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A comparative study of heavy metal concentrations in red seaweeds from different coastal areas of Karachi, Arabian sea

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Comparative study of heavy metals in forty species of red seaweed belonging to twenty six genera from three different coastal areas (Buleji, Paradise Point and Nathia Gali) of Karachi, Arabian Sea was carried out over the period of three years. There is high variability in metals concentration with in, seaweed species, sampling sites and collection time. Concentration of metals Mg> Fe > Mn, Zn > Cu revelas definite trend in most of the species of seaweed. This is in synonymous to the studies along the east and West Coast of India. There was great variation found in accumulation of metals at Buleji, Paradise Point and Nathia Gali. Concentrations of Mg, Ni, Zn, Cr, Pb, Co and Cd were high at Buleji as compared to Paradise Point and Nathia Gali. Accumulations of Mn and Cu were high at Paradise Point and Fe concentration was high at Nathia Gali as compared to Buleji and Paradise Point.

[**Key words:** coastal areas, heavy metals, accumulation, Karachi, pollution, seaweeds]

Introduction

Karachi is located at 24°48´N latitude and 66°59´E longitude on the northeastern border of the Arabian Sea. Its shore is muddy and rocky and have appropriate nutrients and hydrographic condition for the growth of seaweeds[1,2]. Large quantities of seaweed are washed ashore along the Karachi coast[3-5]. The red seaweeds are abundantly found at all sites of Karachi coast[3-6]. The chemical composition of seaweeds varies due to environmental change i.e., the seasons, the habitats, and depth at which they grow. Accumulation of metals in seaweed is related to their concentration present in water[7-11]. The metals are concentrated by a factor of 30,000 to 50,000 as compared to their concentration in the ambient environment[12,13]. Industrial discharges and often environmental factors may lead to metal pollution of seawater[14].

Rajendran *et al*.[15] have analyzed Mn, Fe, Cu and Zn in some red seaweed *Gracilaria*, *Grateloupia* and *Centroceras* from Tamil Nadu coast of India. Basson and Abbas[16] reported elemental composition (Mg, Fe, Cd, Cr, Co, Mn, and Ni) of *Acanthophora*, *Chondria*, *Hypnea*, *Laurencia* and *sarconema* from the Bahrain coastline (Arabian Gulf). HO[17] reports different metals in seven red intertidal macro algae in Hong Kong waters. Turkan *et al*.[18] also reported the accumulation of Cd, Pb, Zn, Cu and Fe in *Gracilaria verrucosa.* Vasquez and Guerra[19] used the red seaweed *Chondras*, *Gigartina*, *Porphyra* and *Gelidium* as bio-indicators of natural and anthropogenic contaminants in northern Chile. Recently Qari and Siddiqui[20] also studied the heavy metals concentrations in green seaweeds of the same coastal areas (Buleji, Paradise Point and Nathia Gali). The rapid growth of population and industries resulted in the problem of pollution, especially of the coastal aquatic environment of Karachi. The extent of pollution has transpired the impetus to initiate a study on the bio-deposition of heavy metals pollution in seaweeds. Present investigation was to assess the practical potential of red seaweeds as a monitor for Mg, Fe, Mn, Cu, Ni, Zn, Cr, Pb, Co and Cd. Attempts had also been done to investigate the seasonal and annual variability of metal concentrations in red seaweeds. It also consists the spatial and ecological features of red seaweeds of different coastal areas of Karachi, Arabian Sea.

Materials and Methods

Red seaweeds were sampled randomly at low tide from three shores of Karachi coast Buleji, Paradise Point and Nathia Gali over the period of three years (Fig. 1).

The rocky coast of Buleji is located near the fisherman's villages of Buleji which lies at 24°54´N and 66°48´E of Karachi, between Hawkesbay and

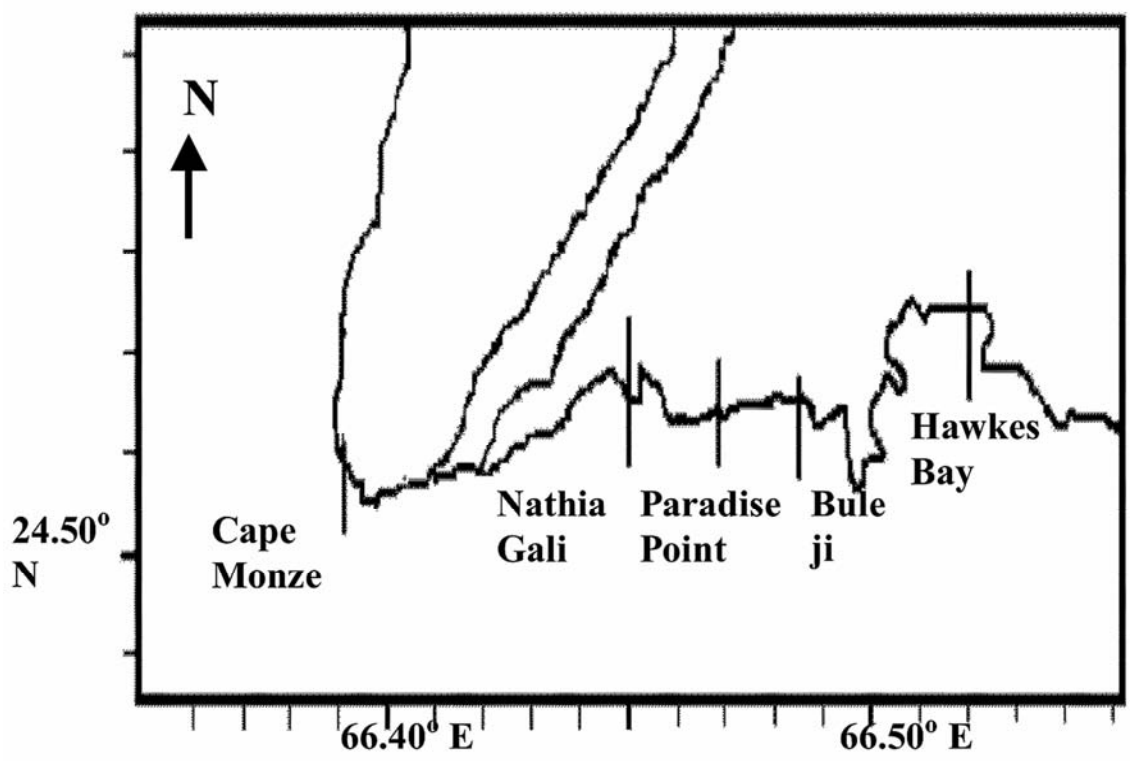

Fig. 1—Coastal area of Karachi

Paradise Point covering a distance of about 800 meter. This is a triangular rocky platform of a wave beaten shore with slightly uneven profile and protruding out in the open Arabian Sea. The Paradise Point is a recreational beach, which lies at 24°4′8′ N and 66°47′20′ E of Karachi between Nathia Gali and Buleji covering a distance of about 18 km on the west of Karachi. The coast is open to sea front and the wave action is intense all along the coast. The shore is turbulent during the southwest monsoon period. The rocky ledge of Paradise Point is mostly wave swept shore. The slope gradient of the shoreline is sharp and as a result the intertidal zone is narrow. The Karachi nuclear power plant (KANUP) is situated near the paradise point beach, with a capacity of 137 megawatt and utilizes about 0.15 millions gallons of seawater per minute for circulation through it "once through' type cooling system[21,22]. Nathia Gali is situated at 24°50′ N 66°42.5′ E on the north eastern coast of Arabian Sea. Its pale yellow jutting rocks lessen the force of the waves thus protecting the backwater beach and along with it the existing life.

All plants were carefully cleaned and dried at 70°C till constant weight. Digestion of samples was carried out by procedure of Denton and Burdon Jones[23]. 1 gram of the sample (whole plant) was digested with 4 ml concentrated nitric acid (purity = 69%) and 2 ml concentrated perchloric acid (purity = 70%) in 50 ml Teflon beaker at 80°C on a hot plate. After digestion and evaporation of acids, metal salts were re-dissolved in deionized water and the final volume was made up to 100 ml in volumetric flask. Standard for calibration were prepared in deionized water from 1mg/ml stock standard AA solution (May and Baker LTD Dagenham England). Reagents blank were treated similarly as samples using same volume of acid and deionized water. In the digested samples of seaweeds, concentrations of Mg, Fe, Mn, Cu, Ni, Zn, Cr, Pb, Co and Cd were measured by Atomic Absorption Spectrophotometer (Varian AA-20).

Results and Discussion

A total of forty species of Rhodophyceae belonging to twenty six genera were studied for the concentration of heavy metals (i.e., Mg, Fe, Mn, Cu, Ni, Zn, Cr, Pb, Co, and Cd) collected from Buleji (35), Paradise Point (34) and Nathia Gali (31). The data presented in tables 1 to 3 show the range and the mean concentration of the ten metals in all species of

Table 1—Annual mean and range of heavy metals concentration in seaweeds from Buleji, Karachi coast
(All results are in µg g^{-1} except Mg in mg g^{-1})

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
1	*Asparagopsis taxiformis*	7.421 2.66-14.4	3.090 0.35-6.6	0.085 0.008-0.3	0.035 0.013-0.062	0.029 0.01-0.07	0.063 0.02-0.29	0.059 0.015-0.26	0.194 0.034-1	0.024 0.005-0.041	0.021 0.004-0.04
2	*Bangia atropurpurea*	8.780 7.56-9.44	0.670 0.342-0.765	0.033 0.024-0.07	0.150 0.122-0.17	0.037 0.035-0.046	0.040 0.028-0.051	0.020 0.012-0.03	0.080 0.061-0.093	0.040 0.02-0.048	0.015 0.012-0.03
3	*Botryocladia leptopoda*	4.896 2.0-7.0	2.487 0.53-3.6	0.277 0.04-0.76	0.028 0.011-0.052	0.032 0.011-0.04	0.040 0.024-0.06	0.039 0.012-0.091	0.047 0.039-0.09	0.023 0.011-0.062	0.022 0.005-0.052
4	*Calliblepharis fimbriata*	4.208 3-4.63	0.435 0.36-0.5	0.042 0.04-0.043	0.006 0.004-0.01	0.040 0.04-0.041	0.041 0.04-0.043	0.020 0.012-0.038	0.050 0.047-0.052	0.042 0.04-0.043	0.049 0.047-0.05
5	*Centroceras clavulatum*	5.760 4.27-6.66	3.450 3.0-5.421	0.040 0.032-0.044	0.060 0.053-0.08	0.044 0.04-0.063	0.054 0.04-0.067	0.054 0.044-0.068	0.460 0.4-0.66	0.054 0.038-0.07	0.420 0.4-0.46
6	*Champia compressa*	6.043 3.68-8.21	1.976 0.53-3.54	0.381 0.32-0.46	0.118 0.03-0.53	0.322 0.018-0.43	0.059 0.04-0.25	0.173 0.016-0.45	0.052 0.036-0.09	0.021 0.014-0.028	0.018 0.01-0.04
7	*C. plumosa*	3.450 3.14-4.11	1.330 1.22-1.87	0.040 0.031-0.062	0.030 0.022-0.04	0.012 0.011-0.03	0.050 0.033-0.063	0.012 0.01-0.014	0.063 0.044-0.073	0.032 0.03-0.04	0.003 0.002-0.007
8	*C. salicornioides*	4.420 3.77-5.871	1.500 0.88-1.54	0.060 0.053-0.065	0.030 0.02-0.053	0.024 0.017-0.04	0.050 0.041-0.1	0.110 0.1-0.17	0.040 0.034-0.05	0.005 0.004-0.1	0.024 0.02-0.04
9	*Coelarthrum muelleri*	13.520 11.66-15.38	0.645 0.49-0.8	0.242 0.23-0.254	0.005 0.004-0.006	0.009 0.007-0.011	0.032 0.023-0.04	0.031 0.021-0.04	0.040 0.03-0.046	0.048 0.04-0.055	0.026 0.012-0.04
10	*Cystoclonium purpureum*	10.423 7.39-13.1	2.268 1.24-3.95	0.172 0.075-0.43	0.045 0.013-0.08	0.027 0.013-0.04	0.078 0.051-0.113	0.046 0.032-0.054	0.067 0.024-0.11	0.049 0.012-0.071	0.025 0.019-0.03
11	*Gelidium pusillum*	5.773 5.65-5.97	1.557 1.34-1.76	0.463 0.44-0.5	0.038 0.031-0.042	0.030 0.011-0.04	0.042 0.04-0.044	0.026 0.016-0.04	0.033 0.02-0.04	0.038 0.034-0.04	0.007 0.004-0.011
12	*G. usmanghanii*	4.128 1.26-5.76	0.635 0.38-1.1	0.024 0.122-0.37	0.033 0.008-0.053	0.033 0.017-0.04	0.045 0.016-0.063	0.027 0.014-0.04	0.074 0.04-0.124	0.032 0.024-0.037	0.020 0.006-0.04
13	*Gracilaria corticata*	4.944 2.2-7.8	1.635 0.75-4.5	0.245 0.08-0.53	0.026 0.005-0.08	0.030 0.009-0.077	0.058 0.015-0.125	0.034 0.011-0.073	0.054 0.011-0.131	0.018 0.004-0.04	0.018 0.002-0.05
14	*G. foliifera*	3.223 2.2-4	1.210 0.26-2.5	0.317 0.06-0.6	0.015 0.01-0.02	0.009 0.005-0.012	0.036 0.024-0.051	0.017 0.012-0.022	0.086 0.033-0.114	0.020 0.004-0.042	0.007 0.004-0.01
15	*G. pygmaea*	3.708 2.97-4.44	0.032 0.034-0.075	0.044 0.04-0.06	0.039 0.012-0.054	0.011 0.007-0.02	0.028 0.011-0.064	0.038 0.01-0.065	0.051 0.012-0.11	0.034 0.008-0.047	0.006 0.003-0.008

Contd—

Table 1—Annual mean and range of heavy metals concentration in seaweeds from Buleji, Karachi coast (All results are in µg g^{-1} except Mg in mg g^{-1})—*Contd*

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
16	*G. verrucosa*	2.515 2.2-2.83	0.390 0.21-0.57	0.049 0.047-0.05	0.035 0.03-0.04	0.012 0.011-0.013	0.050 0.019-0.08	0.013 0.011-0.015	0.017 0.006-0.028	0.034 0.028-0.04	0.005 0.003-0.007
17	*Halymenia porphyraeformis*	5.156 0.92-13.04	0.465 0.14-0.74	0.079 0.023-0.43	0.021 0.006-0.04	0.024 0.007-0.071	0.080 0.025-0.16	0.030 0.007-0.06	0.068 0.023-0.134	0.032 0.012-0.043	0.018 0.003-0.05
18	*Hypnea musciformis*	4.788 2.2-10	2.487 0.573-6.93	0.019 0.014-0.05	0.030 0.005-0.064	0.037 0.011-0.083	0.050 0.011-0.272	0.097 0.027-0.51	0.047 0.033-0.093	0.032 0.012-0.052	0.021 0.004-0.04
19	*H. pannosa*	3.251 1.03-5.94	1.376 0.13-3.83	0.217 0.012-0.41	0.029 0.01-0.056	0.035 0.01-0.043	0.072 0.023-0.3	0.042 0.01-0.1	0.116 0.018-0.33	0.045 0.015-0.19	0.022 0.002-0.04
20	*H. valentiae*	4.786 2.7-14.52	1.753 0.25-4.77	0.098 0.04-0.12	0.035 0.01-0.04	0.026 0.004-0.04	0.054 0.011-0.16	0.039 0.014-0.051	0.048 0.01-0.12	0.039 0.007-0.052	0.030 0.003-0.04
21	*Jania adhaerens*	6.055 5.12-7.7	0.838 0.32-2	0.160 0.11-0.3	0.004 0.003-0.006	0.043 0.023-0.05	0.030 0.023-0.033	0.032 0.02-0.065	0.108 0.061-0.15	0.047 0.022-0.057	0.021 0.006-0.05
22	*Laurencia filiformis*	3.130 4.11-5	2.500 2-3.44	0.110 0.1-0.11	0.040 0.033-0.051	0.040 0.035-0.054	0.300 0.22-0.41	0.040 0.036-0.062	0.040 0.035-0.06	0.041 0.04-0.066	0.011 0.01-0.012
23	*L . obtusa*	5.097 3.98-5.71	2.168 1.28-2.81	0.109 0.1-0.121	0.041 0.04-0.044	0.039 0.032-0.043	0.047 0.04-0.053	0.027 0.016-0.04	0.069 0.04-0.123	0.034 0.011-0.047	0.027 0.007-0.05
24	*Melanothamnus afaqhusainii*	3.407 2.11-4.37	1.430 1.11-2.5	0.133 0.12-0.153	0.017 0.011-0.02	0.010 0.01-0.012	0.034 0.03-0.042	0.051 0.042-0.057	0.200 0.19-0.32	0.040 0.034-0.065	0.002 0.001-0.004
25	*Osmundea pinnatifida*	4.110 0.9-5.61	1.501 0.51-2.4	0.121 0.012-0.243	0.036 0.008-0.051	0.033 0.01-0.04	0.072 0.016-0.11	0.034 0.01-0.061	0.037 0.015-0.11	0.029 0.01-0.062	0.011 0.003-0.022
26	*Plocamium cartilagineum*	6.295 5.82-7.55	3.460 2.9-5	0.670 0.44-0.71	0.005 0.004-0.007	0.020 0.011-0.03	0.054 0.05-0.055	0.040 0.022-0.05	0.040 0.038-0.06	0.014 0.01-0.015	0.040 0.036-0.056
27	*Polysiphonia nizamuddinii*	3.460 3.71-8.88	4.750 3.8-5.7	0.780 0.66-0.9	0.051 0.04-0.061	0.023 0.02-0.025	0.066 0.041-0.09	0.043 0.034-0.051	0.077 0.05-0.103	0.016 0.015-0.034	0.006 0.005-0.006
28	*Sarcodia dichotoma*	4.960 2.92-7.5	0.480 0.37-0.55	1.110 1.1-1.12	0.006 0.005-0.009	0.037 0.036-0.04	0.032 0.027-0.041	0.020 0.01-0.024	0.088 0.05-0.12	0.036 0.026-0.043	0.048 0.04-0.05
29	*Sarconema filiforme*	5.530 2-9.13	0.360 0.28-0.4	0.056 0.04-0.074	0.018 0.009-0.034	0.010 0.007-0.014	0.046 0.026-0.06	0.030 0.009-0.07	0.057 0.014-0.14	0.037 0.025-0.045	0.025 0.005-0.051
30	*S. scinaioides*	9.000 8.88-12.43	0.850 0.66-1.21	0.150 0.11-0.17	0.040 0.035-0.06	0.042 0.036-0.045	0.045 0.04-0.06	0.008 0.006-0.012	0.032 0.028-0.06	0.011 0.01-0.014	0.003 0.002-0.01

Contd—

Table 1—Annual mean and range of heavy metals concentration in seaweeds from Buleji, Karachi coast
(All results are in µg g^{-1} except Mg in mg g^{-1})—*Contd*

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
31	*Scinaia fascicularis*	6.440 2.2-9.53	0.805 0.04-1.11	0.078 0.031-0.23	0.127 0.007-0.341	0.035 0.015-0.05	0.104 0.011-0.632	0.031 0.006-0.09	0.069 0.007-0.12	0.036 0.008-0.045	0.026 0.003-0.052
32	*S. hatei*	6.920 3.56-9.89	1.298 0.5-2.16	0.101 0.033-0.2	0.047 0.028-0.07	0.028 0.016-0.053	0.055 0.034-0.08	0.023 0.015-0.032	0.035 0.02-0.063	0.012 0.011-0.013	0.015 0.007-0.021
33	*Sebdenia flabellata*	4.363 3.68-6.44	1.330 0.87-1.64	0.050 0.044-0.07	0.010 0.01-0.011	0.072 0.04-0.093	0.020 0.012-0.04	0.043 0.04-0.052	0.041 0.03-0.042	0.040 0.038-0.07	0.005 0.004-0.007
34	*Solieria robusta*	5.344 2.44-11.28	0.453 0.036-1.55	0.039 0.031-0.051	0.060 0.007-0.37	0.017 0.006-0.04	0.048 0.015-0.116	0.023 0.007-0.035	0.071 0.016-0.121	0.030 0.004-0.05	0.005 0.004-0.011
35	*Trichleocarpa fragilis*	4.067 2.2-6.3	1.707 0.8-2.38	0.240 0.1-0.38	0.053 0.03-0.09	0.026 0.016-0.04	0.057 0.034-0.074	0.020 0.014-0.025	0.058 0.023-0.091	0.021 0.014-0.033	0.006 0.004-0.007

Table 2—Annual mean and range of heavy metals concentration in seaweed from Paradise Point, Karachi coast
(All results in µg/g except Mg in mg/g)

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
1	*Asparagopsis taxiformis*	2.699 0.5-11	0.548 0.1-2.8	0.064 0.02-0.28	0.044 0.024-0.08	0.039 0.01-0.06	0.047 0.015-0.074	0.055 0.02-0.142	0.071 0.012-0.23	0.030 0.01-0.071	0.011 0.004-0.026
2	*Botryocladia leptopoda*	2.464 1.48-6.89	1.691 0.5-2.52	0.397 0.23-0.7	0.161 0.045-0.24	0.022 0.012-0.037	0.040 0.018-0.061	0.033 0.02-0.04	0.029 0.012-0.073	0.014 0.01-0.017	0.007 0.003-0.01
3	*Calliblepharis fimbriata*	2.660 2.11-3.21	0.367 0.3-0.4	0.323 0.23-0.41	0.040 0.038-0.05	0.042 0.04-0.046	0.049 0.047-0.05	0.030 0.02-0.04	0.046 0.043-0.05	0.040 0.036-0.11	0.050 0.045-0.055
4	*Champia compressa*	4.228 1.4-14.26	1.574 1.1-6.2	0.286 0.1-0.8	0.034 0.021-0.052	0.052 0.022-0.11	0.082 0.01-0.13	0.040 0.02-0.071	0.059 0.022-0.12	0.016 0.012-0.023	0.012 0.005-0.07
5	*C. globulifera*	2.170 2.0-3.0	1.100 1.0-1.2	0.230 0.2-0.3	0.050 0.04-0.07	0.100 0.068-0.14	0.130 0.11-0.21	0.040 0.02-0.11	0.110 0.1-0.22	0.015 0.01-0.02	0.050 0.02-0.14
6	*C. parvula*	2.632 2.43-3	1.918 1.18-2.32	0.075 0.07-0.08	0.157 0.11-0.23	0.012 0.01-0.013	0.117 0.11-0.14	0.064 0.04-0.09	0.041 0.034-0.05	0.011 0.008-0.015	0.005 0.004-0.005
7	*C. plumosa*	2.022 1.54-2.62	2.872 0.64-6.12	0.147 0.06-0.32	0.016 0.01-0.03	0.017 0.01-0.022	0.191 0.073-0.28	0.045 0.02-0.09	0.018 0.015-0.022	0.010 0.008-0.01	0.014 0.004-0.02
8	*C. salicornioides*	2.747 2.33-3.11	0.433 0.4-0.5	0.143 0.14-0.15	0.025 0.017-0.03	0.013 0.012-0.013	0.057 0.055-0.06	0.012 0.011-0.012	0.030 0.02-0.07	0.010 0.006-0.02	0.010 0.004-0.02
9	*Coelarthrum muelleri*	0.806 0.73-0.88	3.918 2.58-4.4	0.228 0.22-0.24	0.158 0.05-0.27	0.012 0.011-0.019	0.193 0.11-0.23	0.019 0.011-0.021	0.063 0.04-0.08	0.010 0.004-0.018	0.005 0.004-0.005

Contd—

Table 2—Annual mean and range of heavy metals concentration in seaweed from Paradise Point, Karachi coast (All results in µg/g except Mg in mg/g)—*Contd*

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
		9.182	0.633	0.086	0.012	0.023	0.026	0.040	0.112	0.012	0.012
10	*Dermonerma abbottiae*	5.34-14	0.4-1.8	0.063-0.1	0.01-0.013	0.02-0.027	0.013-0.034	0.01-0.077	0.074-0.24	0.011-0.015	0.009-0.02
		3.195	2.565	0.330	0.076	0.021	0.044	0.016	0.070	0.012	0.007
11	*Gelidium pusillum*	2.11-4.28	1.53-3.6	0.1-0.56	0.071-0.08	0.012-0.03	0.02-0.068	0.015-0.018	0.04-0.1	0.01-0.14	0.004-0.01
		0.921	0.432	0.204	0.034	0.022	0.029	0.029	0.041	0.013	0.015
12	*Gelidium usmanghanii*	0.33-1.84	0.3-0.6	0.02-0.76	0.011-0.06	0.012-0.052	0.018-0.044	0.015-0.056	0.007-0.021	0.006-0.021	0.004-0.038
		1.732	1.185	0.346	0.045	0.032	0.061	0.038	0.061	0.016	0.007
13	*Gracilaria corticata*	0.173-5.6	0.18-3.1	0.063-1.04	0.01-0.154	0.01-0.12	0.02-0.23	0.011-0.123	0.02-0.25	0.01-0.072	0.003-0.018
		1.908	1.339	0.160	0.016	0.017	0.047	0.048	0.085	0.013	0.006
14	*G. foliifera*	0.95-5	0.27-3.7	0.05-1	0.011-0.03	0.01-0.06	0.02-0.13	0.008-0.14	0.01-0.23	0.01-0.025	0.004-0.01
		3.272	1.192	0.202	0.090	0.018	0.026	0.017	0.195	0.016	0.012
15	*G. pygmaea*	0.71-7.53	0.15-2.33	0.13-0.53	0.032-0.32	0.01-0.022	0.01-0.033	0.011-0.05	0.027-1.1	0.01-0.031	0.003-0.04
		4.850	0.712	0.101	0.018	0.031	0.025	0.041	0.115	0.015	0.009
16	*G. verrucosa*	3-10.7	0.3-1.58	0.046-0.154	0.01-0.052	0.01-0.06	0.016-0.04	0.02-0.1	0.01-0.23	0.006-0.031	0.003-0.011
		1.358	0.288	0.090	0.090	0.024	0.092	0.035	0.028	0.010	0.008
17	*Halymenia porphyraeformis*	1-1.7	0.2-1.1	0.052-0.11	0.012-0.15	0.01-0.05	0.026-0.2	0.015-0.04	0.02-0.054	0.008-0.011	0.003-0.031
		1.336	0.986	0.172	0.029	0.046	0.074	0.034	0.087	0.013	0.011
18	*Hypnea musciformis*	0.89-3.37	0.011-3.54	0.01-0.052	0.045-0.482	0.013-0.066	0.013-0.314	0.01-0.087	0.02-0.11	0.01-0.038	0.004-0.02
		4.319	2.698	0.277	0.042	0.029	0.108	0.023	0.051	0.015	0.006
19	*H. pannosa*	1.33-8.6	1.1-5.13	0.021-1.1	0.011-0.101	0.015-0.054	0.03-0.27	0.02-0.04	0.03-0.1	0.01-0.03	0.004-0.01
		2.050	1.180	0.346	0.070	0.024	0.049	0.044	0.074	0.015	0.006
20	*H. valentiae*	0.7-5.82	0.2-5.32	0.035-1	0.022-0.33	0.009-0.07	0.016-0.17	0.011-0.31	0.022-0.23	0.006-0.042	0.003-0.02
		1.190	0.740	0.071	0.022	0.110	0.029	0.024	0.205	0.022	0.020
21	*Jania adhaerens*	1.18-1.2	0.63-0.85	0.066-0.076	0.02-0.024	0.1-0.12	0.028-0.03	0.02-4	0.19-0.22	0.02-0.023	0.01-0.05
		1.705	1.539	0.297	0.039	0.041	0.037	0.044	0.080	0.012	0.018
22	*Laurencia obtusa*	1.3-2.41	0.96-4.1	0.052-0.8	0.022-0.06	0.014-0.05	0.03-0.043	0.012-0.17	0.03-0.11	0.01-0.0.015	0.002-0.04
		1.338	4.810	0.029	0.039	0.011	0.061	0.026	0.175	0.025	0.021
23	*Melanothamnus afaqhusainii*	0.87-1.84	3.17-7.3	0.02-0.044	0.015-0.06	0.01-0.013	0.043-0.1	0.021-0.03	0.13-0.24	0.01-0.04	0.008-031
		3.674	1.390	0.291	0.024	0.034	0.042	0.086	0.092	0.020	0.012
24	*Osmundea pinnatifida*	1.2-9.5	0.73-3.1	0.084-0.8	0.01-0.04	0.016-0.064	0.02-0.06	0.016-0.17	0.012-0.23	0.01-0.04	0.004-0.06
		1.925	3.963	0.353	0.130	0.022	0.218	0.030	0.054	0.015	0.005
25	*Plocamium cartilagineum*	1.22-2.54	1.2-5.25	0.15-0.8	0.1-0.2	0.02-0.029	0.2-0.23	0.011-0.07	0.024-0.07	0.013-0.018	0.004-0.007
		1.555	5.008	0.880	0.036	0.054	0.091	0.041	0.129	0.018	0.009
26	*Polysiphonia nizamuddinii*	1.4-1.7	4.55-5.6	0.3-1.57	0.02-0.042	0.011-0.144	0.05-0.191	0.012-0.09	0.044-0.21	0.012-0.021	0.004-0.013
		1.900	4.770	0.088	0.018	0.020	0.072	0.060	0.250	0.022	0.006
27	*Porphyra vietnamensis*	1.5-2.0	4-6.1	0.073-0.11	0.011-0.02	0.018-0.03	0.044-0.12	0.044-0.11	0.2-0.3	0.02-0.03	0.006-0.008
		1.860	0.550	0.120	0.040	0.040	0.030	0.011	0.120	0.041	0.040
28	*Sarcodia dichotoma*	1.34-2.4	0.5-0.56	0.11-0.14	0.035-0.044	0.02-0.11	0.011-0.016	0.006-0.12	0.083-0.2	0.012-0.048	0.004-0.044

Contd—

Table 2—Annual mean and range of heavy metals concentration in seaweed from Paradise Point, Karachi coast
(All results in µg/g except Mg in mg/g)—*Contd*

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
		2.224	0.389	0.049	0.023	0.014	0.040	0.010	0.124	0.005	0.005
29	*Sarconema filiforme*	1.88-2.91	0.313-0.44	0.006-0.065	0.01-0.026	0.01-0.02	0.03-0.043	0.01-0.011	0.11-0.22	0.004-0.006	0.004-0.007
		2.000	12.600	0.090	0.012	0.010	0.060	0.014	0.030	0.011	0.010
30	*S. scinioides*	1.65-2.1	5.78-15	0.06-011	0.01-0.014	0.006-0.02	0.04-0.12	0.01-0.02	0.011-0.034	0.011-0.011	0.006-0.012
		2.103	2.845	0.104	0.051	0.040	0.050	0.020	0.104	0.013	0.008
31	*Scinaia fascicularis*	0.93-3.87	0.26-6.66	0.04-0.26	0.007-0.15	0.01-0.07	0.02-0.14	0.01-0.03	0.034-0.24	0.005-0.04	0.004-0.011
		2.155	1.649	0.148	0.037	0.025	0.026	0.022	0.058	0.017	0.007
32	*S. hatei*	1-2.7	0.85-4.5	0.08-0.3	0.03-0.046	0.011-0.04	0.01-0.037	0.017-0.04	0.011-0.3	0.011-0.024	0.004-0.011
		0.870	0.405	0.215	0.049	0.012	0.037	0.306	0.020	0.011	0.010
33	*S. saifullahii*	0.83-0.91	0.4-0.41	0.21-0.22	0.048-0.05	0.01-0.015	0.034-0.04	0.3-0.312	0.01-0.03	0.006-0.02	0.004-0.011
		6.340	0.041	0.095	0.147	0.011	0.027	0.005	0.021	0.010	0.005
34	*Solieria robusta*	5.4-9.17	0.03-.06	0.087-.0.1	0.133-0.16	0.01-0.012	0.016-0.03	0.004-0.01	0.012-0.06	0.01-0.011	0.002-0.01

Table 3—Annual mean and range of heavy metals concentration in seaweed from Nathia Gali, Karachi coast
(All results in µg/g except Mg in mg/g)

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
		3.229	2.504	0.590	0.035	0.026	0.040	0.031	0.045	0.080	0.013
1	*Botryocladia leptopoda*	0.043-9.29	1.11-5.4	0.15-1.16	0.011-0.065	0.01-0.041	0.011-0.073	0.008-0.223	0.012-0.11	0.014-0.2	0.003-0.028
		3.870	0.370	0.049	0.005	0.038	0.040	0.042	0.042	0.039	0.047
2	*Calliblepharis fimbriata*	3.63-4.11	0.34-0.4	0.043-0.056	0.004-0.005	0.036-0.04	0.02-0.056	0.04-0.043	0.041-0.042	0.037-0.04	0.043-0.05
		2.548	0.420	0.111	0.014	0.013	0.039	0.021	0.040	0.010	0.013
3	*Champia compressa*	1-4.72	0.04-0.9	0.04-0.212	0.003-0.02	0.01-0.021	0.031-0.04	0.012-0.036	0.023-0.11	0.008-0.011	0.004-0.03
		2.435	6.790	0.125	0.051	0.026	0.050	0.020	0.088	0.013	0.006
4	*C. plumosa*	2-2.87	6.58-7	0.1-0.15	0.041-0.06	0.022-0.03	0.02-0.08	0.013-0.026	0.032-0.143	0.011-0.014	0.003-0.008
		4.100	1.250	0.052	0.031	0.020	0.045	0.022	0.040	0.006	0.020
5	*C. salicornioides*	4-4.2	1.2-1.3	0.05-0.054	0.03-0.032	0.011-0.023	0.04-0.05	0.02-0.024	0.032-0.063	0.005-0.006	0.011-0.022
		4.775	1.057	0.264	0.012	0.014	0.017	0.033	0.041	0.012	0.011
6	*Coelarthrum murelli*	4-8.2	0.087-2.5	0.05-0.65	0.007-0.02	0.01-0.036	0.011-0.044	0.007-0.16	0.013-0.063	0.011-0.02	0.007-0.012
		1.430	4.703	1.108	0.113	0.024	0.046	0.023	0.027	0.016	0.004
7	*Cystoclonium purpureum*	0.9-2.64	4.23-5.95	1.1-1.11	0.11-0.12	0.020-0.034	0.04-0.062	0.02-0.027	0.02-0.035	0.011-0.03	0.002-0.011
		4.815	0.667	0.051	0.016	0.018	0.190	0.038	0.052	0.016	0.011
8	*Gelidium pusillum*	4.73-4.9	0.333-1	0.04-0.062	0.01-0.021	0.012-0.024	0.17-0.21	0.034-0.041	0.029-0.075	0.01-0.021	0.01-0.012
		5.930	0.490	0.041	0.020	0.037	0.036	0.021	0.032	0.036	0.011
9	*G. usmanghanii*	5.66-6.56	0.44-0.68	0.04-0.043	0.02-0.022	0.032-0.04	0.03-0.04	0.02-0.021	0.031-0.033	0.033-0.04	0.011-0.012
		4.078	0.926	0.286	0.014	0.028	0.040	0.028	0.083	0.012	0.018
10	*Gracilaria corticata*	0.026-11.66	0.073-2.67	0.04-0.763	0.003-0.021	0.01-0.06	0.01-0.065	0.014-0.08	0.04-0.14	0.004-0.024	0.003-0.04

Contd–

Table 3—Annual mean and range of heavy metals concentration in seaweed from Nathia Gali, Karachi coast (All results in µg/g except Mg in mg/g)—*Contd*

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
		4.210	1.442	0.496	0.014	0.011	0.022	0.029	0.095	0.012	0.005
11	*G. foliifera*	0.34-5.91	0.4-3.7	0.13-0.9	0.002-0.03	0.008-0.014	0.011-0.032	0.016-0.056	0.013-0.13	0.006-0.02	0.003-0.007
		5.039	2.383	0.139	0.019	0.025	0.021	0.029	0.068	0.012	0.009
12	*G. pygmaea*	4-13.32	0.038-4.6	0.04-0.44	0.005-0.033	0.003-0.111	0.011-0.081	0.005-0.253	0.031-0.373	0.01-0.021	0.003-0.014
		0.370	0.361	0.120	0.021	0.008	0.029	0.009	0.021	0.009	0.021
13	*G. varrucosa*	0.3-0.4	0.071-0.724	0.071-0.15	0.004-0.05	0.005-0.01	0.02-0.034	0.005-0.011	0.007-0.054	0.005-0.013	0.009-0.033
		2.941	0.371	0.108	0.023	0.043	0.026	0.014	0.069	0.012	0.024
14	*Halymenia porphyraeformis*	0.38-7.7	0.2-0.89	0.04-0.262	0.01-0.04	0.013-0.078	0.01-0.044	0.011-0.042	0.03-0.092	0.01-0.024	0.006-0.053
		3.475	1.346	0.106	0.140	0.026	0.119	0.034	0.050	0.013	0.009
15	*Hypnea musciformis*	0.49-8.6	0.2-2.62	0.021-0.3	0.1-0.51	0.011-0.083	0.02-0.31	0.011-0.083	0.02-0.14	0.004-0.034	0.003-0.03
		1.327	2.262	0.124	0.125	0.043	0.036	0.059	0.083	0.026	0.013
16	*H. pannosa*	0.72-2.51	1.04-5.1	0.021-0.2	0.1-0.16	0.012-0.06	0.02-0.102	0.009-0.132	0.033-0.15	0.01-0.046	0.004-0.021
		0.925	0.463	0.141	0.043	0.016	0.030	0.012	0.098	0.010	0.029
17	*H. valentiae*	0.4-2.3	0.2-2.54	0.02-0.35	0.02-0.062	0.011-0.043	0.008-0.041	0.008-0.032	0.008-0.11	0.009-0.021	0.003-0.042
		3.086	3.123	0.245	0.010	0.027	0.046	0.033	0.090	0.027	0.016
18	*Jania adhaerens*	2-6.3	0.02-6.43	0.01-0.452	0.006-0.014	0.014-0.052	0.01-0.2	0.011-0.072	0.05-0.161	0.011-0.091	0.004-0.04
		4.664	2.225	0.052	0.013	0.011	0.025	0.011	0.020	0.016	0.006
19	*Laurencia obtusa*	2.2-7.37	2.0-2.58	0.04-0.084	0.011-0.027	0.01-0.011	0.02-0.08	0.008-0.015	0.011-0.081	0.011-0.07	0.003-0.011
		2.110	2.500	0.120	0.032	0.020	0.033	0.011	0.030	0.010	0.011
20	*Melanothamnus afaqhusainii*	2-4.32	1.11-3.68	0.11-0.18	0.02-0.05	0.011-0.056	0.021-0.11	0.007-0.02	0.02-0.04	0.004-0.011	0.004-0.02
		1.780	1.145	0.134	0.020	0.013	0.029	0.015	0.108	0.008	0.006
21	*Osmundea pinnatifida*	1.1-5.12	0.4-4.75	0.01-0.56	0.005-0.041	0.011-0.024	0.018-0.1	0.011-0.02	0.033-0.13	0.005-0.011	0.004-0.015
		3.237	3.167	0.043	0.005	0.047	0.020	0.032	0.044	0.010	0.011
22	*Plocamium cartilagineum*	3.1-3.5	3.0-3.3	0.04-0.05	0.004-0.007	0.04-0.06	0.014-0.051	0.025-0.04	0.04-0.051	0.01-0.011	0.01-0.011
		1.189	2.103	0.101	0.085	0.015	0.043	0.027	0.067	0.021	0.008
23	*Polysiphonia nizamuddinii*	1.11-1.74	2-2.32	0.01-0.11	0.004-0.121	0.01-0.035	0.008-0.07	0.02-0.05	0.04-0.15	0.02-0.022	0.006-0.015
		1.693	0.204	0.041	0.010	0.030	0.017	0.031	0.040	0.011	0.011
24	*Sarcodia dichotoma*	1.6-1.87	0.2-0.214	0.022-0.06	0.006-0.012	0.011-0.08	0.011-0.02	0.028-0.032	0.021-0.056	0.01-0.011	0.01-0.012
		5.910	0.752	0.093	0.016	0.027	0.018	0.026	0.051	0.021	0.007
25	*Sarconema filiforme*	0.43-8.52	0.011-1.71	0.063-0.111	0.003-0.041	0.007-0.032	0.01-0.025	0.015-0.038	0.015-0.1	0.003-0.04	0.005-0.009
		4.883	0.440	0.538	0.018	0.018	0.050	0.022	0.043	0.018	0.078
26	*Sciania fascicularis*	0.5-12.57	0.013-2.22	0.05-1.12	0.01-0.08	0.006-0.07	0.012-0.24	0.013-0.042	0.014-0.122	0.005-0.024	0.004-1
		5.028	3.620	0.182	0.028	0.024	0.043	0.023	0.056	0.020	0.013
27	*S. hattei*	1.01-8.7	1.16-10.85	0.082-0.333	0.013-0.044	0.014-0.03	0.033-0.07	0.02-0.024	0.04-0.063	0.012-0.025	0.005-0.015

Contd—

Table 3—Annual mean and range of heavy metals concentration in seaweed from Nathia Gali, Karachi coast
(All results in µg/g except Mg in mg/g)—*Contd*

S. No.	Name of species	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
		5.810	0.353	0.071	0.008	0.011	0.026	0.137	0.068	0.013	0.008
28	*S. saifullahii*	5-6.32	0.32-0.41	0.04-0.134	0.004-0.013	0.011-0.012	0.023-0.032	0.021-0.361	0.02-0.143	0.01-0.02	0.006-0.01
		2.200	0.217	1.160	0.011	0.011	0.210	0.017	0.012	0.011	0.012
29	*Sebdenia flabellata*	2-2.4	0.033-0.4	1.11-1.21	0.01-0.012	0.004-0.033	0.2-0.22	0.014-0.02	0.011-0.012	0.01-0.014	0.011-0.013
		4.069	0.397	0.119	0.014	0.042	0.044	0.024	0.035	0.013	0.004
30	*Solieria robusta*	3.82-4.55	0.027-0.7	0.08-0.16	0.007-0.02	0.023-0.09	0.03-0.08	0.02-0.042	0.013-0.04	0.011-0.031	0.003-0.006
		2.416	2.411	0.107	0.022	0.020	0.026	0.022	0.055	0.016	0.010
31	*Trichleocarpa fragilis*	2-3.1	1.11-4.9	0.04-0.15	0.02-0.03	0.015-0.026	0.018-0.066	0.014-0.031	0.04-0.1	0.011-0.022	0.004-0.011

seaweed samples, collected from Buleji, Paradise Point and Nathia Gali respectively. The data reveals high variability in metals (Mg, Fe, Mn, Cu, Ni, Zn, Cr, Pb, Co and Cd) concentration in seaweed along the Karachi coast within and between seaweed species, sampling sites and collection time.

The concentration of metals were found to vary from 0.026-15.38 mg g^{-1} for Mg, 0.011-12.6 µg g^{-1} for Fe, 0.006-1.57 µg g^{-1} for Mn, 0.002-0.8 µg g^{-1} for Cu, 0.003-0.43 µg g^{-1} for Ni, 0.008-0.632 µg g^{-1} for Zn, 0.004-4 µg g^{-1} for Cr, 0.006-1.1 µg g^{-1} for Pb, 0.003-0.2 µg g^{-1} for Co and 0.002-0.42 µg g^{-1} for Cd at the three sites Buleji, Paradise Point and Nathia Gali (Tables 1-3). The metal distribution patterns in decreasing order was Mg> Fe> Cr> Mn> Pb> Cu> Zn> Ni > Cd > Co.

There was great variation found in accumulation of metals at Buleji, Paradise Point and Nathia Gali. The concentrations of Mg (5.54 mg g^{-1}), Ni (0.037 µg g^{-1}), Zn (0.06 µg g^{-1}), Cr (0.04 µg g^{-1}), Pb (0.109 µg g^{-1}), Co (0.032 µg g^{-1}) and Cd (0.024 µg g^{-1}) were high at Buleji as compared to Paradise Point and Nathia Gali (Table 4). While at Paradise Point the accumulations of Mn (0.24 µg g^{-1}) and Cu (0.048 µg g^{-1}) and at Nathia Gali Fe (2.07 µg g^{-1}) were high as compared to Buleji (Table 5-6).

The Mg and Pb concentrations were high in July. Whereas Fe and Cr concentrations were high in October and August, respectively (Fig. 2). The Mn concentrations were decreasing from January to December. The concentration of Ni decreased from January to June and then increased till September and then again decreased and it became high in December. The concentrations of Co showed nearly the opposite pattern that of Ni. The concentrations of Cd increased from January to May and it decreased till August and then again increased till it was low in December (Fig. 2). The concentrations of Mg, Fe and Cu increased from 1989 to 1991 . The concentration of Ni decreased from 1989 to 1991. The concentrations of Mn, Zn, Cr, Pb and Cd were low in 1990 and the concentrations of Co were high in 1990 (Fig. 3). Comparatively the concentration of Mg, Ni, Zn, Cr,

Table 4—Variability and Confidence intervals of metals in red seaweeds for Buleji coast
(All metals are in µg g^{-1} except Mg in mg g^{-1})

Variable	N	Mean	StDev	SE Mean	95.0 % CI
Mg	36	5.540	1.708	0.285	(4.962, 6.118)
Fe	36	1.555	0.423	0.071	(1.411, 1.698)
Mn	36	0.174	0.075	0.013	(0.148, 0.198)
Cu	36	0.044	0.019	0.003	(0.038, 0.050)
Ni	36	0.037	0.013	0.002	(0.032, 0.041)
Zn	36	0.060	0.027	0.005	(0.051, 0.069)
Cr	36	0.040	0.012	0.002	(0.036, 0.044)
Pb	36	0.109	0.134	0.022	(0.064, 0.154)
Co	36	0.032	0.007	0.001	(0.029, 0.034)
Cd	36	0.024	0.017	0.003	(0.018, 0.029)

Table 5—Variability and Confidence intervals of metals in red seaweeds for Paradise Point coast
(All metals are in µg g^{-1} except Mg in mg g^{-1})

Variable	N	Mean	StDev	SE Mean	95.0 % CI
Mg	36	3.399	1.778	0.310	(2.768, 4.030)
Fe	36	1.517	0.481	0.084	(1.346, 1.687)
Mn	36	0.243	0.061	0.011	(0.221, 0.264)
Cu	36	0.048	0.017	0.003	(0.042, 0.054)
Ni	36	0.030	0.009	0.002	(0.026, 0.033)
Zn	36	0.053	0.019	0.003	(0.046, 0.059)
Cr	36	0.038	0.010	0.002	(0.034, 0.041)
Pb	36	0.076	0.030	0.005	(0.065, 0.086)
Co	36	0.017	0.005	0.001	(0.015, 0.019)
Cd	36	0.011	0.003	0.001	(0.010, 0.012)

Pb, Co and Cd were high at Buleji, Cu concentrations were high at Paradise Point and Fe, Mn concentrations were high at Nathia Gali (Fig. 4).

Among the 40 species studied, the accumulation of different metals was comparatively different in different algal species at the different sites (Table 7). The highest concentration of Mg was found in *Coelarthrum muelleri* (13.52 mg g^{-1}) at Buleji, *Dermonema abbottiae* (9.182 mg g^{-1}) at Paradise Point and *Geliadium usmanghanii* (5.93 mg g^{-1}) and *Scinaia saifullahii* (5.91 mg g^{-1}) at Nathia Gali amongst the other species (Table 1-3 and 7). *S. saifullahii* also showed the highest concentration of Cr with the mean value of 0.306µg g^{-1} at Paradise Point and 0.137 µg g^{-1} at Nathia Gali (Table 2, 3 and 7). *S. hatei* another species of Scinaia has the highest concentration of Co (0.12 µg g^{-1}) at Buleji (Table 1 and 7). *Polysiphonia nizamuddinii* showed highest concentration of Fe (4.75µg g^{-1}) at Buleji and Mn (0.88 µg g^{-1}) at Paradise Point as compare to other species (Table 1, 2 and 7). The highest concentration of Mn was found in *Sarcodia dichotoma* at Buleji with the mean value of 1.11 µg g^{-1} and Co at Paradise Point with the mean value of 0.041 µg g^{-1} (Table 1, 2 and 7). Cu was found high in *Gracilaria pygmaea* at Buleji with the mean value of 0.39 µg g^{-1} (Table 1 and 7). The highest concentration of Ni (0.322 µg g^{-1}) and Cr (0.173 µg g^{-1}) were found in *Champia compressa* at Buleji and Cd (0.05 µg g^{-1}) in *C. globulifera* at Paradise Point. Fe concentrations (6.79 µg g^{-1}) were highest in *C. plumosa* at Nathia Gali (Table 1-3 and 7). *Laurencia filiformis* showed the highest concentrations of Zn (0.3 µg g^{-1}) and *Centroceras clavulatum* has the highest concentrations of Pb (0.46 µg g^{-1}) and Cd (0.42 µg g^{-1}) at Buleji (Table 1 and 7). Maximum concentration of Fe (12.6 µg g^{-1}) was found in *Sarconema scinaioides* at Paradise Point (Table 2 and 7). *Botryocladia leptopoda* had the highest concentrations of Cu with the mean value of 0.161µg g^{-1} at Paradise Point Co with the mean value of 0.08 µg g^{-1} at Nathia Gali (Table 2, 3 and 7). *Jania adhaerens* showed the highest concentrations of Ni with the mean value of 0.11 µg g^{-1} and *Plocamium cartilagineum* showed high concentrations of Zn with the mean value of 0.218 µg g^{-1} at Paradise Point (Table 2 and 7). Concentrations of Pb were high in *Porphyra vietnamensis* with the mean value of 0.25 µg g^{-1}. High value of Co and Cd were found in *Calliblepharis fimbriata* with the mean values of 0.04 µg g^{-1} 0.05 µg g^{-1}, respectively at Paradise Point (Table 2 and 7). Highest concentrations of Mn were found in *Sebdenia flabellata* with the mean value of 1.16 µg g^{-1}, Cu were found in *Hypnea musciformis* with the mean value of 0.14 µg g^{-1} and Ni were found in *H. pannosa* and *Halymenia porphyraeformis* with the mean value of 0.043 µg g^{-1}, respectively at Nathia Gali (Table 3 and 7).

Table 6—Variability and Confidence intervals of metals in red seaweeds for Nathia Gali coast

(All metals are in µg g^{-1} except Mg in mg g^{-1})

Variable	N	Mean	StDev	SE Mean	95.0 % CI
Mg	36	3.685	1.148	0.191	(3.296, 4.073)
Fe	36	2.077	2.055	0.342	(1.382, 2.772)
Mn	36	0.215	0.056	0.009	(0.195, 0.234)
Cu	36	0.035	0.013	0.002	(0.030, 0.039)
Ni	36	0.029	0.014	0.002	(0.024, 0.033)
Zn	36	0.038	0.014	0.002	(0.033, 0.042)
Cr	36	0.037	0.031	0.005	(0.026, 0.047)
Pb	36	0.075	0.037	0.006	(0.062, 0.087)
Co	36	0.02231	0.01076	0.00179	(0.018, 0.025)
Cd	36	0.01997	0.02166	0.00361	(0.012, 0.027)

The completely randomized design with nested treatments analysis of variance (ANOVA) model

Table 7—List of species that accumulated highest concentration of different heavy metals at the study sites of Karachi coast

	Buleji	Paradise Point	Nathia Gali
Mg	*Coelarthrum muelleri*	*Dermonerma abbottiae*	*Gelidium. Usmanghanii and Sarconema filiforme*
Fe	*Polysiphonia nizamuddinii*	*Sarconema scinaioides*	*Champia plumosa*
Mn	*Sarcodia dichotoma*	*Polysiphonia nizamuddinii*	*Sebdenia flabellata*
Cu	*Gracilaria pygmaea*	*Botryocladia leptopoda*	*Hypnea musciformis*
Ni	*Champia compressa*	*Jania adhaerens*	*Halymenia porphyraeformis and Hypnea pannosa*
Zn	*Laurencia filliformis*	*Plocamium cartilagineum*	*Sebdenia flabellata*
Cr	*Champia compressa*	*Scinaia saifullahii*	*Scinaia saifullahii*
Pb	*Centroceras clavulatum*	*Porphyra vietnamensis*	*Osmundea pinnatifida*
Co	*Scinaia hatei*	*S. dichotoma and C. fimbriata*	*Botryocladia leptopoda*
Cd	*Centroceras clavulatum*	*Champia globulifera and C. fimbriata*	*Calliblepharis fimbriata*

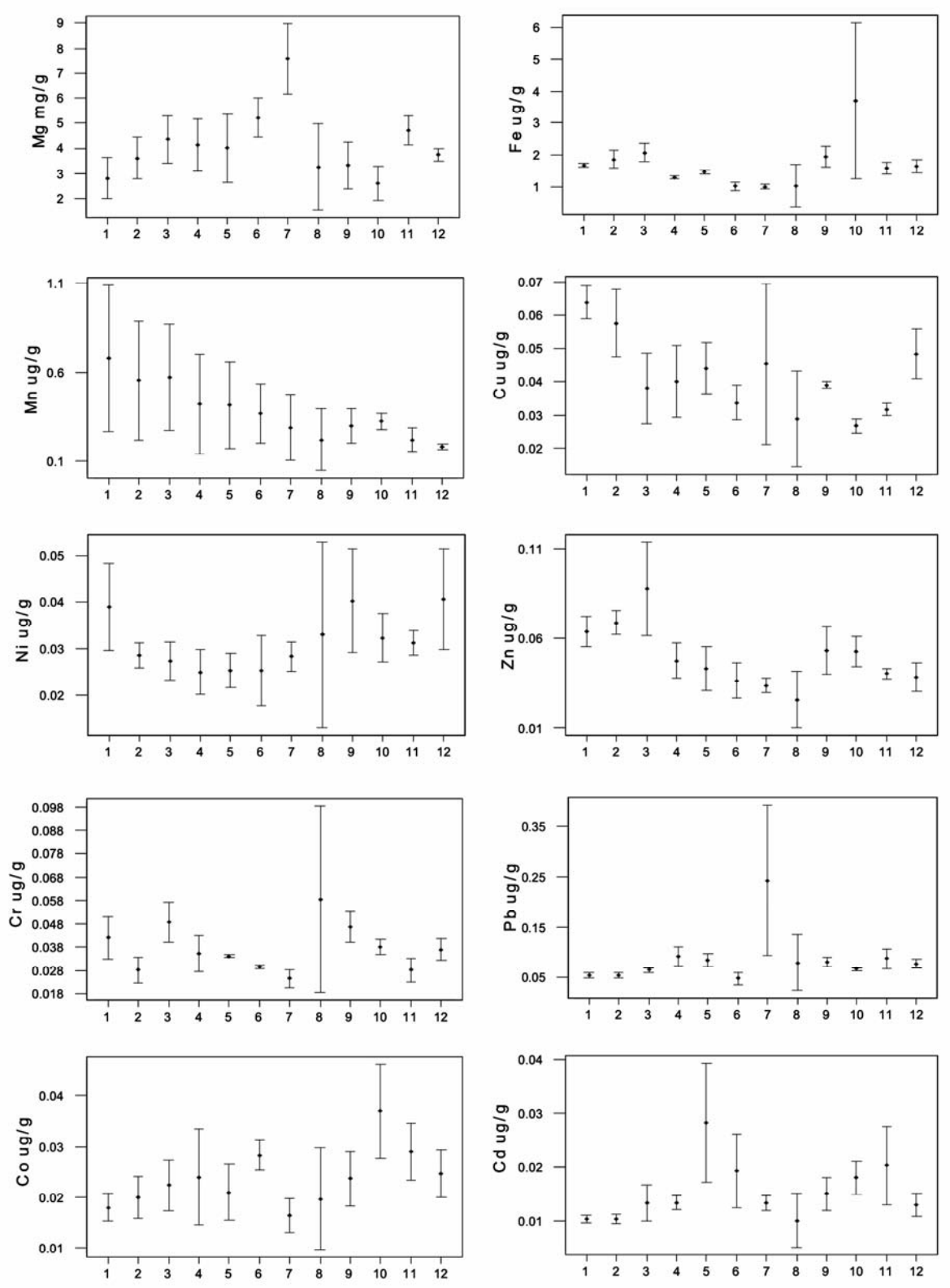

Fig. 2—Monthly variation in heavy metals of red seaweed from Buleji, Paradise Point and Nathia Gali of Karachi coast.

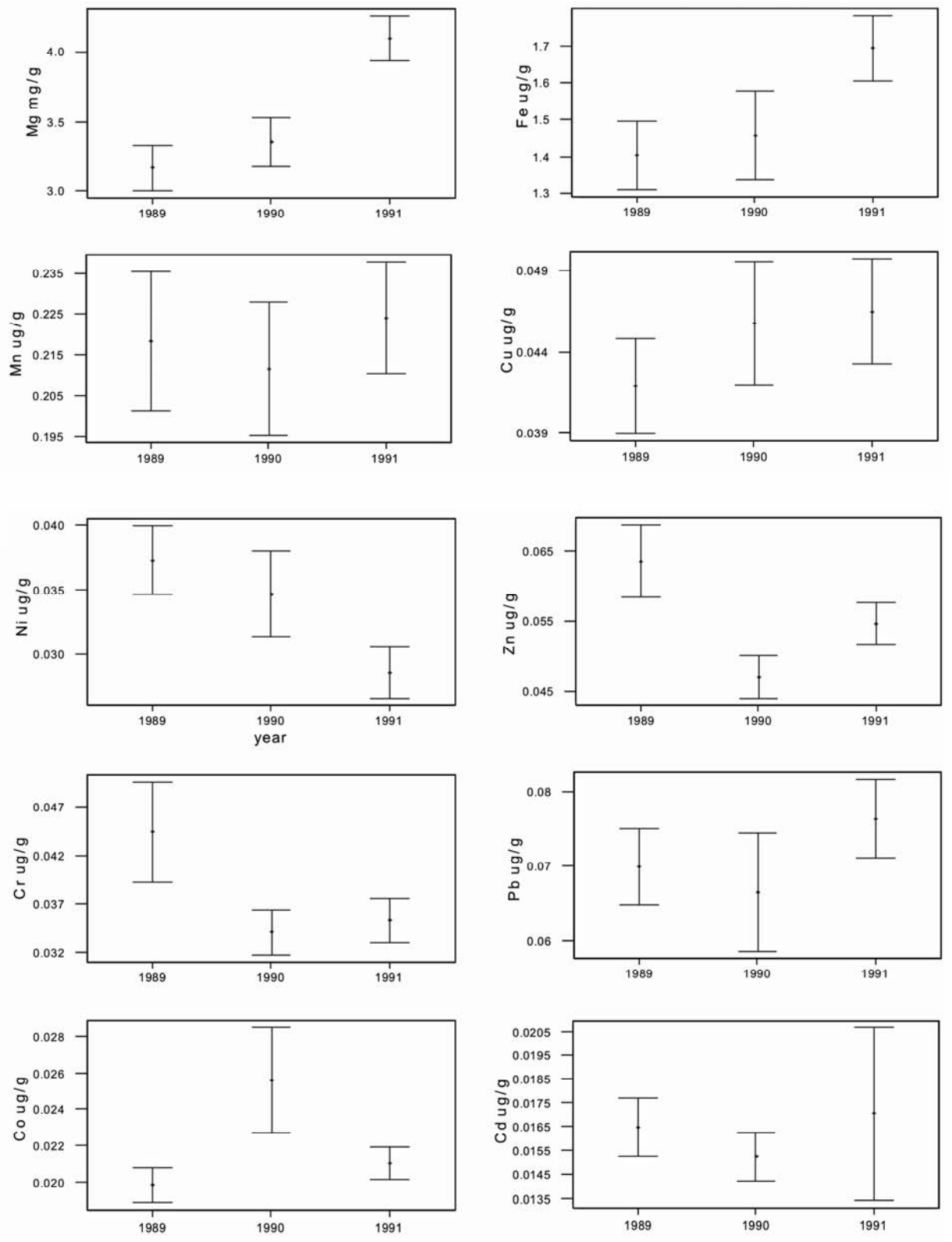

Fig. 3—Interannual variation in heavy metals of red seaweed in different years at Karachi coast.

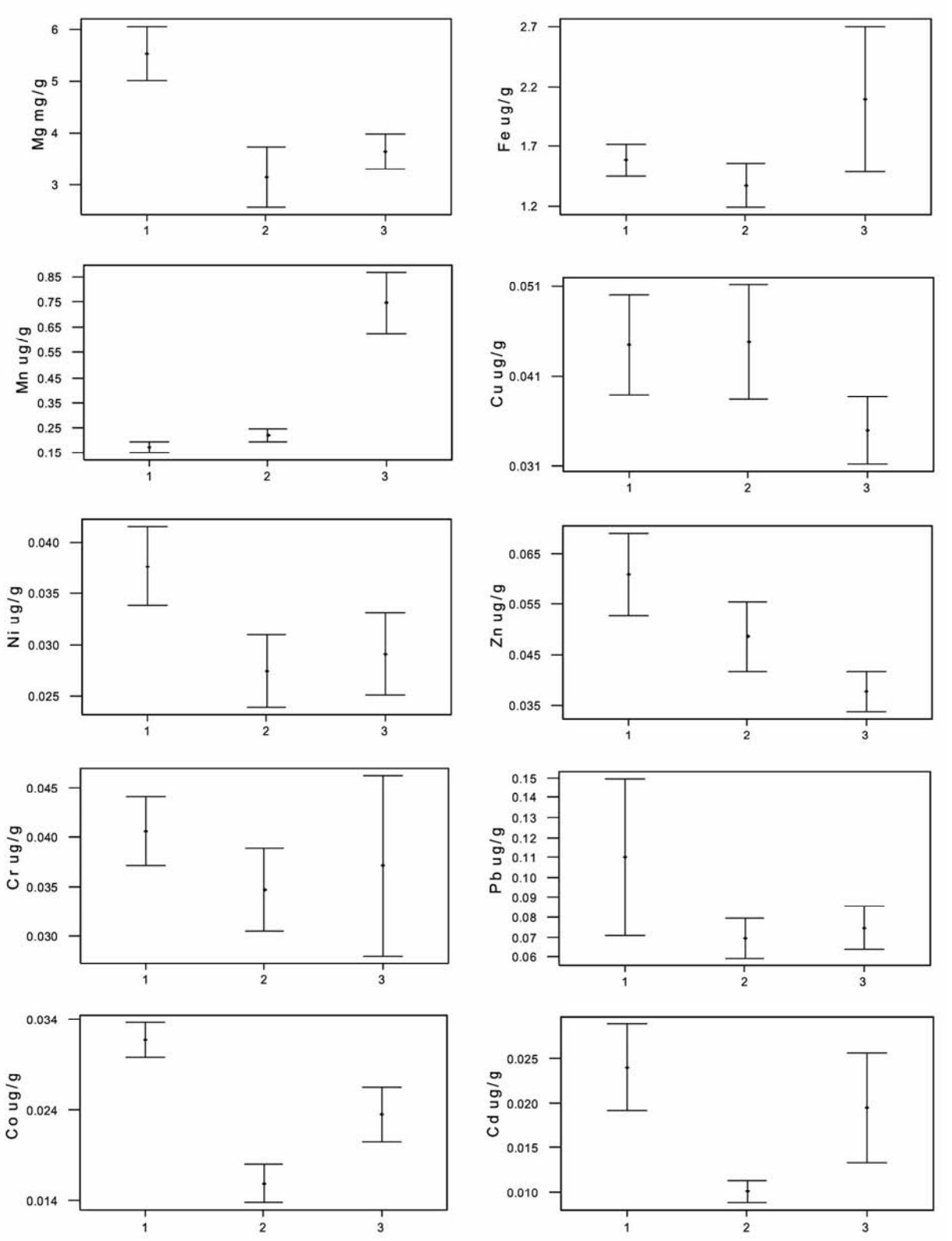

Fig. 4—Variation in heavy metals of red seaweed at 1. Buleji 2. Paradise Point 3. Nathia Gali.

Table 8—Analysis of variance (ANOVA) of heavy metals in seaweeds from Karachi coast (DF is degree of freedom, F is F-statistics and P is the probability level)

Mg

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sites	2	83.189	90.333	45.166	47.85	*** 0.000
Years	2	0.397	0.042	0.021	0.02	0.978
Months	11	146.138	146.136	13.285	14.08	*** 0.000

Fe

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	6.928	7.236	3.618	2.92*	0.059
Years	2	0.003	0.003	0.002	0.00	0.999
Months	11	51.032	51.032	4.639	3.74***	0.000

Mn

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	0.084779	0.071593	0.035796	15.68***	0.000
Years	2	0.002398	0.002398	0.001199	0.53	0.593
Months	11	0.221729	0.221729	0.020157	8.83***	0.000

Cu

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	0.003112	0.003175	0.001587	8.73***	0.000
Years	2	0.000002	0.000002	0.000001	0.01	0.995
Months	11	0.011820	0.011820	0.001074	5.91***	0.000

Ni

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	0.001263	0.001105	0.000552	5.04**	0.008
Years	2	0.000022	0.000022	0.000011	0.10	0.904
Months	11	0.004844	0.004844	0.000440	4.01***	0.000

Zn

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	0.009532	0.009363	0.004681	22.85***	0.000
Years	2	0.000006	0.000006	0.000003	0.02	0.983
Months	11	0.025466	0.025466	0.002315	11.30***	0.000

Cr

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	0.000253	0.000422	0.0002108	0.94	0.394
Years	2	0.0000012	0.0000012	0.0000006	0.00	0.997
Months	11	0.0210993	0.0210993	0.0019181	8.56***	0.000

Pb

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	0.026941	0.025362	0.012681	2.61*	0.079
Years	2	0.000005	0.000005	0.000002	0.00	1.000
Months	11	0.268355	0.268355	0.024396	5.03***	0.000

Co

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	0.00386428	0.00370890	0.00185445	50.27***	0.000
Years	2	0.00003528	0.00003528	0.00001764	0.48	0.622
Months	11	0.00328332	0.00321411	0.00029219	7.92***	0.000

Cd

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Sites	2	0.0029741	0.0031445	0.0015723	8.65***	0.000
Years	2	0.0000006	0.0000006	0.0000003	0.00	0.998
Months	11	0.0101752	0.0101752	0.0009250	5.09***	0.000

* = significant at $P < 0.05$
** = significant at $P < 0.01$
*** = significant at $P < 0.001$

were used to test the significant differences of heavy metals in seaweed between sites, years and months (Table 8). The results show that there were high significant variations found between sites and months for Mg (F = 47.85 and F = 14.08), Mn (F = 15.68 and F = 8.83), Cu (F = 8.73 and F = 5.91), Ni (F = 5.04 and F = 4.01), Zn (F = 22.85 and F = 11.3), Co (F = 50.27 and F = 7.92) and Cd (F = 8.65 and F = 5.09). where as the Fe (F = 3.74), Cr (F = 8.56) and Pb (F = 5.03) concentrations were found highly significant between months but were not significant with sites and years. There was no particular correlation found in between metals studied in seaweed, except Ni and Cr (r^2 = 0.661) and Cu and Pb (r^2 = 0.483) that showed positive significant correlation.

In *Botryocladia leptopoda*, *Gracilaria corticata*, *Hypnea musciformis*, *Osmundea pinnatifida* and *Sebdenia flabellata* Mg and Fe metals concentration were almost same when compared with the previous study reported by Qasim[24] where as the concentrations Cu, Ni, Zn, and Cd were low in *Hypnea pannosa*, *Halymenia, Laurencia* and *Plocamium* species when compared with the study conducted for the species collected from Great Barrier reef, Australia[23]. The concentrations of metal Mn, Cu, Zn, Fe, Cr, Pb, Co and Cd were low compared with the study conducted for the species *G. verrucosa* in Izmir, Turkey[18] and Black sea[14]. The concentrations obtained in the present study for Mn, Cu, Zn and Fe content were low when compared with the study conducted in the Gulf of Mannar, Bay of Bengal for the same species *Gracilaria corticata* and *Hypnea musciformis*[25]. The values of metals Cu, Mg, Fe, Pb, Zn, Cd, Cr, Co, Mn and Ni observed in present study were lower than values found in the local species of *Hypnea*, *Laurencia* and *Sarconema filiforme* from Bahrain coastal area, Arabian Gulf[16]. The concentrations for Mn, Cu, Zn and Fe were low when compared with the study conducted in Tamil Nadu, Coast of India[15] for the same species *Centroceras clavulatum* and *Gracilaria corticata*. The concentrations of metal Ni, Fe and Cr were low in *Gelidium* species when compared with the study conducted for the local species of same genus collected from Northern Chile[19]. Rao[26] gave high concentration of Mg, Cr, Mn, Fe, Cu, Ni, Co, Zn Cd and Pb for total marine algae from Indian coast as compared to present study. Rizvi *et al.*[27] collected seaweed from different sites of Karachi (Buleji, Manora, Sandspit and Paradise Point), observed higher concentrations of heavy metals compared to this study.

Table 9—Annual mean and range of heavy metals concentration in seawater from Buleji, Paradise Point and Nathia Gali of Karachi coast[5,28]
(All results are in mg l^{-1} except Mg in g l^{-1}).

S. No.	Name of Coast	Mg	Fe	Mn	Cu	Ni	Zn	Cr	Pb	Co	Cd
1	Buleji	4.955	0.802	0.143	0.160	0.227	0.139	0.486	0.481	0.191	0.198
		1.99-13.66	0.25-1.64	0.09-3.31	0.094-2.7	0.037-0.42	0.1-0.213	0.103-2.46	0.25-0.63	0.06-0.4	0.017-1.05
2	Paradise Point	3.351	1.114	0.124	0.504	0.182	0.226	0.314	0.477	0.207	0.054
		0.66-8.41	0.33-1.68	0.05-0.22	0.03-1.7	0.08-0.53	0.13-0.35	0.06-1.33	0.28-0.76	0.05-0.42	0.02-0.11
3	Nathia Gali	4.772	0.597	0.124	0.315	0.238	0.257	0.512	0.515	0.323	0.098
		2.13-12.0	0.273-1.05	0.059-0.185	0.0930.47	0.103-0.413	0.091-0.767	0.33-1.04	0.43-0.62	0.25-0.45	0.031-0.15

Distribution trend of metals was Mg> Fe > Mn, Zn > Cu in most of the species of seaweed, and is in identical along the east and west coasts of India[15]. The metals Mg, Fe, Mn, Cu, Ni, Zn, Cr and Pb showed high concentrations and a variable distribution in seaweed species,. This is may be due to the variation of metal concentrations in the seawater[20,28] (Table 9).

The seawater of Karachi coast is contaminated by direct and indirect discharge of industrial and domestic waste, Layari River input [22,28,29]. Relative to the other eight metals (Mg, Fe, Mn, Cu, Ni, Zn, Cr and Pb) seaweeds did not accumulate Co and Cd to such an extent. This due to the fact that the level of contamination of these two metals were not high in Karachi coastal waters[5,28]. Seaweeds has the ability to regulate the uptake of these metals and hence does not accumulate them to such a great extent (Table 9). Present study elucidates that the red algae showed the ability to concentrate Fe, Mn, Cu, Ni, Zn, Cr and Pb in greater amounts as compare to other metals . It also reveals that Buleji was the most polluted coastal area as compare to Paradise Point and Nathia Gali coastal areas of Karachi, Arabian Sea.

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