GROUNDWATER SALINITY IN COASTAL AQUIFER OF KARACHI, PAKISTAN

(A Preliminary Investigation)

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ABSTRACT

Potable groundwater salinity has become a problem of great concern in the Karachi Metropolis, which is not only the most populous and biggest industrial base but also the largest coastal dwelling of Pakistan. Stable isotope techniques [^{18}O content of oxygen in the water molecule and ^{13}C content of the Total Dissolved Inorganic Carbon (TDIC)] have been used, in conjunction with physiochemical tools (temperature, dissolved oxygen, pH, redox, electrical conductivity, salinity), to examine the quality of potable-water and the source of salinity. Surface-water samples (12 No.) were collected from polluted streams, namely: Layari River, Malir River; Hab River/Hab Lake and the Indus River. Shallow groundwater samples (7 No.) were collected from operating dug-wells. Relatively deep groundwater samples (12 No.) were collected from pumping wells/tube-wells.

Physiochemical analysis of water samples was completed in the field. In the laboratory, water samples were analyzed for ^{18}O content of oxygen in the water molecule and ^{13}C content of the TDIC, using specific gas-extraction systems and a modified GD-150 gas-source mass spectrometer. It is concluded from this preliminary investigation that the potable aquifer system in coastal Karachi hosts a mixture of precipitation (rainwater only) from hinterlands, trapped seawater in relatively deep aquifer system, as well as intruded seawater under natural infiltration conditions and/or induced recharge conditions (in shallow aquifers).

INTRODUCTION

Coastal Karachi is by far, the most populous (*~10 million inhabitants, as per 1998 census*) and the largest industrial (*more than 1000 large industrial units*) base of Pakistan, with a coast-line extending up to about 80 km (Figure - 1). The major industries in Karachi include: Tanneries, Textile Industries, Chemical Industries, Detergent Industries, Iron and Steel industries, Paints and Dyes Industries, Pharmaceutical Industries, Plastic Industries, Metallurgical Industries, Vegetable Oil Industries, Food and fig Industries, Oil and Lubricant Industries, Cement Industry, Auto Engineering Works, Machine tool Factory, Power Plants, Oil Refineries, as well as a large number of cottage industries. Discharge of raw sewage into the natural water resources is not only affecting the quality of surface-water resources, but is also expectedly deteriorating the quality of shallow potable groundwater, through seepage of polluted stream waters under natural conditions, as well as under artificially induced recharge conditions caused by heavy pumping of the local aquifer.

In Karachi, freshwater resources are very few. The available shallow groundwater and deep groundwater is exploited for certain domestic and industrial areas. Prolonged over-pumping of groundwater, or other alterations of the natural equilibrium between recharge and discharge regimes of coastal aquifer system in Karachi, can lead to an encroachment of the interface between seawater and freshwater, through intrusion and/or up-coning. Contamination by salty seawater can further increase the deterioration of groundwater quality in the coastal aquifer. A two to three percent mixing of coastal aquifer water with seawater makes freshwater unsuitable for human consumption. A five per cent mixing makes it unusable for irrigation[1].

HYDROGEOLOGY OF THE STUDY-AREA

Hydrogeologically, the city of Karachi lies in the Hab River Basin and the Malir River Basin. The Malir River Basin is drained by the Malir River and the Layari River. The coastal aquifer of Karachi is, therefore, mainly recharged by seepage from Hab River , Hab Dam as well as the Malir and the Layari Rivers. The Hab River lies on the western frontier of Sindh and for some distance the boundary between Sindh and the Baluchistan provinces. It flows about 30 kms to the west of Karachi, along the Karachi-Lasbela boundary. It falls into the Arabian Sea

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near Cape Monze, with a total drainage course length of 336 kms. Its principal tributaries are the Saruna, the Samotri and the Wira hab. Hab River gradually widens and, for some 80 kms from its mouth, is bordered by fine pasture land. Water is always found in pools, but the river is being utilized for irrigation and drinking purposes after building of the Hab Dam in the north-west of Karachi in the year 1980.

WATER-SUPPLY SCENARIO FOR COASTAL BELT OF KARACHI

Karachi has a complex water-supply system, which developed over a period of more than 100 years. The shallow groundwater near the coastal belt is moderately saline. Today, the drinking-water supply to most of the population in Karachi is managed through three schemes: (i) reserves in the nearby Hab Dam; (ii) exploitation of relatively adequate-quality potable water in selective zones within the city, by pumping wells and dug wells; (iii) pumping of piped water from the Indus River near Thatta City, about 160 km away from Karachi. The Hab Dam reservoir-capacity is insufficient to maintain long-term supplies of drinking water to the enormous population of Karachi. During the past 15 years, a number of pumping wells has been installed to meet requirements for the irrigation-water supply (to raise vegetables, fruits, dairy and poultry) and drinking-water supply for the ~10 million inhabitants of Karachi. Excessive pumping of groundwater and continuous lowering of water-table is likely to result in intrusion of sea-water into the Malir Basin under natural seepage conditions and under artificially induced conditions of recharge of saline seawater in the coastal aquifer(s) of Karachi. It is feared that any further lowering of water table in coastal aquifer of Karachi will enhance seawater intrusion, thereby, affecting the quality of drinking water in the coastal aquifer system. Ultimately, the whole aquifer water will be unfit for use, not only for drinking purposes but also for domestic, industrial and irrigation purposes. It is, therefore, necessary to encourage groundwater recharge in the Malir River Basin, on one hand, and define the existing water quality scenario of coastal aquifers of Karachi, on the other hand, using modern & relatively precise techniques, such as nuclear techniques, so as to evaluate possibilities and impacts of sea water intrusion under heavy pumping of the Malir Basin.

OBJECTIVES AND RATIONALE

The growing concern on deterioration of groundwater-systems due to disposal of untreated domestic sewage and industrial effluents into surface-water courses (mainly: Malir River, Layari River etc.) and its partial recharge under natural infiltration conditions, and possibly under artificially induced infiltration conditions, as well as saline sea-water intrusion in coastal aquifers of Karachi, are of great significance from hydrological, environmental and public-health viewpoint. Conjunctive use of hydrochemical, biological and nuclear techniques can provide reliable information on dynamics of groundwater flow, origin and mechanism of groundwater salinity. As a first step, it was considered necessary to initiate primary studies to:

1. Develop a general understanding about the isotopic, chemical and biological labeling of various recharge sources (rain, polluted streams/rivers, lakes, seawater) and the potable shallow and deep groundwater in coastal aquifer of Karachi,
2. Determine surface water and potable groundwater pollution characteristics,
3. Delineate spatial extent of saline groundwater, and
4. Evaluate the possible role of seawater intrusion in the coastal belt of Karachi.

It was decided to focus on evaluation of stable isotope characteristics of Oxygen (^{18}O) of the water molecule; stable isotopes of Carbon (^{13}C) in dissolved inorganic carbon, physiochemical and chemical characteristics (mainly parameters like E.C., salinity, redox, pH, Temperature, and chemical activities of Chloride, Sulfate, bicarbonate) of surface-water sources (polluted rivers, lakes, precipitation, local seawater), potable shallow groundwater and deep groundwater sources (dug wells, hand-pumps, pumping wells, which tap shallow and deep coastal aquifers of Karachi) and shallow sea water off Karachi Coast.

PRESENT INVESTIGATIONS

Field Sampling

Field sampling was performed in the jurisdiction of Karachi Metropolis during the period from November 2000 to December 2000. Figure - 2 shows the location of various sampling points. Surface-water samples and sediment samples were collected from various locations along polluted streams/rivers namely: Layari River and Malir River, Hab Dam, Hab River and local sea (shallow seawater off Karachi coast). Shallow groundwater samples were collected from hand-pumps, dug wells and boreholes /mini pumping wells installed at depths upto 8 - 30 meters. Shallow mixed deep groundwater was collected from bore-holes / tube-wells installed at depths greater than 50 meters. Relatively deeper groundwater was collected from a few tube-wells installed at depths between 70-100 meters. All water-samples were collected in leak-tight /lined cap plastic bottles or glass bottles. Sediment samples were collected in high quality polythene bags. Sterile bottles were used for collection of water for Coliform bacterial analysis. Standard field sample preservation methods were used for subsequent chemical, biological and isotopic analysis in the laboratory[2]. In the field, all samples were stored under cool conditions (<12^{o} C). The location of sampling point was monitored with the help of a Personal Navigator (Model Garmin™ GPS-100, M/S Garmin, 11206 Thompson Avenue, Lenexa, KS 66219).

Field In-situ Analysis

Temperature, electrical conductivity, salinity, turbidity, redox potential, pH and dissolved oxygen were measured in-situe. Turbidity was measured with a portable turbidity meter (Model 6035, JENWAY). Electrical conductivity and temperature were measured with portable conductivity meter (Model HI 8633, M/S HANNA Instruments). Redox was measured with a portable ORP meter (Model: PS-19 ORP Meter, M/S Corning, Canada). Dissolved oxygen was measured with a portable D.O. Meter (Model 9070, JENWAY). Salinity was measured with a portable Salinometer (refractometer) obtained from the Center of Excellence in Marine Biology-Karachi University-Karachi.

Laboratory Analysis

$\delta^{18}O$ values of water samples were determined by using CO_2 – H_2O equilibration method. Stable inorganic carbon isotope analyses of the total dissolved inorganic carbon (TDIC) of collected water samples were determined on CO_2 gas extracted from TDIC using the routine sample preparation system by reacting 50-100 of water with 85% H_3PO_4 [3]. The stable oxygen isotope data is expressed as δ ‰ (delta per mill.) values relative to the international water standard V-SMOW (Vienna Standard Mean Ocean Water). The reproducibility of $\delta^{18}O$ measurements was better than 0.1‰ for the working standards[4]. The stable carbon isotope data is expressed as δ‰ (delta per mill.) values relative to the international carbonate standard PDB (Pee-Dee Belemnite). The reproducibility of $\delta^{13}C$ measurements was better than 0.1‰ for the working standards. HCO_3^-, Cl^- and SO_4^{-2} were determined by titrimetric. Methods[5].

RESULTS AND DISCUSSION

It appears that five possible water-sources are contributing to the groundwater storage in Karachi. The first possible source is the rainfall. As the city of Karachi suffers from deficit of precipitation (only rainfall), the contribution to shallow groundwater storage from rain is very little. However, rainfall in the hinterlands and other areas surrounding Karachi may significantly contribute to the confined groundwater flow-system. The two freshwater sources are the Hab Lake/Hab Dam and the Indus River. Water from Hab Dam and the Indus River is piped to various residential zones in Karachi for drinking and irrigation purposes. The spring water discharges into Malir River and Layari River and the municipal/industrial waste effluents added to these rivers are also contributing to groundwater storage as a fourth recharge source. Seawater intrusion along Karachi coast is the fifth possible source. Keeping in view this recharge-scenario of surface-water sources, we submit the following results / discussions w.r.t. our field and laboratory physico-chemical (temperature, pH, redox, dissolved oxygen, electrical conductivity, salinity and concentrations of major ion viz. HCO_3^{-1}, Cl^-, SO_4^{-2}), and isotopic ($\delta^{13}C$, $\delta^{18}O$ and $\delta^{2}H$) investigations of surface-water and groundwater in Coastal Karachi-Pakistan. Tables-1.1 through 1.4 present a picture of these analyses. Results are discussed in the following section.

Sources of Surface Water

Local Precipitation (Rain)

During the sampling period, no rainfall events occurred in coastal Karachi. Therefore, it was not possible for the sampling team to collect and analyze local rain for chemical and isotopic information. However, stable isotope data on precipitation for the period from 1961 to 1975 is available from the IAEA

Precipitation Network for the Karachi Station (IAEA Precipitation Network Code: 41780000, Lat. 24.90N Long. 67.13E, Alt. 23 meters above mean sea level)[6]. The following stable isotope indices of precipitation in Karachi were, therefore, used for interpretation purposes:

Long Term Weighted Means:
$\delta^{18}O$ (water): - 3.93 ± 1.94 ‰ V-SMOW

Indus River

Physico-chemical and environmental stable isotope analysis was performed on one water-sample collected from the Indus River near Thatta city, where the river-water is partly diverted to Karachi for irrigation and drinking purposes (Table- 1.1). The Indus River waters have electrical conductivity values below 500 μS/cm and salinity below 1ppt. The SO_4^{-2} concentrations in the river water is 86 ppm. The stable isotope indices of total dissolved inorganic carbon (TDIC) in water and of oxygen in water molecule are as follows:

$\delta^{13}C$ (TDIC): + 1.7 ‰ PDB (n=1)
$\delta^{18}O$ (water): - 8.2 ‰ V-SMOW (n=1)

Hab Dam

The water-storage in the Hab Lake was very little because the Hab River was dry, due to drought conditions in and around the study area over the past several years. Thus, most of the Hab Lake had patches of stagnant water. Results of physico-chemical stable isotopic analysis on Hab Lake water are presented in Table-1.1. Different patches of water in the lake showed similar values of mildly alkaline pH (~8.3), E.C (~1.4 mS/cm), and temperature (~ 27°C). The electrical conductivity values (~1500 μS/cm) were three times higher than the Indus river water-supply. Temperature of the water was also higher by about 2-3°C, as compared to the Indus River-water supply. HCO_3^- concentrations are moderate. Both the Cl^- and SO_4^{-2} concentrations in the lake water are around ~ 300 ppm.

The stable carbon isotope index ($\delta^{13}C_{TDIC}$) of total dissolved inorganic carbon (TDIC) in lake-water varies in the range of + 1‰ PDB to +6.3‰ PDB in different patches of stagnant lake water. This is indicative of various sources of dissolved inorganic carbon in the lake or an enrichment due to biological transformation of TDIC into other carbon-containing compounds over the drought regime.

Polluted Rivers

Table-1.2 summarizes the physico-chemical and stable isotope analysis of oxygen in water collected from polluted Layari and Malir Rivers. Results are discussed in the following section.

Layari River: The Layari River was monitored at five locations along its flow from North Karachi (upstream region) to Sher-Shah Bridge (downstream region) near Sea. The range of variation in stable isotope content of total dissolved inorganic carbon (TDIC) and of oxygen in Layari River water are as follows:

$\delta^{18}O$ (Layari River Water): -5 to -2.7 ‰ V-SMOW (n=5)
$\delta^{13}C$ (TDIC - Layari River Water): -7.2 to -0.2 ‰ PDB (n=5)

There is a good correspondence between electrical conductivity and salinity along the flow in the river. Generally, the E.C. and salinity values tend to decrease downstream. Maximum values of EC (9.02 mS/cm) and Salinity (5 ppt) were observed at the origin of the Layari stream, near Yousuf Goth area. In this zone, the Layari stream receives minor spring-water, domestic waste-water from small isolated dwellings and wastewater from industries (flour mills, electronic industry, etc.) which host deep tube-wells with quite high salinity values. Downstream, the Layari River receives highly reducing municipal sewage of the Karachi city which comprises relatively low electrical conductivity water that is a mixture of the Indus River water and the local shallow groundwater supplied to the city for domestic use. High concentrations of Cl^- (3291 ppm) and SO_4^{-2} (ppm), coupled with mildly alkaline pH values, are found in the upstream regions of the river. However, these values decrease significantly along the flow downstream, whereby, the pH values remain slightly above neutral values. This indicates that the source of water in the upstream regions of Layari River is quite different from the downstream regions. Significantly high values of Cl^- and SO_4^{-2} in the upstream region indicate that the source of water in the river is the saline water discharged from deep tube-wells installed in the nearby industrial complexes. The $\delta^{13}C_{TDIC}$ and $\delta^{18}O$ (water) values are also quite enriched in this zone of Layari river, as compared to local shallow groundwater and are, in fact, relatively closer to the sea values. Downstream, as the Layari River receives sewage-water of the city, which is a mixture of the Indus River water and the local shallow groundwater supplied to the city for domestic use, the values of $\delta^{18}O$ are consistently around -5 ‰ V-SMOW. It is, thus, speculated that the water in the extreme up-stream region of Layari River is a mixture of deep groundwater, which is partly trapped seawater (or geothermal water as there are geothermal springs nearby) and the local shallow groundwater.

Malir River:

The Malir River was monitored at three locations along its flow from Karachi East to the Sea before Ghizri Creek. The ranges of variation in stable isotope content of total dissolved inorganic carbon (TDIC) in water and of oxygen in Malir River water are the following:

$\delta^{18}O$ (Malir River Water): -4.9 to -4.6 ‰ V-SMOW (n=2)
$\delta^{13}C$ (TDIC-Malir River Water): -8.4 to -0.2 ‰ PDB (n=2)

Like Layari River, there is good correspondence between electrical conductivity and salinity along the flow in Malir River. However, in contrast to Layari River, the concentrations of these parameters increase downstream. Lowest values of EC and Salinity were observed at the origin of the River behind Shah Faisal Colony. In this zone, the River receives minor spring water, minor domestic waste-water from small isolated dwellings and seepage from agricultural fields / vegetable farms, which use the low E.C Indus River water for irrigation. Downstream, the Malir River mainly receives slightly low reducing and Oxygen-rich municipal sewage from thickly populated areas of Mahmood Abad. The pH of the river water increases by one unit as it receives domestic and industrial alkaline effluents. High concentrations of Cl^- (971 ppm) and SO_4^{-2} (230 ppm) are found in the downstream region of the river. This is perhaps due to the effect of sea tides in the Qayyum Abad area, near Ghizri Creek.

Karachi Sea:

Table-1.3 presents the summary of physiochemical and stable isotope analysis of shallow seawater collected off six representative locations along Karachi coast. The pH values of ~8.1 for open seawater off Karachi Coast generally conform to those for normal ocean waters. However, pH values decrease to levels of ~7.7 near the Ghizri Creek, and the Korangi Creek which receive significant quantities of industrial acidic wastewaters. Similarly, the pH values of seawater increase to ~8.5 in the back-waters of Manora Channel, near Village Shamas-pir. Electrical Conductivity values for Karachi seawater range between 49.3 mS/cm to 53.7 mS/cm, while the salinity values are ~ 39 ppt. The electrical conductivity values higher than 53 mS/cm correspond to relatively non-polluted open seawaters on north-west and south-east sides of Karachi coast. The E.C values of open seawater drop, due to input of wastewaters from Malir River via Ghizri Creek and polluted drains around Korangi Creek. Slightly higher temperature is observed near Ghizri Coast, which is attributed to input of relatively warmer wastewaters of industrial and domestic origin. Cl^- contents of seawater off Karachi coast are in the range of 21,578 to 25,230 ppm, while the SO_4^{-2} concentrations are in the range of 2076 to 2210 ppm. The stable carbon isotope contents ($\delta^{13}C_{TDIC}$) of total dissolved inorganic carbon (TDIC) vary in the range of - 3.9 ‰ PDB to + 0.8 ‰ PDB in different zones off Karachi coast. This is indicative of different levels and sources of dissolved inorganic carbon in seawater, due to input of domestic and industrial wastewater into the sea from key industrial trading estates (LITE, KITE, SITE etc.) via polluted drains. The highest $\delta^{13}C_{TDIC}$ value of + 0.8 ‰ PDB corresponds to relatively non-polluted seawater along north-west coast of Karachi. The lowest $\delta^{13}C_{TDIC}$ value of -3.9 ‰ PDB corresponds to highly polluted seawater in Korangi Creek, which receives industrial and domestic waste drains from Korangi Industrial Trading Estate (KITE). The high tide (HT) stable isotope content of oxygen in relatively non-polluted seawater, along Karachi coast, falls in the following range:

$\delta^{18}O$ $(seawater)_{HT}$: + 0.3 to + 1.1 ‰ V-SMOW (n=5)
$\delta^{13}C$ (TDIC - seawater): -3.9 to 0.8 ‰ PDB (n=5)

The low tide (LT) stable isotope content of oxygen in relatively polluted seawater along Karachi coast falls in the following range:

$\delta^{18}O$ $(seawater)_{LT}$: -1.3 to + 0.1 ‰ V-SMOW (n =5)

Potable Groundwater in Coastal Aquifer

Shallow groundwater samples were obtained from hand pumps (n=1), dug wells (n=1) and shallow bores, with centrifugal pumps (n=8) installed at depths less than 50 meters (mainly between 8-30 meters); and (b) relatively deep groundwater was obtained from pumping wells (cased wells/Tube-wells) installed at depths greater than 50 meters in the coastal aquifer of Karachi. These cased wells also tap various proportions of shallow groundwater, in addition to deep groundwater. Tables - 1.4a and 1.4b present the physico-chemical, bacteriological and stable isotope data of shallow and shallow mixed deep groundwater. The following section presents discussion on these data-elements.

Shallow Groundwater

Physico-chemical data of shallow groundwater (depth less than 30 meters) shows that the shallow wells, located in the vicinity of coast and in the proximity of polluted rivers, have relatively higher values of electrical conductivity, salinity and population of Coliform bacteria. In general, the bacteriological quality of shallow groundwater is quite poor and renders the water unfit for drinking purposes without prior treatment. The shallow groundwater is moderately saline, representing electrical conductivity values in the range of 1.1 to 1.9 mS/cm and salinity in the range of 1 ppt. The pH of shallow groundwater varies from mildly acidic (~6.3) to mildly alkaline values (~7.9). Areas with quite poor sanitary conditions have relatively low values of pH (~6.3 to 6.8). Shallow groundwater below 20 meters is slightly reducing. The dissolved oxygen is in the range of 1.5 to 7.9 mg/L. Turbidity of shallow groundwater varies between 3.6 NTU and 95 NTU. The concentration of HCO_3^- (356 - 514 ppm, n=4), Cl^- (82 - 169 ppm, n=4) and SO4-2 (38-117 ppm, n=4) in shallow groundwater is very reasonable.

The mean chemical concentrations of Cl-, SO_4^{-2} and HCO_3^- in shallow groundwater are as follows:

Mean Cl^- (Shallow Groundwater): 132.8 ± 36.5 ppm (n=4)
Mean SO_4^{-2} (Shallow Groundwater): 63.3 ± 36.7 ppm (n=4)
Mean HCO_3^- (Shallow Groundwater): 423 ± 67.4 ppm (n=4)

The range of variation in stable isotope content of total dissolved inorganic carbon (TDIC) and oxygen in Layari River water is as follows:

$\delta^{18}O$ (Shallow Groundwater) -6.3 to -5.8 ‰ V-SMOW (n=8)
$\delta^{13}C$ (TDIC-Shallow Groundwater): -16.5 to -5.5 ‰ PDB (n=8)

The mean stable isotope content of 18O and 13C in shallow groundwater is as follows:

Mean $\delta^{18}O$ (Shallow Groundwater): -5.9 ± 0.32 ‰ V-SMOW (n=8)
Mean $\delta^{13}C$ (TDIC-Shallow Groundwater): -10.1± 3.3 ‰ PDB (n=8)

The stable-isotope results indicate that the shallow / phreatic aquifers are recharged by a mixture of fresh waters of Indus River and Hab River (draining spring water and flooded rainwater), as well as polluted Layari and Malir rivers and their feeding drains (both under natural infiltration conditions and artificially induced infiltration conditions) and, to a much smaller extent, from direct recharge of local precipitation.

Deep Groundwater

In general, deep groundwater is mostly saline and has high electrical conductivity (range: 1.9- 19.1 mS/cm) and salinity (range: 1.7-7.4 ppt), as compared to shallow groundwater. The sampled deep groundwater from pumping wells is in fact a mixture of various proportions of shallow groundwater from freshwater phreatic/ unconfined aquifer and actual deep groundwater from the confined aquifer. In the absence of well-logs of sampled tube-wells/pumping wells, it is not possible to estimate the proportions of inputs of shallow groundwater in the discharge of these wells. Based on hydrochemical data, it is assumed that the shallow mixed deep groundwater discharged by large-scale pumping wells mainly represents the deep groundwater from confined aquifer. The more representative deep groundwater wells (sample No. G-006, G-012, G-014) are those which have relatively higher values of electrical conductivity (range: 5.1 - 19.1 mS/cm), salinity (range: 2.7 - 7.4 ppt) as well as concentrations of Cl- (range: 1480 - 6034 ppm) and SO_4^{-2} (range: 144 - 2221 ppm). The deep wells located close to the coast/shoreline (sample No. G-016, G-017) also have relatively higher values of electrical conductivity, salinity, Cl^- (3291 ppm each well) and SO_4^{-2} (132 - 445 ppm). The mean chemical concentrations of Cl^-, SO_4^{-2} and HCO_3^- in shallow mixed deep groundwater are as follows:

Mean Cl^- (Deep Groundwater): 2169.2 ± 1828.0 ppm (n=9)
Mean SO_4^{-2} (Deep Groundwater): 458.4 ± 691.4 ppm (n=9)
Mean HCO_3^- (Deep Groundwater): 353.6 ± 215.4 ppm (n=9)

The range of variation in stable isotope content of total dissolved inorganic carbon (TDIC) and oxygen in shallow mixed deep groundwater is as follows:

δ^{18}O (Deep Groundwater): - 6.2 to -4.2 ‰ V-SMOW (n=10)
δ^{13}C (TDIC - Deep Groundwater): -13.2 to -0.3 ‰ PDB (n=10)

The mean stable isotope content of ^{18}O in shallow mixed deep groundwater is as follows:

Mean δ^{18}O (Deep Groundwater): -5.3± 0.7‰ V-SMOW (n=10)
Mean δ^{13}C (TDIC- Deep Groundwater): -10.5±3.7‰ PDB (n=10)

The hydrochemical and stable isotope results indicates that the confined aquifer hosts a mixture of rainwater from hinterlands and surrounding regions around coastal Karachi, as well as sea trapped water / seawater, through intrusion under natural infiltration conditions or under induced recharge conditions.

Groundwater Recharge Characteristics/ Sea water Intrusion

Presently, coastal Karachi is known to have five sources of recharge to its groundwater reserves. These are: (i) rainfall, (ii) Indus River water supply , (iii) Hab-River & Hab Lake water supply; (iv) polluted Layari and Malir rivers/ contributory channels draining mixtures of domestic, industrial and agricultural wastewater, composed of pre-said three sources; and (v) seawater. The possibilities of major contribution to groundwater recharge of shallow / phreatic aquifer directly by local rainfall seems very small, due to very poor frequency of rainfall events and rainfall intensities in the Karachi and high evaporation rates. The long-term (15 years annual record) mean monthly average precipitation for Karachi is between 0-15 mm during the months of January to June, 23 - 91 mm during the months of July to September, and 0-7 mm during the months of October to December . The remaining four sources can play a significant role in recharge of the shallow aquifer-system and deep groundwater system (confined aquifer) in coastal Karachi.

In order to postulate the origin of shallow and deep groundwater and related salinity in the shallow aquifer system and the confined deep aquifer system, the stable isotope composition of oxygen and hydrochemical data of groundwater samples collected in the present investigation is statistically evaluated.

Unpolluted seawater off Karachi coast is characterized by a δ^{18}O value of ~ +1 ‰ V-SMOW and a chloride content of ~23000 ppm. Both the Layari River and Malir River waters, as well as the Indus River water and the Hab Lake water, have extremely very low aqueous contents of chloride and sulfate ions as compared to seawater. The average mean value of δ^{18}O in polluted river waters is ~ 5 ‰ V-SMOW and in shallow groundwater is -5.9 ‰ V-SMOW. Therefore, those pumping wells which are located near the coastline/shore line (where seawater intrusion could be expected) and have high chloride and sulfate values should represent seawater-intrusion and relatively enriched ^{18}O values. However, for pumping-wells located comparatively far away from the coast and representing high salinity (chloride & sulfate concentrations), the contribution of saline water may be derived from upward diffusion from the freshwater-seawater interface, possibly as a result of local fluctuation of water-table due to pumping. In the present investigations, shallow mixed deep-pumping wells installed near the coast (sample No. G-016, G-017) have significantly high values of chloride (in both wells) and sulfate (in well near Clifton coast), but have δ^{18}O values closer to polluted river water and shallow groundwater. This suggests that these coastal pumping-wells are withdrawing significant quantities of water from shallow aquifer, which also hosts recharge of seawater gushed into the coastal zone during summer monsoon period. However, possibilities of direct seawater intrusion in these wells, under prolonged pumping conditions, is yet to be verified. Noteworthy are the pumping wells with significantly high chloride-content and relatively lower sulfate-content (Well No. G-001, G-017). These samples have negative redox values and it is speculated that the lower sulfate contents are due to biological reduction of sulfate. Sulfur Isotopic analysis (δ^{34}S) of aqueous sulfate in these samples is in progress, to fully document this observation.

The relatively deeper groundwaters representing confined aquifer, and sampled from three pumping wells: No. G-006, G-012, G-014, have a mean δ^{18}O value of -4.3 ‰ V-SMOW and excessively high values of aqueous chloride and sulfate. One of the samples No. G-006 has δ^{13}C (TDIC) value of -0.3 ‰, PDB which is very close to the δ13C (TDIC) value for seawater. The other two wells No. G-012 and G-014 have δ^{13}C (TDIC) values of -10.4‰ PDB ‰ PDB and -13.2‰ PDB.

Similar depleted δ13C values have been reported for deep saline groundwater tapped from confined aquifer in the coastal zone of Orissa- India[7]. It is speculated that the groundwater tapped by these wells mainly represents a mixture of recharge from rainfall in the hinterlands, flood water and spring-water drained by the Malir River Basin and the Hab River Basin around coastal Karachi, as well as seawater. For Well No. G-006, we speculate direct intrusion of seawater by excessive pumping. However, in case of the two pumping wells No. G-012 and G-014, the excessively high values of chloride and sulfate in deep groundwater away from the coast suggest possibilities of trapped seawater. To verify possibilities of seawater intrusion in shallow groundwater and mixed deep groundwater and/or existence of trapped seawater in deep groundwater, the concentrations of SO_4^{-2} (in milligrams per liter, log scale) are plotted against SO_4^{-2}/Cl^- ratios (in milliequivalents per liter, log scale) for all analyzed water-samples (Figure - 3). It is obvious that shallow groundwater and deep groundwater plot along two distinct lines.

This is further justified by demonstrating the trend of Cl^- concentrations (in ppm, log scale) versus $\delta^{18}O$ values (in ‰ V-SMOW, linear scale) in shallow and deep groundwater and the local seawater as well as seawater from Doha-Qatar in Gulph Area[8]. It may be realized from Figure-4 that the extrapolated or forecast trend for shallow groundwater samples (with low SO_4^{-2} content) does not fall on the data points for local seawater (or other tropical seawater from Doha/Qatar). However, the extrapolated or forecast trend for deep groundwater samples (with high SO_4^{-2} and Cl^- contents and enriched $\delta^{18}O$ values) falls in the vicinity of the data points for local seawater (or other tropical seawater from Doha/Qatar). This observation strengthens the possibilities of seawater intrusion in the coastal zone and existence of trapped seawater salinity/build-up of salt-water up-coning in the deep confined aquifer in coastal Karachi.

CONCLUSION

The primary studies carried out during the first year of the project on conjunctive use of stable isotope techniques and conventional non-nuclear techniques have successfully provided a general view on the stable isotope composition of oxygen and inorganic carbon in water and its dissolved inorganic carbon, as well as hydrochemistry /salinity and biological pollution of potable groundwater system in coastal Karachi. The conclusions on possibilities of seawater and/or existence of trapped seawater salinity/build-up of salt-water up-coning, in the deep confined aquifer in coastal Karachi, is based on little and scattered data-points. More representative sampling is thus required to be performed during the next sampling phase.

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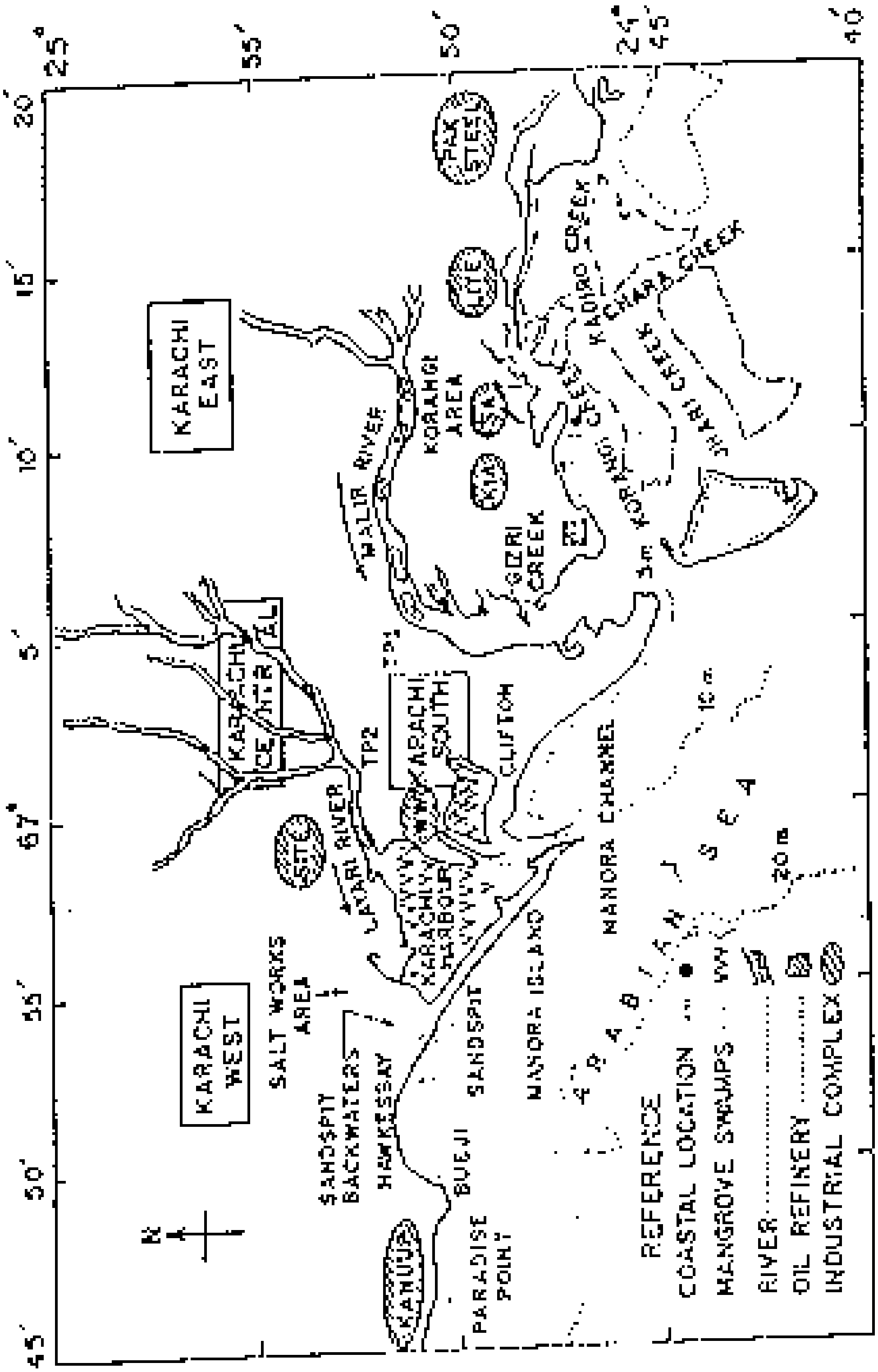

Figure – 1: Map of Karachi (Sources of Pollution, Drainage, Coastline)

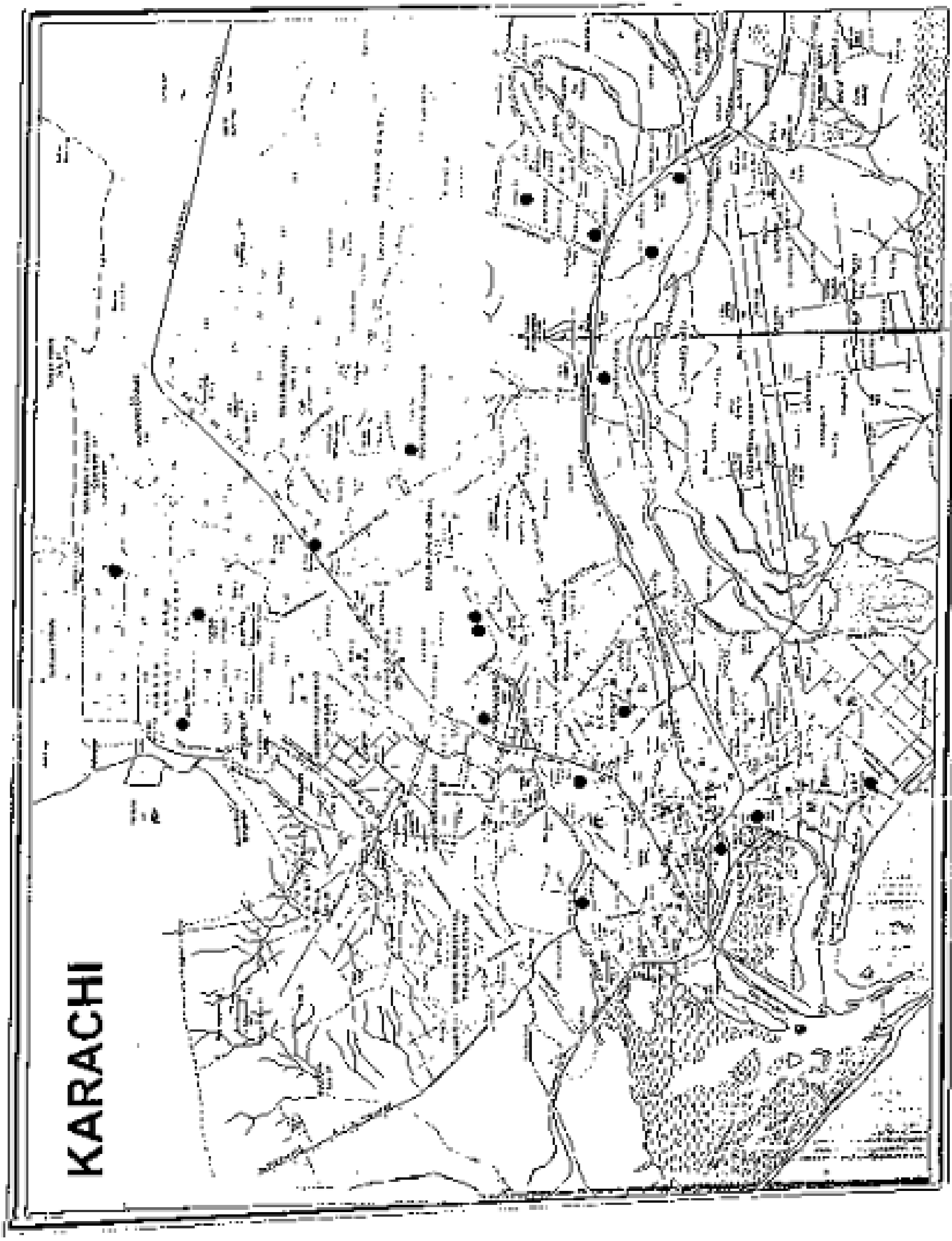

Figure – 2: Map of Karachi Metropolis Showing Location of Sampling Points

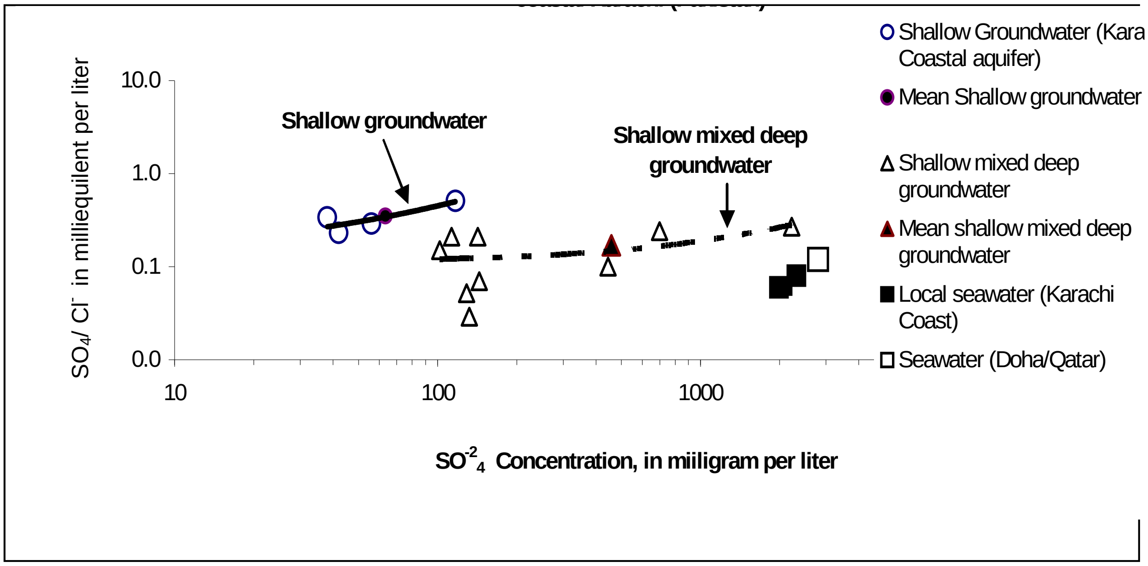

Figure – 3: Graph of SO^{-2}_4/Cl^- Ratio and SO^{-2}_4 Concentration in Shallow and Deep Groundwater, Coastal Karachi (Pakistan)

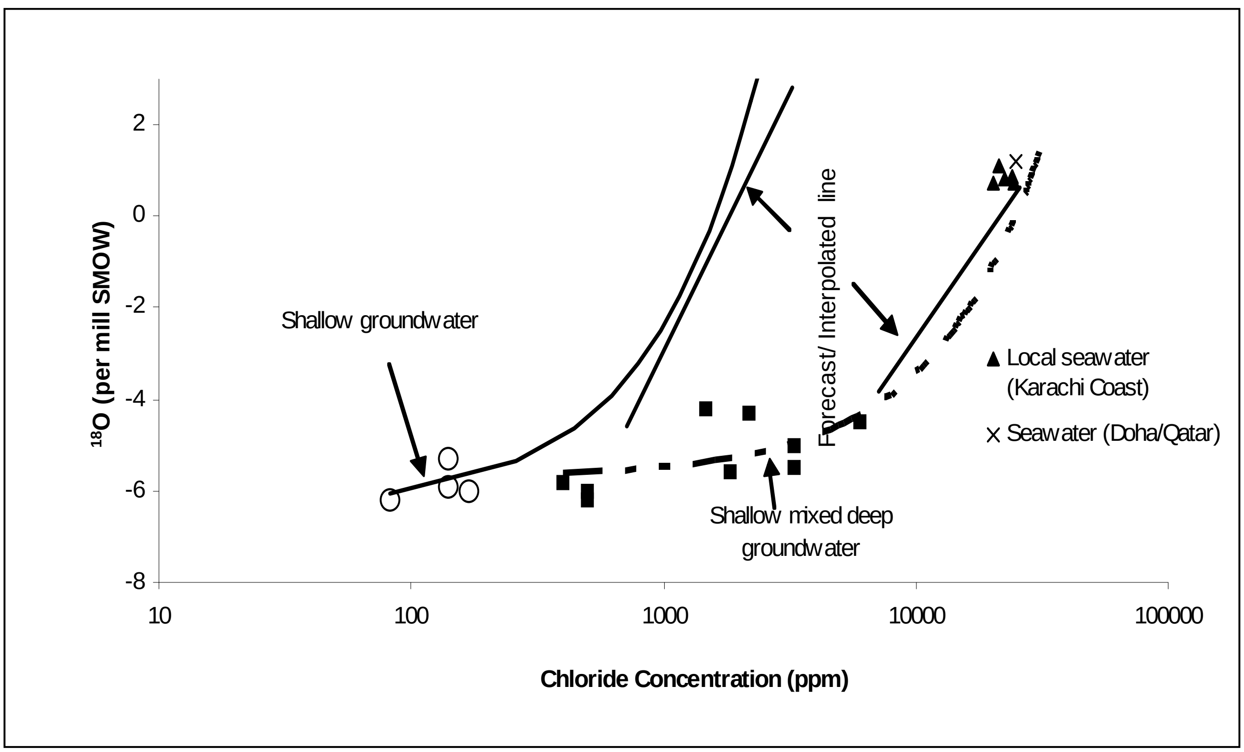

Figure - 4: Chloride Versus ^{18}O Trend Line for Shallow and Shallow Mixed Deep Groundwater, Coastal Karachi (Pakistan)

Table - 2.1 : Physico-Chemical and Stable Isotope Analysis of Potable Surface Water (Coastal Karachi)

Sample Information			Physio chemical analysis							Major ion analysis			Stable isotope analysis		
Sample Code	Sample Location/ collection point	Geographical location Lat/Long	pH	EC (mS/ cm)	Turbidity (NTU)	Temp. (^oC)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^-_3 (ppm)	Cl^- (ppm)	SO^{-2}_4 (ppm)	$\delta^{13}C_{TDIC}$(‰V-PDB)	$\delta^{18}O$(‰V-SMOW)	
Indus River															
G-005	Indus water	---	7.6	0.48	36	24.7	-49	8.3	0	---	---	86	1.7	-8.2	
Hab Dam															
S-008	North west side near exit	25 -14 -54 67 -06- 87	8.3	1.4	58	27	147	---	<1	128	320	289	6.3	2.8	
S-009	Between Rest House and Check post No.1	25 -15- 40 67- 01- 17	8.3	1.47	79	27.3	79	---	<1	98	314	272	5.9	2.9	
S-010	Near Forest Office	25-16- 86 67- 06- 83	8.8	1.47	56	26.7	143	---	<1	---	---	326	1	2.9	
S-011	Mouth of feeding Stream	25 -16- 86 67- 06- 83	8.6	1.5	27	26	178	---	<1	---	---	298	4	2.9	9.8

**Note: --- Not determined*

Table-2.2 : Physico-Chemical and Stable Isotope Analysis of Polluted River/ Major Sewage Drains in Coastal Karachi

Sample Information			Physio chemical analysis							Major ion analysis			Stable isotope analysis	
Sample Code	Sample Location/ collection point	Geographical location Lat/Long	pH	EC (mS/cm)	Turbidity (NTU)	Temp. (^oC)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^{-3} (ppm)	Cl- (ppm)	SO^{-2}_4 (ppm)	$\delta\ ^{13}C$-TDIC (‰ V PDB)	$\delta\ ^{18}O$ (‰ V -SMOW)
Layari River														
S-022	New Karachi near Yousaf Ghoth	25^o-00'-48" 67^o-05'-50"	8.4	9	76	24.5	-13	0.3	5	660	3296	525	-0.2	-2.7
S-021	Gulshan-Abad Bridge	24^o-55'-70" 67^o-05'-28"	7.8	3.7	54	26.5	-345	0.6	3	---	---	---	-7.2	-5.3
S-020	Teen Hatti	24^o-53'-63" 67^o-03'-64"	7.2	1.3	89	26.1	2	0.4	< 1	364	233	52	-3.8	-5.5
S-019	Before Juna Dhobi Ghat (Mirza Adam Khan Road)	24^o-52'-75" 67^o-01'-04"	7.5	1.5	68	25.5	-58	1.2	<1	---	---	---	-6	-5.4
S-018	Before Juna Dhobi Ghat (Mirza Adam Khan Road near Tanga Stand)	24^o-52'-46" 66^o-58'-99"	7.4	2.3	54	24.1	-290	0.8	2	562	443	94	-1.4	-5.2
Malir River														
S-017	Behind Shah Faisal Colony	24^o-52'-31" 67^o-08'-31"	6.9	1.6	75	23.7	-198	0.2	1	462	201	65	-1.4	-4.9
S-015	Bridge between Mahmooda bad and Korangi	24^o-51'-07" 67^o-05'-63"	7.7	3.2	97	21.6	-25	3.4	3.5	---	---	---	---	---
S-014	Quyyum Abad Ghizri Area	24-^{o}49'-44" 67^o-05'-52"	7.9	3.4	98	23.4	-310	24	5	486	971	230	-8.7	-4.6

Note: "---" Not determined

Table 2.3: Physio-Chemical and Stable Isotope Analysis of Local Seawater (Coastal Karachi)

Sample Information			Physio chemical analysis							Major ion analysis			Stable isotope analysis	
Sample Code	Sample Code	Geographical location Lat/Long	pH	EC (mS/cm)	Turbidity (NTU)	Temp. (°C)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^-_3 (ppm)	Cl^- (ppm)	SO^{-2}_4 (ppm)	δ^{13}C-TDIC (‰ PDB)	δ^{18}O (‰ V - SMOW)
K--12	Bule-Ji Coast	24°-49'-04" 66°-50'-41"	---	53.7	78.5	25.4	208	----	39	159	24138	2076	0.76	0.74
K-17	Clifton Coast	24°-47'-43" 67°-01'-40"	8.1	52.8	52.6	25.6	135	8	39	145	25230	2180	-2.77	0.87
K-24	Ghizri Coast	24°-45'-86" 67°-07'-12"	7.8	52.1	195.5	28.3	182	2.7	39	156	24230	2210	-2.72	0.82
K-26	Korangi Coast	24°-47'-99" 67°-12'-22"	7.7	52.1	173.6	25.7	104	3.8	39	---	----	----	-3.86	1.1
K-43	Shams Pir Coast	24 ° -51'-05" 66 ° -55'-05"	8.5	49.3	---	25.3	34	----	32	196	21578	2323	-2.26	0.27

Note: "---" Not Determined

Table 2.4(a): Physico-Chemical and Stable Isotope Analysis of Shallow Groundwater (Coastal Karachi)

Sample Information				Physio chemical analysis							Major ion analysis			Stable isotope analysis	
Sample Code	Sample Location/ collection point	Geographical location (Lat/Long)	Approx Depth (meter)	pH	EC (mS/ cm)	Turbidity (NTU)	Temp (°C)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^-_3 (ppm)	Cl^- (ppm)	SO^{-2}_4 (ppm)	δ^{13}C-TDIC (‰ PDB)	δ^{18}O (‰ V - SMOW)
A: Shallow groundwater															
A-I: Hand pump															
G-008	Azeem Pura (Malir)	24°-52'-60" 67°-09'- 61"	10	7.5	1.4	95	27.3	-34	3.6	0.9	---	---	---	-9.7	-6.2
G-002	Gulshan-e-Iqbal	24°-55'- 00" 67°-04'- 79"	8	6.8	1.7	35	28.6	-12	---	1	---	---	---	-10.7	-5.8
A-II: Dug well															
G-003	Mill Area Liaquat Abad (R_L)	---	15	7.4	1.8	56	29.2	-4	---	1	356	140	56	-5.5	-5.3
A-III: Bores/Pumping wells															
G-004	Garden Zoo Area (R_L)	24°-52'- 41" 67°-01'- 41"	20	7.6	1.9	79	28.8	-52	7.9	1	---	---	---.	-6.6	-6.3
G-009	Shah Faisal Colony (R_M)	24°-52'-47" 67°-10'- 03"	25	7.5	1.1	29	28.2	103	2.4	1	394	140	42	-9.8	-5.9
G-011	Juna Dhubi Ghat (R_L)	24°-52'-76" 67°-01'- 03"	25	6.7	1.1	---	27.5	72	1.9	0.8	428	82	38	-10.6	-6.2
G-013	North Karachi, Iqbal Town	24°-58'-59" 67°-03'- 96"	30	6.3	1.5	3.6	27.4	59	2.8	1	---	---	---	-11.6	-5.8
G-018	Saddar **(C)**	---	20	7.9	1.6	7.8	28.9	37	1.5	1	514	169	117	-16.5	-6.0

C *Close to coast*
R_M *Close to Layari River*
R_L *Close to Malir River*
--- *Not determined*

Table – 2.4(b): Physio-Chemical, and Stable Isotope Analysis of Shallow Mixed Deep Groundwater (Coastal Karachi)

Sample Information				Physio chemical analysis							Major ion analysis			Stable isotope analysis	
Sample Code	Sample Location /collection point	Geographical location (Lat/Long)	Approx .Depth (meter)	pH	EC (mS/cm)	Turbidity (NTU)	Temp (^oC)	Redox (mV)	DO (mg/L)	Salinity (ppt)	HCO^-_3 (ppm)	Cl^- (ppm)	SO^{-2}_4 (ppm)	$\delta\ ^{13}C$-TDIC (‰ V-PDB)	$\delta\ ^{18}O$ (‰ V - SMOW)
G-001	Gulshan-e-Iqbal (R_L)	24°-55'- 01" 67°-04'- 79"	>70	7.0	2.9	27	28.6	-20	0.1	2	241	1829	129	-11.5	-5.6
G-006	PECHS Mahmood Abad	24°-51'-47" 67°-04'- 35"	>70	7.5	5.5	41	30	-51	5.6	2.9	380	1480	144	- 0.3	-4.2
G-007	Gulistan-e-Johar	24°-54'-53" 67°-07'- 23"	>50	6.6	3.4	39	27.3	-2	4.5	2.2	376	501	142	-10.7	-5.9
G-010	Quaid Abad (R_M)	24°-52'-06" 67°-12'- 18"	>50	7.5	2.3	25	22.4	118	---	1.8	---	---.	---	-11.3	-6.2
G-012	Power House Area (R_L)	24°-57'-51" 67°-04'- 49"	~50	7.5	5.1	5.4	24.3	-023	1.7	2.7	373	2194	698	-10.4	-4.3
G-014	New Karachi Near yousaf Ghoth (R_L)	25°-00'-47" 67°-05'- 91"	~100	6.9	19.1	9.9	29.6	45	4.8	7.4	290	6034	2221	-13.2	-4.5
G-015	Model Colony (Malir)	---	45	6.5	3.5	7.7	23.5	139	---	2.2	144	501	102	-11.7	-6.0
G-016	Clifton (C)	24°-49'-91" 66°-57'- 98"	80	7.4	7.8	2.7	28.1	23	3.7	3.6	281	3291	445	-13.2	-5.0
G-017	Sultan A bad, Hijrat Colony (C)	24°-46'-07" 67°-00'- 31"	>70	8.6	6.6	12.2	28.2	-48	2.3	3.2	886	3291	132	-11.0	-5.5
G-019	Malir Halt	---	>50	7.7	1.9	---	---	---	---	1.7	211	402	113	-12.1	-5.8

C *Close to coast*
R_M *Close to Layari River*
R_L *Close to Malir River*
--- *Not determined*