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Estimation of Transfer of Pollutants from Discharge of Thermal Power Plant

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ABSTRACT

The once through cooling system of the Suez thermal power plant was chosen to simulate its marine environment impact as a cooling system that may be used in the suggested Egyptian nuclear power plants (ENPPs). To achieve the present study, the activity concentrations of natural radionuclides (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) in the collected water samples from the discharge of the Suez cooling system and Suez bay water were measured using a gamma-ray spectrometer. In addition, the physical and chemical properties of the water samples were measured. The results of the average activity concentration of the natural radionuclides ^{238}U, ^{226}Ra,^{232}Th and ^{40}K were 0.053, 0.04, 0.057 and 13.2 Bq/L which were within the permissible limits except for activity concentrations of ^{40}K is slightly above the standard limit. The measured activity concentrations of natural radionuclides were used as input data in the computer model which uses mathematical equations. The results of the model showed that increasing the distance from the discharge point, which reached 3500 m, gave the lowest values of radionuclide concentrations ^{238}U, ^{226}Ra, ^{232}Th (0.0026, 0.0, 0.0 Bq/m^3), respectively.

KEYWORDS

Natural radionuclides, Pollutants transfer, Suez bay, Thermal power plant, Mathematical model.

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INTRODUCTION

El-Dabaa the first Egyptian Nuclear Power Plant (ENPP) will be built on the Mediterranean coast. It may be better to use the once-through cooling system for the Egyptian nuclear power plants where large amounts of water are circulated through their condensers in a single pass and discharged back into the water body without much loss from the amount withdrawn **(Tsou *et al.,* 2013**). Under normal operating conditions nuclear power plants have the potential release of radioactive substances into water bodies called routine releases. Liquid effluents contain radioactive substances below the limited value of radioactivity released into the environment so that they can be released into water bodies. Radionuclides are transferred and dispersed in water bodies by advection, diffusion and dispersion processes.

The impact of the cooling system of a power generation plant depends on many comparative parameters such as water consumption, chemical and radiological impacts on the environment. The power generation plant often contains a desalination unit which can help increase the efficiency of the plant **(Shahzad *et al.,* 2016).** The impacts of the brine discharge from the desalination plants contain variable concentrations of different chemicals such as anti-scale additives and organic salts which has the ability to change the salinity, alkalinity, the temperature averages of the seawater and marine environment (**Ahmed *et al.,* 2001).**

The current study was carried out to assess the various characteristics of discharged effluents from Suez once through cooling system of the thermal power plant that its cooling system may be used in the suggested Egyptian nuclear power plants (ENPPs). The chemical and radiological impacts of the discharged effluents were analyzed to evaluate the possible impacts of the effluents on the quality of the Suez marine water.

An estimate of the radionuclides in the marine environment is one of the key parameters for the safety analysis especially for nuclear power plants to assess the dose received by an individual or population group using models. The mathematical model was used in this study to simulate transferring and dispersion of radionuclides in the discharged effluents from Suez once through cooling system along the coast of Suez bay.

Site description

The Suez power plant which is located on Suez bay includes one traditional thermal steam unit, which utilizes natural gas as its primary fuel and heavy fuel oil, mazout as an emergency fuel. Fuel is burned in boilers to convert water to a high-pressure steam then the steam is used to drive a steam turbine to generate electricity. The exhaust steam from the steam turbine is directed to a condenser that is cooled by a direct cooling system that extracts cooling water from the Suez bay.

The water for the Suez plant which is supplied from the Suez bay is used after desalination and demineralization to supply the boiler and is treated in another facility in the plant for producing sewage suitable for drainage in the Suez bay, where the treated wastewater streams are mixed with saline water from the demineralization plant to reduce salinity, and the liquid waste is completely discharged into the Suez bay (**EEHC, 2010**).

The sampling trip in the study area was done in August 2020. The first effluent sample was collected from the outfall of the Suez thermal power plant cooling system on the Suez bay at coordinates of 29°57’5.96”N and 32°30’12.97”E and the other samples were taken at different distances from the outfall as shown in Figure (1).

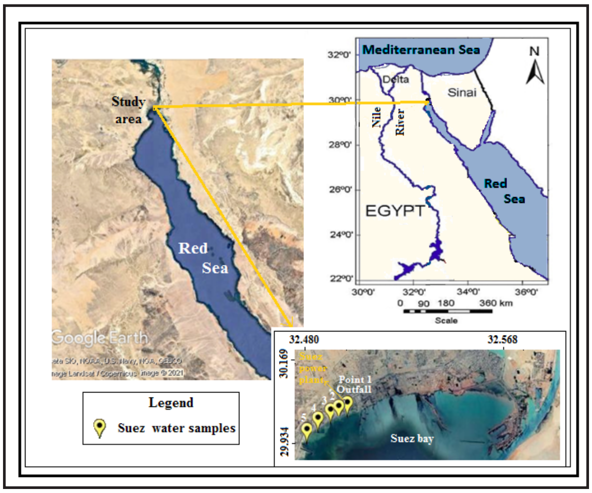

Fig. (1): Location of sampling in the study area.

MATERIALS AND METHODS

Samples preparation

For chemical analyses, a Polyethylene bottle of 1L was used for the collection of the water samples. For heavy metals, analyzed water samples were collected and stored in glass bottles (125 ml) after their treatment with a few ml of concentrated HNO_3 acid.

For radioactivity analysis, an amount of 0.3 L of water samples was packed in a plastic container, sealed, and stored for 4 weeks to establish the secular equilibrium between the natural radionuclides and their respective progenies.

Measurement of physicochemical parameters in water samples

Physicochemical Analyses of the water samples such as temperature, DO, pH, EC, and TDS was performed in situ utilizing portable meters, the portable Manta 2 instrument of accuracy $\pm$ 0.1°C.

Alkalinity**:** The bicarbonate alkalinity was determined by the titration method based on neutralization of the water samples by a titrated acid as 0.01N H_2SO_4,according to (**APHA, 1995)** method. Calculations were conducted using Alkalinity as calcium carbonate.

Chloride: For chloride ion in the water samples were measured by titration with 1.0N $AgNO_3$according to (**APHA, 1995).**

Trace elements*:* Trace elements concentrations in the Suez water samples were measured using Inductively Coupled Argon Plasma iCAP 6500 Duo, Thermo Scientific, England. 1,000 mg/L multi- element certified standard solution, Merk, Germany was used as a stock solution for instrument standardization. Trace elements (Hg, Cd, Al,Fe, Mn, Co, Cr, Mo, V, Ni, pb, Cu and Zn) in the collected Suez water samples concentrations were measured with a measurement uncertainty in the range of 1–10%.

The Mercury concentrations were measured by the direct mercury analyzer (DMA). The DMA-80 is equipped with a circular, stainless steel autosampler. The autosampler can accommodate up to 40 nickel (500 mg) boats. The DMA was calibrated using aqueous standards or Standard Reference Materials (SRM's). The DMA-80 system incorporates a tri-cell spectrophotometer and covered a wide dynamic range from 0.0015 to 1200ng of Hg. To cover this analytical range, each cell was calibrated using different volumes of stock solutions with different concentrations of Hg from 0.1 to 1 ppm, prepared from an NIST traceable 1,000 ppm stock solution. The results were satisfactory and were within uncertainty range of ± 5% and ± 10 for the analyzed mercury and other trace elements, respectively.

Radioactivity Measurements

The prepared samples into plastic containers of 100cm^3 capacity were counted using the gamma-ray spectrometer based on high purity germanium (HPGe) detector, Model Conberra with a relative efficiency of 40%. Efficiency calibration was determined using (RGU-1) reference material with an activity concentration of 4940Bq/K **(Hafızoğlu, *et al.*, 2020)**. The correlation between energy to channel number was 0.5 Kev/channel. The gamma ray spectrum was analyzed using Genie 2000, which measures the positive activity concentration of the samples. Calibration was carried out in the same geometry as that of the sample measurement.

The activity concentration (Bq/Kg) $A_{iE}$of a radinuclide I for apeak of energy E, was calculated using the following equation:

$$A_i = \frac{N\,iE}{\varepsilon E * I\gamma * m * t} \ldots \ldots . . (1)$$

Where N_{iE} is the net peak area at energy E,
$\varepsilon_{\gamma}$is the detection efficiency at the energy E,
t is the counting line time in second,
Iγ is the gamma ray yield for disintegration of the specific radionuclides for a transition at energy E, and m is the mass of the dry weight (Kg) of the measured sample.

Statistical analysis

The geographical information system (Arc GIS 9.1) was used to obtain the spatial graphical distribution which represented the physicochemical concentrations such as temperature, DO, salinity, hardness and alkalinity salinity in the studied area using the inverse distance weighted (IDW) interpolation method. The IDW interpolation method is based on the principle of assigning higher weights to data points closest to unvisited points relative to those which are further away (**Bing *et al*., 2011**). The Spatial distribution maps of water for each parameter were obtained as raster layers.

Analytical solution model

To illustrate the propagation of the radionuclide pollutants that may be discharged from the cooling system of the power plants especially nuclear power plants during normal operation. The mathematical model was used. It is based on analytical solutions with steady- state uniform flow conditions to predict the transport of discharged radionuclide concentrations for different distances x along shore and time periods.

A model of the one-dimensional system with constant characteristics and for the continuous discharge of radionuclides into water bodies used a general governing equation for radionuclide transport in surface water bodies as follows (**Till and Grogan, 2008**):

$$\partial C_{w,tot} / \partial t = U(\partial C_{w,tot} / \partial X) + V(\partial C_{w,tot} / \partial y) + W(C_{w,tot} / \partial z) \ldots ..(2)$$

Where:

C_w is the radionuclide concentration (Bq/m^3); t is thetime (s); U, V, W are the flow velocities in the x, y and zdirections, respectively (m s^{-1}); x, y, z are the longitudinal, lateral and vertical directions, respectively.

The solution of this equation gives the total radionuclide concentrations in coastal water along the shoreline (Bq s^{-1}) (**IAEA, 2001**).

$$C_{w,\,tot} = \frac{962\, U^{0.17} Q i}{D\, X^{1.17}} \exp \frac{\left(-7.28 * 10^{5}\right) U^{2.34} y_0^2}{X^{2.34}} \exp - \frac{\lambda_i X}{U} \ldots \ldots \ldots (3)$$

Where:
C_w,tot: is the total radionuclide concentration in water (Bq/m^3),
Qi: is the average discharge rate for radionuclide *i*(Bq/s),
λ_i: is the radioactive decay constant,
X: is the distance between the discharge point and the receptor (m),
D: is depth (m)
y_0: is the distance between release point and beach (m)
*U:*is the current speed (m/s).

Assuming that exposure occurs at the point of discharge from Suez power plant to coastal waterthe concentration in water under these circumstances is given by:

$$C_w = \frac{Qi}{F} \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

Where

F: is the flow rate of the liquid effluent (m^3/s)

RESULT AND DISCUSSION

Effluent properties

To evaluate the pollution in the effluents from the Suez cooling system and their impact on Suez bay the Suez water samples were analyzed for various physico-chemical parameters. The results of effluents which were represented in sample (1) were compared with values of National Environmental Quality Standards, **(NEQS, 2000)** and Environmental Health and Safety Guidelines **(EHSG, 2017)** for the industrial effluents. Similarly, values of the Suez water samples (2, 3, 4, 5) were compared with the standards of the World Health Organization **(WHO, 2011)**, (**Tech. Manual Excerpt, 2020**), U.S. Environmental Protection Agency **(EPA, 2020)** and other Guidelines.

Effluents from the Suez cooling system in sample (1) and the collected other samples from the Suez bay water close to the outfall of Suez cooling system were analyzed for various physicochemical characteristics such as temperature, DO, pH, alkalinity, EC, TDS, hardness, heavy metals and radioactivity concentrations. The results of the Suez water samples were recorded in Table 1.

Table (1) : *Physicochemical properties of Suez water samples.*

Parameters	1 (Outfall)	NEQS (2000)	2	3	4	5	Standard limits
Temperature (°C)	35.5	40°C[5]	34	33.2	32	31.0	32.0[1]
DO	3.67	-	3.72	3.84	4.1	4.38	3.5[2]
pH	7.94	6-9	8.0	8.0	8.1	8.1	7.7[4]
Alkalinity $CaCO_3$ (mg/L)	130	-	135	145	147	151	116[3]
Ec (mS/cm)	60.8		60.3	60.1	60.0	59.2	60.3[4]
TDS	41.96	3500	41.6	41.4	41.0	40.8	41.3[4]
Total hardness(mg/L)	10,942	-	10,000	8,850	8,650	8,437	8,375[4]
Hg (mg/L)	0.0004	0.01	0.0003	0.001	0.0002	0.0005	0.0005[5]
Cd (mg/L)	0.004	0.1	0.002	0.0039	0.002	0.0016	0.0006[5]
Al (mg/L)	0.01	-	0.1	0.3	0.7	0.4	0.01[5]
Fe (mg/L)	0.02	0.5	0.5	1.0	0.7	0.8	0.02[5]
Mn(mg/L)	0.002	1.5	0.015	0.003	0.004	0.02	0.003[5]
Co (mg /L)	0.02	-	0.01	0.029	0.02	0.027	0.0024[5]
Cr (mg/L)	0.01	1.0	0.01	0.012	0.015	0.01	0.01[5]
Mo (mg/L)	0.04	-	0.004	0.001	0.002	0.001	0.003[5]
V (mg /L)	0.01	-	0.02	0.03	0.01	0.01	0.01[5]
Ni (mg/L)	0.001	1.0	0.006	0.002	0.003	0.002	0.003[5]
Pb (mg/L)	0.009	0.5	0.1	0.11	0.07	0.009	0.006[5]
Cu (mg/L)	0.007	1.0	0.006	0.01	0.008	0.007	0.009[5]
Zn (mg/L)	0.004	5	0.03	0.04	0.02	0.02	0.0006[5]

** 1: Tech. Manual Excerpt, 2020; 2: EPA, 2020; 3: Boyd, 2020; 4: Abdel-Aal et al., 2015; 5: WHO, 2011.*

Figure (2) shows the distribution patterns of the physicochemical concentrations of the Suez water samples in the studied area. It is observed to increase in temperature, TDS, Hardness and decrease in DO and alkalinity concentrations in the effluent sample (1) compared to the other samples.

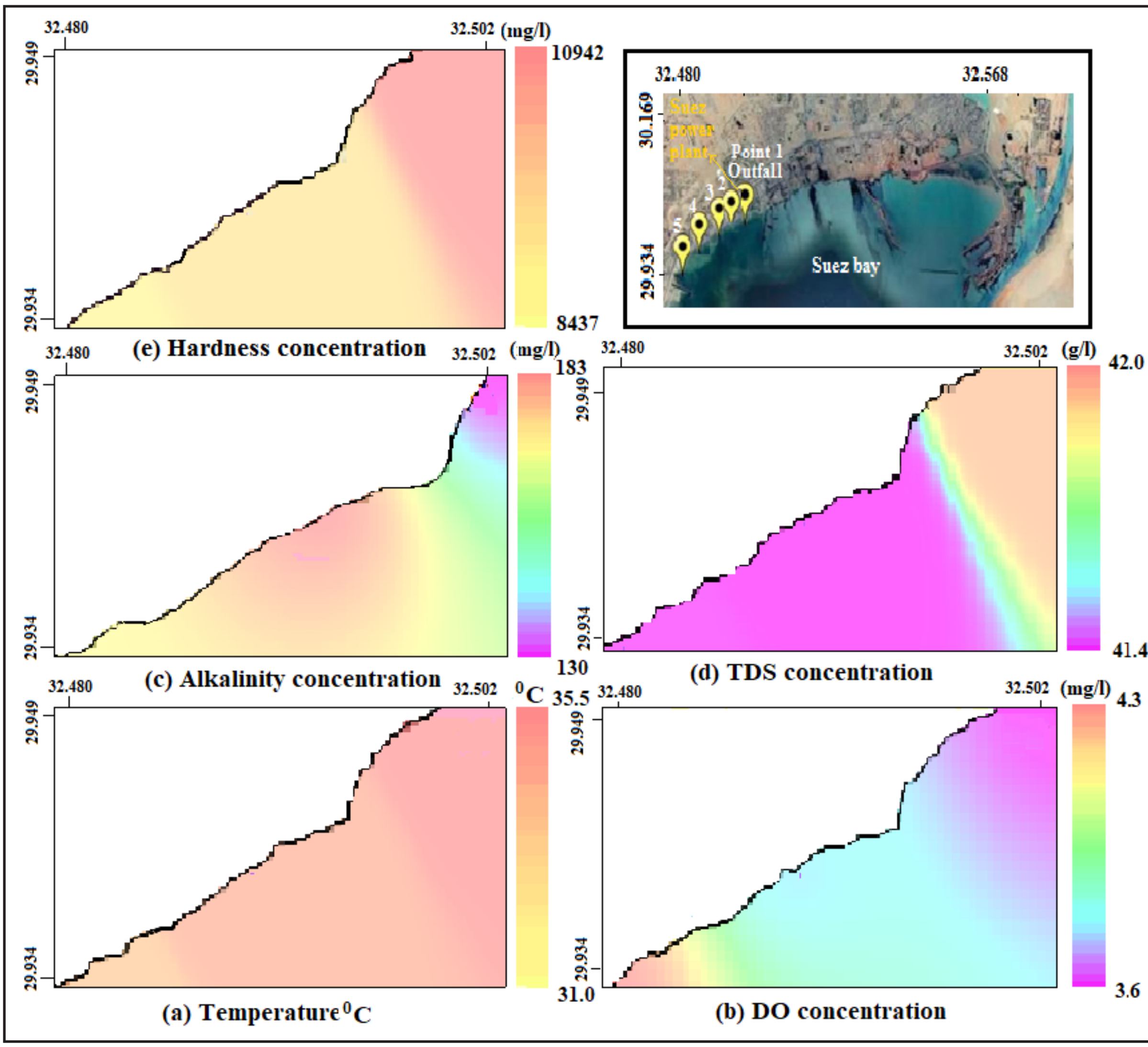

Fig. (2): Spatial representation of physicochemical parameters in the study area.

The obtained physicochemical characteristic results of the effluents and the Suez water samples were discussed as follows:

Temperature

The high temperature in the effluents sample (1) resulted from cooling of the condenser in the Suez power plant. The impacts of the thermal waters may cause a localized increase in seawater temperatures and may directly affect the organisms (**El Fatih, 2010**). The temperature values of Suez water samples ranged from31.0-35.5°C with a mean value of 33.0°C. The highest temperature value of the effluent sample (1) reached 35.5°C at the same time temperature decreased to 31.0°C in water sample (5) which is far from the point of discharge of the cooling system. The average value of the temperature results from the Suez water samples revealed that all values were within the permissible limits of **NEQS (2000) and Tech. Manual Excerpt (2020)**

Dissolved Oxygen

The DO concentration of the effluent in sample (1) was 3.67 mg/L while it increased to 4.38 mg/L in sample (5) suggesting that all the water samples were within the safe limits compared with EPA,2020 as recorded in Table 1.

The decrease of DO in the sample (1) as compared to the other samples is attributed to the oxygen concentrations that remain low when the level of the temperature increases (**Horne, 1969)** as shown in Figure (3). The DO standard is 5mg/L for cold or warm water fish and not less than 3.5 g/L at any time of the year for the protection of aquatic lives (**MPCA, 2019**).

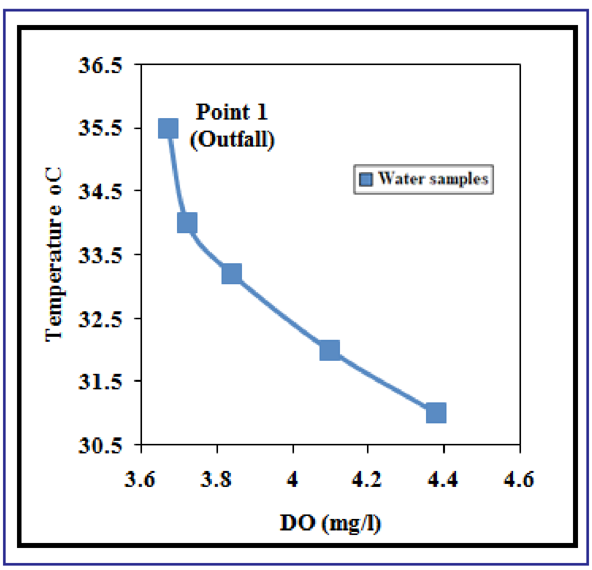

Fig. (3): Reduction of the DO content of Suez water samples.

Alkalinity

The pH of the Suez water samples ranged from 7.9 to 8.1 with a mean value of 7.96. Sample (1) had the lowest pH, while sample (5) had the highest pH. The pH of the Suez water samples tended to be alkaline and similar the pH (7.7) specification of the Red Sea water **(Abdel-Aal *et al.,* 2015)**

Compared to (**NEQS, 2000)** standards the pH values of all the Suez water samples were within the permissible limit. The alkalinity of the Suez water samples ranged between (130 and 151) mg/l while the total alkalinity of seawater ranged from 100 to 130 mg/l as is $CaCO_3$ with an average of 116 mg/L (**Boyd, 2020)**. The decrease in the pH concentration and alkalinity in sample (1) may be due to the discharge of the rejected brine containing acids and chemicals such as ferric chloride ($FeCl_3$) and ferric sulfate ($FeSO_4$) salts that are used for treatment in the desalination unit of the Suez power plant. Therefore the pH of water sample (1) from the Suez cooling system discharge point was less alkaline than the other water samples.

Salinity

Electrical conductivity (EC) is a function of total dissolved solids (TDS) known as ions concentration, which determines the quality of water **(Hem, 1989)**. The averages and ranges EC and TDS of Suez water samples ranged from (59.2 to 60.8 mS/cm) and (41.96 to 40.8 g/L) with a mean value of 60.1 mS/cm and 41.3 g/L respectively. The highest EC and TDS noted in the effluents sample (1) were 60.8 mS/cm and 41.96 g/L. However the lowest EC and TDS in sample (5) were 59.2mS/cm and 40.8 g/L. EC and TDS in the effluent sample (1) exceeded the salinity level of Suez bay ambient this may be due to the discharge of rejected brine water from the Suez cooling system into the Suez bay.

On the other hand, most of the EC and TDS values in Suez water samples were within the safe limits according to the specification of the Red Sea water **(Abdel-Aal *et al.,* 2015)**.

Electrical conductivity (EC) depends on the temperature, salinity, and TDS of the seawater **(Kumar *et al.,* 2018)**. Figure 4" illustrates the relationship between increasing temperature and increase in the salinity in Suez water samples **(Schroeder *et al.,* 2017 & 2020)**.

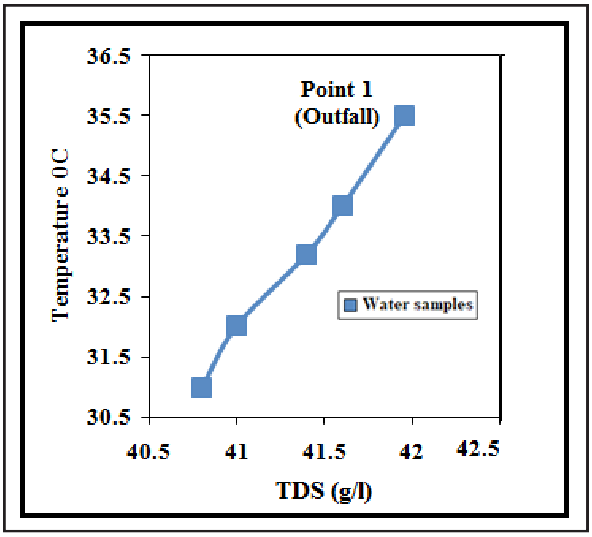

Fig. (4): The relation between temperature and salinity.

TOTAL HARDNESS

The hardness of seawater depends mainly on the presence of dissolved calcium and magnesium salt. The total hardness in Suez water samples varied from 10,942 to 8,437. The highest total hardness 10,942 mg/L was in the sample (1). Increasing hardness in the samples (1) than the Red Sea water specification (8375 mg/L) may be attributed to the discharge of rejected brine from the Suez cooling system to Suez bay (**El Fatih, 2010**).

Trace elements

Corrosion of heat exchanger materials in thermal desalination plants can lead to more significant contamination of the water with the most commonly used elements namely copper and nickel. Effluent discharge usually includes corrosion inhibiting chemicals containing chromium and zinc. The desalination power plant used chemicals for pretreatment and membrane cleaning including discharge of metals mainly Ba, B, Si, Cu, Fe, Ni, Mo, Cr which lead to increasing their concentration to levels that may be harmful to marine organisms **(Odfield *et al.,* 1997)**

The concentrations of heavy metals were from with Hg, 0.0004- 0.001; Cd,0.0016- 0.004; Al; 0.01- 0.7; Fe; 0.02- 1.0; Mn; 0.002- 0.02;Co, 0.02-0.029; Cr;0.01- 0.015; Mo; 0.001- 0.04; V,0.01 -0.03; Ni, 0.001- 0.006;Pb, 0.009-0.11; -Cu, 0.007- 0.01; Zn, 0.004- 0.04mg/L.

The results of the most expected heavy metals concentrations Hg, Cd, Fe, Mn, Cr, Ni, pb , Cu and Zn in the effluent sample (1) were within the permissible limit when compared to standards **(NEQS, 2000)** and **(WHO,2011)** standard limits. This is attributed to the treatment of the wastewater in the Suez power plant before discharging into Suez bay. The increase in the concentrations of most heavy metals in the Suez water samples (2, 3, 4 and 5) slightly than the standard limits of the WHO is due to exposure to the discharge effluents from various industrial activities which reach the Suez bay.

Natural Radionuclides

The measured activity concentrations of natural radionuclides ^{238}U, ^{226}Ra, ^{32}Th and ^{40}K in the Suez water samples were recorded in Table (2).

Table (2) : *Radioactivity concentration in Suez water samples compared to WHO's limits.*

S. Nos.	Water samples (Bq/L)					
	1 (outfall)	2	3	4	5	WHO (2011)
Ra- 226	0.15	0.02	0.025	0.01	0.062	1
U-238	0.1	0.015	0.03	0.015	0.04	1
Th-232	0.2	0.015	0.025	0.01	0.035	1
K-40	16.0	14.0	12.0	13.0	11.0	13.2

The treatment processes in the power generation and water desalination plants may concentrate radionuclides to a significant level. The average activity concentrations of ^{238}U,^{226}Ra,^{232}Th and ^{40}K for the Suez water samples were 0.053, 0.04, 0.057 and 13.2 Bq/L and below the permissible limits of radioactive waste by WHO (1, 1, 1 and 10 Bq/L) respectively except activity concentrations of ^{40}K which is slightly above the standard limit.

The increase of ^{40}K radionuclide in Suez water samples could be attributed to increasing ^{40}K radionuclide in the basement rocks **(Harb *et al.*, 2008).**

Analytical model solution

Dispersion leads to a breakdown of concentration gradients between the effluent and the surrounding seawater. One of the human activities that produce radionuclides is routine releases that occur due to the operation of nuclear power plants. In the current study the initial activity concentration of radionuclides ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K (0.15, 0.1, 0.2, 16.0 Bq/L) of discharged effluent from the outfall of the Suez thermal power plant has been inputted in the analytical mathematical model.

The other parameters used in the model were the rate of the discharge of cooling water which was about 200000 m^3/day and through an open canal extending over a half kilometer (y0) (500m) into the sea (**Abd El-Azim, 2012**). The coastal current (U) (0.1 m/s) which is prevalent inside the Red Sea (**Madah *et al.*, 2015).** The radioactive decay constant (λ_i) for radionuclides ^{238}U, ^{226}Ra and ^{232}Th were used. The rate of the annual radionuclides concentration release in normal operation (Q_i) Bq/s was calculated depending on the measured radionuclide concentrations ^{238}U, ^{226}Ra and ^{232}Th in the effluent discharge (sample 1). Radionuclide concentrations along the coastal current direction from the outfall point to a potential receptor at different locations *x* were calculated along the shoreline of Suez bay.

Simulation results

The calculation of the solution model showed that the activity concentration of natural radionuclides decreased along the coastal waters with an increase in the distance from the discharge point of the Suez power plant to the beach. The lowest concentrations of radionuclides ^{238}U, ^{226}Ra and ^{232}Th were (0.0026, 0.0, and 0.0 $Bq/m^{3)}$ respectively at the distance of 3,500 m from the discharge point as recorded in Table (3).

Table (3) : *The activity concentration of radionuclides along shoreline.*

Distance along shore X	C_w (Bq/m^3)		
(m)	^{238}U	^{226}Ra	^{232}Th
500	0.0169	0.259	0.34
800	0.0109	0.0139	0.021
1000	0.0053	0.0123	0.0173
1500	0.00471	0.0089	0.0125
2000	0.0041	0.0058	0.0077
2500	0.0035	0.0027	0.0
3000	0.00291	0.0	0.0
3,500	0.0026	0.0	0.0

Simulation results are shown as a graphical representation of the radionuclide concentrations at different locations along the Suez shoreline as shown in Figure (5).

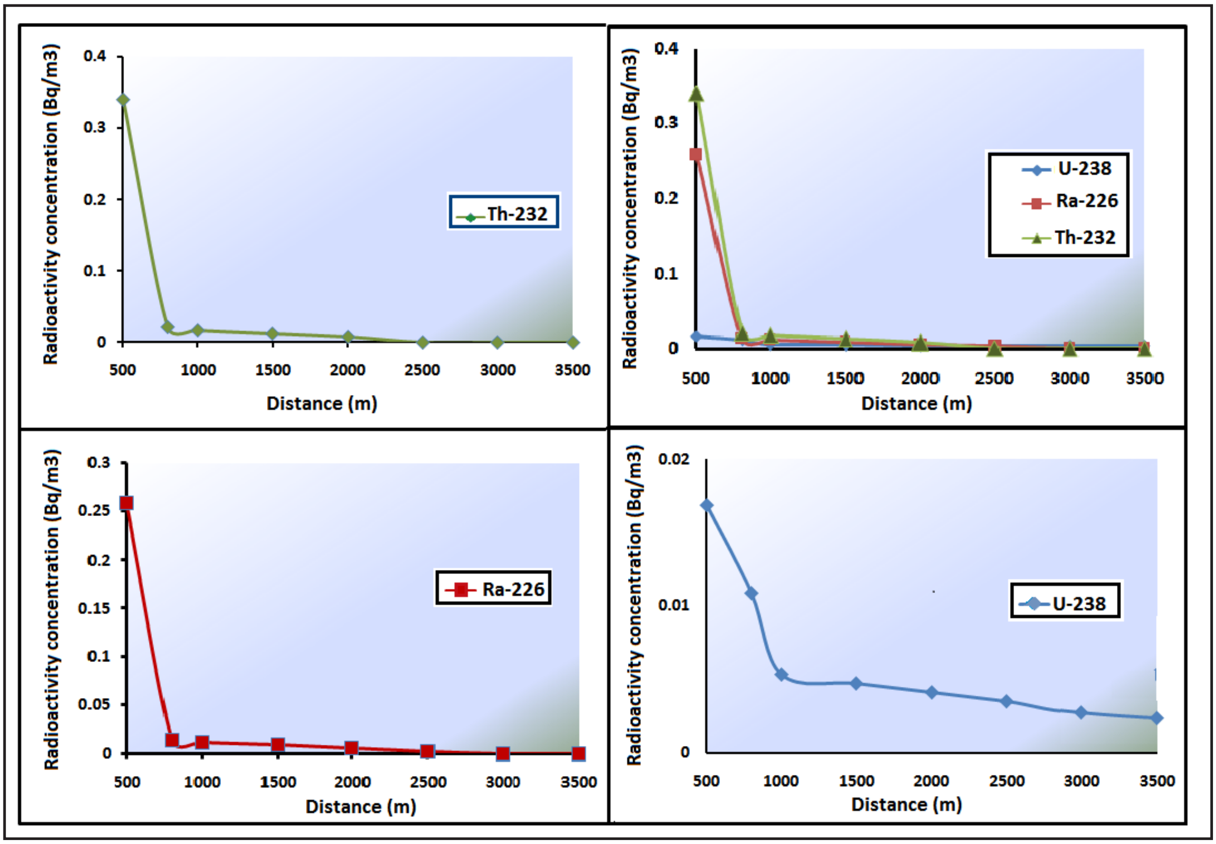

Fig. (5): The activity concentration of radionuclides along shoreline.

It could be noticed in Figure (5) that the results of the activity concentration $C_{w,\ tot}$ on the shoreline of radionuclides ^{238}U, ^{226}Ra and ^{232}Th were increased with increasing the distance until giving a maximum value then it decreases with the distance. This is attributed to the fact that a maximum value occurs when the polluted plume touches the shoreline.

CONCLUSION

The distribution of the physicochemical concentrations of the Suez bay water showed a slight increase in the temperature level in the vicinity of the Suez power plant but the increase in the temperature was within the permissible limit. The DO and pH concentrations in the vicinity of the Suez power plant were slightly decreased when compared to the concentration specifications of DO and pH of the Red Sea water, but the change was within permissible limits. The concentrations of heavy metals in the discharge water from the Suez cooling system were within the standard limits due to the treatment of wastewater from the Suez power plant before discharge into Suez bay. On the other hand, the salinity was slightly increased than the salinity specifications of the Red Sea water, especially near the discharge point of the cooling system. It may be attributed to the drainage of the rejected brine water from the Suez desalination plant to the Suez bay. So it is preferred that efficient environmental laws and social awareness programs must be undertaken for inhabitant's potential threat of industrial effluents to the marine environment.

The measured activity concentrations of natural radionuclides ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K, in Suez water samples, were within the recommended limits except for the activity concentrations of ^{40}K slightly above the standard limit.

The results of the analytical solution model showed minimal radioactivity concentrations of the natural radionuclides along the coastal Suez bay at a distance of 3,500 m from the discharge point.

The results of discharge effluents from Suez once through cooling system showed minimal effect on Suez marine waters therefore it may be used as a suitable cooling system for coastal nuclear power plants.

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