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Original Research Article

Trace Metal Concentrations of Surface Sediments and Total Organic Carbon of Sediment Core Recovered From Lagos Coastal Waters, Southwestern Nigeria

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Abstract

Recent residential and industrial effluents had triggered the need to continually monitor and assess the hydrochemistry and pollution index of Lagos coastal waters and sediments in Southwest Nigeria. To assess environmental contamination in the Lagos coast, twenty stations (with a recent report of anthropogenic activities) were selected, to determine the concentrations and distributions of hydro-chemical characteristics, heavy metals and total organic content (TOC). The hydro-chemical characteristics (pH; temperature; dissolved oxygen; electrical conductivity; salinity; total dissolved solids; sulphate, chloride, phosphate, nitrate, ammonia, sodium and potassium) of water samples from all the stations studied are within desirable levels for healthy marine ecosystems (except for low (<6) pH at station 8 (Ikorodu Port); station 10 and 11 (Mid Lagoon); station 16 (Badore) and station 19 (Ikosi). The concentrations of heavy metals present in the studied area followed the sequence: Fe > Mn > Cr > Zn > Pb > Cu > Cd. The increased TOC concentrations of the representative short sediment core with depth at station 4 (Iddo) and station 15 (Ikota) suggest record of anthropogenic organic pollutions at the stations. The calculated contamination factor (CF) showed extremely severe contamination (CF > 6) of cadmium (Cd) at station 3 (Ijora), station 4, station 5 (Okobaba), station 6 (Unilag), station 7 (Agboyin) and station 12 (Egbin). The pollution load index (PLI) pointed out high pollution risk (PLI > 1) to the marine ecosystems at Ijora; Iddo and Okobaba, which necessitate regular and continuous monitoring of the coastal waters and estuaries of the Southwestern Nigeria to ensure food security and the safety of the marine ecosystems. The outcome of this study will sound alarm on the increasing levels of inorganic and organic pollutants in the Lagos coastal waters. Southwest Nigeria.

Keywords: Lagos coastal waters; sediments; hydrochemistry; heavy metals, pollution index; Southwest Nigeria.

INTRODUCTION

The coastal zones of the world are facing pressures from climate change and environmental contamination processes (Giosan et al., 2014; Yuan et al., 2019). The role of the human-induced anthropogenic activities has exceeded the natural factors of sea-level rise (e.g., natural disaster and hydro-climatological extreme events; Wang et al., 2018; Yuan et al., 2019). Anthropogenic activities further possess the ability to influence the physicochemical properties, inorganic and organic geochemical compositions of coastal sediments and water. The background levels and spatial distributions of these inorganic and organic chemical constituents are often controlled by hydrodynamic and biogeochemical processes (Yuan et al., 2019).

Lagos coastal waters represent one of the densely populated coastal provinces in the world with exacerbated pollution status majorly caused by domestic and industrial pollutants that are triggered by series of coastal engineering projects, sand mining, channel dredging, marine debris (Ajani et al., 2015); petroleum spills (Ajao, 1996), sewage disposal (Ajani et al., 2015); wood logging (Ajao, 1990); dredging and thermal pollution (Ajao, 1990; Don Pedro et al., 2014). These industrial effluents are not unconnected with changes in the physical and chemical status of the Lagos coastal waters and increased cycling and concentrations of toxic trace metals, eutrophication and increased total organic carbon contents of coastal sediments therein (Liu et al., 2019; Yuan et al., 2019). Due to their accumulation over time, surface and sediment core are useful archives to reconstruct environmental changes (e.g., by analyses of heavy metals, the total organic carbon in undisturbed sediment cores; Bennion, et al., 2007; Wu et al., 2016; Sha et al., 2017; Xiang et al., 2019). They also provide valuable information on the impacts of human-induced activities in coastal areas.

This study aims to monitor the distribution of heavy metals (Cu, Zn, Fe, Mn and Cr), selected toxic trace metals (Pb, Cd), of the Lagos coastal sediments. We also analyze the vertical distributions of total organic carbon (TOC) in the short sediments core at selected locations, and the physicochemical characteristics (e.g., temperature, dissolved oxygen, salinity, pH, electrical conductivity, total dissolved solids and biochemical oxygen demand), and nutrients (e.g., nitrate, sulphate, chloride, phosphate, ammonia, sodium and potassium) loads of the Lagos coastal waters.

MATERIALS AND METHOD

Study Area

The Lagos lagoon is a tropical coastal estuary in Southwest Nigeria that discharges into the South Atlantic Ocean through the Lagos Harbour (Amaeze et al., 2015). It stretches from Cotonou in the Republic of Benin and extends to the fringes of Niger Delta in Nigeria along a 257km course (Obi et al., 2016). The Lagoon consists of estuarine water that is fed majorly in the north by Ogun River, with a host of other smaller rivers as well as tidal creeks. Based on the housing density along the Lagoon coastlines, the series of accompanying industrial discharges, effluents and run-offs from the surrounding metropolis makes the Lagos Lagoon an ultimate sink of human-induced anthropogenic effluents.

The study area (Fig. 1) is part of Lagos coastal waters and comprises of 20 stations. Previous studies (Ajao, 1990; 1996; Don Pedro et al., 2014, Ajani et al., 2015, Table 1) have reported a series of anthropogenic pollutants in the station.

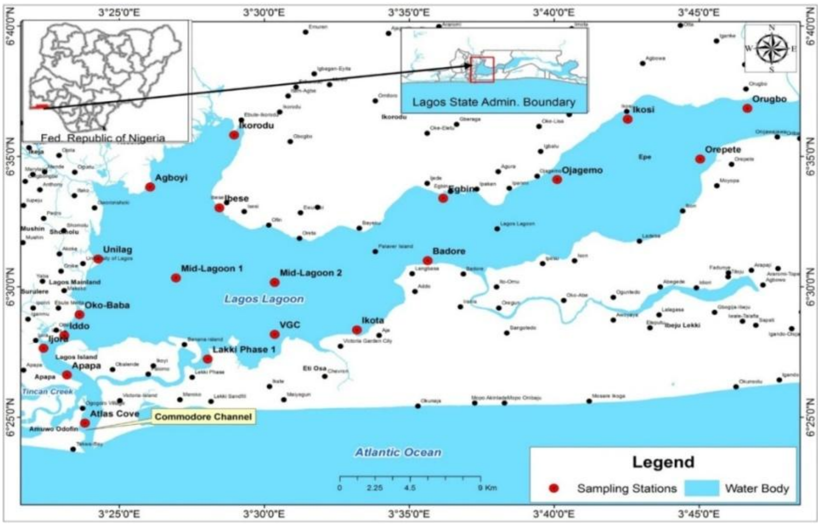

Fig-1: Map of the study area showing the sampling stations

Collection and Analysis of Water and Sediment Samples

Water, surficial sediment samples and short sediment core (0–50 cm), based on the reported anthropogenic activities in Lagos coastal waters were collected from July to September 2019. Surface water was collected from 20 sampling stations located within the Lagos Lagoon and surrounding coastal waters. Physical and chemical characteristics such as pH; Temperature (TEMP); dissolved oxygen (DO), Electrical conductivity (EC), Salinity (SAL), and Total dissolved solids (TDS) were measured in-situ by the use of a U-52 Horiba multi water instrument. Separate water samples were collected in 250ml DO bottles at each station and stored for 5 days, before fixing with 2mls each of Winkler I (manganous-sulphate) and Winkler II (Alkaline Potassium Iodide), and titrated with sodium thiosulphate using starch as an indicator to determine the biochemical oxygen demand (BOD), according to American Public and Health Association APHA (1998) procedure.

Water samples collected for dissolved nutrients analysis were filtered through membrane filters of 0.45-micrometre pore size at the time of sampling and then preserved in a cooler of ice (below 5˚C) and taken to the laboratory for analysis. Nitrates, phosphates, ammonia and sulphate were determined using UV/VIS Spectrophotometer (Model- Jenway 6705) at 543nm, 885nm, 630nm and 420nm wavelength respectively (Ademoroti, 1996). Sodium and potassium were determined by Flame atomic absorption spectrometry (FAAS) according to Chaves et al. (2008), while chloride ion was determined using Mohrs method according to Skoog et al. (1996); Shukla and Arya (2018).

The surface sediment samples from the same stations (collected with the aid of van-Veen grab) were further air-dried, disaggregated and leached with Nitric/Hydrochloric acid (1:3), aqua regia. Heavy metal contents (Cu, Zn, Fe, Cr, Pb, Mn and Cd) were analyzed with Argillent 200 A model, Atomic Absorption Spectrophotometer (AAS) at the laboratory of the physical and chemical oceanography, Nigerian institute for oceanography and marine research, Lagos, Nigeria.

Sediment pollution index (e.g., contamination factor ($CF = \frac{CF\ samples}{CF\ Background}$) and pollution load index ($PLI = (CF1 \times CF2 \times CF3 \times \ldots\ldots \times CFn)^{1/n}$) were calculated according to the method of Hakanson (1980); Tomlinson et al (1980); Ajani et al (2015) and A. Usese et al (2017). For the determination of total organic carbon, the 50cm sediment core samples were divided into 10cm interval. TOC analysis was conducted on 0.5g of representative sediments samples from 9 stations (Apapa (APP), Ijora (IJR), Iddo-1 (IDD), Ibeshe (IBS), Orepete (ORP), Victoria Garden City (VGC), Badore (BDR), Ojagemo (OJG) and Ikota (IKT), (Table 1). Exothermic heating and oxidation of organic carbon of the air-dried sample was conducted with potassium dichromate and concentrated sulfuric acid (H_2SO_4), and the titration of excess dichromate with 0.5N ferrous ammonium sulphate solution to a sharp endpoint. Ten mil (10 ml) of 1 N $K_2Cr_2O_7$ solution was added to about 0.5 g of dried sample in a 500 ml Erlenmeyer flask with subsequent mixing and swirling. TOC was determined using wet oxidation method according to Mopper and Qian (2006); Muyideen et al. (2013); Ajani et al. (2015) and Avramidis et al, (2015).

Table-1: Sampling station, coordinates and associated anthropogenic activities

Station	Name	Latitude	Longitude	Associated anthropogenic activities
1	Atlas Cove (ATC)	6° 24' 46.44"	3° 23' 48.84"	Petroleum discharge, dredging, lead combustion,
2	Apapa (APP)	6° 26' 38.4"	3° 23' 11.04"	Dredging, oil spillages, ship garbage
3	Ijora (IJR)	6° 27' 38.88"	3° 22' 21.72"	Residential, sewage and industrial effluents
4	Iddo (IDD)	6° 28' 7.32"	3° 23' 9.24"	Domestic sewage discharges, Biodegradable organic matter
5	Oko-Baba (OKB)	6° 28' 54.84"	3° 23' 37.68"	Wood logging, saw dust input, (Biodegradable organic matter
6	Unilag (UNL)	6° 31' 1.92"	3° 24' 15.48"	Marine debris
7	Agboyi (AGB)	6° 33' 51.84"	3° 26' 4.92"	Local dredging
8	Ikorodu (IKR)	6° 35' 48.12"	3° 28' 58.44"	Industrial effluents
9	Ibese (IBS)	6° 32' 59.64"	3° 28' 27.84"	Local dredging
10	Mid-Lagoon (MLG-1)	6° 30' 19.8"	3° 26' 53.88"	Recent residential effluents accumulation.
11	Mid-Lagoon 2 (MLG-2)	6° 30' 9.72"	3° 30' 20.88"	Recent residential effluents accumulation
12	Egbin (EGB)	6° 33' 23.4"	3° 36' 9"	Thermal pollution, Elevated watertemperature
13	Lekki Phase 1 (LKP-1)	6° 27' 12.96"	3° 28' 1.2"	Residential effluents accumulation
14	Victoria Garden City (VGC)	6° 28' 6.96"	3° 30' 20.88"	Marine debris
15	Ikota (IKT)	6° 28' 17.04"	3° 33' 12.24"	Residential effluents accumulation
16	Badore (BDR)	6° 30' 58.68"	3° 35' 38.76"	Residential effluents accumulation
17	Ojagemo (OJG)	6° 34' 8.76"	3° 40' 4.8"	Marine debris
18	Orepete (ORP)	6° 34' 52.68"	3° 45' 2.52"	Marine debris
19	Ikosi (IKS)	6° 36' 23.4"	3° 42' 30.24"	Marine debris
20	Orugbo (ORG)	6° 36' 50.76"	3° 46' 38.64"	Marine debris

RESULTS AND DISCUSSION

Hydrochemical Composition of Lagos Coastal Waters

The in-situ physicochemical characteristics of water measured at the sampling stations are shown in Fig.2. The pH value ranged from 5.02 to 6.92 (average value, 5.94), which shows that the coastal waters at Ikorodu Port (IKP), Mid Lagoon-1 and 2 (MLG-1, 2), BDR and Ikosi (IKS) are slightly acidic (pH < 5.5; station 8, 10-11, 16 and 19 respectively). The acidic pH values according to the Federal Ministry of Environment (FMENV, 2001) and Word health organization (WHO, 2004) can be related to residential effluent discharge and marine debris at these stations. The Electrical conductivity (EC) range from 72.9 µS/cm to 451µS/cm (average value, 253.37 µS/cm), showing the proximity of Atlas cove (ATC) and APP `stations (station 1 and 2; with higher EC values of > 400 µS/cm to the Atlantic Ocean (Fig.3). The salinity (SAL) ranges from 10 ‰ to 25‰ (Fig.2). The increased salinity values (>23ppt) at ATC, APP, Ijora (IJR), IDD and Egbin (EGB), (stations 2, 3, 4 and 12) indicates seawater incursion at the station and showed similar trends with the EC concentrations. The total dissolved solids (TDS) range from 36.6mg/l to 223mg/l (average value 123.43mg/l), with slightly higher values (> 200mg/l) at station 1, 2 and 11 (ATC, APP and MLG-2). This is an indication of higher constituents of total dissolved organic and inorganic solids at the stations (Fig 3). The DO and BOD range from 5.0mg/l to 6.3mg/l (average 5.47 mg/l) and 9.3mg/l to 15mg/l (average, 12.47mg/l respectively). The DO values are within the stipulated minimum benchmark level of 5.0 mg/l for normal survival of aquatic life (Ladipo et al., 2011, Popoola et al., 2015; Nkwoji et al., 2016). Higher BOD values (> 14mg/l) analyzed at station 2 and 8 (APP and IKR, Fig.2) is an indication anthropogenic effluents at the aforementioned station compared to other stations but were lower than the permissible limit of 50 mg/l for coastal water bodies (Ibanga et al., 2019).

The temperature values (Fig.2) ranges from 26.12ºC to 27.98ºC (average value 27.01ºC), and are within the range for a permissible limit (< 40ºC) of coastal waters in tropical climate (FMENV, 2001). The Sulphate (SO_4^{2-}), chloride (Cl^-), phosphate (PO_4^{3-}), sodium (Na^+) and potassium (K^+) concentrations range from 20.4-425.7mg/l; 201-3200mg/l; 0.3-1.92mg/l; 8000-1660mg/l and 1-5000mg/l respectively. Higher concentration of SO_4^2 (up to 425.7mg/l), chloride (Cl^- up to 3200mg/l) were analyzed at station 2 (APP), while station 1 (ATC) show higher Na^+ (up to 8000mg/l) and K^+ (up to 600mg/l) (Fig.5). The higher concentration of these anions and cations at the aforementioned stations is an indication of seawater incursion and the proximity of both sampling stations to the Atlantic Ocean. The EC, SAL and TDS values showed similar trends with the Na and K concentrations. The sulphate and phosphate concentration is within the stipulated values (500mg/l and 5mg/l respectively, Fig.4 and 5) for coastal waters, however, the Cl^- concentrations at station 1-2, 5-6, 13-14 (ATC, APP, OKB, Unilag (UNLG), Lekki Phase-1 (LKP) and VGC stations) were above the minimum permissible limit (600mg/l) for coastal waters (Federal Environmental Protection Agency, FEPA, 1991, FMNEV, 2001, Fig.4). Higher phosphate values at AGB, IKD and IBS can be attributed to anthropogenic sourced phosphate-containing compounds from land drainage, domestic and residential washing activities from detergents into the adjoining creeks or water body. Nitrate (NO_3^-) and ammonia (NH_3) ranges from 0.01-0.41mg/l and 0.3-1.92mg/l respectively (Fig.5). Higher NO_3^- (0.41mg/l) and NH_3 (0.56mg/l) concentrations were analyzed at station 5 and 6 (OKB and UNL). The NO_3 concentrations were within the minimum stipulated limit (20mg/l) for coastal water (FEPA, 1991, FMNEV, 2001). The differing trends in the concentration of Na^+, K^+ SO_4, PO_4, Cl^- from NH_3 and NO_3 suggest anthropogenic source enrichment of NO_3^- and NH_3, especially at OKB and UNL (Fig.5).

The correlation matrix (Table 2) were calculated to establish the relationship among the hydrochemical components of the Lagos coastal sediments. Significant positive correlations exist between EC and TDS (r=0.98, P<0.05), EC and Cl^- (r=0.51, P < 0.05), and TDS and Cl^- (r=0.52, P < 0.05). This is an indication that high EC values are related to high levels of dissolved chemical constituents, dissolved cations (e.g., Na^+, K^+) and anions (e.g., Cl^- and SO_4^{2-}) across the sampling stations. These correlations further support the similar trends of the EC, TDS and Cl^- concentrations at station 1 and station 2 (ATC and APP), an indication of the influence of seawater incursion across the two stations (Fig.3 and Fig.5). Other correlation exist between NO_3^- and NH_3 (r =0.73, P < 0.05) and NO_3 and PO_4^{3-} (r=0.54, P< 0.05). These correlations further confirm the similar trend of nitrate, ammonia and phosphate at station 4-7 (IDD, OKB, UNL and AGB, Fig.5). This is an indication of excessive nutrient loads that are related to domestic sewage discharge, biodegradable organic matter, marine debris and local dredging at the stations (Table 1). The low concentrations of these nutrients (NO_3^-, NH_3 and PO_4^{3-}) at station 1 and station 2, suggest a lower rate of anthropogenic (e.g., human-induced and industrial discharges) effluents at ATC and APP compared to IDD, OKB, UNL and AGB (station 4-7). Temperature is inversely correlated with Cl^- (r=-0.51, P< 0.05) and SO_4^{2-} (r=0.54, P< -0.55, Table 2) which indicate that high-temperature conditions in the catchment area are related to the low concentrations of these two aforementioned anions across the stations.

Table-2: Pearson correlation matrix for the hydro-chemical concentration of Lagos coastal waters, Southwest Nigeria

	pH	DO	SAL	EC	TDS	BOD	TEMP	Cl^-	NO_3^-	SO_4^-	PO_4^-	NH_3^-	Na^+	K^+
pH	1.00													
DO	0.21	1.00												
SAL	-0.08	0.14	1.00											
EC	-0.04	-0.25	0.38	1.00										
TDS	-0.06	-0.24	0.40	0.98*	1.00									
BOD	-0.28	-0.02	0.20	0.11	0.16	1.00								
TEMP	-0.08	-0.01	-0.31	-0.55	-0.60	-0.12	1.00							
Cl^-	0.17	0.19	0.47	0.51*	0.52*	0.04	-0.51	1.00						
NO_3^-	0.16	0.18	-0.21	0.07	0.11	-0.13	-0.27	-0.17	1.00					
SO_4^-	0.38	0.23	0.32	0.39	0.43	0.12	-0.55	0.57*	0.17	1.00				
PO_4^-	0.16	0.29	-0.18	-0.14	-0.11	-0.18	-0.41	-0.15	0.54*	0.24	1.00			
NH_3^-	0.23	0.06	-0.38	0.05	0.08	-0.25	-0.18	0.07	0.73*	-0.02	0.21	1.00		
Na^+	0.36	0.12	0.47	0.33	0.33	-0.23	-0.38	0.34	0.05	0.30	0.15	-0.05	1.00	
K^+	-0.23	-0.10	0.13	-0.30	-0.30	-0.43	-0.06	0.03	-0.13	-0.06	0.02	-0.10	-0.04	1.00

Heavy Metals Concentrations in Lagos Coastal Sediments

As shown in Table 3, the contents (mg kg^{-1}) of the heavy metals (Fe, Cu, Zn, Cr, Mn, Pb and Cd) in the Lagos coastal sediments are as follows: Fe (876.60-1890.45, average 1440.05), Cu (11.06-18.89, average 15.79), Zn (86.30-142. 45, average 103.43), Cr (101.67-148. 79, average 116. 54) and Mn (127.28-509.45, average 301.02), Pb (15.37-34.65, average 24.40), and Cd (0.17-0.93, average 0.47). The trend of heavy metals accumulations in the study area was in the order of Fe > Mn > Cr > Zn > Pb > Cu > Cd. Manganese (Mn), copper (Cu), lead (Pb), chromium (Cr), zinc (Zn) and cadmium (Cd) have been reported as associated elements with petroleum spills, fossil fuel combustions and refining processes (Dara, 2001). Enriched Mn, Cr, Pb, Zn and Cu concentrations were analyzed at ATC, APP, IJR, IDD and OKB (stations 1-5) while high concentrations of Cd were analyzed at IDD and AGB (station 4 and 7). The enriched values of the aforementioned metals are not unconnected with petroleum discharge from marine transportation, routine tankers operations and biomass combustion of industrial and residential sewage from these stations. The low values of Mn, Cu, Cd, Zn, and Pb at VGC, OJG and ORG (station 14, 17 and 20) suggest a lower rate of human-induced anthropogenic pollution and industrial effluents of these aforementioned metals at the stations. Marine sediments are an ultimate sink for heavy metals, which generally accumulate into the sediments, and are represented by contamination factor (CF) and pollution load index (PLI) (Mahdi et al., 2017). According to the calculated CF values (n=20), all the stations showed low contamination (CF < 1) for Cu and Mn (Fig.6). Station 13 (LKP-1), station 14 (VGC) and station 15 (IKT) showed low contamination (CF < 1) of Pb, while other stations showed moderate Pb contamination (1 ≤ CF ≤ 3). The Cd concentration showed moderate (1 ≤ CF ≤ 3) CF values at station 1 (ATC), station 9 (IBS), station 14 (VGC), station 16 (BDR), station 17 (OJG) and station 20 (ORG). The result further showed severe contamination (3≤ CF≤ 6) at station 1 (APP), station 8 (IKR), station 10-11 (MIDL-1 and 2), station 15 (IKT), station 18 (ORP) and station 19 (IKS). The calculated CF for Cd showed an extremely severe contamination (CF > 6) at station 3 (IJR), station 4 (IDD), station 5 (OKB), station 6 (UNL), station 7 (AGB) and station 12 (EGB). Zinc and Chromium showed moderate CF values across all the stations (Fig.6). The calculated PLI >1 values (Fig.7) indicated progressive heavy metal pollution and high risk to marine ecosystems at station 3-5 (IJR, IDD and OKB), and background values (PLI < 1) of heavy metals (low risk to marine ecosystems) at station 1-2, 6-20 respectively (Table 4, Fig.7).

We compared the metal concentrations from the Lagos coastal sediments with other Lagoons and coastal sediments (Table 5). The Fe concentrations of the Lagos coastal sediments were lower than those in the Estuarine Lagoon Puerto Rico, United States of America (Acevedo-Figueroa et al (2006), Dumai coast Indonesia (Amin et al., 2009), Sekara Anakan Lagoon, Indonesia (Syakti et al., 2014) and Ilaje coastal sediments, Ondo state, Nigeria (Olatunji-Ojo et al., 2019 and Adesina and Ogunseiju, 2019). However, the Cu and Zn concentrations were significantly higher than those found in Dumai coast Indonesia, but lower than the marine sediments from Italy, Naples (Adamoo et al., 2005), and Port Jackson, Australia (Birch and Taylor, 1999), while the Mn concentration are higher than those found in the Ilaje coastal waters.

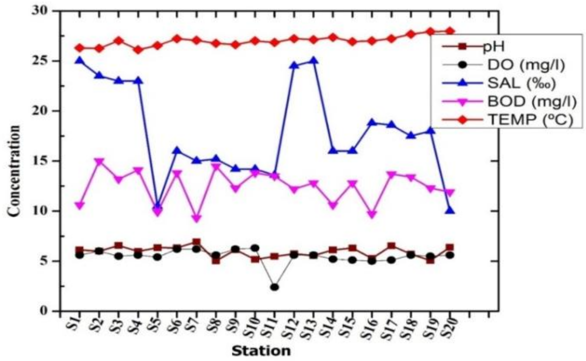

Fig-2: Spatial variation in concentrations of pH, dissolved oxygen, salinity, biochemical oxygen demand and temperature in the Lagos coastal waters

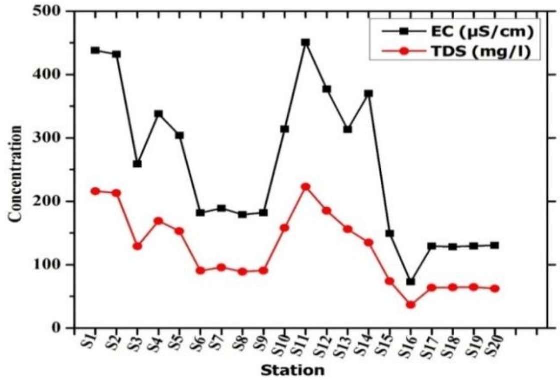

Fig-3: Spatial variation in concentrations of electrical conductivity and total dissolved solids in the Lagos coastal waters

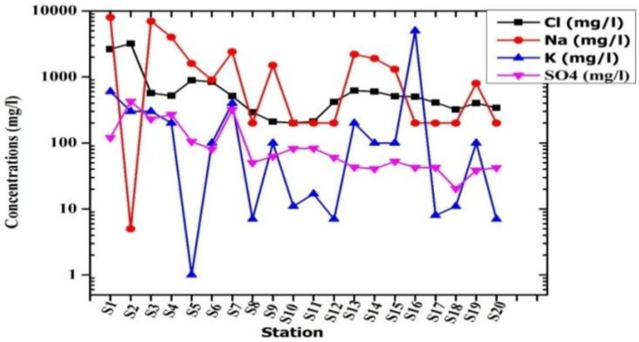

Fig-4: Spatial variation in chloride, sodium, potassium and sulphate in the Lagos coastal waters

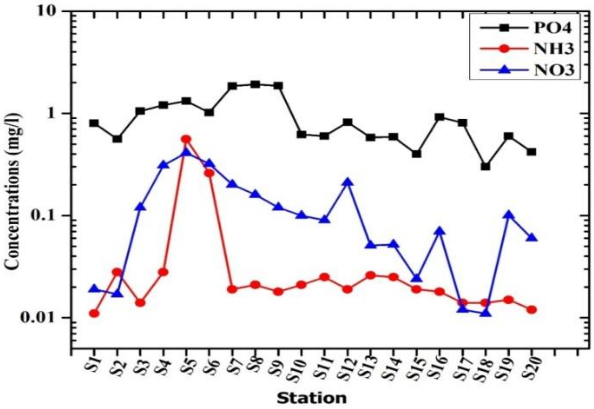

Fig-5: Spatial variation in phosphate, ammonia and nitrate in the Lagos coastal waters

Table-3: Heavy metal concentrations ($mgkg^{-1}$) in surface sediments from Lagos coastal waters

Station	Fe	Cu	Pb	Cd	Zn	Cr	Mn
1	1675.34	17.67	34.16	0.18	127.45	148.01	509.45
2	1545.46	18.56	32.56	0.39	103.45	128.39	407.23
3	1456.03	18.89	34.65	0.87	139.37	148.79	430.37
4	1557.43	17.54	32.76	0.93	105.49	126.48	476.34
5	1143.65	16.45	21.8	0.76	142.45	116.38	467.67
6	1457.56	15.87	18.03	0.76	102.89	109.87	406.9
7	976.78	16.78	27.36	0.82	87.23	102.49	208.34
8	876.6	16.33	24.12	0.37	92.01	104.46	203.45
9	1870.56	16.87	19.78	0.23	109.3	106.56	224.98
10	1890.45	15.67	19.68	0.43	104.43	105.46	217.45
11	1067.89	16.67	21.56	0.41	100.34	115.47	187.56
12	1880.45	15.98	17.34	0.56	98.2	124.19	236.56
13	1876.76	14.78	15.43	0.54	100.67	121.37	306.4
14	956.89	18.33	15.37	0.27	96.48	119.34	301.4
15	1789.98	12.45	16.34	0.41	107.59	108.34	200.34
16	1023.56	16.67	21.45	0.22	87.23	104.46	329.43
17	1678.89	11.06	20.34	0.17	89.98	119.45	127.28
18	1238.08	13.65	34.49	0.46	97.87	117.34	173.45
19	1789.56	12.56	32.56	0.35	89.79	102.3	304.45
20	1049.05	13.04	28.17	0.23	86.3	101.67	301.4
Min	876.6	11.06	15.37	0.17	86.3	101.67	127.28
Max	1890.45	18.89	34.65	0.93	142.45	148.79	509.45
Av	1440.05	15.79	24.4	0.47	103.43	116.54	301.02
STD	363.78	2.2	6.99	0.24	16.04	13.8	113.91
USEPA, 1999	-	4.8	210	42	90	50	-

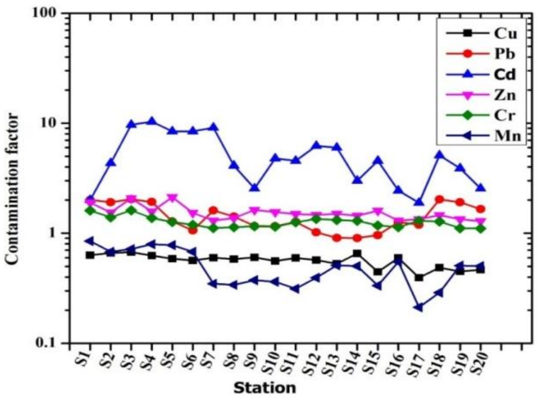

Fig-6: Spatial distributions of contamination factor (CF) of heavy metals in sediment collected from Lagos coastal waters

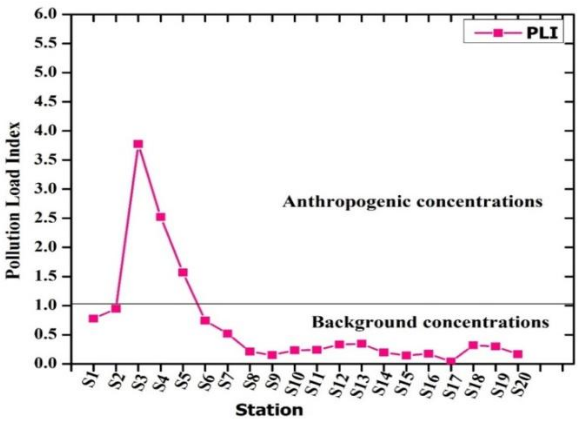

Fig-7: The pollution load index (PLI) and the status of the heavy metals present in the sediment of Lagos coastal waters

Table-4: Standard of contamination factor (CF) and pollution load index (PLI) of heavy metals

	Low	Moderate	Moderate-severe	Severe	Extreme Severe
CF	<1	1-3		3-6	>6
PL1	<1			>1	

Table-5: Heavy metal concentrations (mgkg^{-1}) of samples from Lagos coastal sediments and other selected coastal waters from the literature

	Heavy metals (Mgkg^{-1})						
	Fe	Cu	Pb	Cd	Zn	Cr	Mn
This study	876-1890	11.-19	15-35	0.17-0.93	86-143	101-149	127-510
Puerto Rico Lagoon (n=15)	16000-72000	12-211	-	-	25-1530	-	-
Dumai coast (n=8)	21000-39200	2.0-14.0	-	-	31-87	-	-
Segra Anakan Lagoon (n=10)	26978-467.813	16-84	-	-	39-480	17-340	440-2901
Ilaje coastal sediment(n=12)	152.5-246.7*	5.9-18.1	3.3-110.85	0.0-0.1*	6.4-23.5	0.1-0.2*	0.6-0.7*
Italy, Naples (n=9)	-	40-415	37-314	0.2-2.5	41-1196	0.3-161.8	-
Autralia, Port Jackson (n=8)	-	9.5-105.3	37.9-3604	0.02-24.3	108-7622	-	-

* Cd, Fe, Mn and Cr denoted with * from Ilaje coastal waters were reported by Ojo er al., 2019; Adesina and Ogunseiju, 2017.

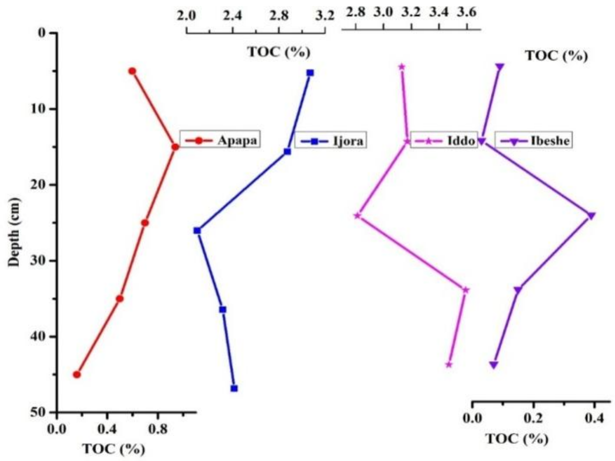

Fig-8: Vertical distribution of organic carbon characteristics in the representative subsurface sediment core (0-50cm) of Apapa (station 2), Ijora (station 3), Iddo (station 4) and Ibeshe (station 9)

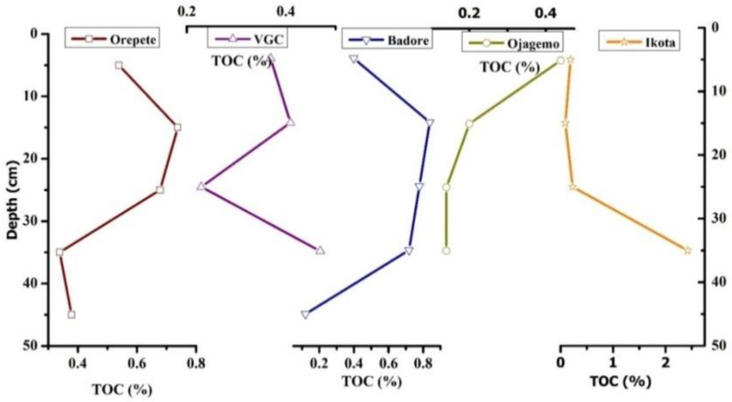

Fig-9: Vertical distribution of organic carbon characteristics in the representative subsurface sediment core (0-50cm) of Orepete (station 18), Victoria Garden City (station 14), Badore (station 16), Ojagemo (station 17) and Ikota (station 15)

Total Organic Carbon Concentration of Short Sediment Core From Lagos Coastal Waters

The TOC analysis (%) across nine selected stations show increasing concentrations with depth (up to 35cmbsf) at IDD (station 4) with values of 3.6%. It further showed an increased concentration with depth (up to 30cmbsf) at IKT (station 15) with values of 2.4% (Fig. 8-9). The increased TOC concentrations with depth suggest increased accumulations of human anthropogenic organic pollutants over the years (although sediment dating is not inclusive) at the aforementioned stations. A decreasing TOC value with depth may be related to a record of reduced accumulations of organic pollutants with depth at APP (station 2), IJR (station 3), IBS (station 9), BDR (station 16), OJG (station 17), VGC (station 14) and ORP (station 18) respectively.

CONCLUSION

The study was conducted to monitor and assess the distribution of hydrochemistry (TEMP, SAL, DO, BOD, EC, TDS, pH, Na, K, NO_3, SO_4, NH_3, and PO_4), heavy metals (Fe, Pb, Zn, Cd, Cu and Cr), pollution index and TOC concentrations of the Lagos coastal water and sediments, Southwest Nigeria. Twenty sampling locations with identified anthropogenic hotspots, such as local dredging, residential and industrial effluents, thermal pollution and marine debris were selected. The hydro-chemical characteristics of water samples from most of the stations are within desirable levels for healthy marine ecosystems stipulated by the Federal Ministry of Environment of Nigeria and World health organization, except for lower (<6) pH values at Ikorodu Port (IKP, station 8), Mid Lagoon-1 (MLG-1, station 10), Badore (BDR, station 16) and Ikosi (IKS, station 19). The increased concentrations of TOC values with depth suggest enhanced record of accumulated organic pollutants over the years at Iddo (station 4), and Ikota (station 15). The concentrations of heavy metals present in the studied area followed the sequence: Fe > Mn > Cr > Zn > Pb > Cu > Cd. Heavy metal contamination status of the study area was also determined by CF and PLI. Zn and Cr showed moderate contamination, while Pb showed low-moderate contamination across the stations. The contamination factor of Cd, however, showed extremely severe contamination at Ijora (station 3), Iddo (station 4), Okobaba (station 5), Unilag (station 6), Agbonyi (station 7), Egbin (station 12) and Ikosi (station 19).

The results of the hydro-chemical characteristic suggest residential effluent discharge and marine debris at Ikorodu, Mid Lagoon 1 and 2, Badore and Ikosi. The heavy metals and TOC concentrations indicated anthropogenic pollutions at station 3 - 7 (Ijora, Iddo, Okobaba, Unilag and Agbonyi), and organic pollutions at stations 4 and 15 (Iddo and Ikota). The pollution load index (PLI >1), indicates a potentially high risk of heavy metal accumulations to the marine ecosystems at Ijora, Iddo and Okobaba (station 3-5 respectively).

The outcome of this study will sound alarm on the increasing levels of inorganic and organic pollutants in the Lagos coastal waters.

Author's Contributions

This work was carried out in collaboration between both authors. Author ORS designed the study, participated in the cruise, generated the digital map of the study area and wrote the protocol and finance the experiment. Author SOP designed the manuscript, performed the statistical analysis and wrote the first draft of the manuscript with contributions from ORS. Both authors read and approved the final manuscript.

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REFERENCES

1. Acevedo-Figueroa, D., Jimenez, B. D., Rodriguez-Sierra, C. J. (2006). Trace metals in sediments of two estuarine lagoons from Puerto Rico. Environmental Pollution, 141, 336–342.
2. Adamo, P., Arienzo, M., Imperato, M., Naimo, D., Nardi, G., Stanzione, D. (2005). Distribution and partition of heavy metals in surface and sub-surface sediments of Naples city port. Chemosphere 61, 800–809.
3. Ademoroti, C.M.A. (1996). Standard method for water and effluent analysis, Environmental Chemistry and Toxicology, Foludex press limited, Ibadan, 3: 29-118.
4. Adesina, R. B., Ogunseiju, P. (2017). An Assessment of Bathymetry, Hydrochemistry and Trace Metals in Sediments of Awoye Estuary in Ilaje Area, Southwestern Nigeria. Journal of Geosciences and Geomatics, vol. 5, no. 2 (2017): 78-86. doi: 10.12691/jgg-5-2-4.
5. Ajani, E.A., Osishanya, Khaphillat I., Popoola, S. Olatunde., Olaoye, O. Peter. (2015). Heavy Metal Pollutions and Its Associated Ecological Risks in Lagos Lagoon Sediments, South-western Nigeria. American Chemical Science Journal, 9 (3): 1-13.
6. Ajao EA. (1990). The influence of domestic and industrial effluents on populations of sessile and benthic organisms in Lagos Lagoon. PhD, thesis University of Ibadan, Nigeria, 413.
7. Ajao, E.A. (1996). Review of the state of pollution of the Lagos Lagoon. Nigerian Institute for Oceanography and Marine Research (NIOMR) Tech. Paper 106:1–15.

8. Amaeze, N.H., Abel, O., Chibueze, J. (2015). Coastal Dump Sites in the Lagos lagoon and toxicity of their leachate on brackish water shrimp (Palaemonetes Africanus), J. Apl.Sci. Environ Manage, Vol 19 (3), 503-510.
9. Amii, Usese O., Lucian, C., Mohammad, M R., Ravi, N., Shoiqul, I., Oyewo, E, O. (2017). Enrichment, contamination and geo-accumulation factors for assessing arsenic contamination in sediment of a Tropical Open Lagoon, Southwest Nigeria. Environmental Technology & Innovation 8:126–131, http: // dx.doi.org/10.1016/j.eti.2017.06.005.
10. Amin, B., Ismail, A., Arshad, A., Yap, C. K., Kamarudin,M. S. (2009). Gastropod assemblages as indicators of sediment metal contamination in mangroves of Dumai, Sumatra, Indonesia. Water Air Soil Pollution, 2011, 9–18.
11. APHA. 1998. Standard method for the examination of water and wastewater. 20th Edn., New York: American Public and Health Association.
12. Avramidisa, P., Nikolaoua, K., Bekiarib, V. (2015). Total Organic Carbon and Total Nitrogen in Sediments and Soils: A Comparison of the Wet Oxidation–Titration Method with the Combustion-Infrared Method. Agriculture and Agricultural Science Procedia 4: 425 – 430.
13. Bennion, H., Battarbee, R. (2007). The European Union water framework directive: Opportunities for paleolimnology. J. Paleolimnol, 38, 285–295.
14. Birch, G., Taylor, S. (1999). Source of heavy metals in sediments of the Port Jackson estuary, Australia. Sci. Total Environ. 227, 123–138.
15. Chaves, E.S., Saint Pierre, D.T., Dos-santos, E.J., Tormen, L., Bascunan, F.A., Curtiusa, J.A. (2008). Determination of Na and K in Biodiesel by Flame Atomic Emission Spectrometry and Microemulsion Sample Preparation Braz. Chem. Soc., Vol. 19, No. 5, 856-861.
16. Dara, S.S. (2009). Energy environment ethics and society. Revised edition, S.Chand and company limited, Ramnagar, New Delhi, 426p.
17. Don-Pedro, KN., Oyewo, EO., Otitoloju, A.A. (2004). Trend of heavy metal concentrations in Lagos Lagoon ecosystem, Nigeria. West African Journal of Applied Ecology, 5:103-114.
18. FEPA. (1991). (Guidelines and Standards for Environmental Pollution Control in Nigeria. Federal Environmental Protection Agency, Lagos.
19. FMENV. (2001). National guidelines and standards for water quality in Nigeria. Federal Ministry of Environment, p. 114.
20. Giosan, L., Syvitski, J., Constantinescu, S., Day, J. (2014). (Protect the world's deltas. Nature 516, 31–33.
21. Hakanson, L. (1980). (Ecological Risk Index for Aquatic Pollution Contro: 1 A Sedimentological 2 Approach. Water Res., 14, 975–1001.
22. Ibanga, L.B., Nkwoji, J.A., Usese, A.I., Onyema, I.C., Chukwu, L.O. (2019). (Hydrochemistry and heavy metals concentrations in sediment of Woji creek and Bonny estuary, Niger Delta, Nigeria. Regional Studies in Marine Science 25, 100436.
23. Ladipo MK, Ajibola VO, Oniye S.J. (2011). Seasonal variations in physicochemical properties of water in some selected locations of the Lagos Lagoon. Science World Journal, 6 (4).
24. Liu, J., Yin, P., Chen, X., Cao, K. (2019). Distribution, Enrichment and Transport of Trace Metals in Sediments from the Dagu River Estuary in the Jiaozhou Bay, Qingdao, China. Minerals, 9, 545.
25. Mahdi, Ahmed M., Doumenq P, Awaleh MO, Syakti AD, Asia L, Chiron S. (2017). Levels and sources of heavy metals and PAHs in sediment of Djibouti-city (Republic of Djibouti). Mar Pollut Bull, 120(1-2):340- 346. doi:10.1016/j.marpolbul.2017.05.055.
26. Mopper, K., Qian, J. (2006). Water Analysis: Organic Carbon Determinations, Encyclopedia of Analytical Chemistry, John Wiley & Sons, Ltd., DOI: 10.1002/9780470027318.a0884.
27. Muyideen, AS., Abiodun, IL., Ismaila, AO. (2013). Environmental impacts of sand dredging in Awoyaya, Lagos State. IISTE, Civil and Environmental Research; 3(2).
28. Nkwoji, J.A., Yakub, A.S., Abiodun, A.O., Bello, B.O. (2016). Hydrochemistry and community structure of benthic macroinvertebrates in Ilaje coastal waters, Ondo State, Nigeria. Regional Studies in Marine Science 8, 7–13, http://dx.doi.org/10.1016/j.rsma.2016.08.009.
29. Obi, CC., Adebusoye, S A., Ugoji, E O., Ilori, M O., Amund, O O., Hickey, W J. (2016). Microbial Communities in Sediments of Lagos Lagoon, Nigeria: Elucidation of Community Structure and Potential Impacts of Contamination by Municipal and Industrial Wastes. Front. Microbiol. 7:1213. doi: 10.3389/fmicb.2016.01213.
30. Olatunji-Ojo, A M., Josephine, O., Olayinka, O., Dominic, O Odedeyi., Aderotimi, A. (2019). Ecological Risk Assessment of Heavy Metals in Sediment from Oil-producing Regions of Ilaje Local Government Area of Ondo State, Nigeria. International Journal of Research and Scientific Innovation (IJRSI) | Volume VI, Issue VI.
31. Popoola, S.O., Udochu, U., Adekunbi, F.O., Nwoko, C.J., Fashade, A.O. (2015). Spatial Variations in the physicochemical parameters of some selected locations in Lagos Lagoon, South Western Nigeria, Journal of Science / Vol 5 Issue 12, pp 1354-1359.
32. Sha, Z.J.,Wang, Q.,Wang, J., Du, J., Hu, J, Ma, Y, Kong, F, Wang, Z. (2017). Regional environmental change and human activity over the past hundred years recorded in the sedimentary record of Lake Qinghai, China, Environ. Sci. Pollut. Res. Int, 24, 9662.
33. Shukla, M., Arya, S. (2018). Determination of Chloride ion (Cl^-) concentration in Ganga River

water by Mohr method at Kanpur, India. Green Chemistry & Technology Letters, 4:1, pp 06-08 https://doi.org/10.18510/gctl.2018.412.
34. Syakti, A. D., Hidayati, N. V., Hilmi, E., Piram, A., Doumenq, P. (2013). Source apportionment of sedimentary hydrocarbons in the Segara Anakan Nature Reserve, Indonesia. Marine Pollution Bulletin, 74, 141–148.
35. Tomilson, D.L, Wilson, I.J., Harris, C.R., Jeffrey,, D.W. (1980). Problem in assessment of heavy metals in estuaries and the formation of pollution index. Helgol Wiss Meeresunlter 33:566–75.
36. USEPA. (1999). National recommended water quality criteria-Correction: EPA 822/Z-99-001.
37. Wang, Z., Saito, Y., Zhan, Q., Nian, X., Pan, D., Wang, L., Chen, T., Xie, J., Li, X., Jiang, X. (2018). Three-dimensional evolution of the Yangtze River mouth, China during the Holocene: impacts of sea level, climate and human activity. Earth Sci. Rev. 185, 938–955.
38. WHO. (1990). Environmental Health Criteria 81: Vanadium [R]. World Health Organization, Geneva, pp 1–35.
39. WHO. (2004. Guidelines for drinking-water quality, 3rd ed., World Health Organization, Geneva.
40. Wu, J., Duan, D., Jian, L., Luo, Y., Wen, X., Guo, X., Boman, B.J. (2016). Inorganic pollution around the Qinghai-Tibet Plateau: An overview of the current observations. Sci. Total. Environ, 550, 628–636.
41. Xiang, J., Wang, J., Chen, L., Ling, Z., Han, J. (2019). Distribution, Source Identification, and Assessment of Potentially Toxic Elements in the Sediment Core from the Estuarine Region of the Golmud River to the Qarhan Salt Lake, Qinghai, China. Minerals 9, 506; doi: 10.3390/min9090506.
42. Yuan, X., Yange, Q., Luo, X., Yue, F., Liu, F., Li, J., Wang, Z. (2019). Distribution of grain size and organic elemental composition of the surficial sediments in Lingding Bay in the Pearl River Delta, China: A record of recent human activity. Ocean and Coastal Management. https://doi.org/10.1016/j.ocecoaman.2019.104849.

APPENDIX 1

Physiochemical Parameters of the Study Area

Station	pH	DO (mg/l)	SAL (‰)	BOD (mg/l)	TEMP (ºC)	EC (µS/m)	TDS (mg/l)
S1	6.11	5.6	25	10.6	26.3	438	216
S2	6	6	23.5	15	26.25	432	213
S3	6.55	5.5	23	13.2	27.03	259	129
S4	5.97	5.6	23	14.1	26.12	338	169
S5	6.34	5.4	10.5	9.9	26.54	304	153
S6	6.33	6.2	16	13.8	27.21	181.7	90.6
S7	6.92	6.2	15	9.3	27.06	189.1	95.8
S8	5.02	5.6	15.2	14.5	26.75	179	89
S9	6.13	6.2	14.2	12.3	26.63	182	90.7
S10	5.17	6.3	14.2	13.8	27.01	314	158
S11	5.46	2.4	13.6	13.5	26.85	451	223
S12	5.73	5.6	24.5	12.2	27.23	377	185
S13	5.55	5.6	25	12.8	27.12	313	156
S14	6.11	5.2	16	10.6	27.35	370	135
S15	6.32	5.1	16	12.8	26.93	149.3	74
S16	5.28	5	18.8	9.7	27.01	72.9	36.6
S17	6.54	5.1	18.6	13.7	27.23	129.2	63.7
S18	5.72	5.6	17.5	13.4	27.68	128.3	64.2
SI9	5.06	5.5	18	12.3	27.92	129.5	64.7
S20	6.39	5.6	10	11.9	27.98	130.3	62.3
Min	5.02	2.4	10	9.3	26.12	72.9	36.6
Max	6.92	6.3	25	15	27.98	451	223
Ave	5.935	5.465	17.88	12.47	27.01	253.365	123.43
WHO,1990	7-8.5	<5	-	-	-	250	500
FMNEV, 2001	6-9	>5	-	50	<40	-	2000

