PINSTECH-162

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CONTENTS

LIST OF FIGURES & TABLES

Abstract

Concentrations of selective natural radionuclides (^{226}Ra, ^{228}Ra, ^{40}K) in shallow marine coastal sediments and sea water off Karachi coast-Pakistan, were measured with a hyperpure germanium (HPGe) gamma spectrometer. Sediment and water samples were collected from polluted Layari & Malir River downstream (pre-outfall), Gizri Creek, Layari River outfall in Karachi harbour, Karachi Harbour/Manora Channel Mains, as well as from open sea (South-East Coast and North-West Coast) within the 10m depth contour. No artificial radionuclides (e.g. ^{60}Co, ^{137}Cs and ^{134}Cs) were detected in both water and sediment samples at any of these locations. The activity of ^{226}Ra in coastal river sediments is found below its limit of detection (<18.35 $Bqkg^{-1}$). Activity of ^{228}Ra in sediments off Karachi Coast ranges between 11.80 ± 3.60 to 37.27± 4.31 $Bqkg^{-1}$; the highest activity was found south of Nuclear Power Station (KANUPP) and the lowest activity was found in the vicinity of Oyster Rocks (open sea). The ^{226}Ra activity ranges from 19.40 ± 5.88 to 67.14 ± 10.02 $Bqkg^{-1}$. The activity of ^{228}Ra in sediments of Manora Channel, South-East Coast of Karachi and the North-West coast of Karachi are also in agreement with the IAEA marine sediment standard namely: IAEA-135 (^{228}Ra = 36.7 ± 3 $Bqkg^{-1}$). The activity of ^{226}Ra for the South-East Coast of Karachi and the North-West coast of Karachi are also in agreement with the IAEA marine sediment standard namely: IAEA-135 (^{226}Ra = 23.9 ± 1.1 $Bqkg^{-1}$) and Pacific Ocean sediment standard namely: IAEA-368 (^{226}Ra =21.4 ± 1.1 $Bqkg^{-1}$). The ^{40}K activity in sea sediments varies from 197.79± 44.24 to 941.90 ± 39.00 $Bqkg^{-1}$. The highest activity is observed in the vicinity of Oyster Rocks (open sea) along the Clifton coast (South-East Coast of Karachi) and the lowest activity is found south of Nuclear Power Station (KANUPP) along the north-West Coast. The North-West Coast of Karachi has relatively lower levels of ^{40}K (ranging between 197. 79± 44.24 to 589.00 ± 34.90 $Bqkg^{-1}$) in bottom sediments. These values are in agreement with the marine sediment standards namely, IAEA-135 (^{40}K= 560 ± 9 $Bqkg^{-1}$) and IAEA SD-N-2. In case of water samples collected from the polluted Layari River, Malir river, and North-West Coast of Karachi, ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K are in concentrations below the limit of detection (LOD) for these radionuclides (^{226}Ra = 1.62 Bql^{-1}, ^{228}Ra = 1.4 Bql^{-1}, ^{137}Cs = 0.32 Bql^{-1}, ^{40}K= 10.96 Bql^{-1}). However, in Karachi Harbour, Manora Channel and the South-East Coast of Karachi, the measured average activity of ^{40}K in water samples ranged from 65.34 ± 4.38, 61.41± 2.54, and 56.34 ± 16.44 Bql^{-1} respectively. In conclusion, the natural radioactivity contents of ^{226}Ra, ^{228}Ra and ^{40}K in marine coastal sediments of Karachi are comparable with the values reported in literature for sediments of Aegean sea, Greece ; French Rivers; Lake Nasser, Egypt ; Karnaphuli River estuary, the Bay of Bangal ; and the Pacific ocean.

1. INTRODUCTION

Natural radionuclides are always present in terrestrial soils in varying concentration along with some artificial radionuclide accumulations on the land due to nuclear fallouts. Both the natural and artificial radionuclides are being washed out to the sea through rains and rivers as sea is the ultimate recipient of run-off from the terrestrial environment. Most of the global radioactivity fallout is deposited directly in the oceans through the air-sea interface. Radionuclides reaching the oceans can thus be found in water and bottom sediments. Since last 10 years, the public has great concern over the radiological effects of ionizing radiation on life both from natural and artificial radionuclides. This situation is considerably aggravated by the increasing anthropogenic releases of artificial radionuclides into the environment by developing nuclear industries, large scale nuclear weapon testing, and by some typical nuclear accidents such as those of Three Mile Island and Chernobyl.

Various characteristics and fates of naturally occurring and specifically, the artificial radionuclides released in to the marine environment are discussed in the literature [1]. Since radionuclides are chemically identical with stable elements, their biogeochemical behaviour in the marine environment is similar to that of stable elements and depends on their chemical properties. They undergo several environmental processes taking place in situ, such as dissolution, precipitation, sorption, complexation, biological ingestion and excretion, etc. in a manner similar to those of stable elements. This is specially true for natural radionuclides coexisting with their stable counterparts in the environment. For example radioactive potassium-40 (K-40 or ^{40}K) behaves in situ exactly like stable potassium-39 (natural abundance ~ 93%) and potassium-41 (natural abundance ~ 7%) although its isotopic abundance amounts to only 0.01%. Similarly, artificial radionuclides such as cobalt-60 (Co-60 or ^{60}Co), cesium-137 (Cs-137 or ^{137}Cs), etc. which have been introduced in the marine environment as a result of human activities, behave similarly to their naturally occurring stable counterparts namely: Co-59 (natural isotopic abundance ~ 100%), Cs-133 (natural isotopic abundance ~ 100%), provided that both the physical and chemical forms of the artificial radionuclides introduced are identical with those of their stable counterparts. Further each radionuclide disintegrates in its specific time (measured in terms of its physical half life for decay) & according to its own specific scheme thereby, emitting spontaneous particles and/or radiation with characteristic energies. This feature facilitates identification and quantitative determination with great certainty even at very low levels of radionuclides often found in environmental matrices.

A large number of artificial radionuclides are being produced intentionally or unintentionally as a result of human activities (operation of nuclear reactors & particle accelerators for research, electric power production, preparation of nuclear medicines radiotracers, etc.; nuclear fuel reprocessing plants, testing of nuclear weapons; nuclear accidents etc.). Many of these radionuclides are short lived and decay quickly after their production. Some of the artificial radionuclides are ,

however, long-lived and are released to the environment under controlled or uncontrolled conditions. Since radioactive waste effluents from nuclear fuel reprocessing plants and nuclear power plants are treated and stored to reduce the radioactivity levels, the quantities and numbers of artificial radionuclides in the effluents released into the environment are low. However, nuclear weapon testing or nuclear accident is an uncontrolled feature and large quantities of radionuclides are released to the environment. Even with these uncontrolled releases many short-lived radionuclides decay in the environment before giving any significant radiation effect on marine organisms and man. Thus, only a limited number of artificial radionuclides are often encountered in marine environments. The artificial radionuclides often found in marine environment are classified as: (i) ***Light nuclides*** *(^{3}H, ^{14}C)*: produced by nuclear weapon testing, and operation of nuclear power plants and nuclear reprocessing plants. Massive quantities of ^{3}H, ^{14}C were introduced to the marine environment during the 1960's nuclear weapon testing; (ii) ***Fission Products*** *(such as ^{90}Sr, ^{106}Ru, ^{137}Cs):* are produced by fission of ^{235}U & ^{239}Pu in nuclear reactors or uncontrolled weapon testing. The atmospheric testing of nuclear weapons has introduced a variety of fission products and neutron activation products into the marine environment. Normally, the fission products and their stable counterparts geochemically behave in an identical manner after release into the marine environments. However, it has been reported that in some cases, fission products like *^{106}Ru and ^{144}Ce etc. In effluents released to the marine environment after waste treatment are in entirely different chemical forms from those of their stable counterparts in the sea water* [2]; (iii) ***Activation Products*** *(^{60}Co, ^{65}Zn etc.)* are produced from neutron activation of stable isotopes of transition metals used for piping, casing etc. of nuclear reactors as well as nuclear weapons. These activation products are removed from time to time from the primary circulating water and after waste treatment are discharged at low level in the environment. ^{60}Co and ^{65}Zn are often found in the effluents released from nuclear power plants; (iv) ***Transuranic Nuclide*** *(^{238}Pu, ^{239}Pu)*: ^{239}Pu is released from nuclear power reactors using ^{238}U as fuel. As ^{239}Pu is used in production of nuclear weapons, its processed waste may contain traces of ^{239}Pu. Further ^{238}Pu and ^{239}Pu are known to be introduced into the marine environment through disintegration of SNAP satellite carrying ^{238}Pu in 1964, loss of nuclear weapon above Spain in 1966 and the crash of an aircraft carrying nuclear weapons at Greenland in 1968 [1].

Although, a common concern is to measure artificial radioactivity by human activities, it is not possible to completely ignore the presence of and environmental role played by naturally occurring radionuclides in the sea as life has always been exposed to their radiation. More than 60 radionuclide are known to occur naturally in the environment. According to their origin, these are classified into two groups: (i) terrigenous and (ii) cosmogenic. The ***terrigenous radionuclides*** are believed to have been present already in the rocks and minerals of the earth's crust, when the earth was formed and include long-lived primordial nuclide (at least 14 radionuclides are known to occur as primordial radionuclides with a common characteristic of their long half life ~ 10^{7} to 10^{15} Years) coexisting with their stable element counterparts as well as three primordial actinide parent nuclides, thorium-

232 (^{232}Th), uranium-235 (^{235}U), uranium-238 (^{238}U) and their descendant products. The principal member in the above category are potassium-40 (^{40}K) and rubidium-87 (^{87}Rb). Both radionuclides belong to the alkali metal group, so they are wide spread specially in the hydrosphere due to their susceptibility to weathering. The radioactivity of ^{40}K thus represents over 90% of the total radioactivity of sea water, while that of rubidium corresponds to only ~1%. The three primordial actinide parents and their daughter nuclides consist of 35 radioisotopes of Pb, Bi, Po, Rn, Ra, Ac, Th, Pa, and U. Depending on their parents mass numbers, these isotopes form three independent decay series, among which the uranium decay series (principal members are ^{238}U, ^{228}Ra etc.), characterized by mass number 4n+1 (where, n is an integer number) includes a series of more familiar radionuclides in the marine environment such as from decay of ^{238}U: ^{234}U, ^{232}Th, and from decay of ^{226}Ra: ^{210}Pb, ^{210}Po, ^{206}Pb. Further, the ocean environments (hydrosphere) are dynamic in nature, whereby, unlike closed system environments, the daughter nuclide may be separated from its immediate parent as the daughter may be quite different chemically from its parent. This causes radiological isotopic disequilibrium between the parent nuclide and the daughter. As for example, in case of isotopic disequilibrium for the uranium decay series in marine environment, it would be important to note that some marine organisms are receiving much higher natural radiation doses than organisms living on land, due to extensive accumulation of Po-210 (a descendant radionuclide of ^{238}U) in some organs of their bodies [3-4]. The ***cosmogenic radionuclides*** are being continuously produced in the earth's atmosphere due to interaction of cosmic ray particles (such as high-energy protons originating from outer space) with gaseous atoms of H, O, C, N, Ar etc. The principal members are tritium (H-3 or ^{3}H) and carbon-14 (C-14 or ^{14}C). These radioisotopes are brought down to earth's surface by processes like precipitation, isotope exchange or dry fallout or they enter directly into geochemical processes taking place on and/or above the earth's surface in a gaseous phase.

It is necessary to differentiate well-defined point sources of radioactive effluent discharges such as nuclear power plants, nuclear waste reprocessing plants etc. from wide-spread or combined sources like atmospheric fallout, river run-off etc. In cases, where the artificial radioactivity is discharged into a stream or river, it will be subjected to various geochemical trapping processes such as hydrolysis, precipitation, sorption, ion exchange etc. before entering the marine environments. As a consequence, the net radioactivity reaching the marine environment will be much smaller as compared to the activity at the release point in the river. Hospitals and scientific laboratories using radioisotopes may be considered as point sources for radionuclide discharge into the environment. Nevertheless, hospitals use short lived radioisotopes such as ^{99m}Tc (half life: 6 hrs.), ^{131}I (half life: 8d), ^{198}Au (half life: 2.7d) and in relatively small quantities and the radioactive wastes at significant level are treated before discharging into the municipal sewage systems. Thus, the hospital wastes do not pose any threat to the marine environment. Uranium mine activities and fly ash from coal power plants may also become a source of marine pollution as these mobilize some natural radionuclides of uranium decay series.

For implementation of marine environment conservation strategies, a prime requirement is to prepare an "assessment document" for protection of the in-shore and off-shore coastal marine environments from Land Based Pollution Sources (LBPS). Such a document in general contains information on : (i) sources, points of entries and amounts of pollution from industrial, municipal and other discharges to the coastal marine environments, (ii) levels of pollution, (iii) effects of pollution, and (iv) present legal, administrative and technical measures at national and international levels to combat pollution. In Pakistan, the Environmental Protection Agency (PEPA) is making an effort to formulate the legal document for implementation of the environmental regulations. A concerted effort is also being made by the IUCN to save the marine environments, specifically, the mangrove ecosystem in the Karachi sea and the Indus River Delta region. Some sporadic pollution surveys involving classical hydrogeochemical and/or biological techniques have been made in the past to estimate the pollution status along the coast of Karachi [5-7]. However, no radioactivity data is yet available on coastal marine environments of Pakistan. The present work aims to initiate a radiological assessment program for Pakistan with the ultimate aim of establishing a baseline map of radioactivity background levels in the coastal areas of Pakistan. The baseline map will be used further as reference information to assess any changes in the radioactivity background level due to various geological processes or any artificial influences on the radiation environment in the area in future.

Although, possible environmental events considered as pollution are only attributed to the release of artificial radionuclides, it is not possible to completely ignore the presence, importance and environmental role played by naturally occurring radionuclides in the sea. The coastal strip of Pakistan is ~960 km long. To date, no baseline marine radioactivity data is available for the entire coast of Pakistan. Nevertheless, a preliminary shallow marine radioactivity analysis has been performed on a number of shallow sea bottom sediment and sea surface water samples collected off Karachi coast during 1996-97 in connection with the IAEA-Research Contract-PAK-8127 awarded to the Radiation and Isotope Applications Division, PINSTECH. This report outlines the shallow marine radioactivity database for the Karachi sea w.r.t. concentration of natural radioactivity in water and sediment samples collected from polluted water sources namely: Layari & Malir River outfall areas, non-polluted water source namely: the Karachi Sea (blue waters) and the significant pollution recipient areas of Karachi Sea, namely: Karachi Harbour/Manora Channel area and the North-West Coast and the South-East Coast of Karachi sea. The **main objective** is to document the existing state of pollution of the Karachi sea by natural and artificial radionuclides, so as to provide a scientific rationale for establishing control measures for prevention of any radioactive pollution inventory in the coastal marine environments of Pakistan.

2. DESCRIPTION OF STUDY AREA

Karachi is the largest city in Pakistan with a coast line extending up to about 30 km. The domestic waste generated by a population of more than 10 million and the industrial waste generated by some more than 1000 large industrial units (chemical industry, textile industry, leather tanning industry, fish processing industry, cement industry, steel mills, thermal power plants, oil refineries etc.) is drained in to the Karachi sea mainly via Layari River, Malir River and Korangi Creek [Fig. 1]. This waste input is further supplemented with oil spills from cargo ships and oil tankers in the Manora Channel/Karachi Harbour.

Karachi Harbour area is considered to be the most heavily polluted marine site in Pakistan. It includes the semi-closed Manora Channel and the Keamari Fish Harbour. Manora Channel is spread over an area of 7.17 km and about 3.4 million cubic meter water enters and leaves the channel during a tidal cycle. The addition of sediments in the Karachi harbour area is mainly brought by the Layari River and the status of sediment input load is so bad that the channel has to be dredged year round. About 45600 cubic meters of silt is removed from the channel annually. Similarly, the area between Gizri Creek, Ibrahim Haideri Fish harbour and Korangi is being seriously contaminated by inputs of domestic and industrial wastes from the Malir River (Gizri Creek) and the Korangi Creek. Inspite of very high pollution levels in the Karachi Harbour area, it is still being used for bathing by tourists and the local population. The fish habitat and the mangroves along the cost of Karachi are now under considerable stress due to significantly growing levels of sewage and industrial pollution along the coast of Karachi. This may have a significant ill effect on health.

3. PRESENT INVESTIGATIONS

3.1 Field sampling and analysis

A number of **low tide sea surface water samples** (17 samples) and sea **bottom sediment samples** (33 samples) were collected from the Manora Channel/Karachi Harbour area as well as from open sea along the Clifton-Ibrahim Haideri-Korangi coast line (South-East Coast of Karachi) and the Manora Island-Paradise Point Coast line (North-West Coast of Karachi). Figure 1 shows the location of selective sampling points. The polluted rivers were approached by road, whereas, the sea water sampling was performed using a motor boat (*Al-Subhani, 818M*) hired from the Keamari Boat Basin. The polluted rivers were tapped during the low tide period and at a point much beyond the influence of high tide so as to assure representative collection of a mixture of municipal waste water, sewage and industrial effluents in the rivers. The location of each sampling point was monitored with the help of a **Garmin GPS-100 Personal Navigator** (M/S Garmin, 11206 Thompson

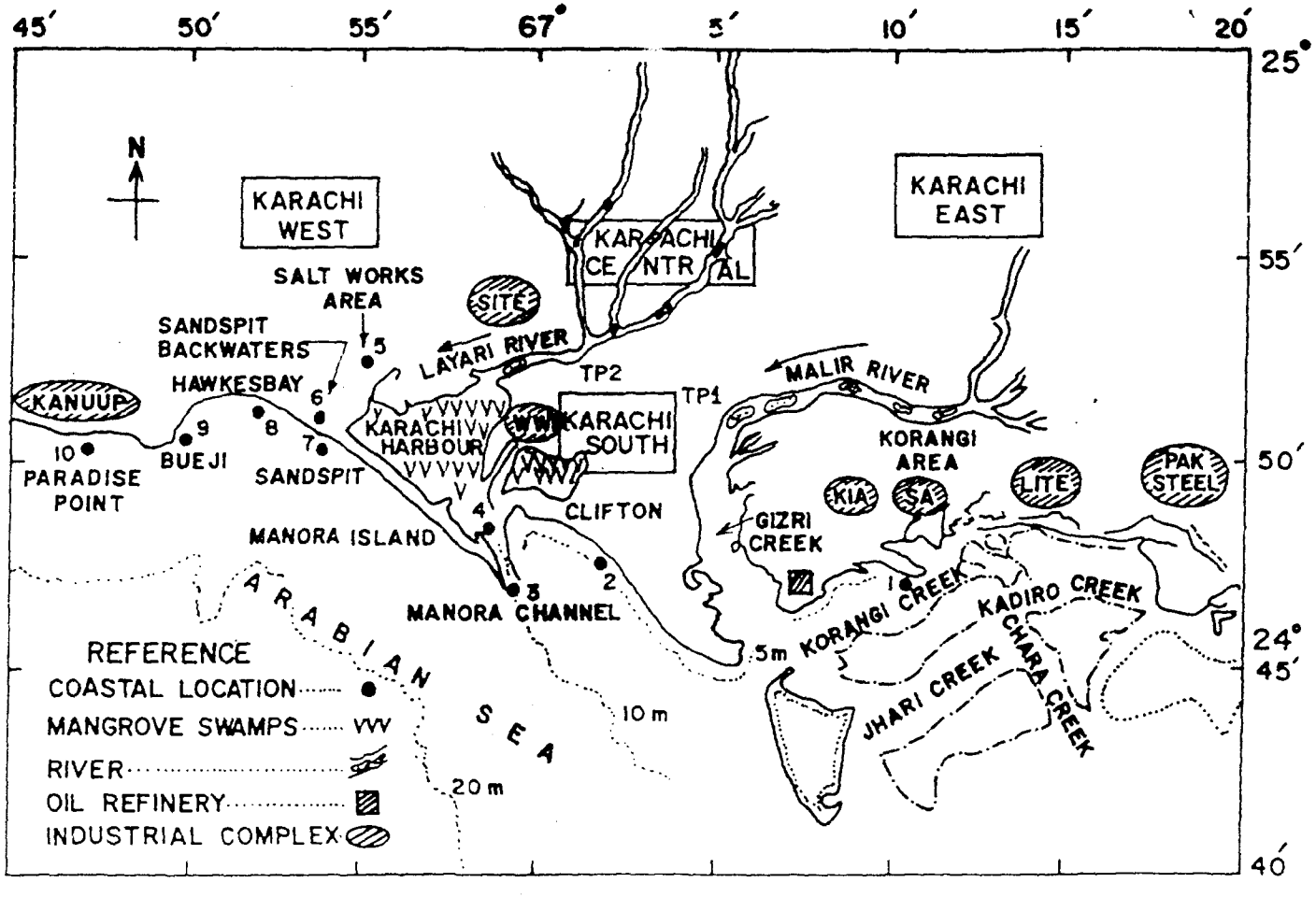

FIG. 1: Coastal map of Karachi (Pakistan) indicating industrial zones and water/ sediments sample locations.

Avenue, Lenexa, KS 66219). All water samples were collected in leak-tight doubled stoppered plastic bottles. The time for occurrence of low tide was deduced from standard **Tide Table Guide-1996** published by the Pakistan Navy. Bottom sediment samples were collected with the help of a Peterson **Grab and** then contained in high quality polythene bags. Turbidity, temperature and electrical conductivity of water samples were measured in-situ. **Turbidity** was measured with a battery operated portable turbidimeter (Model 6035, JENWAY). **Electrical conductivity** and **Temperature** were measured with a portable conductivity meter (Model HI 8633, M/S HANNA Instruments).

3.2 Laboratory methods and analysis

3.2.1 Sample Preparation

Collected sediment and water samples were pretreated for a representative radiometric analysis and to improve the counting/detection statistics. Details are presented in the following section:

3.2.1.1 Sediments

The grab samples weighing about 1-2 kg were as such dried over night in an oven at 80±10 °C to remove moisture. The dried sediments were pulverized and sieved to pass through a coarse mesh (1-2 mm size fraction). The meshed sediments (about 1 mm grain size) were transferred to plastic containers of 200 ml capacity for gamma activity analysis. Each sample was carefully sealed for a period of 4 weeks to attain secular equilibrium between ^{238}U and ^{232}Th and their respective progeny.

3.2.1.2 Water

Water samples were filtered through fast filter papers (Selecta^{TM}, Nr. 595, Dia. 11 cm, Carl Schleicher & Schull, Germany) for the removal of suspended organic matter. Prior to concentrating the water samples for radiometric analysis, about 5 - 10 ml. of conc. HNO_3 was added per litre of the sample water to reduce the pH less than 2. This was necessary to avoid precipitation of salts at the walls of the plastic bottles to be counted. The natural activity of ^{40}K was used to calibrate the equipment for ^{40}K measurements in unknown samples. The calibration standards for K^{40} was prepared by dissolving extra pure KCl salt (Article No. 4935, Emerck Darmstrdt, Germany) in distilled water and contained in 200 ml plastic bottle. Therefore, one litre of sample water was concentrated to a 200 ml volume by evaporation under infra-red lamp (or hot plate), in order to match the geometry of the calibration sources.

3.3 Gamma spectrometric analysis

Gross gamma counting of sediment samples was carried out prior to gamma spectrometry to have a rough idea about the presence of radionuclides [8]. Coarsely sieved (<2 mm size fraction) and dried sediment samples were packed in a specific geometry plastic bottle similar to that used for the calibration source. Measurements were made on a NaI(Tl) detector with a 3 inch x 3 inch size crystal. The detector was calibrated with a single energy radionuclide namely: ^{137}Cs. The average detection efficiency of the system was 20 %.

For gamma spectrometry, the samples were analyzed with a setup comprising the following instrumentation and software: Spectrometer consisting of an EGPC-20 end-window type coaxial hyperpure germanium (HPGe) detector with 103 cm^3 effective volume , coupled with a CANBERRA Series-85 Multi-channel analyzer, detector photopeak relative efficiency of about 20% and an energy resolution of 1.9 keV (FWHM) for 1,332 keV gamma transition of Co^{60} . Spectroscopy amplifier 7200E (Inter Technique), ADC, 8521 (Canberra), Multi-channel Analyser (MCA, Canberra Series-85). The ADC had a gain of 4K, covering the energy upto 1800 KeV. All spectra were collected at "PUR OFF" mode of operation of the amplifier. No hardwired link was established between the amplifier and ADC for Pile-up rejection. Recorded spectra were evaluated with the programme GAMANAL from the software package GANAAS. To reduce gamma ray background, the detector was shielded by an 8 cm thick lead wall with a fixed bottom and sliding cover. The lead shield contained an inner lining of 0.5 cm copper to absorb lead X-rays. The detector was calibrated against the soil standard ***IAEA Soil-375*** containing all the radionuclides of interest for the measurement of sediment samples [9]. To calculate the activity of ^{40}K in water samples, a single point efficiency was calculated by using the laboratory prepared ^{40}K standard solution.

In the present study, only ^{226}Ra, ^{228}Ra and ^{40}K were measured. ^{90}Sr was not measured due to non-availability of certain consumables mainly, fuming nitric acid and instrumental disorder. The physical constants used for the evaluation of the results are given in Table-I.

TABLE-1
Physical constants used in the evaluation of radioactivity results

RADIONUCLIDE	HALF LIFE (Y)	GAMMA -LINE (keV)	EMISSION PROBABILITY (pϒ %)	DETECTION EFFICIENCY
Ra-226	1600	186.21	03.28	0.056
Ac-228/Ra-228	6.78	911.07	27.70	0.009
K-40	1.277E9	1460.80	10.70	0.00584

The gamma transition of energy, 185.9 keV (^{226}Ra) was used to determine the concentrations of ^{238}U series radionuclides. The gamma transitions of energy,

911. 07 keV (^{228}Ac), was used to determine the concentration of ^{232}Th series radionuclides. The 1460 keV gamma of ^{40}K was used to determine the concentration of ^{40}K in different samples. The geometry of the samples was kept identical to that of the standards. The counting time for all the samples was 20,000 Sec. Limit of detection (LOD) i.e. the minimum detectable quantity of radionuclides of interest was calculated by using a generally accepted expression:

$$LOD = 4.66\ S_b / \epsilon\ P_\gamma$$

Where, S_b is the estimated standard error of the net count rate, ϵ is the peak detection efficiency and P_γ is the abundance of the selected gamma line [8]. The following sources of uncertainty were taken into account in the evaluation of over all uncertainties: *counting statistics of the test samples, counting statistics of the detector background and the detector efficiency*. Results are presented in Bqkg^{-1} for sediments (solid samples) and Bql^{-1} for polluted river & Karachi-sea water (liquid samples). For the measurement of sediment samples, "Limits of Detection" (LOD) for various radionuclides are as following: ^{226}Ra = 18.35 Bqkg^{-1}, ^{228}Ra=9.6 Bqkg^{-1}, ^{137}Cs=1.6 Bqkg^{-1}. For the measurement of water samples, "Limits of Detection" (LOD) for various radionuclides are as following: ^{226} Ra =1.62 Bql^{-1}, ^{228}Ra =1.4 Bql^{-1}, ^{137}Cs = 0.32 Bql^{-1} and ^{40}K= 10.96 Bql^{-1}.

4. RESULTS & DISCUSSION

Tables 2 & 3 (parts: 2A through 2G) present the gross gamma activities and radioactivity concentrations of natural uranium decay series radionuclides such as ^{226}Ra (^{238}U decay series radionuclide), ^{228}Ra (^{232}Th decay series radionuclide); Terrigenous radionuclide namely: ^{40}K in sediment samples and water samples pertaining to polluted Layari & Malir River downstream area, Layari River outfall area in Karachi harbour, Karachi Harbour Mains, Manora Channel Mains, as well as South-East Coast of Karachi Sea and North-West Coast of Karachi Sea (within the 10m depth contour). It is worth mentioning that no artificial radionuclides (for example ^{60}Co, ^{137}Cs and ^{134}Cs) are detected in both water and sediment samples at any of the sampling locations (LOD for ^{137}Cs: 1.6 Bqkg^{-1} for sediments and 0.32 Bql^{-1} for water samples). Similarly, in case of water samples ^{226}Ra & ^{228}Ra are also in concentrations below the limit of detection (LOD) for these radionuclides (^{226}Ra=1.62 Bql^{-1}, ^{228}Ra = 1.4 Bql^{-1}). Details on distribution of radioactivity in each coastal marine zone are discussed in the following section.

4.1 Polluted river downstream zone (pre-outfall)

Sediments pertaining to polluted ***Layari River*** downstream (pre harbour outfall) have the lowest average values for gross gamma activity (59.39 ± 5.28 counts/sec/kg dry sediments) and radioactivity concentrations of ^{226}Ra (<18.35 $Bqkg^{-1}$), ^{228}Ra (14.28 ± 3.72 $Bqkg^{-1}$) , ^{40}K (125 ± 28.60 $Bqkg^{-1}$) as compared to values for the Layari River outfall zone in Karachi Harbour, Karachi Harbour Mains, Manora Channel Mains and Karachi Sea off-shore sediments. In case of water samples collected from the polluted ***Layari River (downstream, pre-harbour outfall)*** and ***Malir river (downstream, pre-Gizri Creek outfall)***, ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K are in concentrations below the limit of detection (LOD) for these radionuclides (^{226} Ra=1.62 Bql^{-1}, ^{228}Ra = 1.4 Bql^{-1}, ^{137}Cs = 0.32 Bql^{-1} and ^{40}K= 10.96 Bql^{-1}).

4.2 Layari river outfall zone (Karachi harbour)

Sediments pertaining to Layari River Outfall Zone in Karachi Harbour have slightly higher average gross gamma activity (74.65 ± 13.08 counts/sec/kg dry sediments) and radioactivity concentrations of ^{228}Ra (20.46 ± $Bqkg^{-1}$) and ^{40}K (520.91 ± 112.46 $Bqkg^{-1}$) as compared to those for the Layari River and Malir River sediments. The radioactivity concentrations of ^{226}Ra is mostly below detection limit except for one sample (53.84 ± 6.69 $Bqkg^{-1}$) in the Shamaspir zone. In this zone, highest values of ^{40}K in sediments ranging from 575.24 ± 34.80 $Bqkg^{-1}$ to 636.66 ± 35.66 $Bqkg^{-1}$ are observed in the Manora Channel Backwaters towards Sandspit and Shamspir Villages. In contrast, radioactivity concentrations of ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K in water samples are below the limit of detection (LOD) for these radionuclides (LOD: ^{226}Ra = 1.62 Bql^{-1}, ^{228}Ra = 1.4 Bql^{-1}, ^{137}Cs = 0.32 Bql^{-1}, ^{40}K= 10.96 Bql^{-1}).

4.3 Karachi harbour mains

This area is under constant pressure of navigational activities by private mechanized boats, ships, trollers and navel fleets. In addition, it is being continuously dredged to maintain optimal channel depth for naval vessels etc. Sediments pertaining to Karachi Harbour mains have average gross gamma activity (105.66 ± 11.88 counts/sec/kg dry sediments) and radioactivity concentrations of ^{226}Ra (<18.35 $Bqkg^{-1}$), ^{228}Ra (24.54 ± 4.94 $Bqkg^{-1}$) and ^{40}K (522.65 ± 143.68 $Bqkg^{-1}$). These values are comparable with those for the sediments in Layari River outfall zone. In this zone, highest values of ^{40}K in sediments ranging from 572.47 ± 35.56 $Bqkg^{-1}$ to 634.80 ± 28.80 $Bqkg^{-1}$ are observed in the Keamari Boat Basin area and the Shamspir Channel entrance close to Bhit Island Mangrove Forest. In case of off-shore water samples, average radioactivity concentrations of ^{40}K = 65.34 ± 4.38 Bql^{-1} are observed for the Karachi Harbour Mains. These are quite low as compared to ^{40}K values in sediments.

4.4 Karachi Port Trust (KPT)/Keamari fish harbour channel

This area is under constant pressure of navigational activities by private mechanized boats and fish trollers. In addition, it is being continuously dredged to maintain optimal channel depth for large ships & trollers etc. A long bifurcation wall protects the KPT Shipyard Channel from receiving polluted waters of Layari River Outfall zone. Nevertheless, in high monsoon period (May to August) this area partly receives an over-spilling of Layari River outfall polluted waters under severe wave action only during the high tide regimes. Sediments pertaining to Karachi Port Trust (KPT)/Keamari Fish Harbour Channel have average gross gamma activity (59.77 ± 6.18 counts/sec/kg dry sediments) and radioactivity concentrations of ^{226}Ra (24.23 ± 5.97 Bqkg^{-1}), ^{228}Ra (22.37± 6.72 Bqkg^{-1}) and ^{40}K (373.36 ± 110.5 Bqkg^{-1}). The gross gamma activity values are comparable with those for the sediments in Layari River outfall zone whereas, the ^{226}Ra & ^{228}Ra values are slightly higher than the previously discussed zones. Further, in this zone, the highest values of ^{40}K (451.50 ± 33.23 Bqkg^{-1}) and gross gamma activity (64.14 ± 5.32 Bqkg^{-1}) are observed in sediments pertaining to Boat Building Area. In case of off-shore water samples, average radioactivity concentrations of ^{40}K=27.20 ± 16.97 Bql^{-} are observed for the Karachi Shipyard area. These are quite low as compared to ^{40}K values in sediments.

4.5 Manora channel mains

This area is also under constant pressure of navigational activities by oil tankers, cargo ships, fish trollers, navel fleets, submarines. Like the KPT shipyard channel, Manora channel is being continuously dredged to maintain optimal channel depths for large vessels etc. The average ^{40}K, ^{226}Ra & ^{228}Ra radioactivity concentrations of sediments in Manora Channel are quite similar to that of Karachi Harbour area. However, gross gamma activity levels are lower than the Karachi harbour zone. The ^{226}Ra activity in all sediment samples except one, is below the detection limit for this radionuclide (<18.35 Bqkg^{-1}). Highest concentrations of ^{40}K (748.19 ± 36.89 Bqkg^{-1}) are observed in a dredged sediment sample (obtained from working Dredger B.D. Aftab) near Oil Terminal. Similarly, high ^{40}K values (522.40 ± 34.14 to 615.80 ± 35.30 Bqkg^{-1}) are observed in sediments collected from a nearby station namely Bhaba/Bhit Islands & the Boat Club. In case of off-shore water samples, average radioactivity concentrations of ^{40}K=61.41 ± 2.54 Bql^{-} are observed for the Manora Channel area. These ^{40}K values in water samples are comparable with the Karachi harbour water samples. However, these ^{40}K values are quite low as compared to values in sediments.

4.6 Southeast coast, Karachi Sea

The South-East Coast of Karachi extends from West Wharf-Clifton Beach to Korangi Industrial State. Like Karachi Harbour/Manora Channel area, the South-East Coast of Karachi is a regular recipient of domestic sewage and industrial effluents all along the coast. This area has the highest average gross gamma activity values for sediments (ranging between 89.23± 5.23 to 136.37± 5.90

counts/sec/kg dry sediments, Average: 108.02 ± 25.26 counts/sec/kg dry sediments) and the radioactivity concentrations of ^{40}K (ranging between 659.15 ± 35.83 to 941. 90 ± 39.00 $Bqkg^{-1}$, average: 780.36 ± 126.58 $Bqkg^{-1}$) as compared to Karachi Harbour-Manora Channel zone and the North-West coast of Karachi. Highest values of gamma activities (around 126 $Bqkg^{-1}$) and ^{40}K (around 935 $Bqkg^{-1}$) are observed in the areas encompassed by Oyster rocks, oil jetty (Clifton side) and oil storage tanks along the Clifton Coast . The natural radioactivity concentrations of ^{226}Ra and ^{228}Ra in sediments of South-East coast are comparable to those for the KPT Shipyard Channel, Karachi Harbour, and the Manora Channel zone. In case of water samples, average radioactivity concentrations of ^{40}K=56.34 ± 16.44 Bql^{-1} are observed for the South-East coast. These ^{40}K values in off-shore water samples are comparable with the Karachi harbour/Manora Channel water samples. However, these ^{40}K values are quite low as compared to values in sediments.

4.7 Northwest coast, Karachi Sea

The North-West Coast of Karachi extends from Manora Channel Seaside to Hox-Bay, Paradise Point. Unlike Karachi Harbour/Manora Channel area, the Clifton-Korangi Coast (South-East Coast of Karachi), the North-West Coast of Karachi is not a regular recipient of major discharges of domestic sewage and industrial effluents except minor sewage waste drains from small size dwellings along the coast. Nevertheless, the values of gross gamma activity are quite comparable with those for Manora Channel/Karachi Harbour area. Whereas, the natural radioactivity concentrations of ^{40}K (385 $Bqkg^{-1}$), ^{226}Ra (45.91 $Bqkg^{-1}$) and ^{228}Ra (30.77 $Bqkg^{-1}$) in sediments are slightly higher as compared to other zones in the Karachi Harbour/Manora Channel and the South-East Coast of Karachi. In contrast, radioactivity concentrations of ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K in off-shore water samples collected from the North-West Coast of Karachi are below the limit of detection (LOD) for these radionuclides (LOD: ^{226}Ra = 1.62 Bql^{-1}, ^{228}Ra = 1.4 Bql^{-1}, ^{137}Cs = 0.32 Bql^{-1}, ^{40}K= 10.96 Bql^{-1}).

5. SUMMARY AND CONCLUSIONS

5.1 Sediments

The activity of ^{232}Th series radionuclide (^{228}Ra) found in pre-outfall sediments of polluted Layari river is around 14.28 $Bqkg^{-1}$, whereas that for ^{238}U series radionuclide (^{226}Ra) is below its detection limit i.e. <18.35 $Bqkg^{-1}$. The activity of terrigenous radionuclide ^{40}K found in pre-outfall sediments of Layari River is around 125 $Bqkg^{-1}$ and in pre-outfall water of both Layari and Malir rivers is less than its detection limit (<10.96 $Bqkg^{-1}$). These values are quite lower as compared to those for the IAEA soil standards namely: IAEA-312, IAEA-375 and Soil-6; and stream sediment standards namely: IAEA-313 and IAEA-314.

Similarly, the input polluted river water has quite low gross gamma activities (59.39 ± 5.28 Counts/sec/kg). Relatively high values of ^{40}K (ranging between 512.62 to 780.36 $Bqkg^{-1}$) are observed for Manora Channel mains and the South-East Coast of Karachi. In general, the K^{40} activity in sediments varies from 941.90±39.00 to 197.79±44.24. The highest activity was observed in the vicinity of Oyster Rocks (open sea) along the Clifton coast (South-East Coast of Karachi) and the lowest activity was found south of Nuclear Power Station (KANUPP) along the north-West Coast. Both these zones receive significant discharges from industrial and sewage drains. Interestingly, the North-West Coast of Karachi which receives little or rather no direct discharge from polluted rivers has relatively lower levels of ^{40}K (ranging between 197. 79 to 589.00 $Bqkg^{-1}$) in bottom sediments. These values are in agreement with the marine sediment standards namely: IAEA-135 (^{40}K= 560 ± 9 $Bqkg^{-1}$) and IAEA SD-N-2.

Generally, the activity of ^{232}Th (and hence of ^{228}Ra) found in sediments off Karachi Coast ranges between 11.80 ± 3.60 to 37.27 ± 4.31 $Bqkg^{-1}$, the highest activity is found south of Nuclear Power Station (KANUPP) along the north-West Coast and the lowest activity was found in the vicinity of Oyster Rocks (open sea) along the Clifton coast (South-East Coast of Karachi). The ^{238}U activity (and hence of ^{226}Ra) ranges from 19.40 ± 5.88 to 67.14 ± 10.02 $Bqkg^{-1}$. The highest activity was observed south of Nuclear Power Station (KANUPP) along the north-West Coast and the lowest activity is found in the vicinity of Oyster Rocks (open sea) along the Clifton coast (South-East Coast of Karachi). The activity of ^{232}Th series radionuclide (^{228}Ra) for the Manora Channel, South-East Coast of Karachi and the North-West coast of Karachi are also in agreement with the IAEA marine sediment standard namely: IAEA-135 (^{228}Ra = 36.7 ± 3 $Bqkg^{-1}$). The activity of ^{238}U series radionuclide (^{226}Ra) for the South-East Coast of Karachi and the North-West coast of Karachi are also in agreement with the IAEA marine sediment standard namely: IAEA-135 (^{226}Ra = 23.9 ± 1.1 $Bqkg^{-1}$) and Pacific Ocean sediment Standard namely: IAEA-368 (^{226}Ra = 21.4 ± 1.1 $Bqkg^{-1}$).

The measured values of ^{226}Ra, ^{228}Ra and ^{40}K in marine coastal sediments of Karachi are also in fair agreement with values reported in literature for coastal rivers, estuaries and off shore sediments. For example, in the sediments of Karnaphuli river estuary and the Bay of Bangal, values for the activity of ^{232}Th (and hence ^{228}Ra) in the range from 10.44 ± 2.31 to 84.02 ± 8.13 $Bqkg^{-1}$, activity of ^{238}U (and hence ^{226}Ra) in the range from 5.87±1.21 to 27.85 ±1.71 $Bqkg^{-1}$, activity of ^{40}K in the range from 118.28 ± 19.70 to 608.21 ± 75.70 $Bqkg^{-1}$ have been reported [10]. For the coastal areas in the Aegean sea, Greece, mean activity of 67 ± 26 $Bqkg^{-1}$ for ^{238}U, 45 ±18 $Bqkg^{-1}$ for ^{232}Th, and 691±325 $Bqkg^{-1}$ for ^{40}K have been reported [11]. Sediments of Rhine river, France, have measured activity of 34±5 $Bqkg^{-1}$ for ^{226}Ra and 29 ± 5 $Bqkg^{-1}$ for ^{232}Th [12]. In Lake Nasser Egypt; measured radioactivity of some natural radionuclides in different types of sediments range from 4.2 to 48 $Bqkg^{-1}$ for ^{226}Ra, 8.1 to 50 $Bqkg^{-1}$ for ^{228}Ra and 16 to 487 $Bqkg^{-1}$ for ^{40}K [13].

5.2 Water

In case of water samples collected from the polluted Layari River (downstream, pre-harbour outfall), Malir river (downstream, pre-Gizri Creek outfall), and North-West Coast of Karachi, the radioactivity concentrations of ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K are in concentrations below the limit of detection (LOD) for these radionuclides (^{226} Ra = 1.62 Bql^{-1}, ^{228}Ra = 1.4 Bql^{-1}, ^{137}Cs = 0.32 Bql^{-1} and ^{40}K= 10.96 Bql^{-1}). However, in sea water samples collected from Layari River outfall and KPT Shipyard/Keamari Fish Harbour Channel (West Wharf Area of Karachi Harbour) the measured activity of ^{40}K are found to be 27±16.97 and 36.00 ± 17.23 Bql^{-1} respectively. Similarly, in Karachi Harbour mains, Manora Channel mains and the South-East Coast of Karachi, the measured activity of ^{40}K ranges from 65.34 ± 4.38, 61.41 ± 2.54, and 56.34 ± 16.44 Bql^{-1} respectively. The measured activity of ^{40}K in Karachi sea water samples is in general higher than the normal range of 12.6 Bql-1 for sea water samples quoted in literature [1].

In conclusion, the natural radioactivity contents of ^{226}Ra, ^{228}Ra and ^{40}K in marine coastal sediments of Karachi are comparable with the values reported in literature for sediments of Aegean sea, Greece; Rhine Rivers; Lake Nasser, Egypt ; Karnaphuli River estuary, the Bay of Bangal ; and the Pacific ocean [9]. The present work is the first effort to establish a baseline map of radioactivity as a part of the radiological assessment programme for the coastal marine environment of Pakistan. The baseline map will be used further as reference information to assess any changes in the radioactivity background levels due to various geological processes or any artificial influences on the radiation environment in the Arabian Sea in future. However, more useful information regarding baseline radionuclide concentrations and their behaviour in shallow marine coastal environments will be obtained by counting the biological samples in the food web of Karachi-Sea.

ACKNOWLEDGMENTS

Dr. Riffat M. Qureshi is thankful to IAEA for providing financial assistance for this study under IAEA-Research Contract PAK-8127. Kind guidance provided by Dr. Jane Gerardo-Abaya (Technical Officer, Section of Isotope Hydrology, IAEA) is also highly appreciated. The authors wish to acknowledge Dr. Shahid Amjad, Director General, National Institute of Oceanography, Karachi for provision of NIO-Laboratory facilities and transport to collect water and sediment samples off Karachi coast. Mr. Jehangir Haider (Technical Officer), Mr. Mohammed Zaman Chaudhry (SA-I) and Mr. Mohammad Aslam (Laboratory Attendant) assisted in treatment of water and sediment samples at the Environment Research Laboratory/ RIAD prior to radioactivity analysis at the Health Physics Division, PINSTECH.

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TABLE - 2

Radioactive nuclide concentrations (Bq kg^{-1}) in sediment samples collected from polluted river outfalls and shallow marine coastal environment off Karachi Coast, Pakistan

[*Limit of detection (LOD) for: ^{226}Ra = 18.35 Bq kg^{-1}, ^{228}Ra = 9.6 Bq kg^{-1}, ^{137}Cs = 1.6 Bq kg^{-1}]

2A. Layari River Outfall Area (Pre-Harbour outfall Zone)

Sample Code	Date of Collection/ (Depth-m)	Sample Location	Latitude/ Longitude	Ra-226 (Bq/Kg)	Ra-228 (Bq/Kg)	K-40 (Bq/Kg)	Gross Activity (Gamma) Counts/Sec/Kg
S-34	*17-1-96 (1 m)*	*Layari River Downstream (Pre-Harbour outfall Zone)*	*N 24-52-27 E 66-59-01*	*<18.35*	*14.28± 3.72*	*125.00± 28.60*	*59.39 ± 5.28*

2B. Layari River Outfall Area (Karachi Harbour Backwaters)

Sample Code	Date of Collection (Depth-m)	Sample Location	Latitude/ Longitude	Ra-226 (Bq/Kg)	Ra-228 (Bq/Kg)	K-40 (Bq/Kg)	Gross Activity (Gamma) Counts/Sec/Kg
S-12	29-4-95 (1.5 m)	Layari River Outfall (Opposite Karachi Fish Harbour)	N 24-51-01 E 67-58-25	<18.35	15.95± 3.76	427.32± 32.91	64.30 ± 5.50
S-20	20-4-95 (1.2 m)	Layari River Outfall (Shams-*pir* Village, Channel Side)	N 24-50-34 E 66-55-39	53.84± 6.69	30.65± 4.15	589.95± 34.98	79.95 ± 5.45
S-21	20-4-95 (1.2 m)	Layari River Outfall (Kakk-*pir* Village Backwaters)	N 24-50-05 E 66-55-35	<18.35	20.50± 3.90	375.40± 32.20	95.33 ± 5.58
S-19	29-4-95 (1.2 m)	Layari River Outfall (Shams-*pir* Village Backwaters)	N 24-49-50 E 66-57-27	<18.35	18.22± 3.83	575.24± 34.80	66.66 ± 5.34
S-18	29-4-95 (1.2 m)	Layari River Outfall (Sandspit backwaters before Shamas-*pir* village)	N 24-49-53 E 66-57-10	<18.35	16.98± 3.79	636.66± 35.56	67.03 ± 5.34
		Mean Value (n = 5)		**53.84± 6.69 (n = 1)**	**20.46 ± 5.94**	**520.91± 112.96**	**74.65± 13.08**

Table-2 continued (Radioactive nuclide concentrations in marine sediment samples off Karachi Coast, Pakistan):

2C. Karachi Harbour Mains

Sample Code	Date of Collection (Depth-m)	Sample Location	Latitude/ Longitude	Ra-226 (Bq/Kg)	Ra-228 (Bq/Kg)	K-40 (Bq/Kg)	Gross Activity (Gamma) Counts/Sec/Kg
S-9	26-4-95 (2.5 m)	Near KPT-Shipyard (Butti), Karachi Harbour /Close to Layari Outfall	N 24-49-59 E 66-58-02	<18.35	18.84 ± 3.84	360.69 ± 32.02	91.96 ± 5.55
S-1	26-4-95 (3 m)	Keamari Boat Basin (Near Coast Guard Jetty)	N 24-48-58 E 66-38-30	<18.35	27.66 ± 4.16	572.47± 35.56	111.95± 5.85
S--22	15-1-96 (1.5 m)	Near Mangrove Forest Turn Between Bhit Island & Shamas-*pir* village (Karachi Harbour)	N 24-51-08 E 66-55-05	<18.35	27.12± 4.06	634.80± 28.80	113.08 ± 5.72
		Mean Value (n = 3)		**<18.35**	**24.54 ± 4.94**	**522.65± 143.68**	**105.66± 11.88**

2D. KPT Shipyard/ Kaemari Fish Harbour Channel

Sample Code	Date of Collection (Depth-m)	Sample Location	Latitude/ Longitude	Ra-226 (Bq/Kg)	Ra-228 (Bq/Kg)	K-40 (Bq/Kg)	Gross Activity (Gamma) Counts/Sec/Kg
S-10	26-4-95 (3 m)	Opposite Boat building Area, Karachi Harbour	N 24-46-01 E 67-07-15	20.00 ± 5.90	27.12 ± 4.06	451.50 ± 33.23	64.14 ± 5.32
S-11	26-4-95 (3 m)	Middle of Keamari Fish Harbour (end of KPT Shipyard Channel)	N 24-50-59 E 67-58-39	28.45 ± 6.44	17.62 ± 4.02	295.22 ± 32.83	55.40 ± 5.54
		Mean Value (n = 2)		**24.23 ± 5.97**	**22.37 ± 6.72**	**373.36± 11.05**	**105.66± 11.88**

Table-2 continued (Radioactive nuclide concentrations in marine sediment samples off Karachi Coast, Pakistan):

2E. Manora Channel Mains

Sample Code	Date of Collection (Depth-m)	Sample Location	Latitude/ Longitude	Ra-226 (Bq/Kg)	Ra-228 (Bq/Kg)	K-40 (Bq/Kg)	Gross Activity (Gamma) Counts/Sec/Kg
S-2	26-4-95 (3.5 m)	Bhit Island (Manora Channel inner Extreme)	N 24-49-10 E 66-58-00	<18.35	28.16 ±4.08	572.60 ± 34.77	72.58 ± 5.39
S-3	26-4-95 (3.5 m)	Bhaba Island/Naval Dockyard	N 24-49-27 E 66-57-53	<18.35	25.24 ± 4.01	522.40 ± 34.14	70.21 ± 5.37
S-4	26-4-95 (6.2 m)	Boat Club (Manora Channel Middle)	N 24-48-43 E 66-58-07	29.18 ±6.12	17.35 ± 3.8	615.80 ± 35.30	110.71 ± 5.70
S-5	26-4-95 (6.5 m)	Pakistan Naval Academy (Before Manora Channel Exit)	N 24-48-07 E 66-58-26	<18.35	16.10 ± 3.77	416.90 ± 32.77	52.37 ± 5.20
S-6	26-4-95 (6.9 m)	Manora Lighthouse (Manora Channel Exit -Seaside)	N 24-47-33 E 66-58-52	<18.35	<19.6	199.80 ± 29.77	25.72 ± 4.98
S- 8	26-4-95 (6 m)	Opposite KPT Lighthouse (Dredged Sample from B.D. Fateh Dredger working in Karachi Harbour Channel)	N 24-49-54 E 66-57-59	<18.35	22.15 ± 3.93	748.19 ± 36.89	103.15± 5.64
		Mean Value (n = 6)		**29.18 ±6.12 (n =1)**	**21.8 ± 5.1 (n=5)**	**512.62± 188.06**	**72.46± 31.61**

Table-2 continued (Radioactive nuclide concentrations in marine sediment samples off Karachi Coast, Pakistan):

2F. Karachi Sea, South-East Coast

Sample Code	Date of Collection (Depth-m)	Sample Location	Latitude/ Longitude	Ra-226 (Bq/Kg)	Ra-228 (Bq/Kg)	K-40 (Bq/Kg)	Gross Activity (Gamma) Counts/Sec/Kg
S-7	26-4-95 (3 m)	Close-by Oyster Rocks (Karachi Sea, South-East Coast, Clifton)	N 24-48-18 E 66-59-50	<18.35	21.94 ± 3.92	729.16 ± 36.66	136.37 ± 5.90
S-13	29-4-95 (3.5 m)	Between NIO & Manora Lighthouse (Clifton Coast)	N 24-48-20 E 66-59-33	<18.35	22.57± 3.94	926.44± 38.92	92.69 ± 5.56
S-14	29-4-95 (3.5 m)	Between Oil Jetty & Oyster Rock (Clifton Coast)	N 24-48-12 E 66-59-22	<18.35	11.80± 3.60	941.90± 39.00	117.81 ± 5.76
S-15	29-4-95 (2.5 m)	Near Oil Jetty (Clifton Coast)	N 24-48-00 E 66-59-13	<18.35	24.85 ± 4.00	897.00± 38.59	76.95 ± 5.43
S-16	29-4-95 (2.1 m)	In front of Oil Storage Tanks (Clifton Coast)	N 24-48-37 E 66-59-25	19.40± 5.88	20.50± 3.89	935.96± 39.03	60.75 ± 5.29
S-17	29-4-95 (3.5 m)	Between NIO & Oyster Rocks (Clifton Coast)	N 24-48-36 E 66-59-57	29.40± 6.13	19.67± 3.86	659.15± 35.83	110.62 ± 5.70
S-29	16-1-96 (4.5 m)	Opposite Marina heights-III. Clifton Area, (Clifton Coast)	N 24-48-00 E 67-00-27	22.92 ± 5.97	19.05 ± 3.85	720.50 ± 36.50	109.71 ± 5.69
S-30	17-1-96 (4.5 m)	Opposite Clifton Casino/ Bhutto Casino (Clifton Coast)	N 24-47-37 E 67-01-39	<18.35	13.87 ± 3.70	781.06 ± 37.20	126.09 ± 5.82
S-31	17-1-96 (7.5 m)	Opposite Naval Jetty (Clifton Coast)	N 24-47-04 E 67-02-25	43.84 ± 6.46	22.77 ± 3.90	716.19± 36.50	135.55 ± 5.90
S-32	17-1-96 (6.4 m)	Between Marina club & Jetty (Defense Coast)	N 24-46-23 E 67-03-01	<18.35	18.01± 3.82	707.54± 36.41	89.23 ± 5.23
S-33	17-1-96 (7.4 m)	Middle of Gizri Coast Area	N 24-45-16 E 67-03-35	<18.35	33.70± 4.23	569.00± 34.70	132.55 ± 5.87
		Mean Value (n = 11)		**28.89 ± ? (n=4)**	**20.80 ± 5.77**	**780.36± 126.58**	**108.02± 25.26**

Table-2 continued (Radioactive nuclide concentrations in marine sediment samples off Karachi Coast, Pakistan):

2 G. Karachi Sea, North-West Coast

Sample Code	Date of Collection/ (Depth-m)	Location	Latitude/ Longitude	Ra-226 (Bq/Kg)	Ra-228 (Bq/Kg)	K-40 (Bq/Kg)	Gross Activity (Gamma) Counts/Sec/Kg
S-24	16-1-96 (8.2 m)	Opposite PNS Himalia (Minora Island Passed Lighthouse, Seaside)	N 24-48-30 E 66-56-29	20,30± 5.90	31.47± 4.10	377.90± 32.25	98.15 ± 5.60
S-25	16-1-96 (7.3 m)	Opposite Sandspit Area (Minora Island Extreme, Seaside)	N 24-49-15 E 66-55-23	<18.35	23.56± 3.90	459.26± 33.30	63.84 ± 5.32
S-26	16-1-96 (9.6 m)	Opposite Kakka-*pir* Village (Seaside)	N 24-49-55 E 66-53-55	50.30± 6.60	37.27± 4.31	301.00± 31.20	86.14 ± 5.50
S--27	16-1-96 (8.3 m)	Opposite Buleji Village Area (Seaside)	N 24-49-04 E 66-50-41	<18.35	----	589.00± 34.90	80.04 ± 5.45
S-28	16-1-96 (5.8 m)	Opposite KANUPP (Power House), South side	N 24-50-12 E 67-47-56	67.14 ± 10.02	----	197.79 ± 44.24	51.29 ± 7.78
		Mean Value (n = 5)		**45.91± 23.72 (n=3)**	**30.77 ± 6.88 (n=3)**	**384.99± 148.6**	**75.89± 18.49**

TABLE - 3

K-40 radioactivity (Bql^{-1}) and related physiochemical data of water samples collected from polluted river, outfalls and shallow marine coastal environment off Karachi Coast, Pakistan

[*Limit of detection (LOD) for: ^{226}Ra = 1.62 Bql^{-1}, ^{228}Ra = 1.4 Bql^{-1}, ^{137}Cs = 0.32 Bql^{-1}, ^{40}K = 10.96 Bql^{-1}]

3A. Polluted Rivers Downstream (Pre-Outfall)

Sample Code	Date of Collection/ (Depth in meters)	Sample Location	Latitude/ Longitude	Temperature (°C)	Electrical Conductivity (mS/cm)	Turbidity (NTU)	K-40 Radioactivity (Bq/l)
K- 30	6-12-96 (<0.3 m)	Layari River Downstream (Pre-Harbour outfall)	N 24-52-27 E 66-59-01	21.6	3.0	28.9	<10.96
K- 31	6-12-96 (<0.3 m)	Malir River Downstream (Pre-marine outfall)	N 24-49-26 E 67-05-31	21.5	3.6	23.4	<10.96

3B. Layari River Outfall (Karachi Harbour Backwater Zone)

Sample Code	Date of Collection/ (Depth in meters)	Sample Location	Latitude/ Longitude	Temperature (°C)	Electrical Conductivity (mS/cm)	Turbidity (NTU)	K-40 Radioactivity (Bq/l)
K-9	4-12-96 (<0.3 m)	Layari River Outfall (Shams-*pir* Village, Channel Side)	N 24-50-34 E 66-55-39	21.5	52.7	28.6	36.00 ± 17.08

3C. KPT-Shipyard/Kaemari Fish Harbour Channel

Sample Code	Date of Collection/ (Depth in meters)	Sample Location	Latitude/ Longitude	Temperature (°C)	Electrical Conductivity (mS/cm)	Turbidity (NTU)	K-40 Radioactivity (Bq/l)
K-7	4-12-96 (<0.3 m)	Opposite KPT-Shipyard (Karachi Fish Harbour Channel)	N 24-50-15 E 66-58-01	21.5	52.7	26.7	27.20 ± 16.97

Table-3 continued (K-40 radioactivity and related physiochemical data of shallow marine water samples off Karachi Coast, Pakistan):

3D. Karachi Harbour Mains

Sample Code	Date of Collection/ (Depth in meters)	Sample Location	Latitude/ Longitude	Temperature (°C)	Electrical Conductivity (mS/cm)	Turbidity (NTU)	K-40 Radioactivity (Bq/l)
K-6	4-12-96 (<0.3 m)	Outside KPT-Shipyard Butti	N 24-49-59 E 66-58-02	21.4	45.2	29.6	70.81 ± 17.48
K-8	4-12-96 (<0.3 m)	Layari River Outfall (Mangrove Forest Turn Near Shamas-*pir* Village, Channel side)	N 24-51-08 E 66-55-05	21.6	51.3	32.1	60.81 ± 17.36
K- 28	6-12-96 (<0.3 m)	Opposite KPT Shipyard (Shipyard Crane Area)	N 24-51-01 E 66-58-25	21.7	43.6	21.8	64.41 ± 17.41
		Mean Value (n=3)		**21.6 ± 0.2**	**46.7 ± 4.1**	**27.8 ± 5.4**	**65.34 ± 4.38**

3E. Manora Channel Mains

Sample Code	Date of Collection/ (Depth in meters)	Sample Location	Latitude/ Longitude	Temperature (°C)	Electrical Conductivity (mS/cm)	Turbidity (NTU)	K-40 Radioactivity (Bq/l)
K-5	4-12-96 (<0.3 m)	Opposite Bhaba Island (Manora Channel Start)	N 24-49-26 E 66-58-00	21.5	50.2	23.5	59.61± 17.35
K-3	4-12-96 (<0.3 m)	Opposite Boat Club (Manora Channel Middle)	N 24-48-43 E 66-58-08	21.4	53.7	17.5	63.21± 17.39
K-1	4-12-96 (<0.3 m)	Opposite Manora Lighthouse (Manora Channel Exit)	N 24-47-34 E 66-58-52	21.4	55.4	11.6	< 10.96
		Mean Value (n=3)		**21.4 ± 0.1**	**53.1 ± 2.7**	**17.8 ± 5.9**	**61.41 ± 2.54**

Table-3 Continued (K-40 radioactivity and related physiochemical data of shallow marine water samples off Karachi Coast, Pakistan):

3.F Karachi Sea (South-East Coast)

Sample Code	Date of Collection/ (Depth in meters)	Sample Location	Latitude/ Longitude	Temperature (°C)	Electrical Conductivity (mS/cm)	Turbidity (NTU)	K-40 Radioactivity (Bq/l)
K- 20	5-12-96 (<0.3 m)	Start of Ghizri Coastal Area	N 24-44-15 E 67-04-02	21.7	51.7	36.5	28.40± 16.99
K- 21	5-12-96 (<0.3 m)	Opposite Ghizri- Korangi Coast Junction (Ghizri Creek Mouth)	N 24-44-52 E 67-05-03	21.5	46.7	3.9	57.21 ± 17.32
K- 22	5-12-96 (<0.3 m)	Ibrahim Haideri Jungle Area	N 24-46-01 E 67-07-15	21.6	52.2	6.9	64.81 ± 17.41
K- 23	5-12-96 (<0.3 m)	Inside Ibrahim Haidery Fish Harbour	N 24-47-03 E 67-08-39	21.7	53.9	18.3	49.21 ± 17.23
K- 24	5-12-96 (<0.3 m)	Korangi Fish Harbour Zone	N 24-50-59 E 66-58-39	21.8	53.4	23.1	76.81 ± 17.55
K- 25	5-12-96 (<0.3 m)	Korangi- Phatti Creek Junction Area	N. D.	21.7	55.1	10.9	61.61 ± 17.37
		Mean Value (n=6)		**21.4 ± 0.1**	**52.2 ± 2.9**	**16.6 ± 12.1**	**56.34 ±16.44**

3.G Karachi Sea (North-West Coast)

Sample Code	Date of Collection/ (Depth in meters)	Sample Location	Latitude/ Longitude	Temperature (°C)	Electrical Conductivity (mS/cm)	Turbidity (NTU)	K-40 Radioactivity (Bq/l)
K- 32	6-12-96 (<0.3 m)	Opposite Paradise Point (Hox-Bay Coast)	N 24-50-52 E 67-45-46	21.9	54.3	1.8	16.00 ± 16.84