate (0.11 μmol.L^{-1}) was measured at surface and the maximum (0.15 μmol.L^{-1}) at 60 m. The maximum concentrations of chlorophyll-a (1.24 μg.L^{-1}) and pheopigments (0.35 μg.L^{-1}) were recorded at surface. At 40 m the concentrations for both biological parameters were considerable, 0.54 μg.L^{-1} for chlorophyll-a and 0.11 μg.L^{-1} for pheopigments. The minimum concentrations, 0.17 μg.L^{-1} for chlorophyll-a and 0.03 μg.L^{-1} for pheopigments were recorded at 20 m. At 60 m depth the concentrations were also low 0.23 μg.L^{-1} for chlorophyll-a and 0.03 μg.L^{-1} for pheopigments. The ratios chlorophyll/pheopigments at surface (3.5) and at 40 m (4.9) was lower than those measured at 20 m (5.7) and 60 m depth (7.7). The fecal coliforms density decreased gradually from 11 CFU/100 mL at 60 m till becoming null at surface. The densities of fecal streptococci were low in the whole water column with a maximum value of 80 CFU/100 mL recorded in surface water.

Matrix of correlation

The application of Pearson matrix of correlation among parameters defined the strength of the existing relation. The nitrate was shown to be correlated with the representative of phytoplankton biomass the chlorophyll-a ($r=0.51$; $p<0.05$; K=18) and its derivative pheopigments ($r=0.57$; $p<0.01$; K=18), while the phosphate was strongly correlated to the fecal coliforms ($r=0.86$; $p<0.01$; K=18) and fecal streptococci ($r=0.81$; $p<0.01$; K=18) densities. Add also that chlorophyll-α is strongly correlated to pheopigments ($r=0.97$; $p<0.01$; K=18) and fecal coliforms is extremely correlated to fecal streptococci ($r=0.99$; $p<0.01$; K=18).

DISCUSSION

The quick decline in water temperature during the profiles of October and August is simply explained by the presence of the seasonal thermocline, which is a natural phenomenon that stratifies the water column into 2 overlapping water masses of different characteristics. The tight variability of water temperature through the water column during the profiles of November and April was the consequence of water mixing where the thermocline is being absent (Abboud-Abi Saab et al ., 2004). The gradual decrease in water temperature is normal in spring season where the water column is subjected to complete mixing leading to “Homoeothermy” (Thouvenin, 1990) and the slight increase of temperature in deeper water is the consequence of water masses exchange during mixing.

In except to the profile of April where water salinity was lower at surface because of rain’s influence, the salinity during the 4 other profiles (dry seasons) was lower at 60 m depth than at surface. The bottom water was less saline because of the dilution effect of domestic treated wastewater discharged from the main pipe of discharge.

The measurements of nutrients provided supplement information on the contamination of water column. At 60 m the water was expected to be more loaded with nutrients because of its vicinity to the main outfall. This was the case during the profile of November 2007 where the concentrations of the 3 elements (phosphate, nitrate and nitrite) were higher at 60 m especially for nitrite which was about 35 times greater than at surface. Even in the absence of DBO_5 measurements, this value indicated a strong contamination with organic matters that has consumed part of the oxygen and has increased the ratio nitrite to nitrate (Wakelin et al., 2008). During other profiles, as in October 2008, even in the presence of seasonal thermocline, the whole water column was rich in nutrients, mainly the phosphate, one of the most representative elements of sewage water (Yilmaz et al., 1992), where its concentration at surface was almost the double than at 60 m depth. Theses concentrations in general were high if compared to oligotrophic regions (Abboud Abi-Saab et al., 2008) and which might be attributed to the presence of domestic detergents and soaps mainly composed of phosphate derivatives and to the biochemical degradation of organic matters contained in sewage water (Martinez, 1999). The elevated concentration at surface let us assume that the presence of seasonal thermocline at 50 m depth did not prevent the contaminants to reach the surface. During the profile of April 2009, where the thermocline was absent, the surface water was also more loaded with nutrients than deeper layers. The concentrations of nitrate were greater than those of orthophosphate. This confirms well that the drop in salinity value at surface was closely related to rain water which is usually rich in nitrate. The low concentrations in orthophosphate could be linked to the spring season where any extra amount of phosphate could be consumed by phytoplankton (Codispoti, 1989, Chocat, 1997). The concentrations of orthophosphate measured at surface represent the normal concentrations usually found in the oligotrophic water of the Mediterranean Sea (Abboud Abi-Saab et al., 2008).

In general the concentrations of chlorophyll-a and its derivative pheopigments were low during the 5 profiles and fit well the results obtained from the work of Fakhri et al. (2005) done in the Lebanese waters where the mean annual values of chlorophyll-α varied between 0.17 and 0.38 $\mu g.L^{-1}$. Add also that values of chlorophyll-a obtained in the Eastern Mediterranean were low not exceeding 1 $\mu g.L^{-1}$ even in coastal waters (Abdel-Moati, 1990; Yacobi et al., 1995; Herut et al., 2000). They seemed to be closely related to seasonal changes (Alpine & Cloern, 1992) and to pollution. In November 2007, the whole water column was poor in chlorophyll-α and pheopigments, a normal situation that usually occurs during this period of the year, but the concentration of pheopigments at 60 m was equal to that of chlorophyll-α with a low ratio (chlorophyll/pheopigments = 1). In April and August 2009, the concentrations of chlorophyll-α were higher at surface with a relative higher concentration of pheopigments when compared with the values measured in deeper water while the ratio chlorophyll/pheopigments at surface was lower than in the whole water column. The low ratios chlorophyll/pheopigments, at surface or near the end of the pipe of discharge, usually means that phytoplankton cells could be subjected to greater stress. The unfavorable conditions created by the discharged of contaminated water at 60 m depth and their upwelling till surface where they accumulate, are able to modify the quality of phytoplankton by the degradation of chlorophyll-α into pheopigments (Rivard, 2005). This may be considered as evidence of the perturbation state created along the water column. The contamination seems not to be limited around point of discharge at 60 m but it can be transferred up till surface to be lately spread not only vertically but also horizontally. As chlorophyll-α is considered a quantitative indicator of vegetal biomass in water (Berland et al., 1987; Alpine & Cloern, 1992), this let us consider that the phytoplankton was taking advantage at surface from the presence of available amount of nutrients but in the same time the cells seem to be physiologically perturbed due to their exposition to severe stress. It also appears that a strong relation was established between chlorophyll-α and nitrate for the whole period of the study ($r=0.51$; $p<0.05$; $K=18$), which explains well the dependent of phytoplankton on nutrients availability mainly the nitrate which is considered with phosphate as limiting elements (Berland et al., 1980).

The microbiological analysis showed that the whole water column contained microbial agents with various degrees of contamination. During the profile of October 2008 the density of fecal streptococci at surface was almost the double than that of fecal coliforms. During the profile of August 2009, there was a complete absence of fecal coliforms at surface while fecal streptococci showed somehow elevated density. In both, October and August profiles, the permanent presence of fecal streptococci at surface allowed us to assume that the contamination was not instant and that a certain time has passed since the discharge of contaminants, may be few hours before the profile execution. This comes from the fact that fecal streptococci survive longer than fecal coliforms in seawater and should be considered, perhaps, better indicators of fecal pollution for marine ecosystems (Slanetz & Bartley, 1965; Evison & Tosti, 1980). During these profiles the seasonal thermocline could not be considered as a limiting factor in preventing the ascent of bacteria up till surface. The same case was confronted during the absence of thermocline like in the profile of April 2009, where fecal streptococci density was higher in surface water. At surface, the fecal contamination coincides well with the elevated concentrations of phosphate and they were statistically related ($p<0.01$). These 2 major indicators of sewage water translated the high level of contamination of the treated wastewater of Al-Ghadir treatment plant.

During almost all of the profiles the surface water was more contaminated than the bottom one and with the dominance of fecal streptococci. The contaminants were able to reach the surface water in the absence or presence of the seasonal thermocline, a natural phenomenon supposed to form a barrier preventing the mixing of bottom waters with those of surface. The deeper water loaded with contaminants were able to regain the surface due to a hydrodynamic upwelling that might be the consequence of several combined forces such as waves' movements, strong currents, wind and lower depth of the sampled area. These factors may contribute to the creation of a zone of turbulence able to break the natural line of stratification produced by the thermocline and a similar situation was mentioned by Denis-Karafistan et al. (1998) where the combination of some natural factors on surface layer increase the depth of the mixed layer.

CONCLUSION

The treated wastewater from Al-Ghadir treatment plant was found to be still loaded with various types of contaminants mainly the microbial agents. The contaminated water discharged at 60 m depth was able to regain surface due to several combined natural factors by crossing the stratified layers of water which are supposed to form a natural barrier for any exchange between depth and surface. It seems that the pipe of discharge at its present location is of limited efficiency and more studies are advised to be run in the aim to define the right depth at which the treated wastewater has to be discharged in order to increase its chance for dispersion and degradation. Additional work has to be done to prove that the contamination of offshore surface water is the consequence of upwelling through water column and not the drifting of contaminated wastewater discharge out of the coastal emergency outfall.

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