5. CHAPTER V: SEDIMENTATION RATE IN BERA LAKE

5.1. Introduction

Determination of sedimentation rate in Bera Lake is the most important objectives of the present study. The main aims of this research are therefore, to estimate the historical changes of sedimentation rates at Bera Lake and to correlate dated layers to land development projects which were carried out in the catchment area. Section 3-5-1 has explained the method of ^{210}Pb and ^{137}Cs activity analysis, geochronology, and and sedimentation rates. Stratigraphic dates based on ^{317}Cs horizons in ten studied cores marked a constant rate of ^{210}Pb supply especially along four distinct layers. The Lithology of layers, however, affected variation ^{210}Pb values with depth. Lithological change in four distinct layers created hiatus or severe dilution on ^{210}Pb content. The Bera Lake sediment chronology was determined using the CRS models. Assumptions for application of CIC model were not met in this study. As extreme mixing was recognized at the top of the sediment column in Core 10, it had to be discarded in the interpretation of sedimentation rate.

5.2. ^{210}Pb and ^{137}Cs Inventories and ^{210}Pb Flux

Calculation of inventory and flux of fallout radionuclide ^{210}Pb is based on equations 2 and 3 in Section 3.5.1.1. The mean maximum and minimum ^{210}Pb inventories at Bera Lake were 5112±70 and 1440±41 Bq m^{-2}, respectively (Table 5.1). The estimated value of the ^{210}Pb flux along the mainstream of Bera Lake is 90±5 Bq m^{-2} y^{-1}. An increase in ^{210}Pb flux of 159±2 Bq m^{-2} y^{-1} is observed towards the edge of the lake due to divergent currents which release sediments in a semi closed area (Fig. 5.1). In other words, morphological shape and stream pattern are controlling ^{210}Pb distribution at the Bera Lake.

Previous studies (Neergaard et al., 2008; Othman et al., 2003; Barokah et al., 2001; Moungsrijun et al., 2010) which were carried out in Malaysia, Thailand and Indonesia highlighted the low activity of ^{137}Cs (<400 Bq m^{-2}) which is in accordance with ^{137}Cs activity in tropical Australia. They stressed also the ability of ^{137}Cs for soil redistribution studies and as a time confirmation marker in sedimentation studies in tropical areas. The expected low activity of ^{137}Cs in Malaysia thus anticipated in this study. ^{137}Cs activities in sediment column can be divided into two distinctive categories. The first involves known ^{137}Cs horizons (1954, 1963, and 1986) while the second category implied reworked and erosion-induced ^{137}Cs from catchment area. Although ^{137}Cs showed peaks in studied cores coincide with Chernobyl accident in 1986, scientific reports to verify its fallout in Malaysia are not available.

Table 5.1: ^{210}Pb inventory and flux in sediments cores

Core No.	Pb210 Inventory Bq m-2	Pb210 Flux Bq m-2 y-1
1	2245.87±81	69.64±3
2	2898.00±162	90.24±5
3	3054.40±51	95.11±2
4	3657.35±128	113.90±4
5	3228.00±113	100.52±3
6	2920.47±72	90.94±2
7	2496.00±61	77.41±2
8	1440.28±41	44.85±1
9	5129.01±70	159.71±2

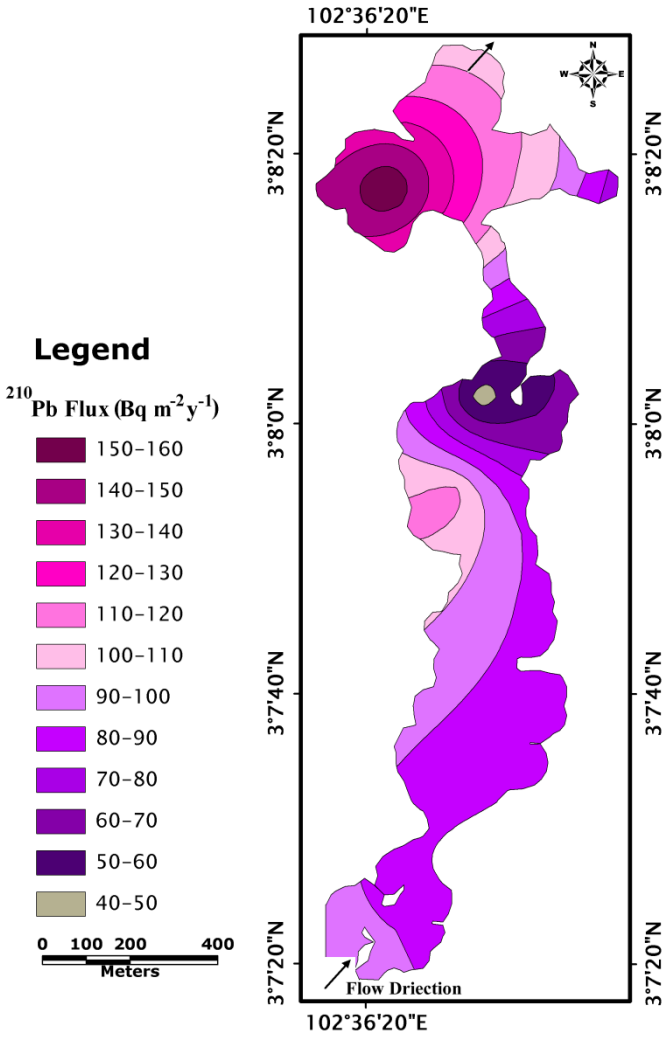


Figure 5.1: Annual flux and distribution of ^{210}Pb in Bera Lake

5.3. Sedimentation Rate at the South of Bera Lake

Unsupported ^{210}Pb inventory and its variation with depth and sedimentation rate at the south of Bera Lake were studied in Cores 2, 3, and 7. The ^{226}Ra activity gained a mean value of 38±6.5 Bq kg^{-1} in the studied cores. Equilibrium of total ^{210}Pb activity with the supporting ^{226}Ra obtained at depth of 60 cm in master Core 2. The maximum unsupported ^{210}Pb concentrations obtained were between 60.45±11, 40.50±11, and 38.20±16 Bq kg^{-1} in Core 2, 3, and 7, respectively. On the other hand, the lowest unsupported ^{210}Pb values in

Cores 2, 3, and 7 were 2±9, 2±9, and 0.5±11Bq kg^{-1}. The unsupported ^{210}Pb variation versus depth (Figs. 5.2, 5.3, and 5.4) revealed a clear lithological dependence of ^{210}Pb activity in Bera Lake sediment. The unsupported ^{210}Pb values decreased with a number of minor irregularities in separate layers. The deeper zones (Layers 2 and 1) depict an exponential variation of unsupported ^{210}Pb with depth in Cores 2 and 7. However, an exponential decreasing in ^{210}Pb value were observed in the uppermost layer of Cores 2 and 3 until depth 30 cm. Sediment mixing appeared from depths of 0-2 cm in Cores 2 and 7, probably because of bioturbation.

A northward increase in the mean sedimentation rate was observed at the south of Bera Lake, with accumulation rates of 0.24±0.32, 0.27±0.25 and 0.47±0.54 g cm^{-2} y^{-1} at Cores 2, 3 and 7, respectively. These were much higher compared to the pre-1950 sedimentation means of 0.06±0.02, 0.07±0.07 and 0.21±0.21 g cm^{-2} y^{-1} at core 2, 3 and 7.

Layer 2 which composed of grey to dark grey sandy mud experienced several sediment fluxes since 1950 to 1970. Two sediment flux events were recorded at Core 7 in which sedimentation rate increased significantly to 1.88 and 2.39 g cm^{-2} y^{-1} in 1952 and 1963, respectively. Similarly, at Core 3 three peaks in sedimentation rates were observed 0.48, 0.64, 0.43 g cm^{-2} y^{-1} in 1950, 1957, and 1962, respectively.

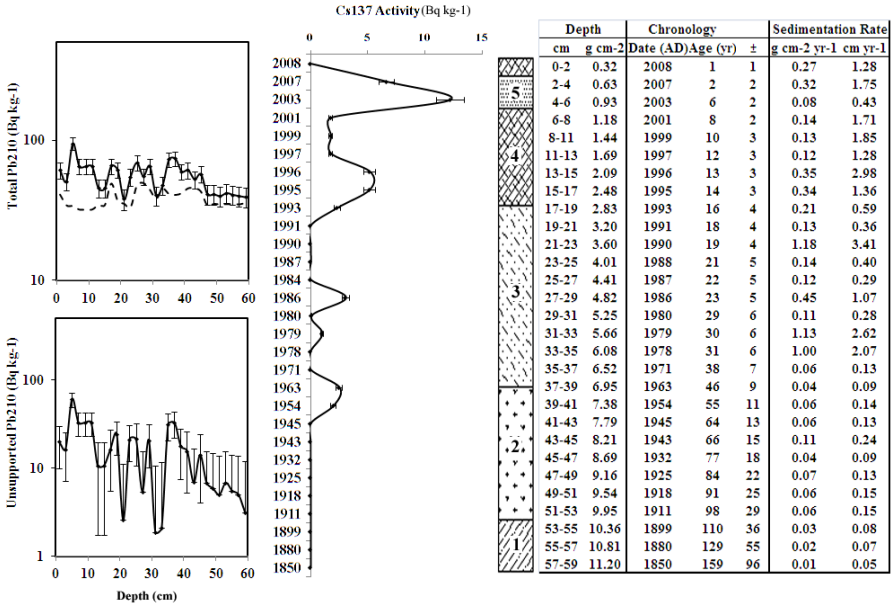
Bera Lake experienced a remarkable accumulation of terrestrial sediments during Layer 3 deposition with mean rates of 0.48±0.48, 0.39±0.13, and 0.41±0.29 g cm^{-2} yr^{-1} at Cores 2, 3, and 7, respectively. Five FELDA land development projects mark sediment fluxes with rates of 0.43, 0.12, 0.17, 0.34, 0.82 g cm^{-2} yr^{-1}, respectively at Core 7. General upward growth of sedimentation rate in Layer 3, decreased gradually in 1996 with a rate of 0.51 g cm^{-2} yr^{-1} when deforestation prohibition rule has established in 1994. Similar

upward increase in sedimentation rate from the first to forth FELDA land projects was recorded at Core 3 in which sediment flux varies between 0.29 to 1.18 g cm^{-2} yr^{-1}. At the beginning of the south of Bera Lake (Core 2) similar trend of sediment fluxes were detected. From the first to fifth FELDA projects, sedimentation rates vary between 1 to 1.18 g cm^{-2} yr^{-1}. This process continued with a mean rate of 0.22±0.1 g cm^{-2} y^{-1} at the uppermost layer of Bera Lake sediment column. The mean accumulation rate for layer 4 at Cores 3 and 7 were 0.27±0.34 and 0.29±0.24 g cm^{-2} y^{-1}. Lithological descriptions suggest that the contribution of land clearing projects were slightly extended in Layer 4. Their effects were observed in 1996 at Core 2 and 1998 at Core 7 with the rates of 0.35 and 0.62 g cm^{-2} y^{-1}. Another vivid organic-rich sediment flux recorded at both Cores 2 and 7 in 2001 with rates of 0.14 and 0.67 g cm^{-2} y^{-1}, respectively. A clear sediment flux with rates of 0.32 and 0.17 g cm^{-2} y^{-1} in cores 2 and 7 were recorded at depths of 2 to 4 cm and mark a great flood in December, 2007. ^{210}Pb dates using CRS model and peaks in reworked ^{137}Cs was in good agreement with FELDA land development dates and natural events particularly in layer 3 and 4.

^{137}Cs showed well-resolved peaks at depths of 39 and 37 cm at Core 2 which is in agreement with ^{210}Pb dating using CRS model. An inventory of 8.38 Bq m^{-2} marked the first appearance of ^{137}Cs in 1954 at the south of Bera Lake sediment column (Fig. 4.43). Another remarkable ^{137}Cs peak with an inventory of 10.66 Bq m^{-2} was observed at depths of 39 cm which is in agreement with the 1963 maximum ^{137}Cs fallout because of atmospheric atomic bomb testing. Difference in bed morphology caused in deeper depths of 1954 and 1963 ^{137}Cs horizons in cores 3 and 7. Once again, northward increasing in sedimentation rate at the south of Bera Lake has revealed based on stratigraphic dates of

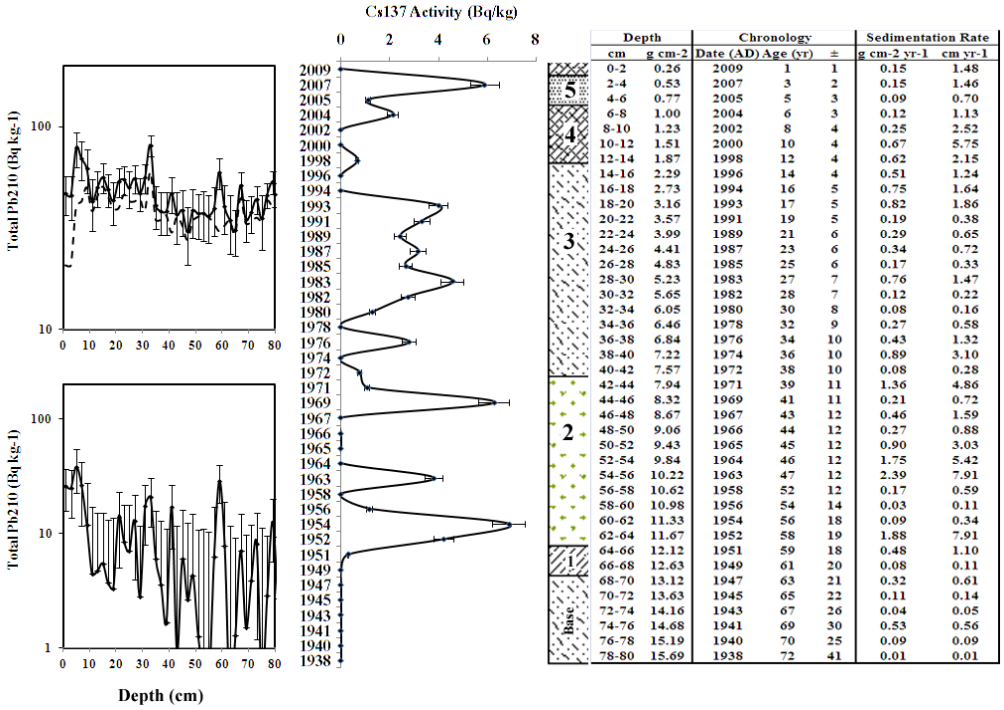
^{137}Cs radionuclide. For instance, in Core 7, ^{317}Cs peaks of the first appearance and the 1963 maximum fallout calculated to be 23.32 and 15.06 Bq m^{-2}, showing greater inventories than Core 2. Another considerable ^{137}Cs peak appeared at depths of 30 and 36 cm (Fig 5.3 and 5.4), with 13.34 and 21.52 Bq m^{-2} inventories in cores 2 and 3, probably indicating ^{137}Cs fallout in 1986 due to Chernobyl accident.

In addition, ^{137}Cs peaks reflected natural events in the study area. For instance, Layer 5 is an indicator of a huge flood taht occurred in 2007, highlighted properly by peaks at depths of 3 to 6 cm and ^{137}Cs inventory of 37.25 and 15.37 Bq m^{-2} at cores 2 and 7, respectively. As a result, ^{137}Cs horizons expressed the ability of CRS model in chronology of Bera Lake sediment. The mean sedimentation rates based on stratigraphic depths of ^{137}Cs horizons at Bera Lake sediment column were 0.7, 1 and 1.12 cm y^{-1} at Cores 2, 3 and 7, respectively. These results are in agreement with the mean sedimentation rate calculated by a slope regression model in Cores 2 and 3 (Fig. 5.5).



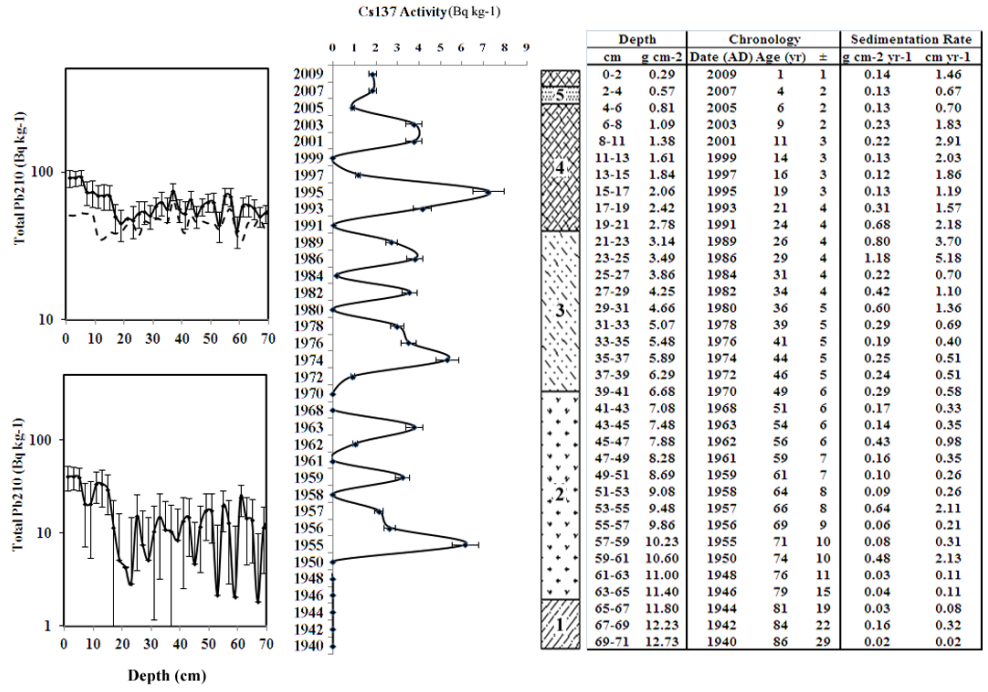
Depth		Chronology			Sedimentation Rate	
cm	g cm-2	Date (AD)	Age (yr)	±	g cm-2 yr-1	cm yr-1
0-2	0.32	2008	1	1	0.27	1.28
2-4	0.63	2007	2	2	0.32	1.75
4-6	0.93	2003	6	2	0.08	0.43
6-8	1.18	2001	8	2	0.14	1.71
8-11	1.44	1999	10	3	0.13	1.85
11-13	1.69	1997	12	3	0.12	1.28
13-15	2.09	1996	13	3	0.35	2.98
15-17	2.48	1995	14	3	0.34	1.36
17-19	2.83	1993	16	4	0.21	0.59
19-21	3.20	1991	18	4	0.13	0.36
21-23	3.60	1990	19	4	1.18	3.41
23-25	4.01	1988	21	5	0.14	0.40
25-27	4.41	1987	22	5	0.12	0.29
27-29	4.82	1986	23	5	0.45	1.07
29-31	5.25	1980	29	6	0.11	0.28
31-33	5.66	1979	30	6	1.13	2.62
33-35	6.08	1978	31	6	1.00	2.07
35-37	6.52	1971	38	7	0.06	0.13
37-39	6.95	1963	46	9	0.04	0.09
39-41	7.38	1954	55	11	0.06	0.14
41-43	7.79	1945	64	13	0.06	0.13
43-45	8.21	1943	66	15	0.11	0.24
45-47	8.69	1932	77	18	0.04	0.09
47-49	9.16	1925	84	22	0.07	0.13
49-51	9.54	1918	91	25	0.06	0.15
51-53	9.95	1911	98	29	0.06	0.15
53-55	10.36	1899	110	36	0.03	0.08
55-57	10.81	1880	129	55	0.02	0.07
57-59	11.20	1850	159	96	0.01	0.05

Figure 5.2: Geochronology of sediment Core 2, using ^{210}Pb dates and CRS model



Depth		Chronology			Sedimentation Rate	
cm	g cm-2	Date (AD)	Age (yr)	±	g cm-2 yr-1	cm yr-1
0-2	0.26	2009	1	1	0.15	1.48
2-4	0.53	2007	3	2	0.15	1.46
4-6	0.77	2005	5	3	0.09	0.70
6-8	1.00	2004	6	3	0.12	1.13
8-10	1.23	2002	8	4	0.25	2.52
10-12	1.51	2000	10	4	0.67	5.75
12-14	1.87	1998	12	4	0.62	2.15
14-16	2.29	1996	14	4	0.51	1.24
16-18	2.73	1994	16	5	0.75	1.64
18-20	3.16	1993	17	5	0.82	1.86
20-22	3.57	1991	19	5	0.19	0.38
22-24	3.99	1989	21	6	0.29	0.65
24-26	4.41	1987	23	6	0.34	0.72
26-28	4.83	1985	25	6	0.17	0.33
28-30	5.23	1983	27	7	0.76	1.47
30-32	5.65	1982	28	7	0.12	0.22
32-34	6.05	1980	30	8	0.08	0.16
34-36	6.46	1978	32	9	0.27	0.58
36-38	6.84	1976	34	10	0.43	1.32
38-40	7.22	1974	36	10	0.89	3.10
40-42	7.57	1972	38	10	0.08	0.28
42-44	7.94	1971	39	11	1.36	4.86
44-46	8.32	1969	41	11	0.21	0.72
46-48	8.67	1967	43	12	0.46	1.59
48-50	9.06	1966	44	12	0.27	0.88
50-52	9.43	1965	45	12	0.90	3.03
52-54	9.84	1964	46	12	1.75	5.42
54-56	10.22	1963	47	12	2.39	7.91
56-58	10.62	1958	52	12	0.17	0.59
58-60	10.98	1956	54	14	0.03	0.11
60-62	11.33	1954	56	18	0.09	0.34
62-64	11.67	1952	58	19	1.88	7.91
64-66	12.12	1951	59	18	0.48	1.10
66-68	12.63	1949	61	20	0.08	0.11
68-70	13.12	1947	63	21	0.32	0.61
70-72	13.63	1945	65	22	0.11	0.14
72-74	14.16	1943	67	26	0.04	0.05
74-76	14.68	1941	69	30	0.53	0.56
76-78	15.19	1940	70	25	0.09	0.09
78-80	15.69	1938	72	41	0.01	0.01

Figure 5.3: Geochronology of sediment Core 7, using ^{210}Pb dates and CRS model



Depth		Chronology			Sedimentation Rate	
cm	g cm-2	Date (AD)	Age (yr)	±	g cm-2 yr-1	cm yr-1
0-2	0.29	2009	1	1	0.14	1.46
2-4	0.57	2007	4	2	0.13	0.67
4-6	0.81	2005	6	2	0.13	0.70
6-8	1.09	2003	9	2	0.23	1.83
8-11	1.38	2001	11	3	0.22	2.91
11-13	1.61	1999	14	3	0.13	2.03
13-15	1.84	1997	16	3	0.12	1.86
15-17	2.06	1995	19	3	0.13	1.19
17-19	2.42	1993	21	4	0.31	1.57
19-21	2.78	1991	24	4	0.68	2.18
21-23	3.14	1989	26	4	0.80	3.70
23-25	3.49	1986	29	4	1.18	5.18
25-27	3.86	1984	31	4	0.22	0.70
27-29	4.25	1982	34	4	0.42	1.10
29-31	4.66	1980	36	5	0.60	1.36
31-33	5.07	1978	39	5	0.29	0.69
33-35	5.48	1976	41	5	0.19	0.40
35-37	5.89	1974	44	5	0.25	0.51
37-39	6.29	1972	46	5	0.24	0.51
39-41	6.68	1970	49	6	0.29	0.58
41-43	7.08	1968	51	6	0.17	0.33
43-45	7.48	1963	54	6	0.14	0.35
45-47	7.88	1962	56	6	0.43	0.98
47-49	8.28	1961	59	7	0.16	0.35
49-51	8.69	1959	61	7	0.10	0.26
51-53	9.08	1958	64	8	0.09	0.26
53-55	9.48	1957	66	8	0.64	2.11
55-57	9.86	1956	69	9	0.06	0.21
57-59	10.23	1955	71	10	0.08	0.31
59-61	10.60	1950	74	10	0.48	2.13
61-63	11.00	1948	76	11	0.03	0.11
63-65	11.40	1946	79	15	0.04	0.11
65-67	11.80	1944	81	19	0.03	0.08
67-69	12.23	1942	84	22	0.16	0.32
69-71	12.73	1940	86	29	0.02	0.02

Figure 5.4: Geochronology of sediment Core 3, using ^{210}Pb dates and CRS model

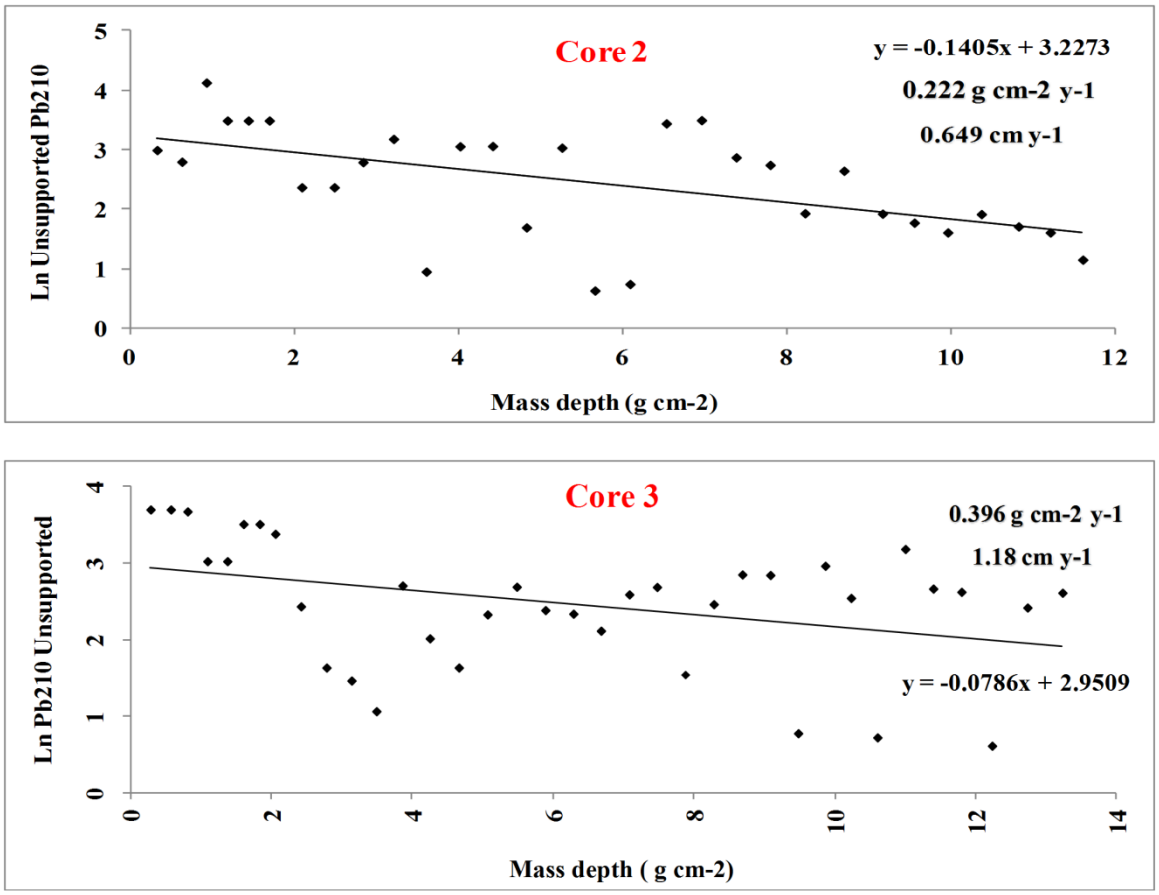


Figure 5.5: Mean sedimentation rates at Cores 2 and 3 using slope regression model

5.4. Sedimentation Rate at the Middle of Bera Lake

Sedimentation status at the middle of Bera Lake was investigated in Cores 6, 4, and 8. Detailed unsupported ^{210}Pb and ^{137}Cs inventories and their variation with depth and sedimentation rate were analyzed in master Core 8. The ^{226}Ra activity gained a mean value of 40.4±7.5 Bq kg^{-1} in the studied cores. Equilibrium of total ^{210}Pb activity with the supporting ^{226}Ra calculated at a depth of 70 cm. The unsupported ^{210}Pb concentration at north and east of Bera Lake main open water ranged between 0.2±8 and 18.78±18 Bq kg^{-1} (Fig. 5.6), while at the deepest part; it varied between 1±10 and 95.35±19 Bq kg^{-1} in Core 6 (Fig. 5.7). The results once again emphasized lithological effects on unsupported ^{210}Pb

distribution with depth at the middle of Bera Lake. The unsupported ^{210}Pb values decreased steeply with a few irregularities until lower contacts of layers. An exponential variation of unsupported ^{210}Pb with depth appeared at uppermost layer of Core 6. The unsupported ^{210}Pb activity showed a peak slightly below the sediment surface at Core 8. This peak may be caused by steep redox gradients across the uppermost few centimeters of sediment.

A northward decrease in the mean sedimentation rate was recognized at the middle of Bera Lake, with deposition rates of 0.4±0.59, 0.35±0.75, and 0.13±0.16 g cm^{-2} y^{-1} at cores 6, 8, and 4, respectively. The mean accumulation rates prior to 1950 were 0.05±0.01 and 0.16±0.16 g cm^{-2} y^{-1} at Core 6 and Core 8. As a result, sediment flux and sedimentation rate at the south and along the main axes of Bera Lake show similar values with the pre-development period. The grey to dark grey sandy mud (Layer 2) was deposited from 1950 to 1970 with mean rates of 0.12±0.11, 0.44±0.62 at cores 8 and 6, respectively. Two remarkable fluxes of sediments were recorded at the middle of Bera Lake in the year 1954 and 1962 with a mean rate of 0.53 and 0.975 g cm^{-2} y^{-1}, respectively.

White sandy mud (Layer 3) was deposited at the middle of Bera Lake with mean rate of 0.78±0.75 g cm^{-2} yr^{-1} in Core 6, and 0.54±1.2 g cm^{-2} y^{-1} in Core 8. The contribution of land development projects in sediment fluxes into the middle of Bera Lake is appeared in the Layer 3. For instance, five FELDA land development projects contributed to sediment flux along the main axes of Bera Lake (Core 6) at rates of 0.69, 0.52, 1.01, 1.53, and 2.16 g cm^{-2} y^{-1}, respectively. In Core 8, furthermore, the first FELDA project gave an estimate of 0.17 g cm^{-2} y^{-1}. The maximum calculated sediment flux was 3.95 g cm^{-2} y^{-1} during the second and the third FELDA land development projects from the year 1976

until 1985. Sedimentation in Layer 3 continued with a rate of 0.17 g cm^{-2} y^{-1} during the fourth FELDA land development project.

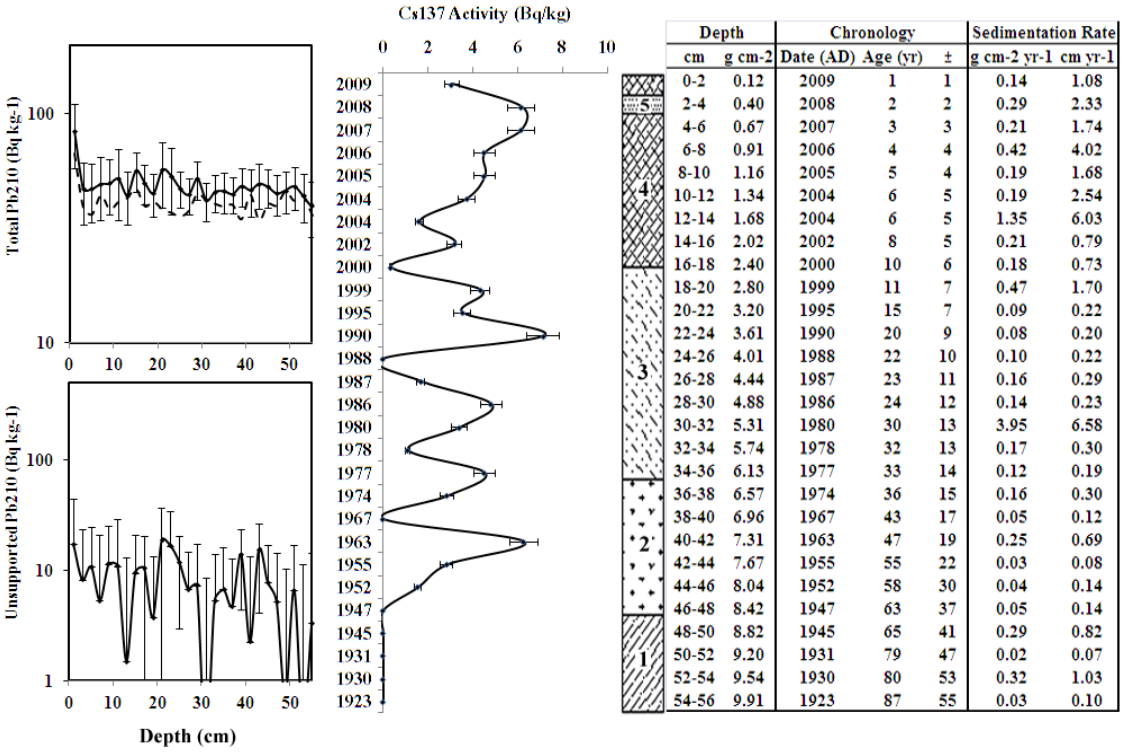
A decline in deposition rate of organic rich sediments is evident in the uppermost Layer (4) of sediment column. For instance, the highest accumulation rate was recognized at Core 8 with a mean rate of 0.35±0.38 g cm^{-2} y^{-1}, while organic-rich deposits settled with a mean rate of 0.08±0.02 g cm^{-2} y^{-1} at the deepest part of Bera Lake. Although forest clearing have ceased in 1994, but local deforestation activities are continuing with sediment fluxed into the north margin of the middle of Bera Lake with a rate of 0.47 g cm^{-2} y^{-1}. Sedimentation rate was dramatically increased further to 1.35 g cm^{-2} y^{-1} in the year 2004.

The CRS ^{210}Pb dating model placed the first appearance of ^{137}Cs, 10.5 Bq m^{-2} value at a depth of 44 cm. A well-resolved peak appeared at depths of 40 cm with 26.41 Bq m^{-2} inventory, signals the 1963 maximum ^{137}Cs fallout which is in agreement with ^{210}Pb dates using CRS model. A clear correlation exists between depths of this peak at both the south (Core 2) and the middle (Core 8) of Bera Lake.

A remarkable peak in ^{137}Cs of 19 Bq m^{-2} inventory was detected at depth of 30 cm (Fig. 5.6). This suggests ^{137}Cs fallout in 1986 due to Chernobyl accident. Similar peak in ^{137}Cs activity was detected at depth 25 cm by CRS ^{210}Pb dating model in Core 6. Other ^{137}Cs peaks were detected between depths 0 to 40 cm in Core 8 and from 0 to 45 cm in Core 6 inferred reworked and erosion-induced ^{137}Cs sources because of deforestation projects. For example, ^{137}Cs fluxes which caused by FELDA projects remarkably recorded in Core 6 (Fig. 5.7), are in good agreement with ^{210}Pb dates using CRS model. Another peak in ^{137}Cs activity was observed at depth of 3 to 5 cm in Core 8, which coincided with a

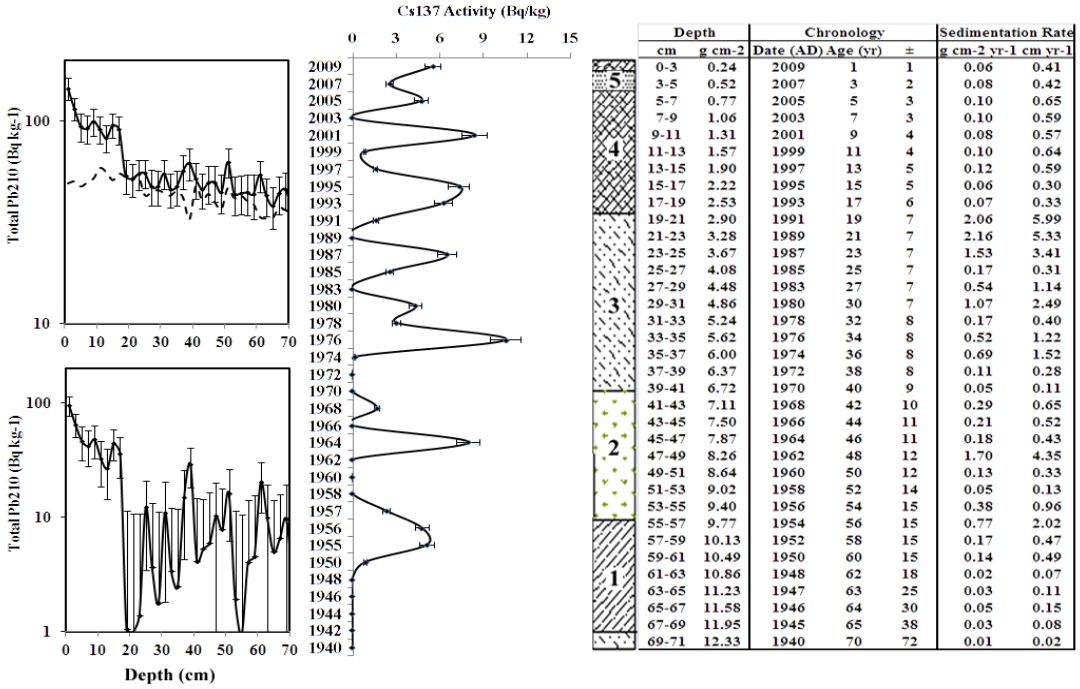
huge flood in December, 2007. As a result, the ability of CRS model in establishes chronology the sediment dates is verified by ^{137}Cs horizons at the middle of Bera Lake.

Stratigraphic dates based on records of fallout ^{137}Cs in sediment column represent a mean sedimentation rate of 0.8 and 1.01 cm y^{-1} in Core 8 and Core 6, respectively. This value in master Core 8 agrees with the mean sedimentation rate that was calculated by a slope regression model in which unsupported plotted versus accumulative mass depth (Fig. 5.8).



Depth		Chronology			Sedimentation Rate	
cm	g cm-2	Date (AD)	Age (yr)	±	g cm-2 yr-1	cm yr-1
0-2	0.12	2009	1	1	0.14	1.08
2-4	0.40	2008	2	2	0.29	2.33
4-6	0.67	2007	3	3	0.21	1.74
6-8	0.91	2006	4	4	0.42	4.02
8-10	1.16	2005	5	4	0.19	1.68
10-12	1.34	2004	6	5	0.19	2.54
12-14	1.68	2004	6	5	1.35	6.03
14-16	2.02	2002	8	5	0.21	0.79
16-18	2.40	2000	10	6	0.18	0.73
18-20	2.80	1999	11	7	0.47	1.70
20-22	3.20	1995	15	7	0.09	0.22
22-24	3.61	1990	20	9	0.08	0.20
24-26	4.01	1988	22	10	0.10	0.22
26-28	4.44	1987	23	11	0.16	0.29
28-30	4.88	1986	24	12	0.14	0.23
30-32	5.31	1980	30	13	3.95	6.58
32-34	5.74	1978	32	13	0.17	0.30
34-36	6.13	1977	33	14	0.12	0.19
36-38	6.57	1974	36	15	0.16	0.30
38-40	6.96	1967	43	17	0.05	0.12
40-42	7.31	1963	47	19	0.25	0.69
42-44	7.67	1955	55	22	0.03	0.08
44-46	8.04	1952	58	30	0.04	0.14
46-48	8.42	1947	63	37	0.05	0.14
48-50	8.82	1945	65	41	0.29	0.82
50-52	9.20	1931	79	47	0.02	0.07
52-54	9.54	1930	80	53	0.32	1.03
54-56	9.91	1923	87	55	0.03	0.10

Figure 5.6: Geochronology of sediment Core 8, using ^{210}Pb dates and CRS model



Depth		Chronology			Sedimentation Rate	
cm	g cm-2	Date (AD)	Age (yr)	±	g cm-2 yr-1	cm yr-1
0-3	0.24	2009	1	1	0.06	0.41
3-5	0.52	2007	3	2	0.08	0.42
5-7	0.77	2005	5	3	0.10	0.65
7-9	1.06	2003	7	3	0.10	0.59
9-11	1.31	2001	9	4	0.08	0.57
11-13	1.57	1999	11	4	0.10	0.64
13-15	1.90	1997	13	5	0.12	0.59
15-17	2.22	1995	15	5	0.06	0.30
17-19	2.53	1993	17	6	0.07	0.33
19-21	2.90	1991	19	7	2.06	5.99
21-23	3.28	1989	21	7	2.16	5.33
23-25	3.67	1987	23	7	1.53	3.41
25-27	4.08	1985	25	7	0.17	0.31
27-29	4.48	1983	27	7	0.54	1.14
29-31	4.86	1980	30	7	1.07	2.49
31-33	5.24	1978	32	8	0.17	0.40
33-35	5.62	1976	34	8	0.52	1.22
35-37	6.00	1974	36	8	0.69	1.52
37-39	6.37	1972	38	8	0.11	0.28
39-41	6.72	1970	40	9	0.05	0.11
41-43	7.11	1968	42	10	0.29	0.65
43-45	7.50	1966	44	11	0.21	0.52
45-47	7.87	1964	46	11	0.18	0.43
47-49	8.26	1962	48	12	1.70	4.35
49-51	8.64	1960	50	12	0.13	0.33
51-53	9.02	1958	52	14	0.05	0.13
53-55	9.40	1956	54	15	0.38	0.96
55-57	9.77	1954	56	15	0.77	2.02
57-59	10.13	1952	58	15	0.17	0.47
59-61	10.49	1950	60	15	0.14	0.49
61-63	10.86	1948	62	18	0.02	0.07
63-65	11.23	1947	63	25	0.03	0.11
65-67	11.58	1946	64	30	0.05	0.15
67-69	11.95	1945	65	38	0.03	0.08
69-71	12.33	1940	70	72	0.01	0.02

Figure 5.7: Geochronology of sediment Core 6, using ^{210}Pb dates and CRS model

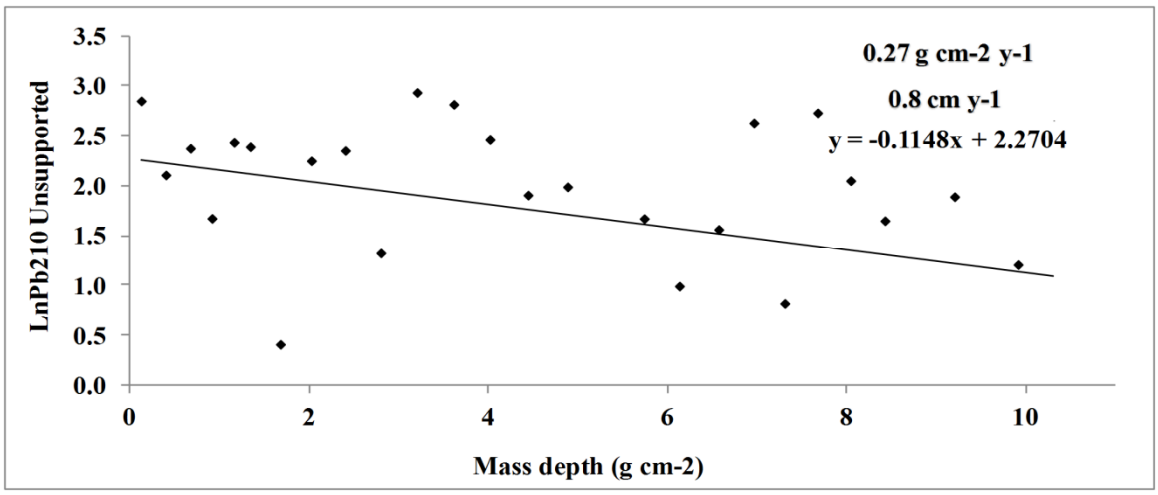


Figure 5.8: Mean sedimentation rate at Core 8, using slope of the regression model

5.5. Sedimentation Rate at the North of Bera Lake

Sedimentation rates at the north of Bera Lake were evaluated in Core 1, Core 5, and Core 9. Detailed unsupported ^{210}Pb and ^{137}Cs inventories and their variation with depth and sedimentation rate are shown in master Core 5 (Fig. 5.9). The ^{226}Ra activity gained a mean concentration of 36±7.8 Bq kg^{-1} at the north of Bera Lake. The total ^{210}Pb activity approached equilibrium with supporting ^{226}Ra at a depth of 65 cm. The unsupported ^{210}Pb values at the north of Bera Lake vary between 66 and 5.28 Bq kg^{-1}. A clear steep decline in unsupported ^{210}Pb values is observed at layer 3 contacts (Fig. 5.10) which reveals the effects of lithology and sedimentary conditions on the radionuclides concentration. An exponential variation of unsupported ^{210}Pb versus depth with some minor irregularities appeared along layers 3 and 4, separately.

The mean sedimentation rate at the north of Bera Lake in semi closed open water (Core 9), was 2.58±2.1 cm y^{-1}. At such area, the maximum ^{210}Pb flux into the north of Bera Lake was 159±2 Bq m^{-2} y^{-1}. The mean sediment fluxes rate of 0.17±0.23 and 0.34±0.5 g cm^{-2} y^{-1} were observed at Core 1 and Core 5, respectively. Therefore, the mean sedimentation rate along the main axes of Bera Lake especially at the middle and the north basin was 1.06 cm y^{-1}. The mean pre-1950 (Layer 1) deposition rate calculated to be 0.06±0.01, 0.05±0.02, 0.14±0.26 g cm^{-2} y^{-1} at cores 1, 9, and 5, respectively. Sediment has thus been mainly deposited along the main axes of Bera Lake at the north, slightly more than the south and middle of basin.

Sediment fluxes into the north of Bera Lake continued by accumulation of high organic content, grey to dark grey sandy mud deposits in Layer 2. The estimated mean sedimentation rates were 0.11±0.03, 0.1±0.02, and 0.55±0.9 g cm^{-2} y^{-1} at cores 1, 9, and 5,

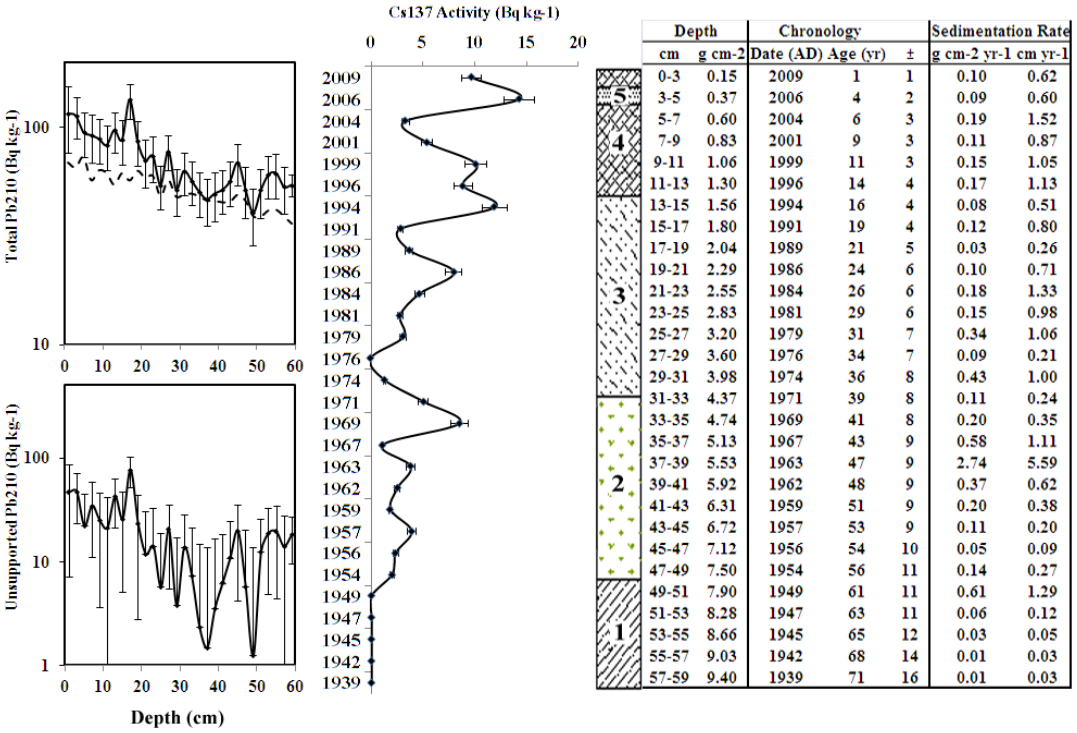
respectively. Similar to the south and the middle of Bera Lake, two peaks in sediment flux occurred in the year, 1955 and 1963 at the north of basin. The most important peaks was recorded at depth of 40 cm in which sedimentation rate increased dramatically to 2.74 g cm^{-2} y^{-1} in 1963. The accumulation rate decreased to 0.58 and 0.28 g cm^{-2} y^{-1} in 1967 and 1969, respectively.

New sediment fluxes commenced with deposition of the white sandy mud of Layer 3 at the north of Bera Lake. Terrestrial sediment indicates a remarkable accumulation of erosion induced deposits at the north of Bera Lake with mean rates of 0.55±0.43, 0.17±0.12, and 0.2±0.08 g cm^{-2} y^{-1} in cores 1, 5 and Core 9, respectively. Five land development projects manifested clearly in Layer 3 in which sediment fluxed into the north of Bera Lake at rate of 0.43, 0.34, 0.18, 0.12, and 0.17 g cm^{-2} y^{-1}, respectively. Similarly, five distinctive peaks in sediment fluxes recorded in semi closed basin at the north of study area where accumulation rates calculated to be 0.17, 0.16, 0.2, 0.26, 0.39 g cm^{-2} y^{-1}, respectively. In comparison with Core 5, deforestation phases caused an upward trend in sedimentation rate in the semi closed area at the north of basin.

Sedimentation continued at the uppermost layer of the sediment profile with organic-rich sediments since 1992. The highest accumulation rate of this layer was recognized at Core 9 at rate of 0.28 g cm^{-2} y^{-1} (1.35 cm y^{-1}). Semi closed basin (Core 9) at the north of Bera Lake experienced four sediment fluxes in which organic-rich deposits accumulated at rates of 0.43, 0.36, 0.54, 0.55 g cm^{-2} y^{-1} from 1996 until 2002. Organic-rich deposits settled at mean rate of 0.13±0.04 and 0.1±0.07 g cm^{-2} y^{-1} at Core 5 and Core 1, respectively. CRS model dating placed a sediment flux of organic-rich deposits at cores 1

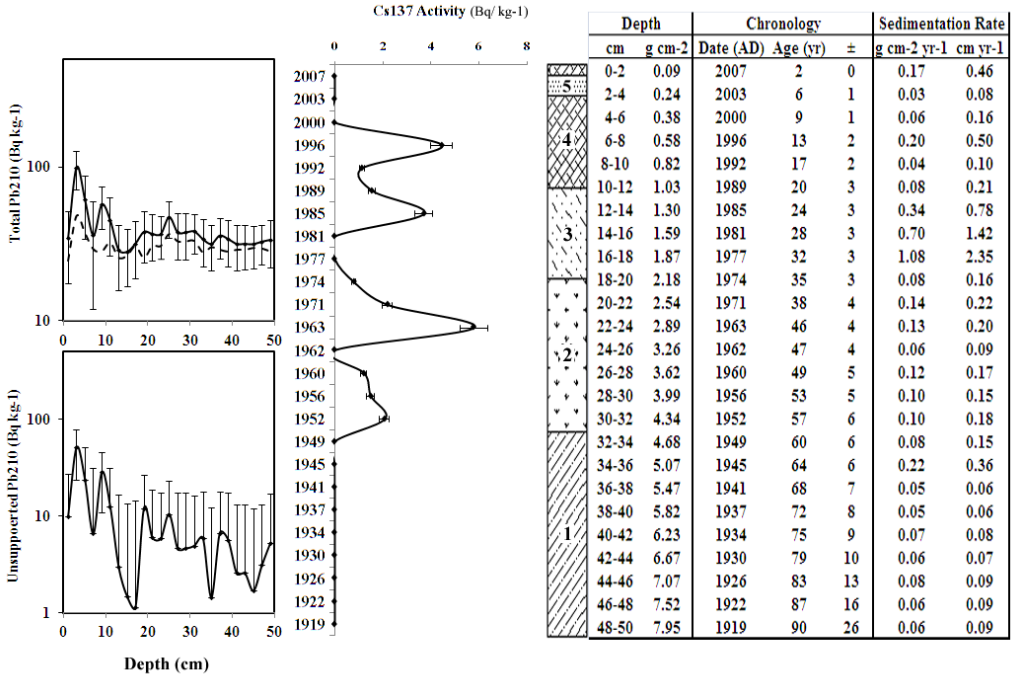
and 5 in 1996 with the rate of 0.17 and 0.2 g cm^{-2} y^{-1}. The huge flood in December, 2007 which was detected at depths of 2 to 4 cm at Core 5, accumulated at rate of 0.1 g cm^{-2} y^{-1}.

The first appearance of ^{137}Cs of 7.93 Bq m^{-2} inventory was marked at the north of Bera Lake sediment column in 1954. A well-resolved peak appeared at depth 39 cm with 15.35 Bq m^{-2} inventory, depicts maximum ^{137}Cs fallout in year 1963, which is in good agreement with ^{210}Pb dates using CRS model. Clear correlation recorded between depths of this peak at sediment column of cores 2, 8, and 5. ^{137}Cs inventories in Core 9 are not compatible with dates which were calculated by CRS model. However, stratigraphic correlation of layers in Core 9 with other cores and lithology of layers verified the ^{210}Pb dates using CRS model. Other ^{137}Cs peaks at 0 to 38 cm depths in master Core 5 inferred reworked and erosion-induced ^{137}Cs sources because of deforestation and land clearing activities. Once again, ^{137}Cs confirmation horizons approved that CRS model as geochronology tool of Bera Lake sediments. The means calculated sedimentation rate were 0.83 and 0.56 cm y^{-1} at Core 5 and Core 1 based on the stratigraphic depths of ^{137}Cs horizons. Sedimentation rate based on ^{137}Cs horizons in Core 5 is in accordance to the mean sedimentation rate that is calculated by CRS model.



Depth		Chronology			Sedimentation Rate	
cm	g cm-2	Date (AD)	Age (yr)	±	g cm-2 yr-1	cm yr-1
0-3	0.15	2009	1	1	0.10	0.62
3-5	0.37	2006	4	2	0.09	0.60
5-7	0.60	2004	6	3	0.19	1.52
7-9	0.83	2001	9	3	0.11	0.87
9-11	1.06	1999	11	3	0.15	1.05
11-13	1.30	1996	14	4	0.17	1.13
13-15	1.56	1994	16	4	0.08	0.51
15-17	1.80	1991	19	4	0.12	0.80
17-19	2.04	1989	21	5	0.03	0.26
19-21	2.29	1986	24	6	0.10	0.71
21-23	2.55	1984	26	6	0.18	1.33
23-25	2.83	1981	29	6	0.15	0.98
25-27	3.20	1979	31	7	0.34	1.06
27-29	3.60	1976	34	7	0.09	0.21
29-31	3.98	1974	36	8	0.43	1.00
31-33	4.37	1971	39	8	0.11	0.24
33-35	4.74	1969	41	8	0.20	0.35
35-37	5.13	1967	43	9	0.58	1.11
37-39	5.53	1963	47	9	2.74	5.59
39-41	5.92	1962	48	9	0.37	0.62
41-43	6.31	1959	51	9	0.20	0.38
43-45	6.72	1957	53	9	0.11	0.20
45-47	7.12	1956	54	10	0.05	0.09
47-49	7.50	1954	56	11	0.14	0.27
49-51	7.90	1949	61	11	0.61	1.29
51-53	8.28	1947	63	11	0.06	0.12
53-55	8.66	1945	65	12	0.03	0.05
55-57	9.03	1942	68	14	0.01	0.03
57-59	9.40	1939	71	16	0.01	0.03

Figure 5.9: Geochronology of sediment Core 5, using ^{210}Pb dates and CRS model



Depth		Chronology			Sedimentation Rate	
cm	g cm-2	Date (AD)	Age (yr)	±	g cm-2 yr-1	cm yr-1
0-2	0.09	2007	2	0	0.17	0.46
2-4	0.24	2003	6	1	0.03	0.08
4-6	0.38	2000	9	1	0.06	0.16
6-8	0.58	1996	13	2	0.20	0.50
8-10	0.82	1992	17	2	0.04	0.10
10-12	1.03	1989	20	3	0.08	0.21
12-14	1.30	1985	24	3	0.34	0.78
14-16	1.59	1981	28	3	0.70	1.42
16-18	1.87	1977	32	3	1.08	2.35
18-20	2.18	1974	35	3	0.08	0.16
20-22	2.54	1971	38	4	0.14	0.22
22-24	2.89	1963	46	4	0.13	0.20
24-26	3.26	1962	47	4	0.06	0.09
26-28	3.62	1960	49	5	0.12	0.17
28-30	3.99	1956	53	5	0.10	0.15
30-32	4.34	1952	57	6	0.10	0.18
32-34	4.68	1949	60	6	0.08	0.15
34-36	5.07	1945	64	6	0.22	0.36
36-38	5.47	1941	68	7	0.05	0.06
38-40	5.82	1937	72	8	0.05	0.06
40-42	6.23	1934	75	9	0.07	0.08
42-44	6.67	1930	79	10	0.06	0.07
44-46	7.07	1926	83	13	0.08	0.09
46-48	7.52	1922	87	16	0.06	0.09
48-50	7.95	1919	90	26	0.06	0.09

Figure 5.10: Geochronology of sediment Core 1, using ^{210}Pb dates and CRS model

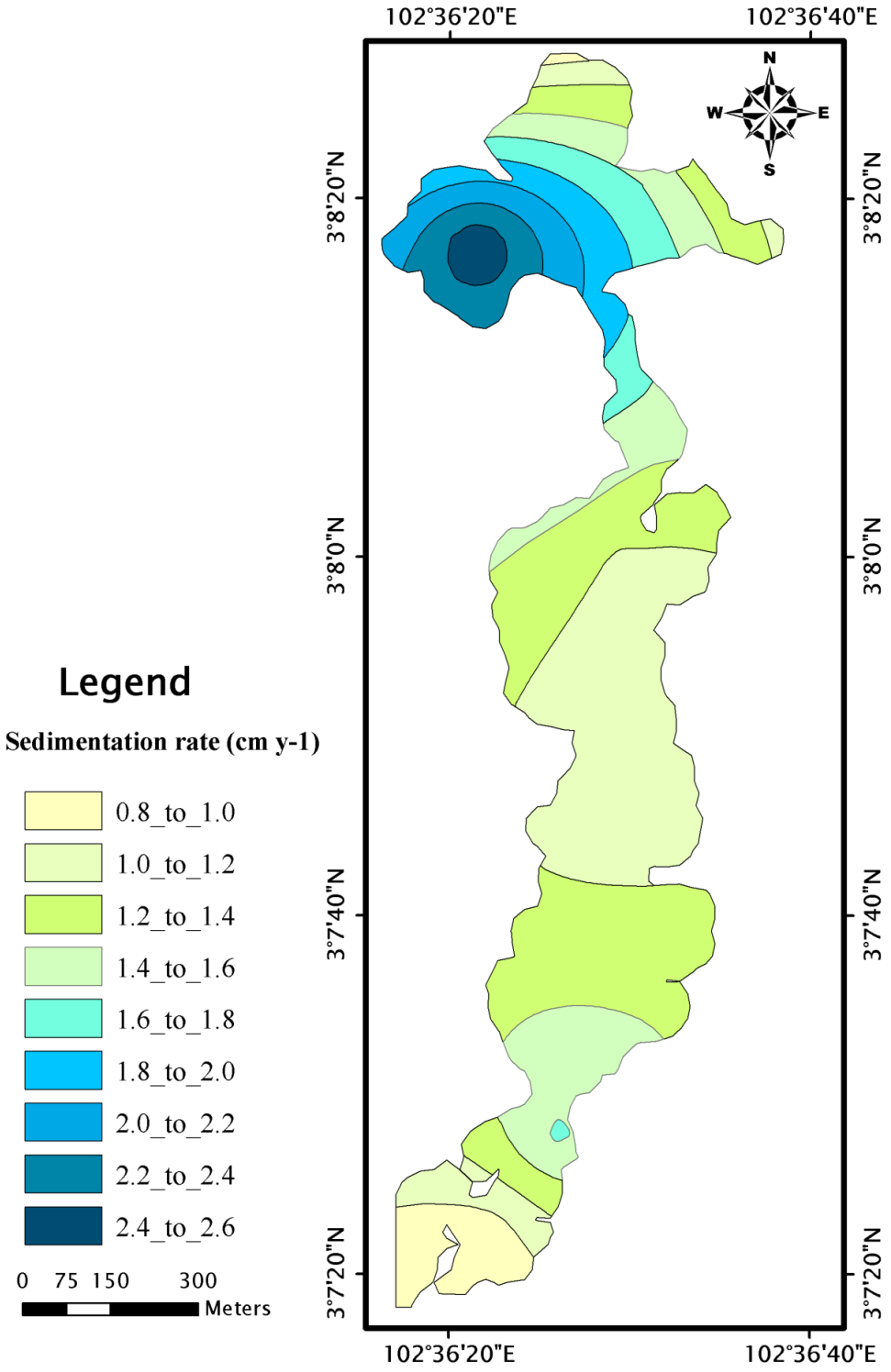


Figure 5.11: Sediment distribution and sedimentation rate map of Bera Lake

5.6. Discussion

Natural phenomenon like tilting in geological structure of Bera Lake basin played a vital role in the evolution of low land areas and trapping of water bodies (Hutchinson & Tan, 2009). The evidences, support the effect of strike-slip faults in shaping of BLC valleys and control the elongated shape of wetlands and open waters. Accumulation of detritus sediments at the depths of 8-9 m had happened 5,500-6,500 yrs BP (Wüst & Bustin, 2004) due to a tilting and rapid steepening of the main valley. In addition, forest and reed swamps were developed mainly along depressions which had already been created by the strike-slip faults especially in the first, third, fourth, and twelfth sub-catchments.

Although physiographic parameters play minor roles in soil erosion process, their contribution to sedimentary processes is significant. These parameters remarkably affect the shape of sub-catchments and time of water concentration. The time of concentration in BLC is 8.53 hours. This value, furthermore, decreases in the order of 7.79> 6.42> 3.61> 3.38> 3.11> 2.94> 2.84> 2.45> 2.09> 1.45> 1.05> 0.89 hour in the sub-catchments 4, 12, 8, 3, 1, 5, 9, 2, 10, 6, 11, and 7, respectively. The contribution of sub-catchments in sediment transport to the sink areas in the similar rainfall intensity will therefore, follow reverse order of time of concentration. In other word, the seventh sub-catchment requires shorter time for transport and drainage of water and sediments in compare to other sub-catchments.

A total of 5,705 hectare is covered by wetlands and open waters, which are topographically located at elevations lower than 20 m from sea level. This area is part of low land which are distributed between 0 and 2 degree slopes. The main stream at Bera

Lake with a length of 23 km drains water and transports sediments northward and also widens with several retention ponds and open waters. This means contribution of the main stream in terms of sediment supply into the Bear Lake is 90%. In addition, the results reveal that the capability of Bera Lake for trapping sediments would increase up to 70% during wet seasons especially from the south inlet. The elongated shape and abundance of distributaries are other reasons for increase in sediment residual in Bera Lake.

An estimation of sedimentation rate based on Bera Lake area and trap efficiency revealed that the annual accumulation rate is 12,550 m^3. In conclusion, the relative sedimentation rate based on the Bera Lake areas (1,126,315 m^2) can be estimated at 1.11 cm y^{-1}. This rate is very close to 1.025 cm y^{-1} which calculated using the ^{137}Cs technique.

Medium-term variation in the rate of sediment supply into Bera Lake and the lithology of the deposited sediments were studied through ^{210}Pb dating using the CRS model. The chronology of sediment columns can be separated into two phases of prior and post land use changes in the catchment area. The pre-1970 period could also be divided into two periods of 1950 to 1970 and pre-1950, respectively. The actual clearance of forest by FELDA for oil palm plantations has been commenced in 1960 (Henson, 1994) and two FELDA projects were implemented between years 1960 and 1965, and between 1966 and 1970, respectively. Although, published data is not available on FELDA projects in the BLC at this range of time, a remarkable influx of sediment has been recorded between 1961 and 1966. During this period the mean sedimentation rate significantly increased to 0.9 g cm^{-2} y^{-1}; a value comparable with values quoted by FELDA or other responsible government agencies in 1980 decade.

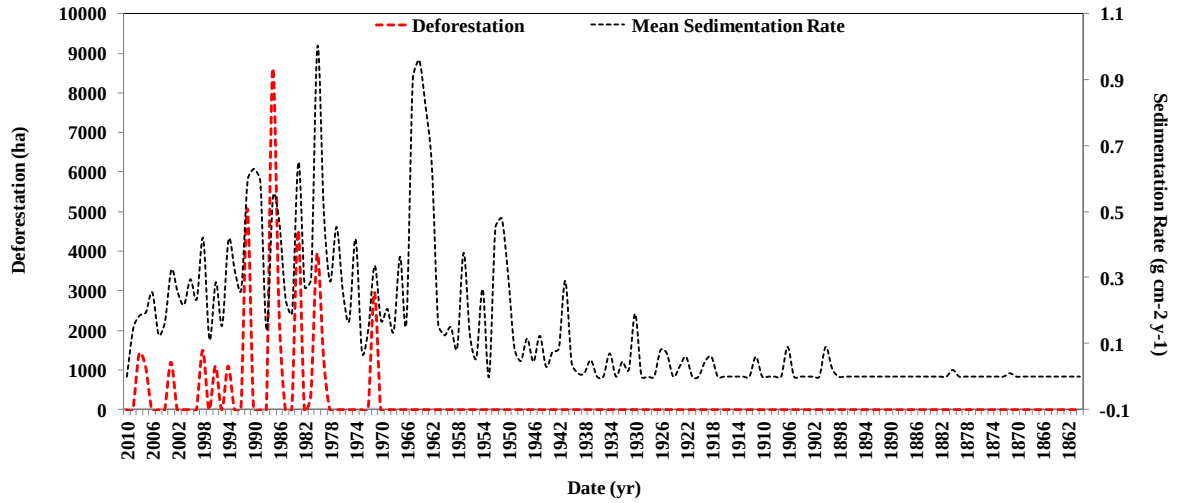


Figure 5.12: Correlation between deforestation phases and sedimentation rate

A rapid sedimentation rate between the years 1961 to 1966 may be due to some natural reasons such as a wet season or a period of heavy rain fall. The long-term available and reliable rainfall data from 1961 shows some similarity with the mean sedimentation rate (Fig. 5.13).

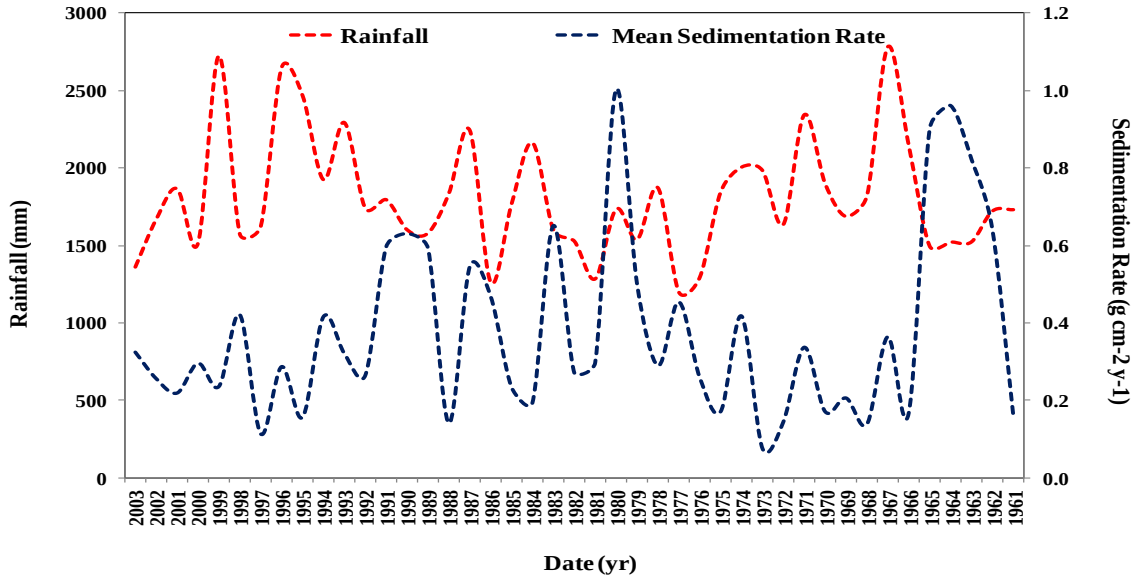


Figure 5.13: Correlation between rainfall and sedimentation rate

A moderate correlation between the rainfall data and sedimentation rate indicates that dramatic increase in sediment influx is probably due to some artificial reasons rather than natural. Tachibana (2000) stated that Malaysia has played an important role as suppliers in international wood markets since the 1960s. The BLC like other rainforest catchments in Malaysia has been significantly harvested for timber and log during the first Malaysia Plan (1960 to 1965). The real history of timber harvesting is not available and most official data is only available after 1970 from government agencies that deal with land development projects.

Stratigraphic descriptions and the ^{210}Pb dating using CRS model clearly confirmed that the grey mud of Layer 1 was deposited prior to 1950 and the grey to dark grey sandy mud of Layer 2 was deposited between year 1950 and 1970. The low variation in the composition and sedimentation rate of Layer 1 indicates a stable condition without effective anthropogenic activities. However, high contribution of organic matters in composition and significant variations in sedimentation rate in Layer 2 are comparable with natural and anthropogenic changes as shown in Figure 5.12.

According to Henson (1994), five FELDA projects were carried out in Pahang between 1970 and 1995. Land development phases were conducted between years 1970 and 1975, 1976 and 1980, 1981 and 1985, 1986 and 1990, and between 1991 and 1995, respectively. Further phases of land development are still continued by the locals since 1995. Tan et al., (2009) reported that a typical oil palm land development project comprised six main stages, the most important of which is land clearing. The duration of land clearing and preparation for 2,000 hectares of oil palm farm usually takes about 14 months. Severe and continuous exposure of Permian, Triassic–Jurassic continental rock

units (Semantan Formation) during the FELDA projects has thus led to several tons of sediments being transported to Bera Lake wetlands and open waters.

Deposition of the deeply eroded sediments in the Bera Lake basin started with the white sandy mud layer. A clear correlation between the start of FELDA land development projects in the catchment area and the increased sediment supply is affirmed by ^{210}Pb dating and ^{137}Cs horizons. A dilution of the atmospheric ^{210}Pb fallout by increased sedimentation coincided with FELDA projects in the Bera Lake sediment column. Additionally, the normal process of sediment accumulation of pre-1970 was interrupted. Clear differences exist between sediment influx prior and post FELDA land development projects (Fig 5.12). Sedimentation dramatically increased 22 times by the first and second phases when white sandy mud was deposited at Bera Lake.

For instance, the pre-1970 mean sedimentation rate in master Core 2 was calculated to be 0.06±0.02 g cm^{-2} y^{-1}. This mean deposition rate increased dramatically to 1.13 g cm^{-2} y^{-1} after implementation of the first and second FELDA projects from 1972 to 1980. The fifth FELDA land development phase, was also recognized as a main contributor to deposition of the white sandy mud layer. An influx of sediment at the top of sediment column was correlated with a huge flood in December, 2007, when 1,200 mm of rain were precipitated in 11 days and the water level rose and inundates to drown the whole Bera Lake lowland area. This natural event was verified by the highest reworked of ^{137}Cs activity at the top of the sediment column. The ^{137}Cs value was 5 times greater than the value of the 1963 maximum artificial fallout of ^{137}Cs in master Core 2. The ^{210}Pb dating of core samples, however, points out that the environmental impact was not recorded uniformly in all parts of Bera Lake. For example, the impacts of the first FELDA project in

the sediment profile at the north end of Bera Lake appeared two years later than those at the south end.

Maximum sedimentation rates in the south, middle and north of Bera Lake were recorded in 1987, 1980 and 1974 with mean values of 3.3, 1.3, and 0.43 g cm^{-2} y^{-1}, respectively. These influxes of sediments occurred during the first, second, and fourth FELDA development projects.

Land preparation in the BLC involved clearing and burning of biomasses. A remarkable charcoal horizon was detected at the lower contact of Layer 3 when terrestrial sediment was deposited in all sectors of Bera Lake. Plotting of ^{210}Pb dating using the CRS model with deforestation phases revealed that significant sediment delivery from the catchment area into Bera Lake was delayed by 1 to 2 years.

Organic-rich and peat sediments at the top of the Bera Lake sediment column were deposited mostly since 1994 when highly organic waste production was associated with the mature oil palm plantations. According to MPOC (2007), oil palm plantations accumulate 8.3 tons of biomass per year; a value that is 2.5 tons more than a rain forest produces per year. In addition, the annual dry matter productivity of an oil palm is about 36 tons, as compared with about 26 tons for a rain forest.

Based on the distribution of oil palm plantations and rainforest areas in Bera Lake, annual bio mass productivity was estimated at 1.5 million cubic meters. This amount of biomass could potentially cover BLC at a rate of 0.4 cm yr^{-1}. In such situation, however, runoff transport organic matter and organic-rich sediments being the main sediments deposited in Bera Lake. The mean sediment supply after the fifth FELDA development

project decreased gradually to 0.2, 0.21, 0.153, 0.29, 0.11, 0.08, 0.13, 0.24, and 0.17 g cm^{-2} y^{-1} in Cores 1, 2, 3, 4, 5, 6, 7, 8, and 9, respectively.

A clear contribution of this research project towards knowledge is demonstrating the capability of ^{137}Cs as an independent time marker and its usefulness in study of historical sedimentation rates in Malaysia. Although ^{137}Cs activity in soil and sediment profile of Malaysia is very low in comparison with that of the European and American continents, its vertical distribution appeared in an ideal form. Furthermore, the peaks in the ^{137}Cs inventory, show excellent correlations with anthropogenic changes especially in the upper parts of Bera Lake sediment columns. Stratigraphic dates based on records of fallout of ^{137}Cs and ^{210}Pb supply rates to these core sites have remained relatively constant. The Bera Lake sediments could therefore, be dated by the CRS model.

Another achievement and new finding in this research is the good correlation of the mean sedimentation rates based on a slope regression model and the stratigraphic dates of ^{137}Cs time markers in Malaysia. In other word, the stratigraphic dates of ^{137}Cs horizons (1954, and 1963) have confirmed the application of slope regression model in which ^{210}Pb unsupported values were plotted against cumulative mass depth. This study therefore, recommends application of a slope regression model as a simple dating method for further research in areas Malaysia with similar conditions as those of Bera Lake.

Questions and uncertainties about the adverse impacts of land use changes on the sedimentation rates in Bera Lake have also been clearly answered in this study. The main objective of the present research has been successfully achieved with sedimentation rates in different parts of Bera Lake and the historical trend of deposition, calculated using several methods and their results confidently confirmed selected methodologies and each

others. Now the RAMSAR site decision makers could estimate adverse effects of previous land development projects on Bera Lake sedimentation rate. Therefore, they could provide a sustainable land use programme for further conservation and replanting in BLC area to avoid further deposition of sediments.

6. CHAPTER VI: SOIL AND NUTRIENT REDISTRIBUTION AT THE BERA LAKE CATCHMENT

6.1. Introduction

Soil erosion and redistribution of eroded materials in the BLC has been investigated using radioisotopes. This is one of the most important objectives of the present research. The soil sampling strategy, soil sample preparation and conversion models have been appropriately discussed In Sections 3.2.5, 3.3.1, and 3.5.2. In this chapter, the results of the applications of models in soil erosion and redistribution of eroded materials in the study area are presented. Finally, the results are presented in a soil erosion map of BLC.

6.2. ^{137}Cs Inventory in Soil Samples

Atomic bomb-derived nuclides are difficult to detect in the soil profiles of equatorial areas. Previous studies in Malaysia (Neergaard, 2008; Othman, 2003), Indonesia (Barokah, 2007; Suhartini, 2006), Vietnam (Hien et al. 2002; Hai et al. 2008) , Philippine and Sri Lanka (IAEA, 2003), and in Taiwan (Chiu et al. 1999) have highlighted the applicability of ^{137}Cs in measuring rates of soil redistribution in tropical areas. However area generally low inventory of ^{137}Cs (<400 Bq m^{-2}) as found in tropical Australia by Hancock (2008). The expected low activity of ^{137}Cs in Malaysia was thus anticipated in this study and has affected the sampling strategy.

The reported mean ^{137}Cs reference inventory in Indonesia has been varied from 261±37 and 286±47 Bq m^{-2} (Barokah, 2001; Suhartini, 2006), and varied between 450±280 and 170±160 Bq m^{-2} in Philippines (IAEA, 2003). The ^{137}Cs inventory at the reference sites ranged between 237 to 1097 Bq m^{-2} in Vietnam (Hien et al. 2002; Hai et al.

2008), varies between 154 to 317 Bq m^{-2} in Taiwan (Chiu, 1999), and in tropical Australia from 129 and 209 Bq m^{-2} (Hancock, 2008).

The mean value of the ^{137}Cs reference inventory was calculated to be 125.39±36 Bq m^{-2} with coefficient of variation (CV) of 0.29 and ranged from 85 to 193 Bq m^{-2}. ^{137}Cs reference inventory in the study area is within the range of ^{137}Cs inventory in tropical Australia and Philippines has lower than reference inventories in the neighbor its countries. Mabit (2008b) has stated that the CV of reference samples in forested sites is large (0.19–0.47), but low in pasture and grassland sites (0.051–0.41). The CV of the reference samples is of low-variance and therefore, considered to be reliable for the assessment of base level of ^{137}Cs with moderate spatial variability in fallout inputs. The reference samples in the study area have an average clay content of 7.25%, while the average silt and sand contents are 46.43, and 46.31, %, respectively. When the ^{137}Cs inventory in all samples was compared with the soil particle sizes, it showed a moderate correlation with silt sized particles (r=0.4; p<0.05), but a weak correlation (r=0.2; p<0.05) with sand sized particles. A strong positive correlation (r=0.74; p<0.05) was found between ^{137}Cs inventory and fine grain size (mud fraction) of reference samples. The data thus highlights the importantes role of parent rocks and rate of soil disturbance in the study area in terms of ^{137}Cs adsorption in the soil profile. Strong negative correlations between ^{137}Cs inventory and TOC (r=-0.92; p<0.05) versus depth found in reference sample (Fig.3). For depth between 0 to 4 cm, the forest soils mainly consist of organic material with little inorganic compounds and thus show low ^{137}Cs activity.

The scattered plan of sampling as well as the variations in slope gradient, parent rocks and rate of soil mixing during planting of oil palm and rubber has caused variation in

^{137}Cs activity and particle size distributions of samples (Table 6.1). It is to be noted that soils in the developed land covered by oil palm and rubber plantations have a sandy loam texture. Soil profile in areas still being developed or covered by immature oil palm and rubber plantations has a loamy texture. In other word, immature oil palm states have a short duration of exposure and erosion rather than developed lands.

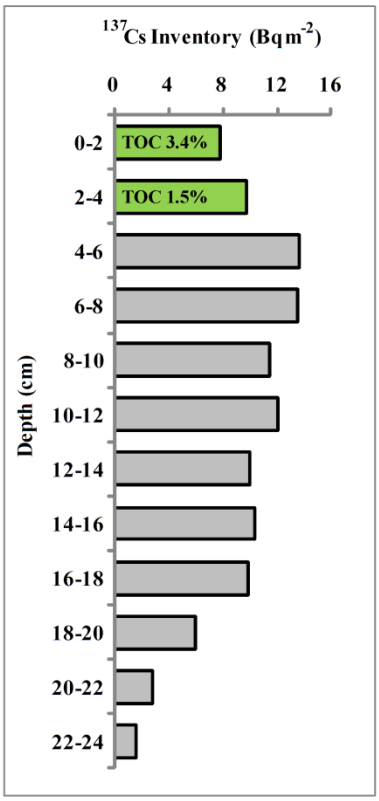


Figure 6.1: Variation of ^{137}Cs inventory with depth at the reference site

Table 6.1: ^{137}Cs inventory, grain size distribution, and classification of studied samples

Sample ID	Land Use	Cs137 Bq m^{-2}	Bulk Density kg m^{-3}	Clay %	Silt %	Sand %	Classification
1	OilPalm	103.72	1405	3.58	30.74	65.68	Sandy loam
2	OilPalm	79.40	1472	7.15	34.94	57.91	Sandy loam
3	OilPalm	69.91	1275	7.27	48.34	44.40	Loam
4	OilPalm	97.46	1137	10.46	54.14	35.40	Silt loam
5	OilPalm	45.00	1130	4.84	24.19	70.97	Sandy loam
6	OilPalm	47.22	1996	6.31	43.09	50.60	Sandy loam
7	OilPalm	67.71	1178	3.14	20.04	76.82	Loamy sand
8	OilPalm	77.44	1533	3.34	30.67	65.99	Sandy loam
9	OilPalm	79.53	1230	3.46	26.08	70.45	Loamy sand
10	OilPalm	2.20	1200	5.11	28.47	66.42	Loamy sand
11	OilPalm	36.50	1573	7.36	60.08	32.56	Silt loam
12	OilPalm	246.64	935	6.80	39.46	53.74	Sandy loam
13	Rubber farm	167.80	1258	6.70	51.84	41.47	Silt loam
14	OilPalm Developing	30.83	1623	18.25	58.97	22.78	Silt loam
15	OilPalm Developing	59.04	1231	8.35	11.03	80.62	Loamy sand
16	OilPalm Developing	41.26	1300	7.56	47.31	45.13	Loam
17	OilPalm Developing	78.35	1230	7.10	48.07	44.83	Loam
18	OilPalm Developing	43.88	1478	8.03	48.39	43.58	Loam
19	OilPalm Developing	60.48	1140	7.60	46.61	45.79	Loam
20	OilPalm Developing	45.00	1580	5.04	32.53	62.44	Sandy loam
21	OilPlam Developing	51.92	1478	7.45	53.26	39.30	Silt loam
22	Cleared Land	20.84	1791	11.05	40.88	48.07	Sandy loam
23	Cleared Land	1.74	1407	11.67	60.46	27.87	Silt loam
24	Cleared Land	43.64	989	4.17	38.21	57.62	Sandy loam
25	Cleared Land	72.37	1409	8.52	48.76	42.72	Loam
26	Cleared Land	17.10	1536	6.03	43.82	50.15	Sandy loam
27	Reference	85.00	1290	4.50	35.79	59.71	Sandy loam
28	Reference	96.40	1359	6.44	45.88	47.69	Sandy loam
29	Reference	98.00	1314	7.14	36.73	56.12	Sandy loam
30	Reference	137.60	941	8.04	52.55	39.41	Silt loam
31	Reference	100.01	1754	4.12	29.42	66.46	Sandy loam
32	Reference	193.00	1366	8.53	53.41	38.05	Silt loam
33	Reference	153.40	1166	7.36	60.89	31.75	Silt loam
34	Reference	157.00	1246	9.38	53.13	37.50	Silt loam
35	Reference	108.10	1164	9.78	50.10	40.12	Silt loam

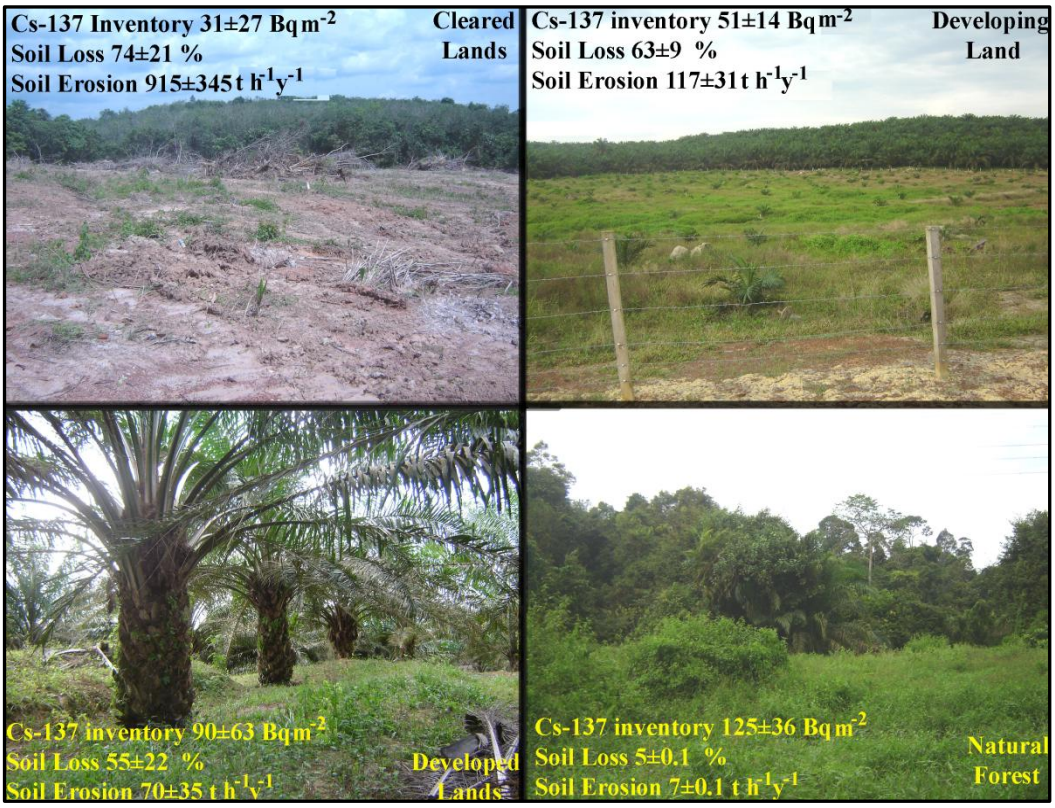


Figure 6.2: ^{137}Cs inventories, soil loss and soil erosion rate for various land use types

6.3. Soil loss estimation

The results properly highlighted effects of the deforestation dates on the soil loss and erosion rate in the BLC (Table 6.2). This study shows that different land use in areas of similar topographic and parent rocks results in different rates of soil loss in the BLC. The results show that mean percentage of soil loss for developed oil or rubber plantations in the different subcatchments is 55±22% with a CV of 0.41.

The estimate of mean erosion, therefore, was 70±35 t h^{-1} y^{-1} with a CV of 0.5. The tillage depth was 250 kg m^{-2} (ca. 25cm) and from which 137.5 kg m^{-2} (or ca. 13.75 cm) has been lost by erosion since the land clearance started. The estimated mean erosion during the first, second, third, and the fourth FELDA land development projects based on their tillage beginning date were 0.58±0.15, 0.47±0.17, 0.71±0.41, and 1.13±0.13 cm y-1,

respectively. The maximum soil redistribution was 119 t h^{-1} y^{-1} at the north-east of catchment (Bera-Selatan (4) FELDA district). The bedrock comprises red colored, continental facies rocks, mainly areno-argillaceous strata with rudaceous and carbonaceous bands of the Redbeds Formation (This is probably the Tembeling Formation). As a result, the maximum erosion rate of 1.56 cm y^{-1} was obtained (Fig. 4). On the other hand, the lowest soil loss, erosion magnitude and medium-term erosion rate obtained were 27.72%, 30.42 t h^{-1} y^{-1}, and 0.35 cm y^{-1}, respectively, in Triang-Selatan (1) oil palm district which was developed in 1979 in the north west of the catchment.

Intense surface erosion here led to the removal of fine grains and increasing concentrations of coarse grains at the soil surface (Fig. 6.3a); a feature similar to that of a desert pavement. Stone pillars (Fig. 6.3b) are common features in the study area where a gravel sized particle forms the cap rock for a column of fine grains. Continued erosion leads to the collapse of the pillars and repetition of the surface erosional processes.

Figure 6.3: Intense surface erosion and its feature in exposed areas

Literature shows that most studies in the neighing countries have applied ^{137}Cs technique in the different land use scheme or conversion models in comparison with the

BLC. Nonetheless, the Proportional model was used in Seri Lanka and Philippines (IEAE, 2003) to estimate soil redistribution in a converted rainforest to monoculture crop (tea and coffee farms) showed an erosion rate of 43 and 33 t h^{-1} y^{-1}, respectively. These values were calculated in a quite smaller farms, non-machinery deforestation, and different tillage commencement. They could be comparable with the lowest magnitude of erosion in developed lands in BLC although the overall situations were quite different.

The mean soil erosion of developed oil palm/rubber plantations have been reported as 56±20 t h^{-1} y^{-1} in previous studies (Leigh, 1973; Malmer et al., 1990; Shallow et al., 1956; Douglas et al., 1992; Paramananthan, 1984). This value which was calculated using the Universal Soil Loss Equation (USLE) appears to under-estimate soil erosion when compared with the results of the Proportional model and ^{137}Cs technique. Further work, therefore, is needed to calibrate the empirical USLE Method with the ^{137}Cs technique in order to estimate soil erosion in the BLC. Although different assumptions and parameters in ^{137}Cs technique and USLE dictated different soil erosion values, oil palm plantations have developed in a similar situation in different parts of Malaysia.

One form of land use which influenced soil redistribution in the BLC is establsihment of oil palm/rubber plantations. They involve land with partially covered ground surfaces as well as partially covered with very young planted trees, or areas of re-planted oil palm. The updated land use map and a published Report (Henson, 1994) show that such areas were mainly cleared by local residents despite the gazettement of the BLC as a RAMSAR site and after the prohibition of FELDA development projects in 1994. Tillage commencement dates of the areas of developing plantations are thus assumed to be 1995 with the total elapsed period being 16 years. The results clearly confirmed the erosion

magnitude of developing lands with a mean soil erosion rate of 117±31 t h^{-1} y^{-1} and a CV of 0.3. The mean soil loss percentage in these developing areas was furthermore, calculated to be 63±9 with a CV of 0.14. This indicates that soil loss in the developing lands have been similar for the past two decades with the lowest variance. According to the tillage depth (250 Kg m^{-2}) and tillage commencement date, soil loss and the mean medium-term soil erosion rate in the developing land has been 156.5 Kg m^{-2} (or ca. 15.56 cm) and 1.57±0.24 cm y^{-1}, respectively. The maximum rate of erosion determined for developing land is 1.79 cm y^{-1} in the RAMSAR site district where there has been encroachment by local residents.

Field observations show that most of the recent land being developed in the BLC is being cultivated with rubber trees. Rubber trees are preferred to that of oil-palm by the local residents in view of easier land preparation, maintenance, and harvesting (Henson, 1994). The erosion magnitude in BLC is comparable with soil erosion in the Seberang Perai Selatan area, Penang State, Peninsular Malaysia, where the highest contribution of soil loss among cultivated lands was recorded for rubber plantations to be 122 t h^{-1} y^{-1}. This value is much higher than that of oil palm plantations with a soil loss of 34 t h^{-1} y^{-1} (Shamshad et al., 2008).

Table 6.2: Soil loss, erosion magnitude, and erosion rate at BLC

Sample ID	Sub-Catchment	Land Use	Soil Lost %	Erosion t $ha^{-1}y^{-1}$	Elapsed Time (yr)	Erosion Rate cm y^{-1}
1	1	OilPalm	27.72	-36.49	32	0.29
2	2	OilPalm	44.67	-65.75	30	0.50
3	3	OilPalm	27.48	-40.43	26	0.35
4	4	OilPalm	29.17	-35.53	28	0.35
5	4	OilPalm	67.30	-121.21	27	0.83
6	8	OilPalm	56.32	-86.47	39	0.48
7	10	OilPalm	64.92	-58.83	25	0.87
8	11	OilPalm	49.52	-87.59	25	0.66
9	12	OilPalm	58.79	-90.40	25	0.78
10	12	OilPalm	97.80	-140.83	25	1.30
11	12	OilPalm	81.09	-153.06	25	1.08
12	12	OilPalm	*27.79	*26.09	*25	*0.37
13	9	Rubber farm	*14.48	*34.15	*16	*0.24
14	4	OilPalm Developing	71.48	-144.96	16	1.49
15	5	OilPalm Developing	57.09	-131.78	16	1.19
16	6	OilPalm Developing	70.01	-170.65	16	1.46
17	2	OilPalm Developing	45.40	-55.85	16	0.95
18	7	OilPalm Developing	56.12	-155.52	16	1.17
19	8	OilPalm Developing	68.28	-186.23	16	1.42
20	2	OilPalm Developing	68.64	-108.33	16	1.43
21	9	OilPlam Developing	63.82	-176.93	16	1.33
22	8	Cleared Land	84.85	-1519.73	3	9.43
23	1	Cleared Land	98.79	-1389.92	3	10.98
24	6	Cleared Land	56.05	-638.96	3	6.23
25	8	Cleared Land	47.40	-667.90	3	5.27
26	7	Cleared Land	82.90	-1273.34	3	9.21

* Remark of soil accumulation and deposion rate

Serious erosion is found at cleared lands in the BLC. Recent encroachments into the RAMSAR site by local residents have been detected at 187 locations where the ground surface is entirely cleared and exposed to weathering and erosion processes. A satellite image (Spot 5, 2009) of spatial resolution 10 m served as the base for recognizing cleared lands in the BLC. It can therefore, be assumed that tillage of cleared lands started in 2008 as normal land clearing and preparation takes 12-14 months for a 2,000 hectare land development project (Tan et al., 2009). In such situation, mean soil loss percentage was

74±21 with a CV of 0.29 in cleared lands. Maximum, minimum, and mean soil loss magnitudes of 1266, 532, and 915±345, t h^{-1} y^{-1} respectively, with CV of 0.4 were calculated for the newly open land. As a result, the medium-term mean erosion rate is currently 7.4±2.1 cm y^{-1} with a CV of 0.29 in the cleared lands at BLC.

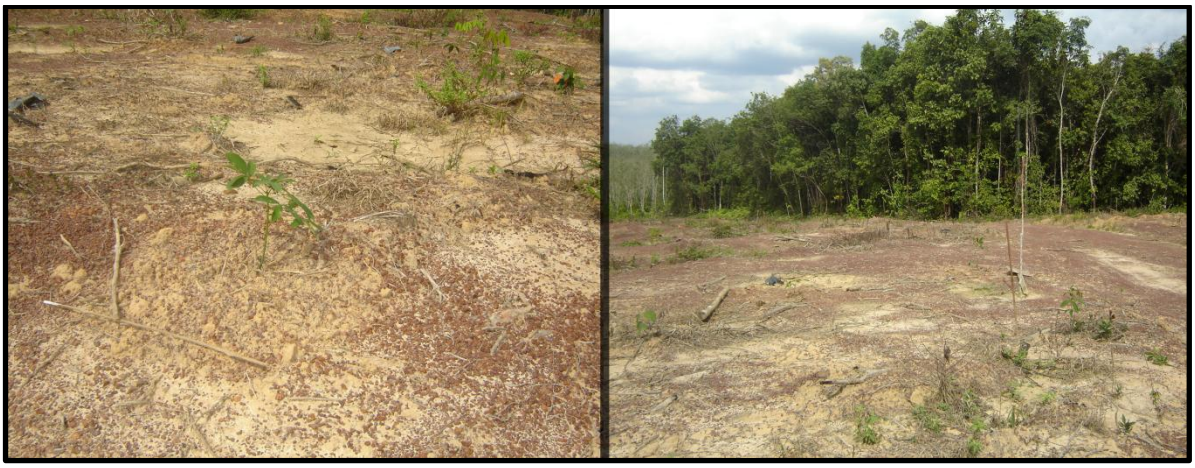


Figure 6.4: Intense surface erosion observed at recent cleared and exposed lands

The maximum rate of erosion furthermore, occurs in cleared land in the subcatchment 1 at the north of the BLC with a value of 9.88 cm y^{-1}. The results show that the erosion rate in the cleared lands in the RAMSAR site is about half of the value from areas that were previously covered by oil palm and recently cleared for replanting of oil palm/rubber. Site preparation which involves burning during land preparation has caused significant increases in soil loss from the BLC (Henson, 1994). The effect of forest burning on increase of soil loss was reported by Field (2000). Further studies are needed to evaluate forest burning in BLC, but available evidences of forest burning in the land preparation is clearly manifested in the sediment column as the charcoal horizon especially at lower contact of white sandy mud deposits. Recent felled-land burning can be found at

the north of the study area where some land has been converted to rubber by the local people (Fig. 6.5).

Figure 6.5: Burning features was observed at the north of the study area

Models calibrated for cultivated land usually assumed very low soil loss from natural forest (Walling & He, 1999). Ling et al., (1979), (unpublished) Wiersum (1985), (unpublished) Northcliff (1990), (Malmer, 1990), and Shamshad et al., (2008) have estimated soil loss from Malaysian natural rainforests to be 10, 6.2, 5.1, 0.036 and 0, t ha^{-1} y^{-1}, respectively. These values were determined using the USLE equation and obtained from sediment discharge analyses. Although it can be assumed that soil erosion in the natural rainforest at BLC is very low, field observations show that recent encroachments into the forest area for timber and other natural products have led to erosional features as gullies and landslips. A mean soil erosion value of 7 t a^{-1} y^{-1} from the just mentioned studies has been used to illustrate soil loss from the natural forest at BLC.

6.4. Nutrient Content in Bera Lake Catchment Soil Profile

Agronomic activities are well-known anthropogenic projects which have significantly changed the features of Malaysian rainforests. Progressive global demands for oil palm as well as a suitable agro-climatic situation and Malaysian land development projects since 1961 have contributed to the establish 20 million hectares of planted land. Although oil palm plantations are introduced as sustainable agricultural practices (Basiron, 2006), they significantly affect soils and sediments nutrient concentrations (MPOC, 2007; Chiew, 2002; Wakker, 2004). This section discusses the nutrient contents, physical properties, and inventories of ^{137}Cs that have analyzed in 35 samples collected from the four groups of land uses in the study area (Table 6.3). Clear variations in nutrient contents and radiocesium inventory were obtained due to different land uses in the BLC. The geographical distributions of nutrients in the catchment area are presented in Figures 6.6 and 6.7.

The lowest nutrient contents obtained are in cleared lands with TOC and TN mean values of 1.09±0.2 % and 0.11±0.02 % with coefficient variations of 0.18 and 0.2, respectively. In this situation, the maximum ^{137}Cs loss was recorded where the lowest mean inventory of this fallout radionuclide was 31.14±27.5 Bq m^{-2} with a coefficient variation of 0.88. Furthermore percentage losses of carbon, nitrogen and ^{137}Cs were 52%, 31.2% and 74%, respectively. A significant negative correlation (r= -0.82, p<0.05) between ^{137}Cs value and depth-wise TOC content was obtained in soil samples collected from cleared land.

Developed oil palm and rubber plantations are another land use group where deforestation and land development has contributed significantly to decrease nutrient contents and radioisotopes inventories.

Table 6.3 Nutrient contents, ^{137}Cs inventory, and physical properties of soil samples

Land use	Bulk Density kg m-3	TC %	TN %	Cs-137 Bq m^{-2}	Clay %	Silt %	Sand %
Developed Oil Plam and Rubber Plantations (n=12)							
Mean	1400	1.22	0.13	66.11	5.72	37.66	56.62
STDEV	261	0.62	0.07	30.22	2.41	13.13	15.21
CV	0.19	0.51	0.53	0.46	0.42	0.35	0.27
Developing Oil Palm Farms (n=8)							
Mean	1369	1.33	0.13	64.28	8.45	44.22	47.33
STDEV	173	0.31	0.02	41.15	3.80	14.33	16.07
CV	0.13	0.23	0.16	0.64	0.45	0.32	0.34
Cleared Land (n=5)							
Mean	1426	1.09	0.11	31.14	8.29	46.43	45.29
STDEV	290	0.20	0.02	27.50	3.21	8.77	11.11
CV	0.20	0.18	0.20	0.88	0.39	0.19	0.25
Natural Forest (n=9)							
Mean	1254	2.40	0.16	137.52	7.21	45.74	46.31
STDEV	234	1.14	0.05	51.53	1.87	9.97	11.87
CV	0.19	0.48	0.31	0.37	0.26	0.22	0.26

These areas have experienced phases of land clearance and development, though the nutrient cycle has only marginally improved. The mean values of TOC and TN obtained are, 1.22±0.62 % and 0.13±0.07 % with coefficient variations of 0.51 and 0.53, respectively. Carbon, nitrogen and ^{137}Cs percentage losses in developed oil palm plantations were 49%, 18.75%, and 55%, respectively. Continuous erosion has removed fine particles and a coarsening of soil texture is the dominant process in developed land in BLC. The results show that the average nitrogen loss percentage in the land being developed for oil palm plantations is similar to that of developed oil palm areas. However, the percentage losses in carbon and ^{137}Cs were 44.6%, and 62.0%, respectively.

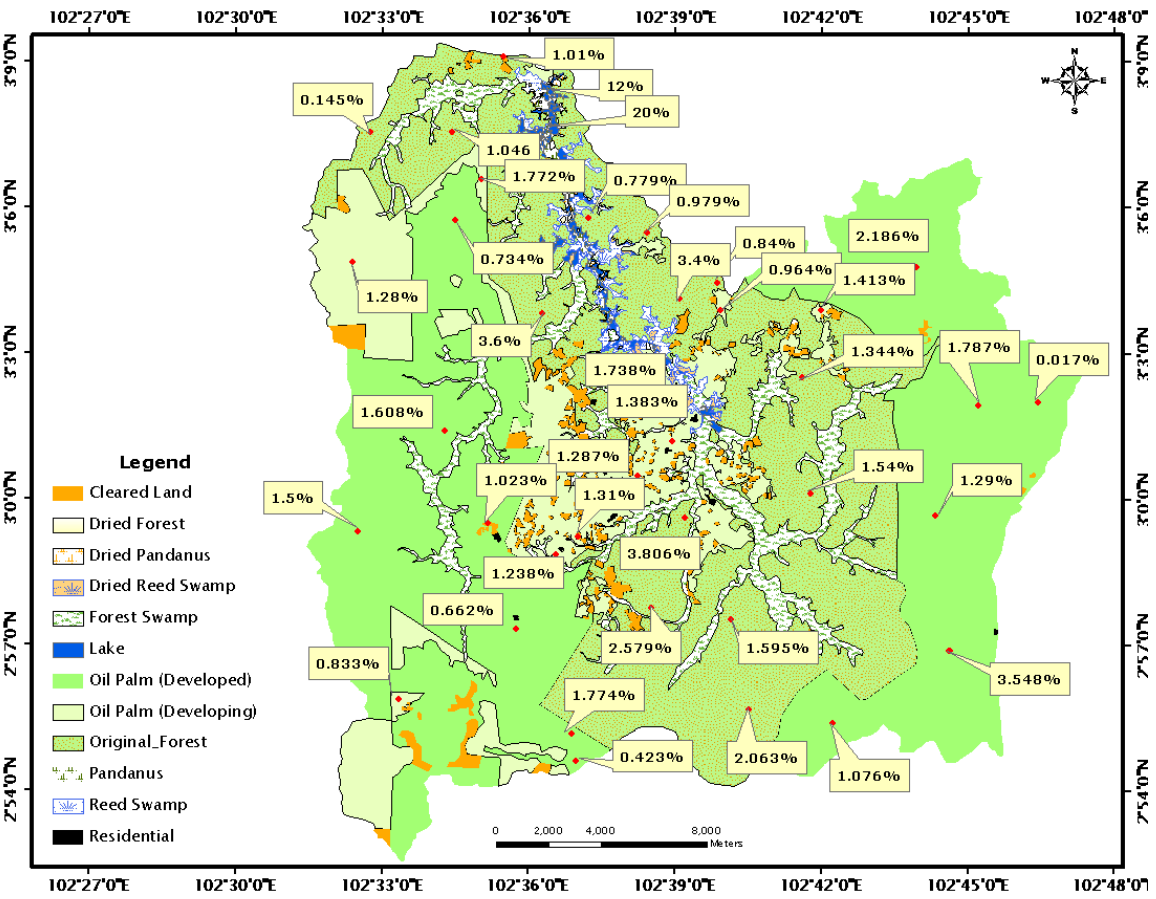


Figure 6.6: TOC values at different land use districts

Cultivation of new forest has improved carbon contents in the land being developed. Organic matter has also been derived from the trunks, fallen leaves, and remaining roots and from felled palm tree in replanted area. Chiew (2002) showed that the release of EFB in oil palm plantations rebuilt nutrient cycles and increased leaf N, P, K and Mg over and above the effects of EFB or N alone. A mean value of 24,000±1.14 (2.4%), and 1,600±0.05 mg kg^{-1} (1.6%) was obtained for carbon and nitrogen contents in rainforest samples. PFE in BLC was gazzetted as the first RAMSAR site in Malaysia, 1994 and the surrounding developed land established as buffer zones. Local residents have been deforesting small areas in the RAMSAR site since 1994 and leaving destructive effects on

BLC ecosystems. This is in spite of government regulations stipulating that any project beyond 500 hectare should have an EIA (ECD, 2002).

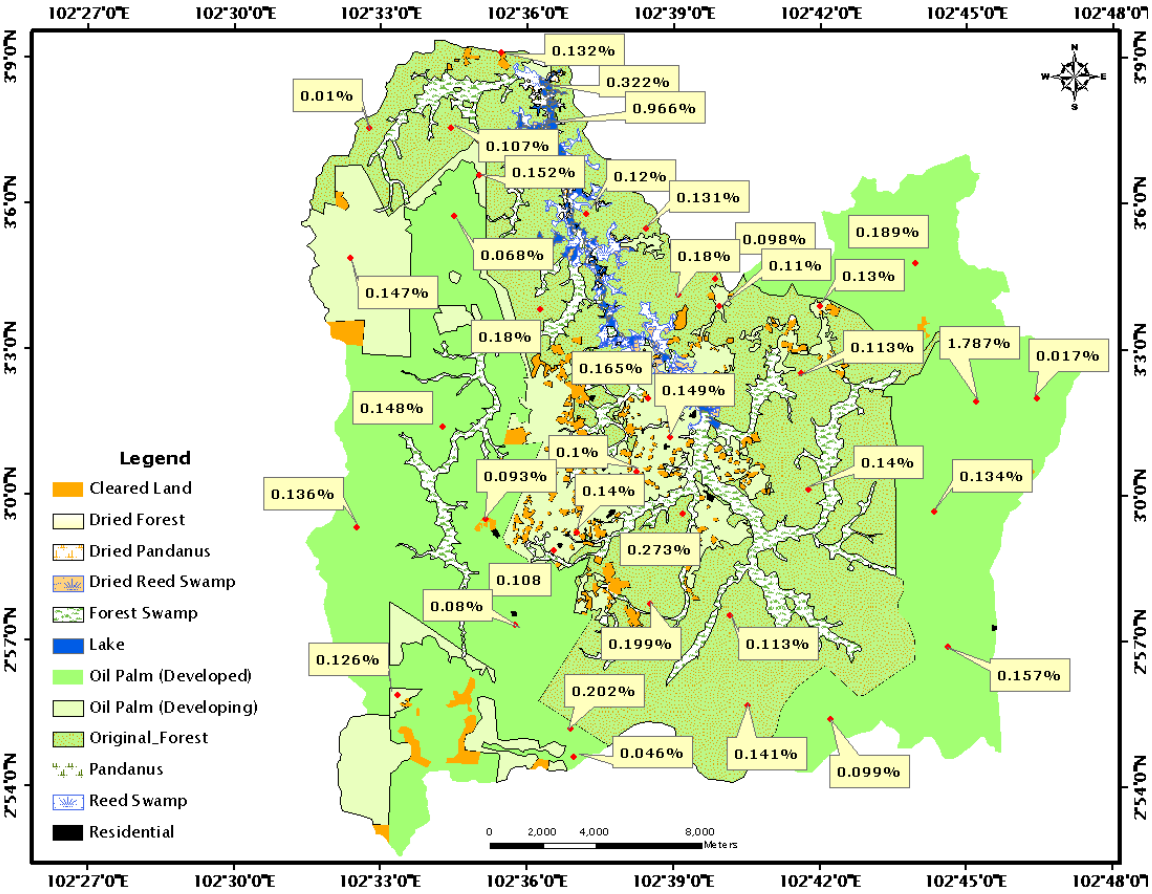


Figure 6.7: TN values at different land use districts

6.5. Soil Accumulation Rate in Wetlands and Open Waters

Wetlands and open waters covering some 57 km^{-2} in area are recognized as natural soil traps and retention pounds within the BLC. Large amounts of eroded soil has accumulated in sink area which show many depositional features such as sediment dumping in wetlands, narrowing of water bodies by sand barriers and serious depth reduction. In the present study, organic-rich sediments in the uppermost layer of the Bera Lake sediment column were studied in order to find out the fate of eroded soil. The study is based on the ^{137}Cs inventory in organic-rich Layer 4, until a depth of 25 cm, similar to the depth of soil samples analyzed for their ^{137}Cs inventory in source area (Table 6.4). The organic-rich layer can be recognized by its very low submerged bulk density (194±93 kg m^{-3}), high porosity (0.87±0.07), and very low inorganic content.

Table 6.4: ^{137}Cs inventory and accumulation rate in wetlands and open waters samples

Sample ID	Layer thickness m	Porosity %	Weight kg	Submerged Bulk Density kg m^{-3}	Inventory Bq m^{-2}	Accretion %	Accretion Rate t $ha^{-1}y^{-1}$
1	0.22	81.00	0.06	445	367.70	60.97	21.32
2	0.19	79.30	0.09	171	1139.11	87.40	17.75
3	0.23	79.70	0.09	148	1097.71	86.93	16.44
4	0.16	89.80	0.06	148	361.52	60.31	5.71
5	0.21	79.10	0.09	143	1389.44	89.67	9.97
6	0.20	79.40	0.09	169	1153.38	87.56	22.77
7	0.15	74.00	0.06	134	367.41	60.94	11.14
8	0.20	80.00	0.09	167	1274.82	88.74	24.70
9	0.25	86.00	0.10	248	4386.80	96.73	33.23
10	0.16	70.00	0.09	169	2360.93	93.92	36.28

The ^{137}Cs inventories in samples from the wetlands and open waters were compared with the main reference sample which shows 143.5 Bq m^{-2} ^{137}Cs inventory of the same bulk core diameter. The mean ^{137}Cs inventory in submerged soil samples was

determined to be 1390±1216 Bq m^{-2} with a coefficient variance of 0.87. A great enrichment in ^{137}Cs inventory is thus recognized in the studied samples. Geographical parameters like the dendritic pattern of wetlands and water bodies play an important role in ^{137}Cs enrichment in their sediments. For instance, samples which were collected from semi closed areas at the north of Bera Lake had the highest inventory that was up to 4 times the value of open water samples. The accretion frequency and rate was also morphologically controlled in the study area. A mean accretion rate of 20±9 t ha^{-1} y^{-1} with a coefficient variance of 0.49 was obtained achieved for the wetlands and open waters. This study indicates that after the implementation of the fifth Malaysian land development project between 1990 and 1995 (Henson, 1994) oil palm/rubber estates were established as the mature forests. Annual biomass productivity based on MPOC (2007) report and land area covered by rainforest and oil palm/rubber plantations was 1.5 million tones. Potentially, organic-matter could make a cover on the whole of catchment area with 0.4 cm thickness. Therefore, the run-off load and the accumulated soils in the sink area have been organic-rich due to the abundance of biomass production. The elapsed time for the accumulation of organic-rich soils in the study area is assumed to be 16 years after development of mature oil palm/rubber plantations. Therefore, the mean of estimated soil accumulation rate in the wetlands and open waters was 1.025 cm y^{-1}.

6.6. Soil Redistribution Mapping

The soil redistribution mapping technique is based on ^{137}Cs variability as introduced by Mabit (2007, 2008b) where geostatistics was coupled with a GIS. The method is applicable to small catchments with uniform land use and topographic conditions. Soil redistribution mapping in this study is based on land use and dates of

tillage commencement as well as similarities in soil textures and geological setting of each sub-catchment. The FELDA land development districts with certain dates of tillage and elapsed time were the basic units for mapping. Soil erosion values obtained for cleared land with similar elapsed times were extended to other cleared lands within the same sub-catchment. Mean values of soil loss from undisturbed rainforest were obtained from previous studies and applies for considering natural forest in the BLC. Mean accretion rates for sink areas in BLC furthermore, was based on ten bulk core samples in the wetlands and open waters. The soil redistribution map of BLC (Fig. 6.8) is the first attempt in applying the ^{137}Cs technique in Malaysia and catchment sacle. It illustrates well erosional and depositional trends in the catchment scale. This map prepared valuable guideline for soil conservation and management practices. Decision makers can focus on districts where soil erosion is in a critical condition and experienced intensive erosion.

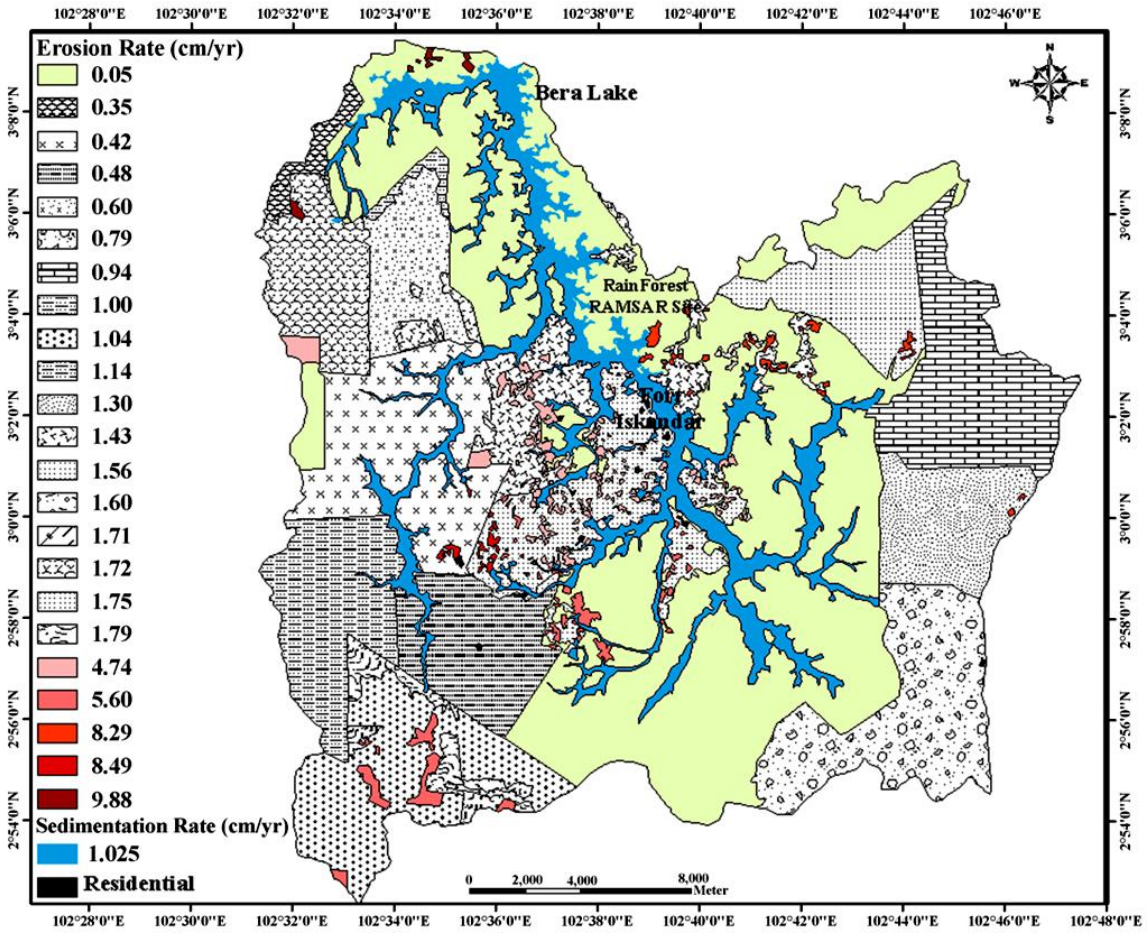


Figure 6.8: Soil erosion rate map of BLC

6.7. Discussion

Soil erosion is a natural process in which different phenomenon occurs. It can occur in short to long-term periods, depending on the original rock, climate, and topographic situations, but more recently human activities have accelerated erosion.

Soil erosion at BLC area is controlled by several natural and artificial factors. The low drainage density (2.248 km km^{-2}) and semi elongate shape (Horton form factor, 1.12), as well as gentle slope (0 to 2 degree) of BLC indicate that physiographic factors play a minor role in soil erosion. The tendency to generate surface runoff is dictated by other factors. On the other hand, physiographic factors and vegetation cover could increase

infiltration and in the study area. Climate also plays an important role in tropical countries. The mean humidity of 70 to 90%, heavy rainfall and the low evapotranspiration rate of 4-4.5 mm per day has an effective impact on soil erosion in the study area. Deep chemical weathering can therefore, be expected in the original bedrock.

The Bera and Semantan Formations which are entirely composed of sedimentary rocks cover 96.7% of the BLC. Their lithology mainly comprises deeply weathered brown-yellowish argillaceous, arenaceous to rudaceous rocks. Undifferentiated strata of massive mudstone, tuffaceous sandstone, siltstone, and conglomerates also outcrop under the soil profiles in the study area. Secondary iron oxide concretions as a result of intense chemical weathering of the bedrock are observed at lower contact of Bera Formation. Joints and fractures have also increased the depth of chemical and physical weathering. The overall evidence demonstrates that the bedrock is susceptible to weathering and thus contributed significantly to generation of erodible soil profiles. The contribution of natural parameters in soil erosion rates for natural rainforest in different parts of Malaysia have been reported in previous studies (Ling et al., 1979; Shamshad et al., 2008) using the USLE equation. The mean soil erosion rate has been calculated to be 7 ± 4 t ha^{-1} y^{-1}. However, natural parameters have played different roles in the varied type of land uses especially for converted lands to agricultural states.

Site preparation by burning is one of the land development phases that have caused a significant increase in soil loss in the BLC (Henson, 1994). The importance of forest burning to increase the rate of soil loss has been reported by Field and Carter (2000). A mean soil erosion rate based on previous work using the USLE equation (Leigh & Low, 1973; Shallow, 1956; Douglas et al., 1992; Paramananthan & Eswaran, 1984) was reported

to be 56±20 t h^{-1} y^{-1}. This value which was calculated using the USLE appears to under-estimate soil erosion when compared with the results of the Proportional model (70±35 t h^{-1} y^{-1}) and ^{137}Cs fallout radionuclide inventory.

In the Seberang Perai Selatan area of Penang State, Malaysia, soil erosion in rubber plantations was reported to have the highest value amongst cultivated lands with a soil loss of 122 t h^{-1} y^{-1} (Shamshad et al., 2008b). The rate of soil loss from rubber plantations in Penang State is close to the mean value of soil loss (117±31 t h^{-1} y^{-1}) which has been estimated by the ^{137}Cs technique in the BLC for under developing lands.

Soil loss from cleared land at two small catchments at Sipitang (Midmore et al., 1996), and at Ulu Segama (Malmer, 1990), Sabah, Malaysia calculated using the USLE equation was found to be 6.60, and 16 t ha^{-1} y^{-1}, respectively. In these cases, the calculated soil erosion magnitude is under-estimated in comparison with the soil erosion rate (915±345, t h^{-1} y^{-1}) calculated with the ^{137}Cs technique in the BLC. It is evident that the size of catchment area plays an important role in determining the soil loss by any technique. For instance, Walling (1982) estimated soil erosion in the Cikeruh and Cigulung catchments in tropical Java with areas of 250, and 43, km^2 area, at 112, and 10.85, t ha^{-1} y^{-1}, respectively. Further work, therefore, is needed to calibrate the empirical USLE Method with the ^{137}Cs technique to estimate soil erosion in the BLC. All in all, soil erosion rate studies using the USLE at several catchments in Malaysia indicate under-estimated rates in comparison with soil erosion rates which were calculated with the ^{137}Cs technique at BLC.

One of the main contributions in knowledge which has been gained in this research is selection of the Proportional Model from several available models for conversion of soil loss frequency to soil erosion rate. In other words, this model was recognized as the best

model for catchments which were deforested once and covered by oil palm and rubber plantations. All assumptions such as exact date of tillage and soil disturbance occasions were met in this model. Although, the Mass Balance I, II, III are known to be more advanced models to reduce uncertainties in the calculations, they are suitable for farms and cultivated lands where there is annual ploughing. Direct communication with Professor Dess Walling, Exeter University who developed the conversion models (Walling & He, 1999) has confirmed application of the Proportional Model to estimate soil erosion rate in such catchments which are the most common agricultural scheme in the Malaysia. The ^{137}Cs technique has allowed preparation of a soil erosion rate map (Fig. 6.8) for BLC where certain land use districts show actual rates of have soil loss based on cultivation dates. According to this map, the annual soil erosion from source areas is calculated to be 4.5 million tones which could potentially cover the whole wetlands and open waters at a rate of 6 mm per year. The ^{137}Cs technique revealed that the deposition rate in the mentioned sink areas has been 1.025 cm y^{-1} since 1994. Therefore, this research has been successful in achieving one of its main objectives in that it has shown how much and where soil resources of BLC have been removed since and after deforestation phases. The erosion map can also be used as a base map for soil conservation and management practices in the BLC area. According to Tan et al., (2009) oil palm plantations last for about 25 years and they will then be replanted with new oil palm trees or other agricultural crops. In view of this, it can be assumed that the Bera Lake oil palm plantations are old and need replanting. The results of this study can therefore, be used as a guideline for decision makers to take an appropriate policy to approach a sustainable land use scheme at any replantation districts.

One of expected environmental impacts of land use changes in BLC is the interruption and disturbance in carbon and nitrogen cycles. Carbon and nitrogen exchange occur by biogeochemical processes among several media like biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth. The cyclic movement of nutrients is recognized as one of the most important cycles of the earth and allows for nutrients to be recycled in organic and inorganic forms. Rainforests, wetlands and open waters are the main storages of nutrients and they play vital roles in nutrient cycles. Bera wetlands and open waters were introduced as sites of peat accumulation in Malaysia (Phillips, 1998). Wȕst and Bustin (2001) have properly stated that there is low ash peat accumulation in the study area. Interruption of, and changes in, the coalification mechanism due to land use changes over the recent decades, however, has been the main gap in their studies. Evaluation of the effects of land use changes on the nutrient cycle in the BLC area and open water was thus considered to be one of the objectives of the present research. This objective was studied by comparing nutrient contents in different land use districts in the catchment area and application of radioisotopes for historical reconstruction of nutrient variations in Bera Lake. Similar to other independent time markers, particular charcoal and organic matter horizons in sediment columns were highlighted to verify ^{210}Pb resultant dates using the CRS model.

The highest and the lowest values of TOC were calculated to be 3.8 and 0.14% for rainforest, and cleared lands, respectively. Similarly, the highest and the lowest values of TN were 0.27 and 0.01 % for rainforest and cleared lands. The maximum ^{137}Cs loss has furthermore, been recorded in cleared land where the lowest mean activity of this fallout radionuclide was determined to be 31.14±27.5 Bq m^{-2} with a coefficient variation of 0.88.

Several mechanisms have contributed to decreasing nutrient contents in the BLC, particularly in cleared land. Clear-felling and burning are two major procedures in land preparation (Tan et al., 2009) for oil palm planting and this has been extensively used by FELDA in the BLC. Malmer (1996) investigated effects of forest burring in the Mendolong catchment area in Malaysia and reported that concentrations of nutrients in suspended load during clear-felling and after burning rose 10-100 times higher than the background level. Trammell et al., (2004) estimated that adverse effects of forest burning in terms of nitrogen loss will be equivalent to 4.5 years of atmospheric input. Oxidation and volatilization of nutrients stored in all kinds of fineable vegetation, leaching, surface runoff, and convection of ash are the main mechanisms which promote nutrient loss from ecosystems during and after burning of forests (Fisher & Binkley, 2000). In addition, Grigal and Bates (1992) introduced forest burning as one of main reasons to consume nutrients especially nitrogen and some phosphorus by volatilization and escape to the atmosphere.

Another destructive effect of forest burning in the land clearing process reported by Debano (1998) is disruption of hydrological properties of the soil. The volume and rate of air and water movement through soil is mainly controlled by pore size and space. Loss of aggregation from the destruction of organic matter binding mineral soil particles decreases pore volume and impedes flow of air and water through the soil. This process affected cleared land in the BLC in terms of bulk density with some 10 % increment on average.

7. CHAPTER VII: CHEMICAL PROPERTIES AND QUALITY ASSESSMENT OF BERA LAKE SEDIMENT

7.1. Introduction

Determination of the chemical composition and quality of the sediments at Bera Lake and its' ecological risk assessment is one of main the objectives of this research. Medium-term heavy metal fluxes into the Lake and contamination of distinct strata will support and verify resultant ^{210}Pb dates as well as assist in determining sedimentation rates. Furthermore, sediment quality assessments will reveal ecological risks due to sediment pollution and provide vital data for ecological risk management of Bera Lake. Details on sample preparation and chemical analyses as well as ecological risk assessment methods have been explained in Sections 3.33 and 3.5.3, respectively. This chapter discusses the chemical composition of the Bera Lake sediments as well as cluster analyses of the major and minor metals. Details on the sediment quality and ecological risk assessment of Bera Lake are also presented in this Chapter.

7.2. Background Concentration of Heavy Metals in Bera Lake Sediments

Calculation of ecological risk indices requires background values, or pre-land use change concentrations, of metals. Physico-chemical analyses of Bera Lake sediments from the lower part of cores (depths exceeding 32 cm) can be considered to provide data that representative of the sediments that were deposited under natural conditions. Average values of major and minor elements in the lower layers of the core are therefore, assumed to be background values (Table 7.1). Deposition of major and minor elements at Bera Lake has occurred under natural conditions with some minor variations since the creation of the

wetlands and Bera Lake about 4,500 BP (Morley, 1981). Over the last four decades, however, Bera Lake has experienced fluxes in lithogenic and anthropogenic derived metals since part of the drainage catchment was cleared for oil palm monoculture. Evidence of this is distinctly seen in Figure 7.1 which shows concentration of Fe was constant below 32 cm depth. Then, concentration has experienced significant upward variation, signaling the anomalies in Fe flux into Bera Lake.

Table 7.1: Major and minor metals background levels in Bera Lake

Element	Al	Na	K	Fe	Mg	Ca
Natural Value %	9.68±7.4	2.6±0.01	1.1±0.22	0.78±0.15	0.17±0.04	0.1±0.01

Element	V	Cr	As	Li	Sr	Zn	Mn	Cu	Pb	Ni	Co	Cd
Natural Value (mg/kg)	113±15.5	56±10	52.59±7.5	48.77±8.7	39±5.8	32.02±8.9	27.77±3.7	25.89±8.4	17.59±12	16.34±2.6	2.77±1.2	0.19±0.01

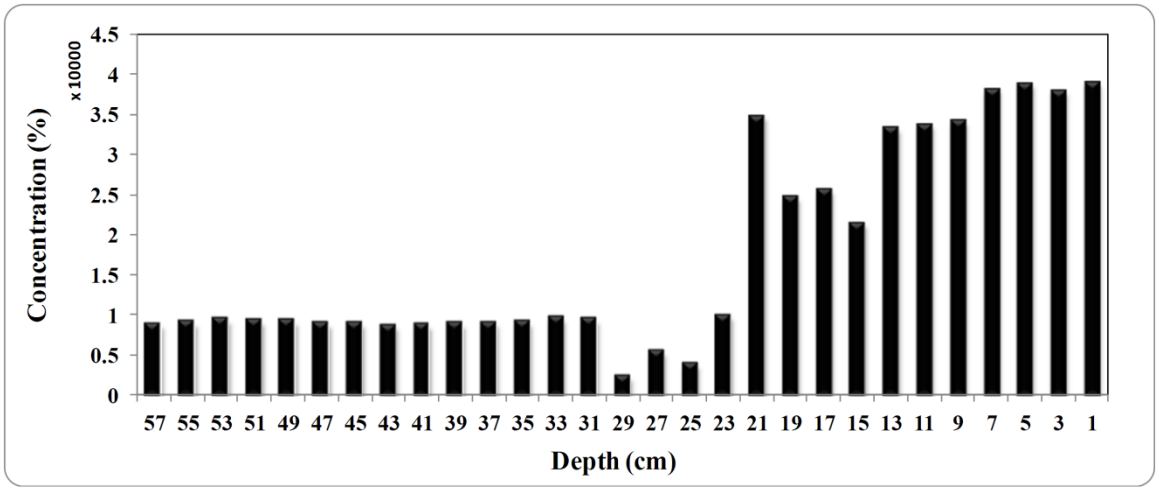


Figure 7.1: Variation in Fe concentration prior and post land use changes (Core, 5)

7.3. Heavy metal Concentration in Bera Lake Sediments

Minimum, maximum and mean values as well as standard deviations and coefficients of variation for each individual metal were determined in all the core samples. High concentrations of Cr, Ni, Cu, Zn, and Pb were found in the south of Bera Lake, while the highest mean values of Fe, K, V, Mn, Co, As, and Cd were recorded in the north of the

Lake. The highest concentrations of Ca, Mg, Na, Li, and Sr were also, found in the deepest part or in the middle of Bera Lake. The highest percentages levels of the major metals were Al (15.4%) and Fe (3.9%) while the highest concentrations of trace metals were V (157 mg kg^{-1}) and As (160 mg kg^{-1}). The highest concentration of As was found in Core 3 at the exit point of the lake at a depth of 58 cm. In the Bera Lake sediments, Cd had the lowest recorded concentration among the heavy metals with a maximum value of 0.2 mg kg^{-1} at the main sediment entry point of Bera Lake.

The mean values of Al, Fe, K, Na, Mg, and Ca were calculated to be 9.78±2.7, 1.1±0.6, 0.94±1.3, 0.22±0.01, 0.14±0.03, and 0.1±0.01%, respectively. Besides, the mean values of minor elements in Bera Lake sediments was decreased to 108.7±14> 60±4> 52±11> 39.3±12> 37.4±7> 35±9> 33.2±3> 37±8> 17.5±4> 17±10> 4.3±3> 0.18±0.01 mg kg^{-1} for V, As, Cr, Zn, Li, Mn, Sr, Cu, Ni, Pb, Co, and Cd, respectively.

An increasing trend northwards in concentrations of Fe, K, V, Mn, Co, As, Cd, and Sr were observed in the Bera Lake sediment profiles, whilst there was a corresponding decreasing trend in concentrations of Cr, Ni, Cu, Zn, and Pb. Dramatic upward variations (CV, 48-78%) in concentrations of metals were also observed in the sediment columns of the Lake. The results therefore, show that chemical composition trends are significantly controlled by environmental changes and physico-chemical conditions in the Bera Lake basin.

The Mn/Fe ratio is a good indicator of redox condition with low concentrations of Mn coinciding with low Mn/Fe ratios and high C concentrations (Koinig et al., 2003). The calculated Mn/Fe ratio in Cores 1, 2, 3, 4 and 5, are 0.007, 0.0027, 0.003, 0.018, and 0.003, respectively. An upward decrease in the Mn/Fe ratio was also found in all the Bera Lake

sediment profiles. According to Koinig et al., (2003) Mn^{2+} mainly precipitates as $MnCO_3$ and it is therefore, also dependent on pH. Conditions at Bera Lake were found to be acidic with a measured pH <5; a value that is in agreement with that of Wüst & Bustin (2004). As pH decreases, $MnCO_3$ become less stable and the mobility of Mn increased and the Mn/Fe ratio thus reduced.

7.3.1. Pearson Correlation Coefficient

Countless studies support the importance of statistical methods for identifying similarities and dissimilarities in origins, conditions of storage and the distribution of metals (Brereton 2007; Einax 1997). Calculated Pearson correlation coefficients of metal levels in the five sediment profiles of Bera Lake are presented in Table 7.2.

Significant positive and negative *r* values with *p*-value<0.05 are highlighted in Table 7.2. Strong positive and significant correlations ($r \geq 0.7$) were observed in the five sediment cores and are summarized in Table 7.3.

A strong positive correlation between Li and Al, K, Mg, and Sr with *r*-values of 0.89, 0.82, 0.91, and 0.83, respectively, at the south of Bera Lake is observed. The Al value also increases with increasing K, Mg. Similarly, Sr concentrations increase with increasing Cr, Cu and K concentrations. The concentration of Sr also showed strong positive correlation with Mg and Na with *r*-values of 0.82, and 0.84.

Table 7.2: Correlation coefficients between metalloid elements in Bera Lake

Variables	Li	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb	K	Ca	Mg	Na	Sr
Li	**1**																	
Al	**0.893**																	(a)
V	0.032	0.019	**1**															
Cr	**0.535**	**0.471**	-0.194	**1**														
Mn	**-0.381**	-0.210	0.128	**-0.484**	**1**													
Fe	**0.466**	**0.570**	0.071	0.153	**0.475**	**1**												
Co	**-0.442**	-0.339	0.189	**-0.645**	**0.503**	-0.036	**1**											
Ni	-0.093	-0.055	-0.139	**0.603**	-0.058	-0.076	-0.209	**1**										
Cu	0.147	0.142	-0.088	**0.765**	-0.249	0.034	**-0.511**	**0.772**	**1**									
Zn	0.353	**0.406**	0.326	0.252	0.098	**0.421**	-0.060	0.040	0.129	**1**								
As	-0.210	-0.069	0.256	**-0.452**	**0.387**	0.218	0.299	-0.069	-0.090	0.075	**1**							
Cd	0.291	0.183	**0.452**	0.354	-0.035	0.331	-0.326	0.032	0.262	**0.542**	-0.104	**1**						
Pb	-0.209	-0.320	**0.417**	**-0.396**	0.050	-0.260	0.093	-0.329	-0.219	0.040	0.308	-0.020	**1**					
K	**0.820**	**0.799**	0.105	**0.721**	**-0.476**	0.292	**-0.458**	0.221	**0.424**	**0.466**	-0.209	0.309	-0.283	**1**				
Ca	**0.392**	**0.456**	0.208	0.085	**0.549**	**0.897**	0.097	0.018	0.070	**0.455**	0.349	0.319	-0.156	0.254	**1**			
Mg	**0.910**	**0.942**	0.015	**0.537**	-0.225	**0.592**	-0.332	0.023	0.198	**0.411**	-0.066	0.246	**-0.363**	**0.848**	**0.533**	**1**		
Na	**0.626**	**0.657**	0.318	**0.446**	-0.327	0.245	-0.321	0.017	0.176	**0.828**	-0.113	**0.484**	-0.042	**0.748**	0.214	**0.640**	**1**	
Sr	**0.826**	**0.815**	0.036	**0.572**	**-0.451**	0.315	**-0.398**	0.001	0.140	**0.592**	-0.293	0.328	-0.205	**0.841**	0.218	**0.817**	**0.836**	**1**

Variables	Li	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb	K	Ca	Mg	Na	Sr
Li	**1**																	
Al	**0.930**	**1**																(b)
V	**-0.430**	**-0.419**	**1**															
Cr	**0.915**	**0.978**	-0.295	**1**														
Mn	**-0.677**	**-0.645**	**0.800**	**-0.528**	**1**													
Fe	**-0.889**	**-0.802**	**0.671**	**-0.731**	**0.911**	**1**												
Co	**0.369**	**0.395**	**-0.497**	**0.357**	**-0.676**	**-0.600**	**1**											
Ni	-0.265	-0.259	**0.523**	-0.159	**0.687**	**0.545**	**-0.446**	**1**										
Cu	0.069	-0.060	-0.128	-0.095	-0.228	-0.254	**0.415**	-0.110	**1**									
Zn	**-0.883**	**-0.878**	**0.620**	**-0.830**	**0.852**	**0.928**	**-0.636**	**0.524**	-0.042	**1**								
As	-0.112	0.040	0.003	0.046	-0.121	-0.036	**0.651**	-0.076	**0.443**	-0.109	**1**							
Cd	**-0.621**	**-0.714**	**0.373**	**-0.683**	**0.528**	**0.560**	-0.231	**0.460**	0.088	**0.646**	0.017	**1**						
Pb	**0.452**	**0.385**	-0.257	**0.394**	**-0.508**	**-0.592**	**0.801**	-0.245	**0.627**	**-0.570**	**0.676**	-0.171	**1**					
K	**0.977**	**0.912**	**-0.383**	**0.900**	**-0.620**	**-0.829**	0.264	-0.194	-0.055	**-0.841**	-0.232	**-0.584**	0.336	**1**				
Ca	**-0.442**	**-0.503**	**0.474**	**-0.450**	**0.610**	**0.516**	-0.348	**0.598**	**0.540**	**0.675**	0.084	**0.453**	-0.082	**-0.474**	**1**			
Mg	**0.984**	**0.954**	**-0.395**	**0.950**	**-0.656**	**-0.865**	**0.410**	-0.226	0.083	**-0.885**	-0.015	**-0.631**	**0.490**	**0.963**	**-0.414**	**1**		
Na	**0.986**	**0.904**	**-0.435**	**0.881**	**-0.691**	**-0.887**	**0.358**	-0.249	0.105	**-0.869**	-0.133	**-0.582**	**0.455**	**0.982**	**-0.421**	**0.971**	**1**	
Sr	**0.926**	**0.830**	**-0.372**	**0.805**	**-0.580**	**-0.781**	0.221	-0.200	-0.009	**-0.769**	-0.294	**-0.543**	0.279	**0.952**	**-0.401**	**0.900**	**0.938**	**1**

Variables	Li	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb	K	Ca	Mg	Na	Sr
Li	**1**																	
Al	**0.968**	**1**																(c)
V	0.211	0.196	**1**															
Cr	**0.922**	**0.959**	0.203	**1**														
Mn	**-0.613**	**-0.549**	-0.136	**-0.418**	**1**													
Fe	-0.293	-0.208	-0.258	-0.091	**0.855**	**1**												
Co	**-0.627**	**-0.587**	-0.131	**-0.481**	**0.978**	**0.817**	**1**											
Ni	-0.190	-0.249	-0.129	-0.284	**0.407**	0.257	**0.455**	**1**										
Cu	0.129	0.161	0.215	0.223	0.079	0.151	0.103	0.009	**1**									
Zn	**-0.578**	**-0.562**	0.001	**-0.430**	**0.928**	**0.749**	**0.923**	**0.431**	0.178	**1**								
As	**-0.402**	-0.338	**-0.390**	-0.308	**0.737**	**0.663**	**0.754**	**0.584**	0.222	**0.614**	**1**							
Cd	0.070	0.078	-0.151	0.132	0.354	**0.445**	0.276	0.231	0.030	0.212	0.237	**1**						
Pb	0.072	0.004	0.163	-0.079	**-0.646**	**-0.789**	**-0.624**	-0.075	0.048	**-0.599**	-0.321	-0.285	**1**					
K	**0.802**	**0.758**	**0.410**	**0.693**	**-0.871**	**-0.744**	**-0.888**	-0.348	0.042	**-0.771**	**-0.694**	-0.206	**0.525**	**1**				
Ca	0.184	0.257	0.312	**0.415**	**0.467**	**0.629**	**0.414**	0.078	**0.543**	**0.477**	0.236	**0.423**	**-0.501**	-0.121	**1**			
Mg	**0.948**	**0.947**	**0.410**	**0.912**	**-0.646**	**-0.409**	**-0.681**	-0.274	0.165	**-0.583**	**-0.501**	-0.015	0.180	**0.897**	0.207	**1**		
Na	**0.770**	**0.715**	**0.377**	**0.640**	**-0.900**	**-0.791**	**-0.906**	-0.339	0.063	**-0.795**	**-0.696**	-0.223	**0.589**	**0.992**	-0.174	**0.859**	**1**	
Sr	**0.790**	**0.796**	0.124	**0.694**	**-0.717**	**-0.468**	**-0.722**	-0.310	0.038	**-0.732**	**-0.469**	-0.111	0.292	**0.746**	-0.046	**0.782**	**0.748**	**1**

Variables	Li	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb	K	Ca	Mg	Na	Sr
Li	**1**																	
Al	**0.564**	**1**																(d)
V	-0.075	-0.098	**1**															
Cr	**-0.426**	0.009	-0.018	**1**														
Mn	-0.007	0.248	**-0.554**	0.355	**1**													
Fe	0.360	0.333	**-0.558**	0.054	**0.826**	**1**												
Co	0.073	0.015	**-0.854**	0.148	**0.647**	**0.586**	**1**											
Ni	0.028	0.065	**-0.856**	0.206	**0.831**	**0.739**	**0.938**	**1**										
Cu	**-0.441**	-0.086	**0.632**	0.132	-0.106	-0.318	**-0.551**	**-0.425**	**1**									
Zn	0.140	0.245	**-0.629**	0.212	**0.713**	**0.622**	**0.711**	**0.765**	-0.103	**1**								
As	0.124	0.230	**-0.822**	0.124	**0.576**	**0.515**	**0.897**	**0.836**	**-0.494**	**0.677**	**1**							
Cd	0.222	-0.051	**-0.867**	-0.027	**0.431**	**0.552**	**0.854**	**0.794**	**-0.644**	**0.603**	**0.789**	**1**						
Pb	-0.173	-0.321	**0.841**	-0.136	**-0.731**	**-0.677**	**-0.826**	**-0.864**	**0.512**	**-0.715**	**-0.699**	**-0.711**	**1**					
K	-0.338	**0.427**	0.152	0.390	0.144	-0.216	-0.269	-0.137	**0.567**	0.079	-0.046	**-0.401**	0.050	**1**				
Ca	-0.248	0.065	-0.355	**0.557**	**0.577**	**0.439**	0.388	**0.514**	-0.091	**0.419**	0.335	0.338	**-0.431**	0.104	**1**			
Mg	**0.534**	**0.958**	0.034	0.050	0.171	0.256	-0.146	-0.081	-0.100	0.069	0.061	-0.208	-0.194	**0.406**	0.047	**1**		
Na	-0.203	**0.507**	0.257	0.286	0.066	-0.210	-0.331	-0.216	**0.658**	0.077	-0.088	**-0.447**	0.136	**0.958**	0.005	**0.462**	**1**	
Sr	-0.140	0.285	**0.583**	0.226	-0.334	**-0.397**	**-0.746**	**-0.644**	**0.572**	-0.353	**-0.525**	**-0.667**	**0.528**	**0.675**	-0.167	0.369	**0.688**	**1**

Continued.....

Table 7.2: Correlation coefficients between metalloid elements in Bera Lake

Variables	Li	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb	K	Ca	Mg	Na	Sr
Li	**1**																	
Al	0.268	**1**																
V	0.446	0.106	**1**															
Cr	**0.863**	0.392	0.439	**1**														
Mn	0.078	-0.304	**0.579**	-0.058	**1**													
Fe	0.020	**0.860**	-0.234	0.172	-0.480	**1**												
Co	**-0.712**	-0.070	-0.014	-0.480	0.314	0.050	**1**											
Ni	-0.206	0.018	**-0.599**	-0.288	-0.420	0.269	-0.006	**1**										
Cu	0.133	-0.259	0.139	-0.155	0.311	-0.272	-0.149	-0.107	**1**									
Zn	-0.201	-0.197	**0.598**	-0.255	**0.650**	-0.349	**0.491**	-0.363	0.300	**1**								
As	-0.292	-0.372	-0.203	-0.111	0.094	-0.249	0.282	0.177	**-0.715**	-0.150	**1**							
Cd	-0.284	0.344	-0.245	-0.166	-0.310	0.449	0.260	0.454	-0.309	-0.161	0.069	**1**						
Pb	0.025	**-0.508**	**0.562**	-0.191	**0.527**	**-0.599**	0.020	-0.164	**0.625**	**0.674**	-0.256	-0.209	**1**					
K	0.141	**0.556**	0.156	0.212	-0.129	0.316	0.235	-0.028	-0.022	0.159	-0.383	0.202	-0.174	**1**				
Ca	**-0.736**	-0.104	-0.110	**-0.564**	0.328	0.095	**0.867**	0.117	-0.349	0.335	**0.531**	0.294	-0.054	-0.096	**1**			
Mg	0.102	**0.902**	0.202	0.291	-0.136	**0.751**	0.248	-0.100	-0.289	0.061	-0.285	0.384	-0.412	**0.686**	0.152	**1**		
Na	-0.025	**0.631**	0.122	0.083	-0.057	0.467	0.413	-0.021	-0.076	0.294	-0.327	0.296	-0.201	**0.928**	0.148	**0.813**	**1**	
Sr	**0.797**	0.350	0.050	**0.832**	-0.243	0.231	**-0.565**	0.023	-0.180	**-0.522**	0.008	-0.206	-0.414	0.194	**-0.607**	0.145	0.043	**1**

(e)

The sediment profile in Core 4 reveals a clear correlation between Fe and Co, Ni, An, As, And Cd metals. In such condition, Mn shows a vivid correlation with Fe, Co, Ni, Zn, As, and Ca with high *r*-values. A positive correlation between the alkaline metals as Li, Al, Cr, Mg, Na, and Sr is also seen in the middle and north of study area.

Similar similarities of Al and Cr, K, Mg, Na, and Sr metals settled at the middle and the north of Bera Lake sediment profiles. Table 7.3 shows a variation in Mn with other metals in different parts of Bera Lake. This is in agreements with concentrations of Fe, Co, Zn, and As in the middle of Bera Lake, though some metals as Fe and Zn are enriched with Mn in the north of the study area. There is a remarkable positive affinity between concentrations of Co and Zn and As in the middle of the study area. Furthermore, Co showed a positive correlation with Pb only in the north of Bera Lake. positive correlations between cations Mg, Sr, K, and Na exist in all sections of the Bera Lake sediments.

7.3.2. Cluster Analysis

The Hieratical Cluster Analysis (HCA) method is an unsupervised technique that can be applied to reveal any natural populations in the analyzed metals. This method is a common statistical technique in ecological studies to recognize relative sources and physico-chemical conditions of the depositional media (Brereton 2007; Einax et al. 1997). Graphic interpoint distances between all of the metals in the Bera Lake sediment columns in the form of two-dimensional plots or dendogram are shown in Figures 7.2 to 7.6. Clusters have been achieved based on complete linkages analyzes. The resultant clusters indicate significant positive correlations between the closest metals and similar clusters plotted in the closest distance. On the other hand, significant negative correlations are found between analyzed metals plotted at maximum distances and separate clusters.

Similarities and dissimilarities between the analyzed metals in the south of Bera Lake are represented in three classes (Fig. 7.2). A positive correlation with different *r*-values is calculated for Classes 1 and 2. On the other hand, metals Co, Mn, As, Pb, and V, which do not cluster so well in class 3 show a significant negative correlation (Fig. 7.2) with other metals when plotted in classes 1 and 2.

Maximum similarity at the middle of Bera Lake appeared in class 2 between metals Na and Li, and with both of them and K and Sr, and in the pair between Cr and Al (Fig. 7.3). Classes 1 and 2 indicate moderate positive correlations between the concentrations of clustered metals. Both classes also, show negative correlations with metals clustered in class 3. A negative *r*-value for instance, represented the correlations between the concentrations of Fe and Na or Zn and Li.

Table 7.3: Strong positive correlation (*r*-value>0.7) between metalloid elements

Core 2			Core 6			Core 5			Core 4			Core 1		
Object1	Object2	Similarity	Object1	Object2	Similarity	Object1	Object2	Similarity	Object1	Object2	Similarity	Object1	Object2	Similarity
Li	Al	0.89	Li	Al	0.93	Li	Al	0.97	Li	Cr	0.86	Al	Mg	0.96
Li	K	0.82	Li	Cr	0.92	Li	Cr	0.92	Li	Sr	0.80	V	Pb	0.84
Li	Mg	0.91	Li	K	0.98	Li	K	0.80	Al	Fe	0.86	Mn	Fe	0.83
Li	Sr	0.83	Li	Mg	0.98	Li	Mg	0.95	Al	Mg	0.90	Mn	Ni	0.83
Al	K	0.80	Li	Na	0.99	Li	Na	0.77	Cr	Sr	0.83	Mn	Zn	0.71
Al	Mg	0.94	Li	Sr	0.93	Li	Sr	0.79	Fe	Mg	0.75	Fe	Ni	0.74
Al	Sr	0.81	Al	Cr	0.98	Al	Cr	0.96	Co	Ca	0.87	Co	Ni	0.94
Cr	Cu	0.76	Al	K	0.91	Al	K	0.76	K	Na	0.93	Co	Zn	0.71
Cr	K	0.72	Al	Mg	0.95	Al	Mg	0.95	Mg	Na	0.81	Co	As	0.90
Fe	Ca	0.90	Al	Na	0.90	Al	Na	0.72				Co	Cd	0.85
Ni	Cu	0.77	Al	Sr	0.83	Al	Sr	0.80				Ni	Zn	0.76
Zn	Na	0.83	V	Mn	0.80	Cr	Mg	0.91				Ni	As	0.84
K	Mg	0.85	Cr	K	0.90	Mn	Fe	0.85				Ni	Cd	0.79
K	Na	0.75	Cr	Mg	0.95	Mn	Co	0.98				As	Cd	0.79
K	Sr	0.84	Cr	Na	0.88	Mn	Zn	0.93				K	Na	0.96
Mg	Sr	0.82	Cr	Sr	0.81	Mn	As	0.74						
Na	Sr	0.84	Mn	Fe	0.91	Fe	Co	0.82						
			Mn	Zn	0.85	Co	Zn	0.92						
			Fe	Zn	0.93	Co	As	0.75						
			Co	Pb	0.80	K	Mg	0.90						
			K	Mg	0.96	K	Na	0.99						
			K	Na	0.98	K	Sr	0.75						
			K	Sr	0.95	Mg	Na	0.86						
			Mg	Na	0.97	Mg	Sr	0.78						
			Mg	Sr	0.90	Na	Sr	0.75						
			Na	Sr	0.94									

At the north of Bera Lake, minimum distances in classes 1 and 2 appear between metals Co and Mn, and between Na and K, respectively. On the other hand, a maximum distance appeared between concentrations of Pb and Co. Class 3 includes metals which show significant negative correlation with concentration of metals in classes 1 and 2 (Fig. 7.4).

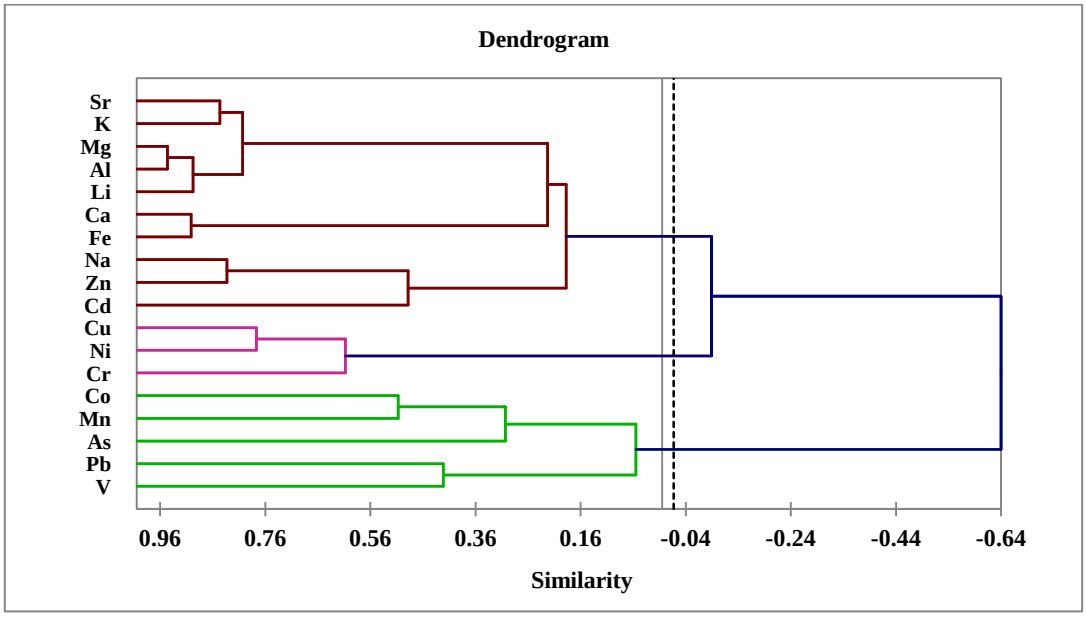


Figure 7.2: Clusters and relationships between metalloid elements in Core 2

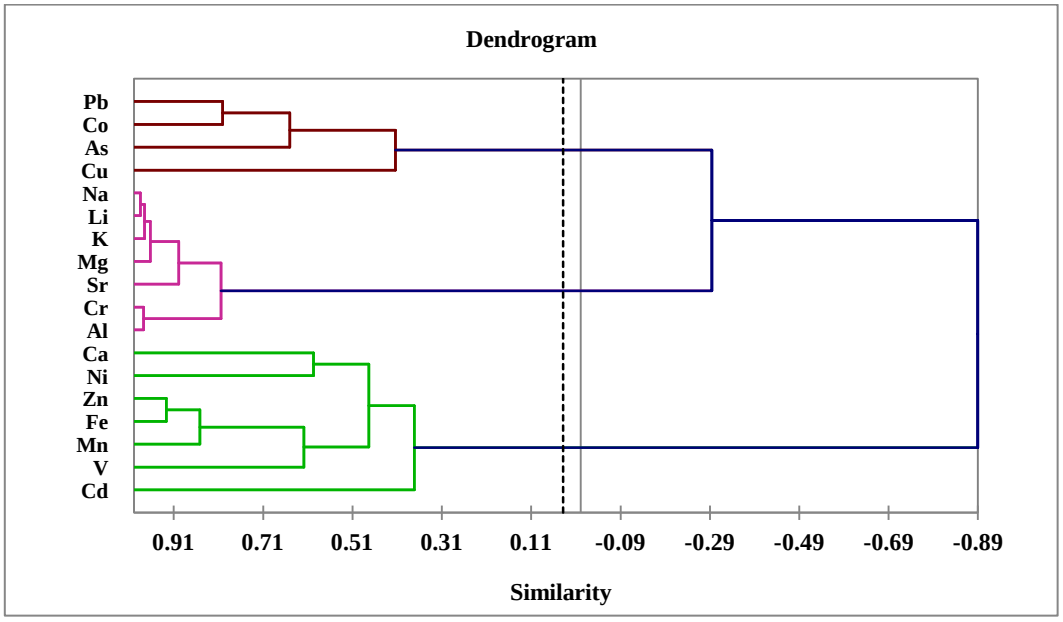


Figure 7.3: Clusters and relationships between metalloid elements in Core 6

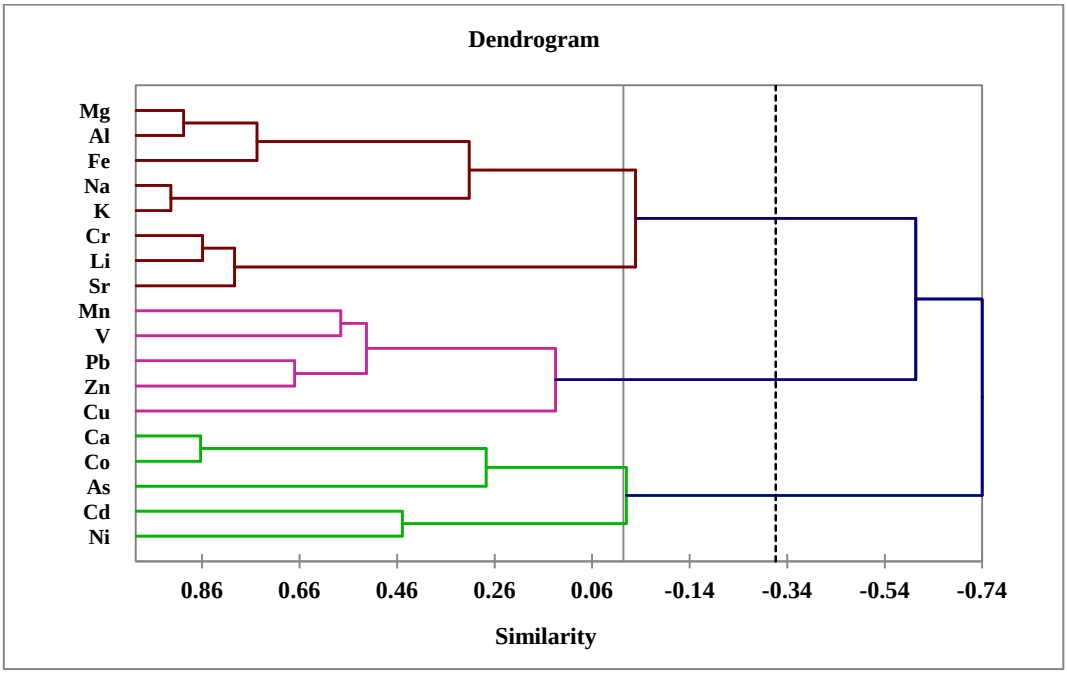


Figure 7.4: Clusters and relationships between metalloid elements in Core 4

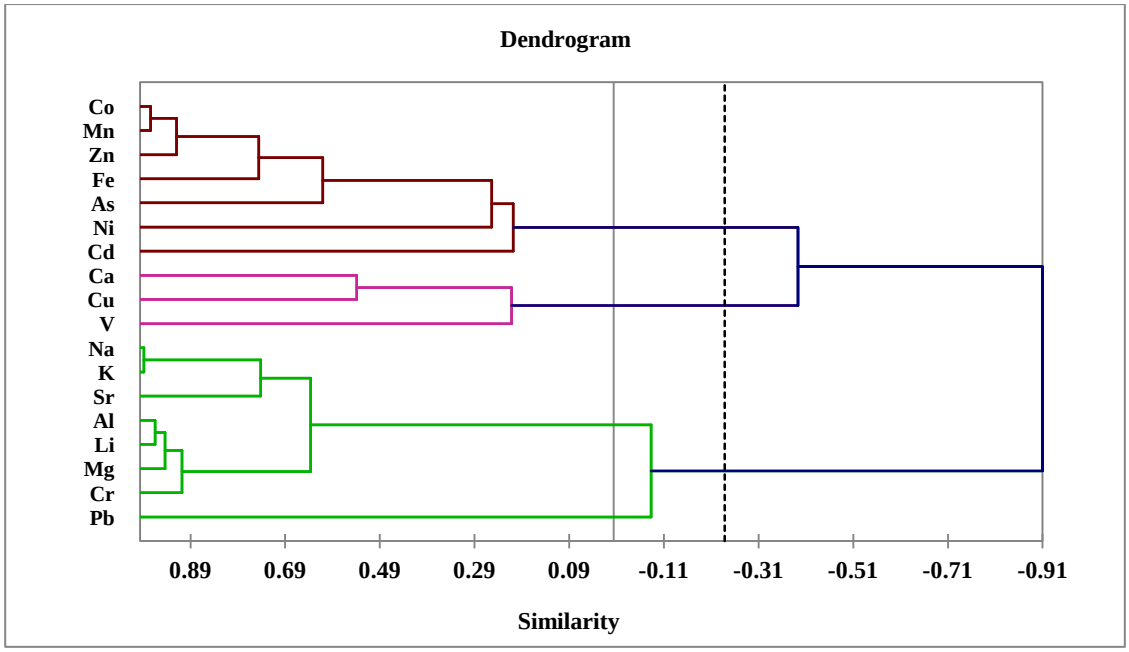


Figure 7.5: Clusters and relationships between metalloid elements in Core 5

A general trend of metal populations is recognized in the sediment profiles of the semi-closed area in the northwest of Bera Lake (Core 1). The first group of metals involves

Fe, Mn, Zn, Ni, Co, As, Cd, and Cr classified in class 1 with a positive *r*-value. Class 2 includes metals Mg, Al, and Li with an implied maximum positive correlation. In this part of lake, although Na, K, Sr, Cu, Pb, and V are in clear agreement with each together, they show negative correlations with metals classified in classes 1 and 2 (Fig. 7.6).

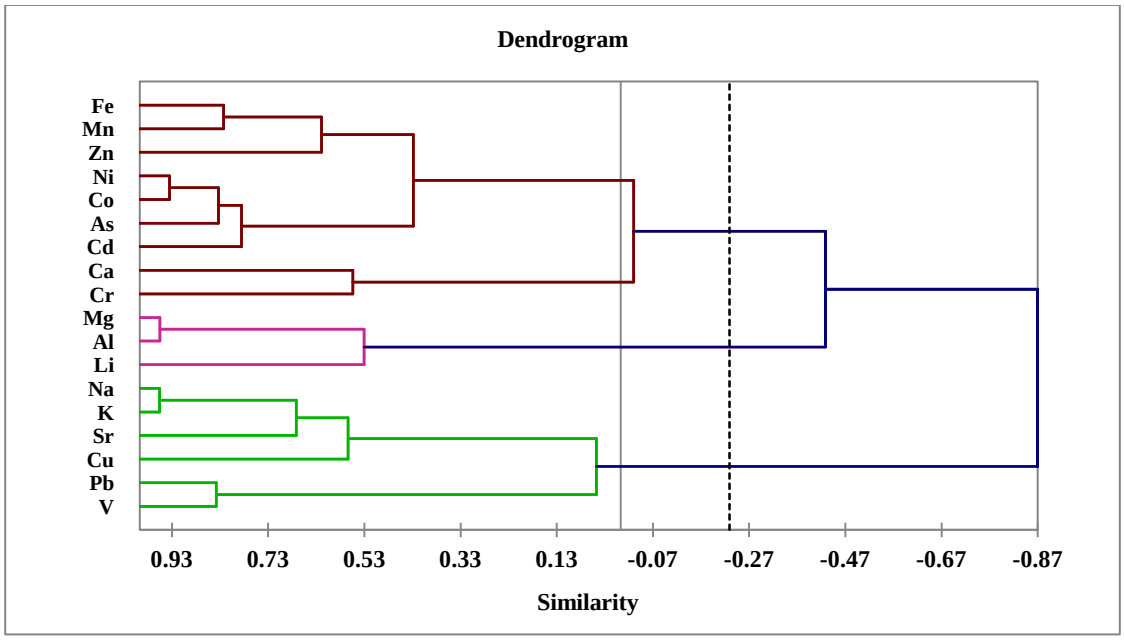


Figure 7.6: Clusters and relationships between metalloid elements in Core 1

7.4. Bera Lake Sediment Quality

Sediment quality indices were compared with Fe, As, Ni, Cr, Cd, Zn, Cu, and Pb levels to assess the pollution status at Bera Lake. These selected metals were recognized to be the most common metals for comparisons with the threshold limits of standard levels (Table 3.3). The overall levels of Zn and Cd metals plot below the LEL in all of the Bera Lake sediment profiles. There is, however, marked enrichment in Zn and Cd levels at the north of the study area. Cu levels in different parts of the study area indicate slight contamination with copper levels appearing to exceed the LEL and SBSQ limits, especially in the top of Cores 1 and 4 and in the middle of Core 6, and above the SEL (120, mg kg^{-1}).

Furthermore, the Bera Lake sediments, are assessed to be slightly to moderately contaminated by Ni metals, especially in the southern and northwest sections. The results show that background values of Ni plot remarkably below the LEL, though their concentrations exceed the LEL value with increasing organic matter in the uppermost layer.

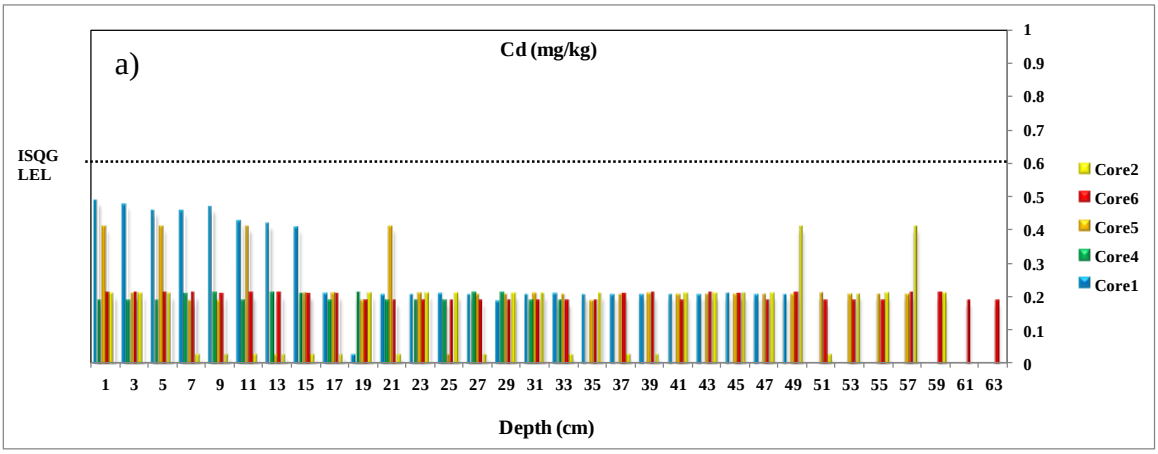
Standard levels compared with Pb levels from different parts of the study area show that sediments are slightly contaminated by Pb metal at the sites of Cores 1, 2 and 4. Lead levels plotted higher than the LEL (31mg kg^{-1}) and far from the SEL limit (120 mg kg^{-1}). The Bera Lake sediment profiles therefore, indicate a general upward decline in Pb levels except in Core 4 where there is a reverse trend.

Iron is recognized as a plentiful metal in the Bera Lake sediments. Sediment quality assessment shows that concentration of Fe in Cores 1, 4, and 6 plots below the LEL and ISQG levels. On the other hand, iron concentrations in the top of Cores 5 and 6 plots above the SEL and the sediments are severely contaminated by this metal.

Assessment of the Bera Lake sediments using standard limits revealed a significant contamination by arsenic throughout the study area. Maximum, minimum, and average values of As in the studied cores are much higher than the severe effective level. Further, calculated arsenic background value furthermore, exceeds the LEL in all sections of Bera Lake.

Chromium levels in the sediment profiles were compared with standard values to assess the pollution status of Bera Lake. The results show that Cr levels plot above the

LEL, ISQG, and CBSQG threshold limits in all samples. Chromium has also caused moderate pollution at depths of 15-40 cm in the Bera Lake sediment profiles (Fig. 7.7).



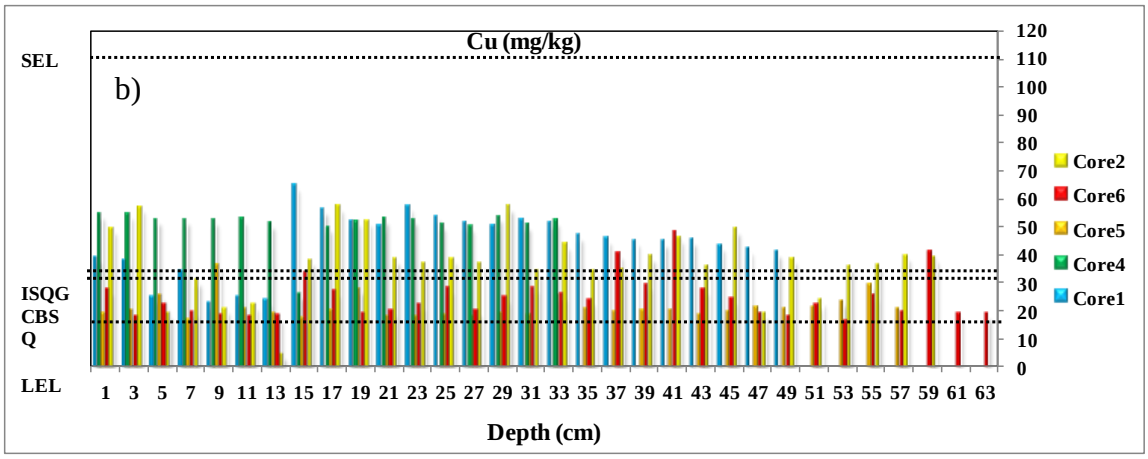
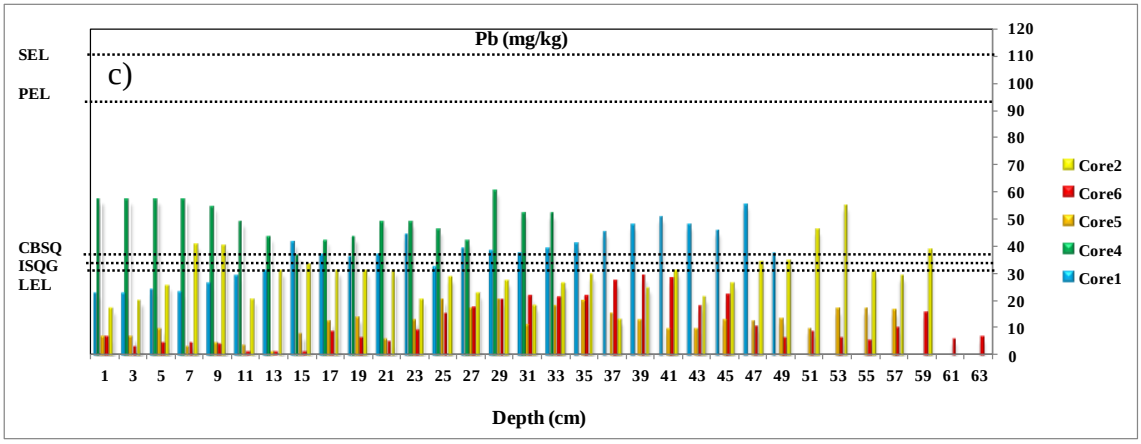
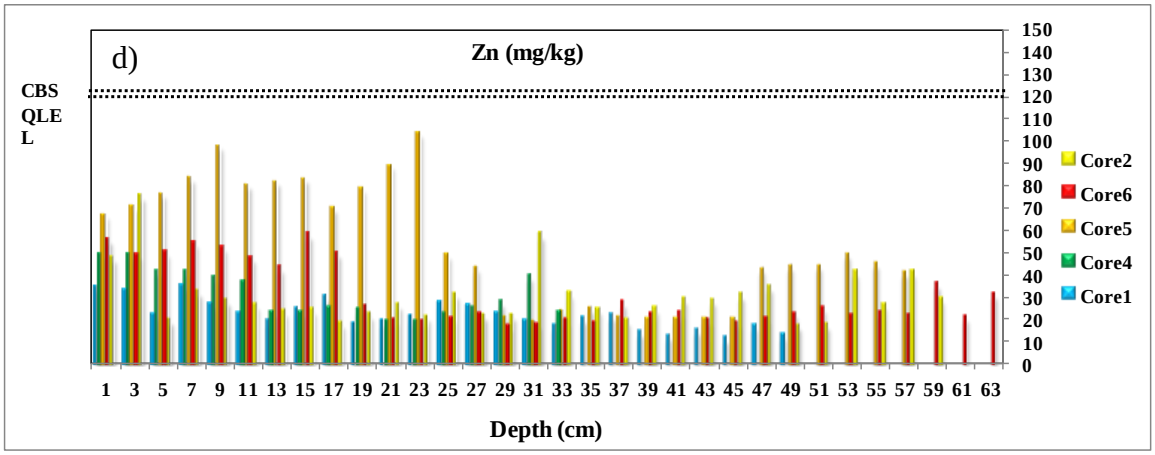


Figure 7.7a, b: Contamination levels in compare with the Sediment Quality Guidelines





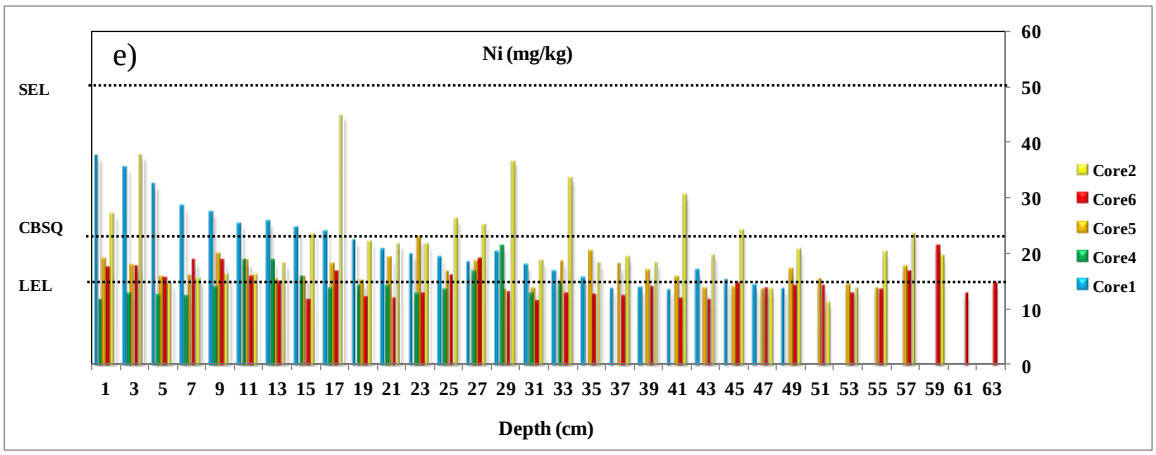


Figure 7.7c, d, e: Contamination levels in compare with the Sediment Quality Guidelines

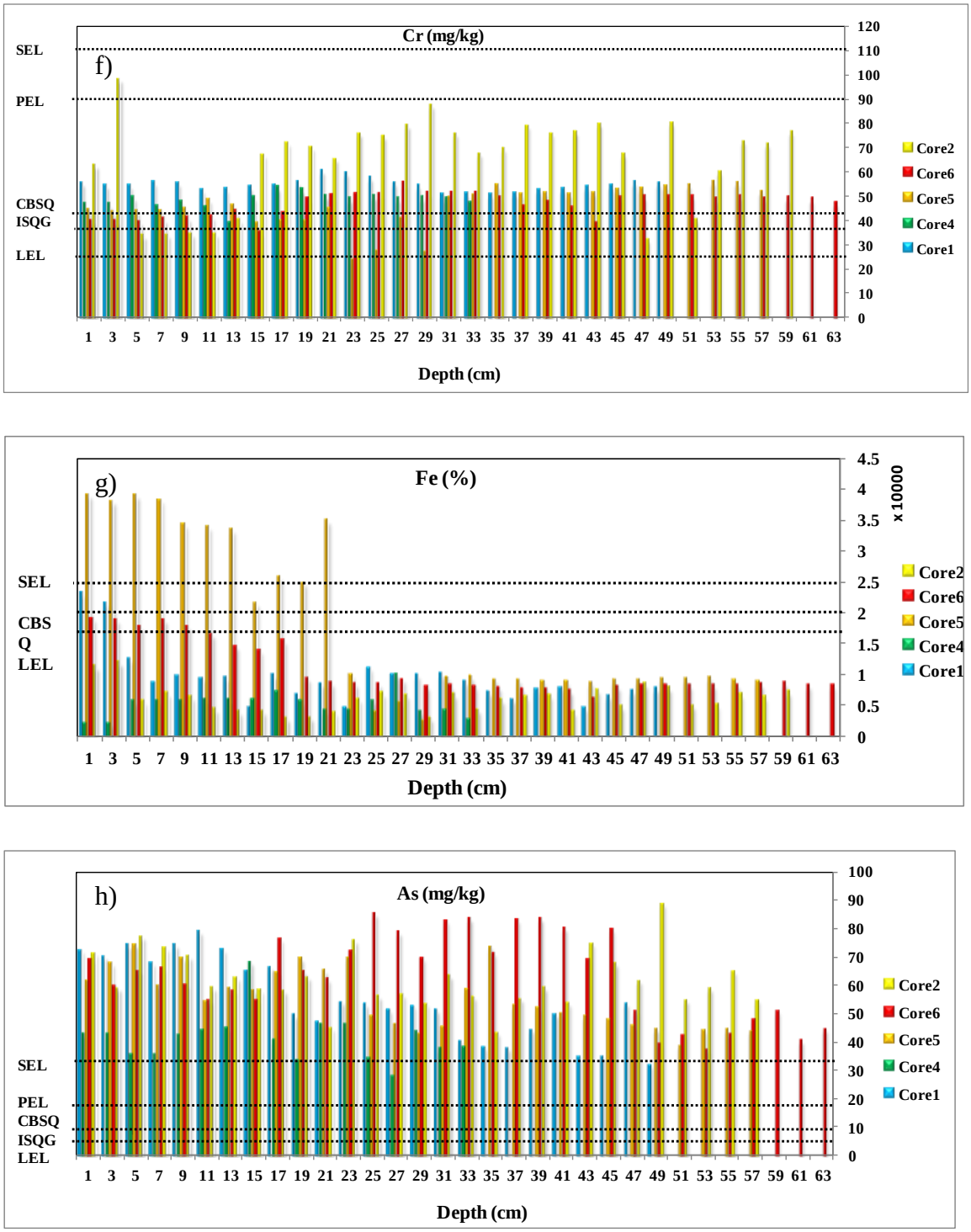


Figure 7.7f, g, h: Contamination levels in compare with the Sediment Quality Guidelines

7.5. Historical Ecological risk Assessment of Bera Lake Sediment

The preceding sections of this Chapter have explained the significant contribution of lithogenic and organic-bond metals in terms of the Bera Lake sediment pollution. The results further, reveal the special clustering of metals in different parts of the study area. The reconstruction of the history of Bera Lake as well as documenting of land use changes using anomalies in sediment profiles is one of the objectives of the present research. From the data that was obtained and following Hakanson's (1980) method, calculations were made to determine the parameters C_f, C_d, E_r, and RI (Tables 7.4, and 7.5). Calculations have been based on the seven heavy metals identified in Hakanson's method as well as another 11 major and minor elements. The EF for all layers of the three cores (2, 5, and 6) was calculated according to instructions provided in the Global Investigation of Pollution in the Marine Environment (GIPME, 1999). In this research, it was assumed that each 2-cm layer was once the uppermost layer or the surface layer at some point in time. The contamination factors and degrees of contamination were therefore, calculated separately for individual layers.

Certain anomalies and variations in the levels of pollutants can be used as an independent time marker for verification of dates obtained using radioisotopes (Section 2.4.4.1). Detailed Bera Lake sediment profile dating has already been described in Section 4-3. In this section, the result of ^{210}Pb dates are compared with vertical variations in ecological risk indices to document historical impacts of land use change in Bera Lake sediment quality. Figures 7.8, 7.9, and 7.10 illustrate historical variations of EF values in sediment columns in the south, middle and north of Bera Lake, respectively.

7.5.1. Historical Ecological Risk Assessment at South of Bera Lake

Lower risk indicators of 8, 40, and 65 were obtained for the degree of contamination, ecological risk indices for all metals, and ecological risk, samples collected in the south basin of Bera Lake, respectively (Tables 7.6, and 7.7). In distinct strata at depths of 0-15, 29, 33, 49, and 57 cm, however, Bera Lake appears to have experienced influxes of heavy metals and sediments that have given rise to moderate to significant contamination by some individual pollutants (Fig. 7.8). Organic matter at depths of 0-15 cm also have selectively controlled concentration of heavy metals where calculated contamination factors indicate low contamination for Cu, Zn, Li, Ni, V, Cd, Cr, Na, K, Mg, and Ca. This top layer appears to be enriched moderately and contaminated with Co, As, and Mn, the metals that cluster in class 3 (Fig. 7.2).

The general increase of the EF from the bottom to the top of the sediment column from the south end of Bera Lake is an indication of the significant role of organic matter especially since 1994. A huge flood in December, 2007 was the main reason for considerable increment in concentrations of Ni, Fe, As, Cd at a depth of 3 cm where ecological risk indices indicated moderate risk. The results also emphasize the significant effects of Cd and As on the values of ecological risk indices in the Bera Lake basin.

The *EF* revealed clear evidence of heavy metal fluxes especially in the white sandy mud and organic-rich layers (0-39 cm). Based on the resultant dates, the south or main entrance to Bera Lake has experienced two major enrichments of heavy metals in 1986 and in 1994-1995 during the fourth and fifth phases of the FELDA project, and two minor influxes of heavy metals between 1971 and 1979, and in 1991, due the first to third, and fifth, FELDA land development projects, respectively (Fig. 7.8).

Table 7.4: Contamination factor and degree of contamination for cores 2, 5, and 6

	Cf																					Cd		
Heavy Metal	Cr			Ni			Cu			Zn			Cd			Pb			As					
Core No.	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5
Depth (cm)																								
63-65		1.0			1.0			0.8			1.3			1.0			0.7			0.9			6.6	
61-63		1.0			0.9			0.8			0.9			1.0			0.6			0.8			5.9	
59-61	1.1	1.0		1.0	1.4		1.1	1.9		0.7	1.5		1.1	1.1		1.2	1.7		0.9	1.1		7.1	9.6	
57-59	1.1	1.0	1.0	1.2	1.1	1.1	1.1	0.9	1.0	1.0	0.9	1.2	2.1	1.1	1.0	0.9	1.0	1.3	1.1	1.0	0.9	8.4	7.0	7.5
55-57	1.1	1.0	1.0	1.0	0.9	0.9	1.0	1.1	1.4	0.6	0.9	1.3	1.1	1.0	1.0	0.9	0.5	1.3	1.0	0.9	1.0	6.7	6.4	7.9
53-55	0.9	1.0	1.1	0.7	0.9	0.9	1.0	0.7	1.1	1.0	0.9	1.5	1.1	1.0	1.0	1.7	0.6	1.3	0.9	0.8	0.9	7.2	5.8	7.8
51-53	0.6	1.0	1.0	0.6	0.9	1.0	0.6	1.0	1.0	0.4	1.0	1.3	0.1	1.0	1.0	1.4	0.9	0.7	1.4	0.9	0.8	5.2	6.7	6.9
49-51	1.2	1.0	1.0	1.1	0.9	1.1	1.1	0.8	1.0	4.3	0.9	1.3	2.1	1.1	1.0	1.1	0.6	1.0	1.0	0.8	1.0	11.8	6.2	7.4
47-49	0.5	1.0	1.0	0.7	0.9	0.9	0.5	0.8	1.0	0.8	0.8	1.3	1.1	1.0	1.0	1.1	1.1	0.9	1.1	1.1	1.0	5.7	6.7	7.0
45-47	1.0	1.0	1.0	1.2	1.0	0.9	1.4	1.1	0.9	0.7	0.8	0.6	1.1	1.1	1.0	0.8	2.4	1.0	1.2	1.7	1.0	7.4	9.0	6.4
43-45	1.2	0.8	1.0	1.0	0.8	0.9	1.0	1.2	0.9	0.7	0.8	0.6	1.1	1.1	1.0	0.7	1.9	0.7	0.9	1.5	1.1	6.4	8.1	6.1
41-43	1.1	0.9	1.0	1.6	0.8	1.0	1.3	2.2	0.9	0.7	1.0	0.6	1.1	1.0	1.0	1.0	3.1	0.7	1.0	1.7	1.1	7.7	10.6	6.3
39-41	1.1	1.0	1.0	0.9	0.9	1.1	1.1	1.3	0.9	0.6	0.9	0.6	0.1	1.1	1.0	0.8	3.2	1.0	0.9	1.8	1.1	5.5	10.2	6.7
37-39	1.2	0.9	1.0	1.0	0.8	1.2	1.0	1.8	0.9	0.5	1.1	0.6	0.1	1.1	1.0	0.4	3.0	1.1	0.7	1.7	1.1	4.8	10.5	6.9
35-37	1.0	1.0	1.0	0.9	0.8	1.3	0.9	1.1	1.0	0.6	0.8	0.7	1.1	1.0	0.9	0.9	2.3	1.5	0.9	1.5	1.6	6.4	8.5	8.1
33-35	1.0	1.0	1.0	1.7	0.9	1.2	1.2	1.2	1.2	0.8	0.8	0.7	0.1	1.0	1.0	0.8	2.3	1.4	1.0	1.8	1.3	6.6	8.9	7.7
31-33	1.1	1.0	0.9	1.0	0.8	0.9	0.9	1.3	0.8	1.4	0.7	0.6	1.1	1.0	1.0	0.6	2.3	0.8	0.9	1.7	1.0	6.9	8.8	6.0
29-31	1.3	1.0	0.5	1.9	0.9	0.9	1.6	1.1	0.9	0.5	0.7	0.6	1.1	1.0	1.0	0.8	2.2	1.6	0.9	1.5	0.9	8.1	8.3	6.4
27-29	1.2	1.1	0.8	1.3	1.3	1.2	1.0	0.9	0.8	0.5	0.9	1.3	0.1	1.0	1.0	0.7	1.9	1.3	0.9	1.7	1.0	5.7	8.7	7.4
25-27	1.1	1.0	0.5	1.3	1.1	1.1	1.1	1.3	0.9	0.8	0.9	1.5	1.1	1.0	0.1	0.9	1.6	1.6	1.2	1.8	1.1	7.4	8.6	6.6
23-25	1.1	1.0	0.4	1.1	0.9	1.5	1.0	1.0	0.8	0.5	0.8	3.1	1.1	1.0	1.0	0.6	0.9	1.0	0.7	1.5	1.5	6.2	7.1	9.3
21-23	1.0	1.0	0.8	1.1	0.8	1.3	1.1	0.9	0.8	0.6	0.8	2.7	0.1	1.0	2.0	1.0	0.5	0.4	1.0	1.3	1.4	5.9	6.2	9.4
19-21	1.0	1.0	0.8	1.1	0.8	1.0	1.4	0.8	1.3	0.5	1.1	2.4	1.1	1.0	0.9	1.0	0.6	1.0	0.9	1.4	1.5	7.1	6.6	8.8
17-19	1.1	0.9	0.7	2.3	1.1	1.2	1.6	1.2	0.9	0.4	2.1	2.1	0.1	1.1	1.0	1.0	0.9	0.9	0.9	1.6	1.4	7.4	8.8	8.3
15-17	1.0	0.7	0.7	1.2	0.8	1.0	1.0	1.5	0.8	0.6	2.4	2.5	0.1	1.1	1.0	1.0	0.0	0.5	1.0	1.2	1.2	6.0	7.7	7.9
13-15	0.6	0.9	0.9	0.9	1.0	1.0	0.1	0.8	0.9	0.6	1.8	2.5	0.1	1.1	0.1	1.0	0.0	0.0	1.0	1.2	1.3	4.2	6.8	6.6
11-13	0.5	0.8	0.9	0.8	1.1	1.2	0.6	0.8	1.0	0.6	2.0	2.4	0.1	1.1	2.0	0.6	0.0	0.2	1.1	1.1	1.2	4.4	6.9	8.9
8-11	0.5	0.8	0.8	0.8	1.3	1.3	0.6	0.8	1.7	0.7	2.2	2.9	0.1	1.1	0.9	1.3	0.4	0.3	1.2	1.3	1.5	5.1	7.8	9.5
6-8	0.5	0.8	0.8	0.8	1.3	1.0	0.8	0.9	0.8	0.8	2.3	2.5	0.1	1.1	0.9	1.3	0.4	0.2	1.3	1.4	1.3	5.5	8.1	7.5
4-6	0.5	0.8	0.8	0.7	1.1	1.0	0.5	1.0	1.2	0.5	2.1	2.3	1.1	1.1	2.0	0.8	0.4	0.7	1.0	1.4	1.6	5.0	7.7	9.7
2-4	1.4	0.8	0.8	1.9	1.2	1.2	1.6	0.8	0.9	1.8	2.0	2.1	1.1	1.1	1.0	0.6	0.3	0.5	1.2	1.3	1.5	9.6	7.4	8.0
0-2	0.9	0.8	0.8	1.4	1.2	1.2	1.4	1.2	0.9	1.1	2.3	2.0	1.1	1.1	2.0	0.5	0.7	0.5	1.3	1.4	1.3	7.7	8.7	8.8

Table 7.5: Ecological risk index for individual metals and for basin in Cores 2, 5, and 6

	Er																					IR		
Heavy Metal	Cr			Ni			Cu			Zn			Cd			Pb			As					
Core No.	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5	2	6	5
Depth (cm)																								
63-65		1.9			4.9			4.2			1.3			6.0			3.3			9.3			30.9	
61-63		2.0			4.3			4.2			0.9			5.9			2.9			8.5			28.6	
59-61	2.3	2.0		5.0	7.2		5.4	9.3		0.7	1.5		31.9	66.1		6.0	8.4		8.9	10.7		60.2	105.2	
57-59	2.1	2.0	2.0	6.0	5.6	5.7	5.5	4.4	4.9	1.0	0.9	1.2	63.9	66.1	30.0	4.5	5.2	6.3	10.6	10.1	9.4	93.6	94.2	59.5
55-57	2.1	2.0	2.1	5.2	4.5	4.5	5.0	5.7	7.0	0.6	0.9	1.4	32.0	6.0	29.9	4.7	2.6	6.5	9.6	9.0	9.5	59.3	30.8	60.8
53-55	1.8	2.0	2.1	3.5	4.3	4.7	4.9	3.6	5.5	1.0	0.9	1.5	31.9	5.9	30.0	8.6	3.0	6.4	8.9	7.9	9.4	60.6	27.6	59.7
51-53	1.2	2.0	2.1	2.8	4.7	4.9	3.2	5.0	4.9	0.4	1.0	1.3	2.9	5.9	30.1	7.2	4.4	3.6	14.4	8.9	8.3	32.2	32.0	55.2
49-51	2.4	2.0	2.0	5.3	4.7	5.6	5.3	4.0	4.9	4.3	0.9	1.3	63.8	66.1	29.9	5.4	3.0	5.0	10.0	8.3	9.5	96.6	89.1	58.3
47-49	0.9	2.0	2.0	3.5	4.6	4.3	2.5	4.2	5.0	0.8	0.8	1.3	31.9	5.9	30.0	5.4	5.5	4.6	11.0	10.7	9.8	56.1	33.8	56.9
45-47	2.0	2.0	2.0	6.2	4.9	4.5	6.8	5.4	4.6	0.7	0.8	0.6	32.0	66.0	30.0	4.1	11.9	4.9	12.2	16.7	10.3	63.9	107.7	56.9
43-45	2.4	1.6	1.9	5.0	3.9	4.4	4.9	6.2	4.4	0.7	0.8	0.6	32.0	66.1	30.0	3.3	9.7	3.6	8.7	14.6	10.5	57.0	102.9	55.4
41-43	2.3	1.8	1.9	7.9	4.0	5.1	6.3	10.9	4.7	0.7	1.0	0.6	32.0	5.9	29.9	4.8	15.5	3.5	9.6	16.8	10.7	63.6	55.9	56.4
39-41	2.2	1.9	1.9	4.7	4.7	5.5	5.4	6.6	4.7	0.6	0.9	0.6	2.9	66.2	30.1	3.8	15.9	4.9	9.0	17.5	11.1	28.6	113.8	58.8
37-39	2.3	1.9	1.9	5.0	4.2	5.9	4.8	9.2	4.5	0.5	1.1	0.6	2.9	66.0	30.0	2.0	14.9	5.7	7.0	17.4	11.3	24.4	114.6	60.0
35-37	2.1	2.0	2.1	4.7	4.2	6.7	4.7	5.3	4.9	0.6	0.8	0.7	31.9	5.9	27.0	4.6	11.7	7.7	9.1	15.0	15.8	57.6	44.9	64.8
33-35	2.0	2.1	1.9	8.7	4.3	6.1	6.0	5.8	6.0	0.8	0.8	0.7	2.9	6.0	30.0	4.1	11.5	6.9	10.3	17.5	12.5	34.7	47.9	64.2
31-33	2.2	2.1	1.9	4.8	3.8	4.4	4.6	6.4	4.2	1.4	0.7	0.6	32.0	5.9	30.1	2.8	11.7	4.2	8.7	17.4	9.7	56.5	48.0	55.1
29-31	2.6	2.1	1.0	9.4	4.4	4.3	7.9	5.5	4.4	0.5	0.7	0.6	32.0	5.9	30.0	4.2	10.9	7.8	9.2	14.6	9.2	65.9	44.1	57.4
27-29	2.3	2.2	1.5	6.5	6.4	6.1	5.1	4.4	4.2	0.5	0.9	1.3	2.9	6.0	30.0	3.5	9.5	6.4	9.1	16.5	9.9	29.9	46.0	59.5
25-27	2.2	2.1	1.0	6.7	5.4	5.4	5.3	6.3	4.3	0.8	0.9	1.5	31.9	5.9	30.0	4.4	8.1	7.8	12.3	17.9	10.5	63.7	46.5	60.6
23-25	2.2	2.1	0.9	5.5	4.3	7.5	5.0	4.9	4.1	0.5	0.8	3.1	31.9	5.9	30.1	3.1	4.6	4.8	7.3	15.2	14.9	55.7	37.8	65.5
21-23	1.9	2.0	1.7	5.6	4.0	6.3	5.3	4.4	4.2	0.6	0.8	2.7	2.9	5.9	60.1	4.8	2.3	2.0	10.2	13.0	14.0	31.4	32.5	90.9
19-21	2.1	2.0	1.5	5.7	4.0	4.9	7.2	4.2	6.6	0.5	1.1	2.4	31.9	5.9	27.1	4.8	3.0	5.2	9.4	13.6	14.9	61.7	33.8	62.5
17-19	2.1	1.7	1.5	11.5	5.6	5.9	7.9	6.0	4.7	0.4	2.1	2.1	2.9	66.0	30.1	4.8	4.3	4.7	9.5	16.0	13.9	39.2	101.8	62.8
15-17	2.0	1.4	1.5	6.1	3.9	5.1	5.2	7.5	4.1	0.6	2.4	2.5	2.9	66.0	30.1	5.2	0.1	2.7	10.2	11.5	12.5	32.1	92.9	58.5
13-15	1.2	1.8	1.7	4.7	5.0	4.9	0.5	4.0	4.4	0.6	1.8	2.5	2.9	66.1	30.1	4.8	0.1	0.2	9.6	12.2	12.7	24.2	91.1	56.5
11-13	1.0	1.7	1.8	4.1	5.3	6.1	3.0	3.9	4.9	0.6	2.0	2.4	2.9	6.0	60.2	3.1	0.1	1.0	11.4	11.5	11.6	26.2	30.4	88.1
8-11	1.0	1.7	1.7	4.1	6.3	6.5	2.8	4.1	8.6	4.5	2.2	2.9	2.9	5.9	27.1	6.3	1.8	1.6	11.9	12.6	15.0	33.5	34.6	63.3
6-8	1.0	1.6	1.7	3.9	6.3	5.2	4.2	4.4	4.0	0.8	2.3	2.5	2.9	66.1	27.1	6.4	2.2	0.8	12.6	13.9	12.8	31.7	96.8	54.1
4-6	1.0	1.6	1.7	3.7	5.3	5.1	2.5	4.9	6.0	0.5	2.1	2.3	32.0	66.0	60.2	4.0	1.9	3.6	9.6	13.7	15.9	53.3	95.5	94.8
2-4	2.9	1.6	1.6	9.7	6.0	5.8	7.9	4.0	4.6	1.8	2.0	2.1	32.0	132.1	30.1	3.1	1.4	2.5	11.6	12.5	14.5	68.9	159.6	61.3
0-2	1.9	1.6	1.7	7.0	5.9	6.2	6.8	6.2	4.5	1.1	2.3	2.0	31.9	132.0	60.2	2.6	3.4	2.5	12.6	14.5	13.2	63.9	166.0	90.2

In view of this, it can be said that, the fourth and additional fifth, FELDA developments projects have played a major role in exposure of weathered bed rock. Therefore, moderate levels of enrichment associated with Cr, Cu, Ni, Cd, As, Pb, Zn, Fe, Co, V, Mn, Sr, Ca, K, and Na were found at depths of 37-39, 29-31, and 17-21. Enrichment continued considerably with Cr, Ni, As, Pb, Co, V, Mn, K, and Na where EF values increased more than 20 (Fig. 7.8).

Exchangeable cation ratios also significantly support the variations in the plots of EF values versus depth. The pre-1970 mean exchangeable cation ratio was 4.79±0.76, though during the first, second, fourth and fifth FELDA projects it increased to 6.99, 7.78, 6.66, and 11.8, respectively. The mean exchangeable cation ratio for organic-rich deposits (Layer 4) was 4.3±1.15 which represents a negative correlation with organic compounds.

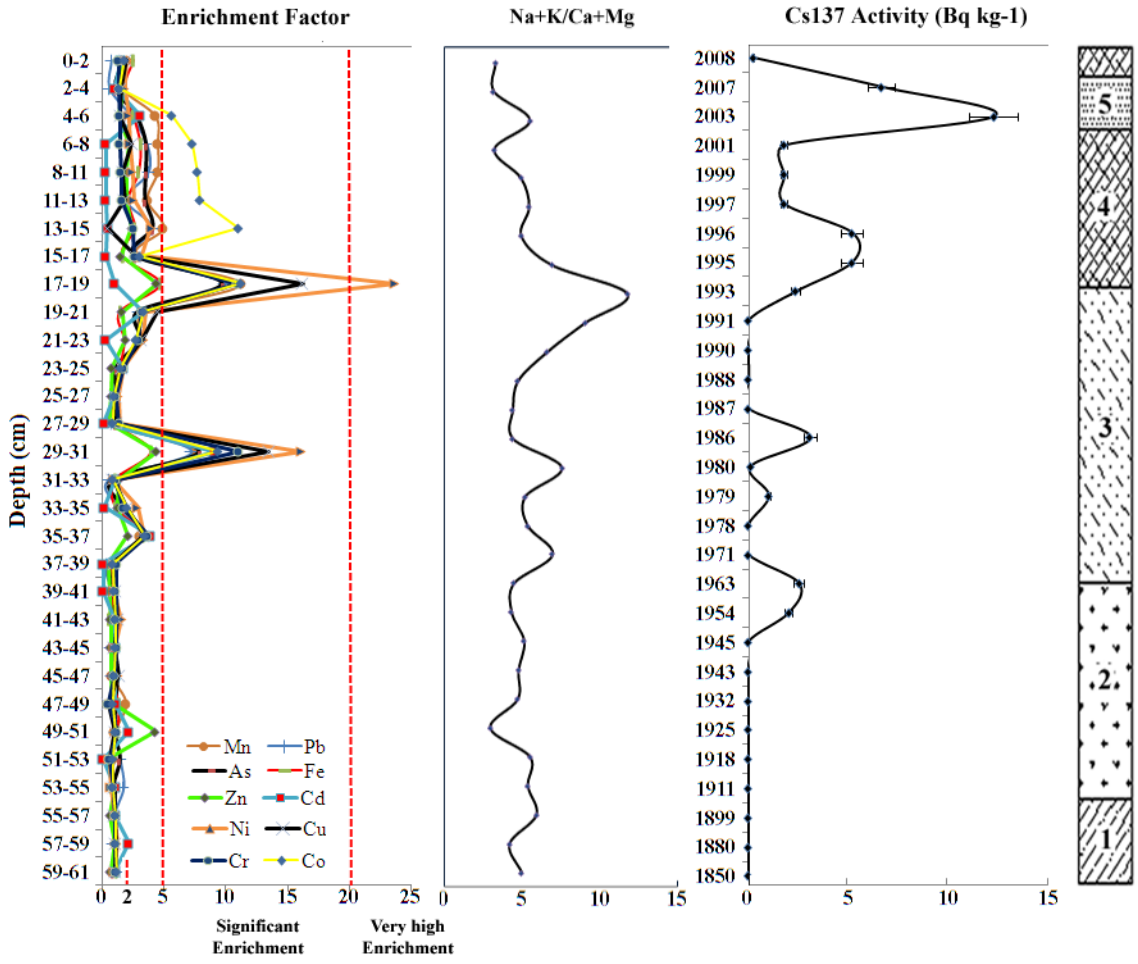


Figure 7.8: Historical changes of EF value at the south of Bera Lake

7.5.2. Historical Ecological Risk Assessment at the Middle of Bera Lake

As with Core 2, the ecological risk indices and EF (of 2 to 5) for Core 6 at the top of the sediment column (0-18 cm) were controlled significantly by organic matter (Fig.

7.9). A low contamination level at the uppermost layer is induced by lithogenic metals (Cu, Co, Li, Cr, Pb, Sr, Na, Al, Mg, and K). On the other hand, this layer is contaminated moderately by organic bond metals (Zn, Fe, V, Ni, Mn, and Ca) which cluster together in class 2 (Fig. 7.3). At depths in the range of 18-50 cm, heavy metal influx into the middle of Bera Lake increased the ecological risk indices from moderate to considerable contamination. White sandy mud layers (18-43 cm) which were deposited during and after deforestation phases in the catchment area are moderately contaminated by Cu, Zn, Pb, As, Mn, Co, and Ca but polluted considerably by Pb at a depth of 38-43 cm (Tables 7.5 and 7.6). These anomalies are in agreement with the influx of ^{137}Cs recorded in 1964, 1983, and 1993. It appears that variations in ^{137}Cs value are controlled by anoxic condition due to re-dissolution of heavy metals combined with horizontal transport to adequately oxygenated parts of Bera Lake. Similar conditions for re-dissolution of major elements and ^{210}Pb has been reported by Robbins et al (1978) for Lake Erie. Minor peaks of enrichment of heavy metals at the middle part of Bera Lake are also in agreement with the dates of the third and fifth FELDA land development projects. A general upward increase in EF values of Ni, Cd, Zn, Fe, V, Mn, and Ca (Fig. 7.9) organic bond metals at the middle of the Bera Lake sediment column signals the significant role of organic matter especially since 1993. Furthermore, at depths between 50 and 73 cm, natural conditions have dominated the concentration of heavy metals. The minor influxes of Cu, Pb, and Ni were, however, recorded at a depth of 60 cm in 1955. Although, the sediment column in the middle of Bera Lake was classified in the low risk category, after Cd (moderate risk), the highest Er values were for As, Pb, and Cu (though they are still considered to be low risk).

A vivid decrease in the exchangeable cation ratio was obtained for organic-rich deposits in the uppermost layer of the sediment column. The FELDA developed lands apparently have had a major contribution to variation of the exchangeable cation ratio. The maximum value appears at a depth of 68 cm which indicates a natural event in the catchment area in 1943. Sediments were moderately enriched by Pb metal during this event.

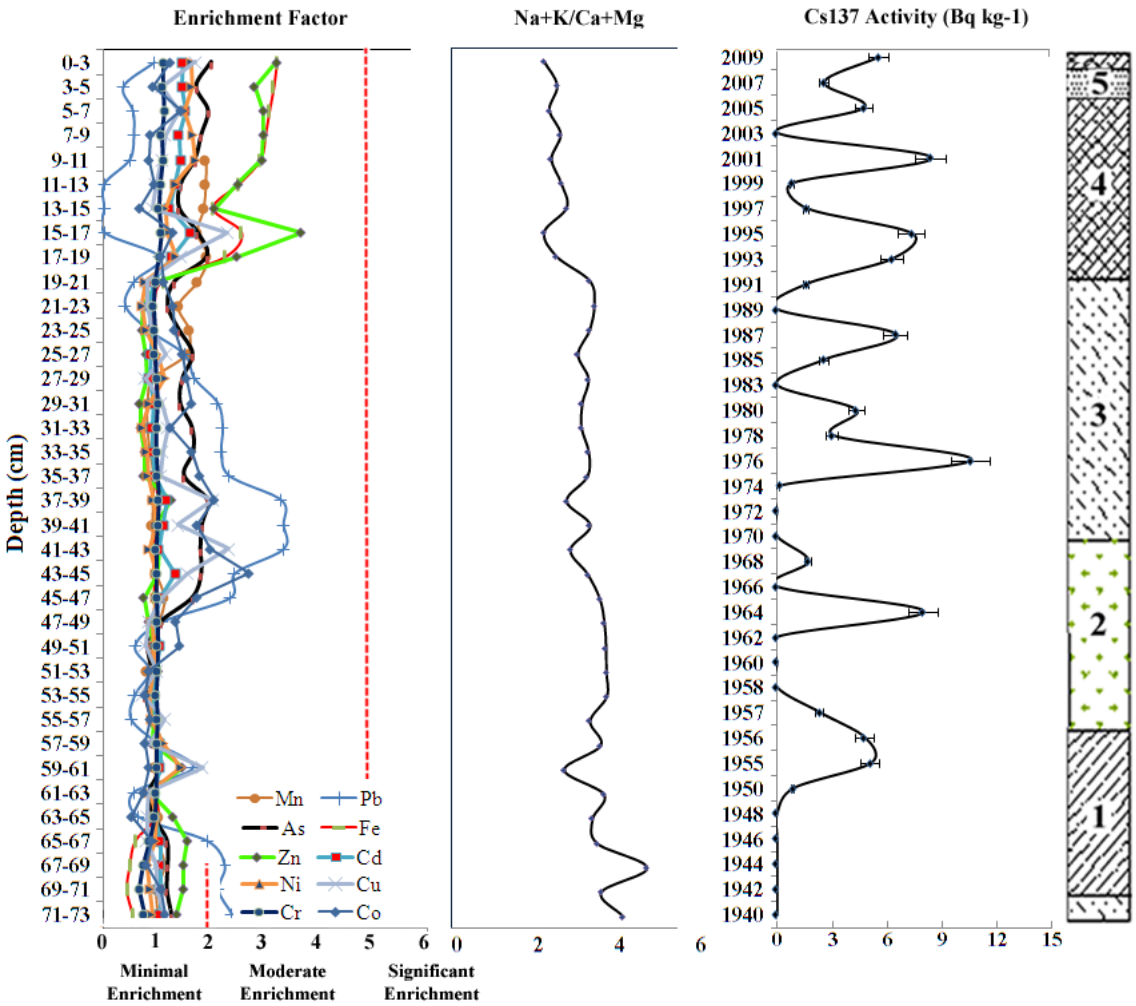


Figure 7.9: Historical changes of EF value at the middle of Bera Lake

7.5.3. Historical Ecological Risk Assessment at the North of Bera Lake

The organic-rich layer (0-24 cm) showed an increase in the degrees of contamination and EF by Co, Fe, Mn, Zn, Cd, As, Cu, Ni, and Ca especially since 1994. On the other hand, those metals (Al, Li, Mg, Cr, and Pb) that clustered together in class 3 (Fig. 7.5) represent a lower degree of contamination in this layer.

There is a distinct difference between the degree of contamination, EF and ecological risk index before, and after, the FELDA land development projects in the northern part of Bera Lake. Contamination factors prior to land use changes in the catchment area were in the non-contaminated mode with the EF of all major and minor elements being less than a factor of 2 or minimal contamination. On the other hand, three remarkable influxes of heavy metals occurred in the northern Bera Lake sediment profile between 1971 and 1974, 1981 and 1983, and between 1986 and 1994 during the first to fourth FELDA land development phases. Enrichment of heavy metals mainly occurred during deposition of the white sandy mud sediments. Normalizing values of metals with Al in this layer, show that the white sandy mud deposits were enriched moderately by a wide range of lithogenic and organic-bond metals (Cr, Cu, Ni, Cd, As, Pb, Zn, Fe, Co, V, Mn, Sr, Ca, K, and Na).

The strong affinity of As, Cr, Cu, and Ni for aquatic particles, particularly iron and manganese oxides also demonstrated in their deposition at Bera Lake in association with these materials. This fact can be clearly correlated with the significant increase of Fe and Mn concentrations in the sediment profile since 1972 after land use change. The organic-rich layers in the uppermost part of the north Bera Lake sediment profile are more highly

enriched with Fe, Mn and Co as compared with similar layers in the middle part of the basin.

A significant correlation was obtained between the exchangeable cation ratio and EF at the north of Bera Lake (Fig. 7.10). The pre-1970 mean exchangeable cation ratio was calculated to be 5.02±0.33, a quite similar value to that in the south of the study area. This ratio, however, dramatically increased to 10.85 and 9.90 during the first and second FELDA projects. It then decreased to 4 during the third and fourth land development phases. Another peak of 5.20 in this ratio was obtained when the fifth FELDA project started. The mean exchangeable cation ratio for organic-rich deposits was calculated to be 3.64±0.26 which is lower than the background value prior to anthropogenic activities.

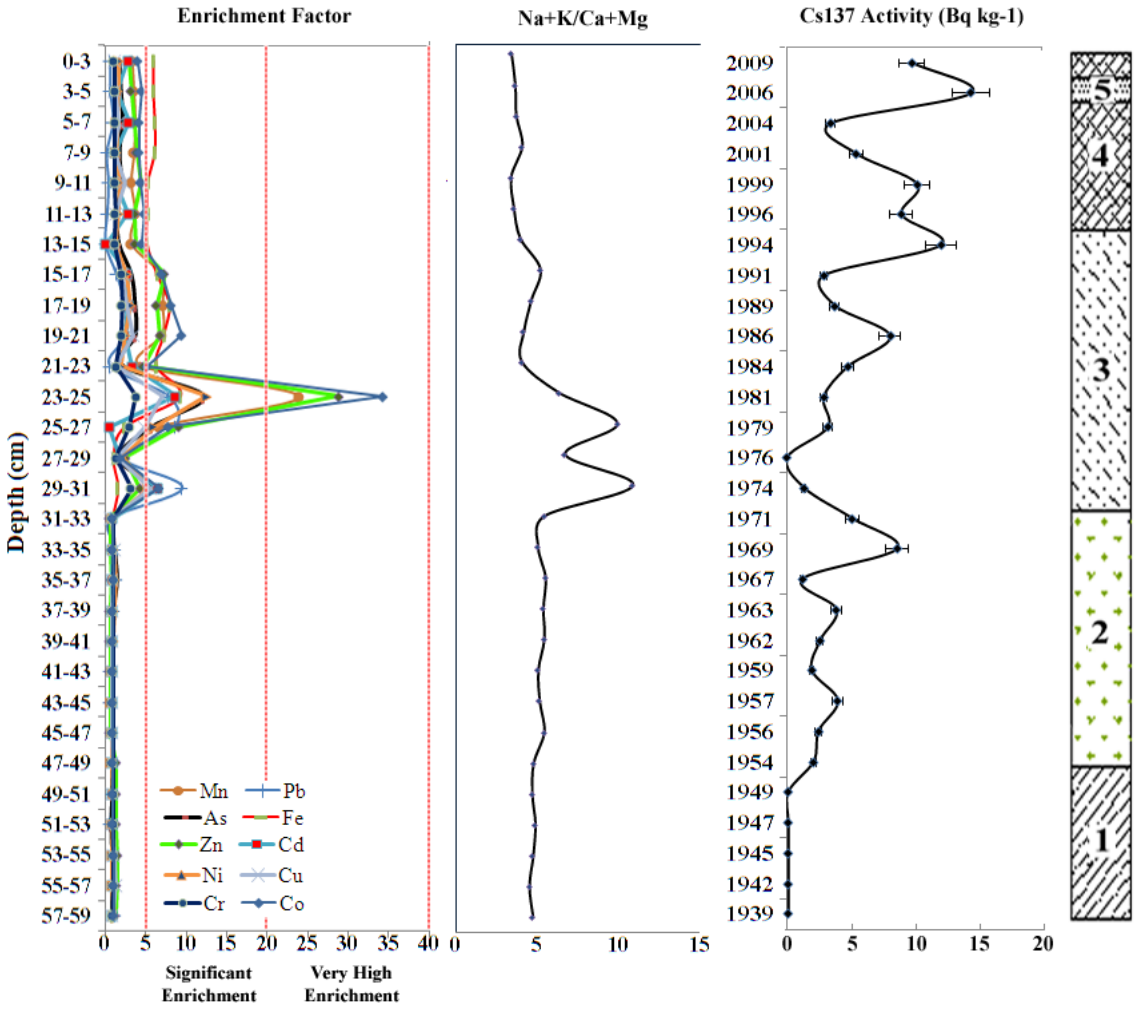


Figure 7.10: Historical changes of EF value at the north of Bera Lake

7.6. Historical Variation of Nutrient Contents in Bera Lake Sediments

Clear variations and some anomalies in TOC and TN were recorded in the core samples. Concentration of other important nutrients (K, Mg, Ca) in the same samples were used to support interpretation of accumulation conditions in Bera Lake sediments over the last decades. The sulfur contents of Bera wetlands and Lakes reported by Wüst et al. (2003) of 0.05% to 0.5% are comparable with those for freshwater peat deposits. Total concentration of nutrients in the sediment profiles at the main open water and north of Bera

Lake decreased in the order of TOC> K> TN> S> Mg> Ca. Figures 5.30 and 5.31 illustrate historical variations of nutrient contents in master cores 5 and 6, respectively.

The acidic condition of Bera Lake sediments (pH; 4.2 and 5.2) was observed by Wüst et al. (2003) and by in-situ water chemistry analyses using Hydrolab5 in this research. In such environments the total C is equal to total organic C. Reported TOC in this research involves carbon content of sediments as well as POC (Charcoal, roots, pieces of barks and stems) were abundantly recognized in distinct layers (Fig. 7.13). Table 7.6 shows the POC contents in terms of the dry weight of samples in master Cores 2, 6, and 5 which serve as indicators for the south, middle, and north of Bera Lake, respectively. These components were interpreted as signals of environmental events that released large amounts of POC into the basin.

For example, Field and Carter (2000) reported that the percentage of organic matter content in the sediment derived from burnt land during the first storm event was relatively high at 56% with remarkable amounts of suspended charcoal carried to the sink area. Evidence of land development projects is obvious in POC contents, especially that from depths of 20-34, and 15-40 cm, in cores 2 and 6, respectively.

These ranges of depth represent layer 3 comprising white sandy mud which accumulated between 1970 and 1993. The maximum POC contents in layer 3 of cores 2 and 6 were 8.36 and 11.21% which correspond to the fifth and first FELDA land development projects.

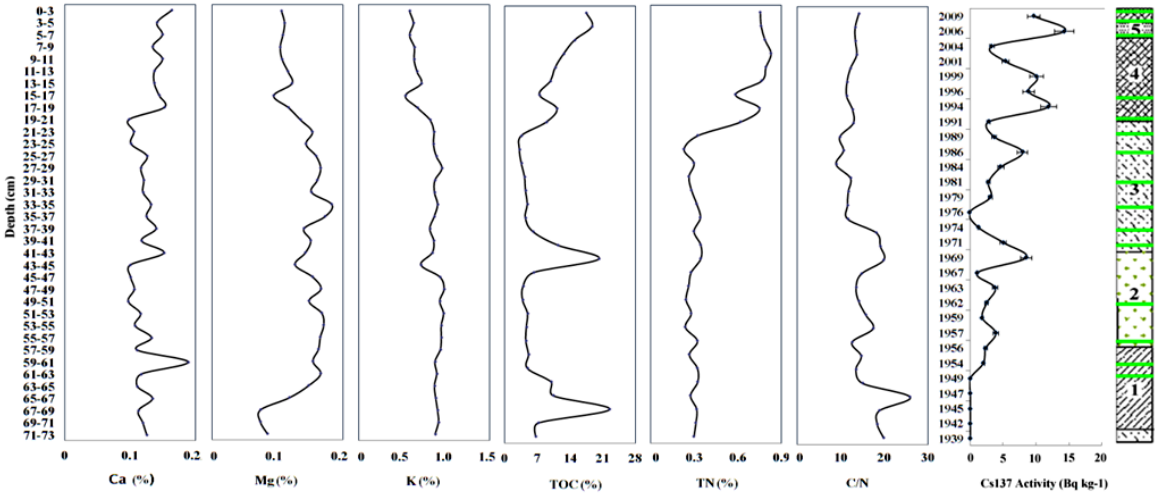


Figure 7.11: Historical variations of nutrient contents at the middle of Bera Lake

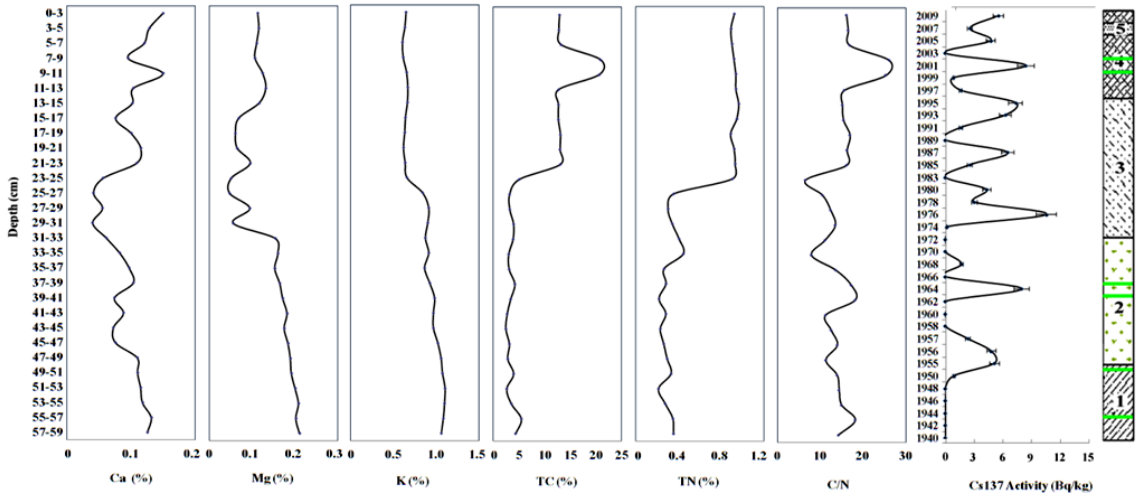


Figure 7.12: Historical variations of nutrient contents at the north of Bera Lake

Figure 7.13: Charcoals found from different layers in the core samples

The contribution of the POC content reaches 62.45% in layer 4 of Core 2 which is mainly composed of organic-rich deposits. Master cores 2, 6, and 5 show that POC content in the Bera Lake sediment column accumulated in layers 2 and 1. Maximum POC content in grey to dark sandy mud sediments (layer 2) in cores 2 and 5 were calculated to be 4.16 and 1.36%, respectively.

The pre-1950 deposits (Layer 1) contain a remarkable POC content (14.11 %) especially in Core 6 at a depth of 60 cm. This signals a natural event which released significant amounts of organic matter into the sink area. The results also reveal that nutrient contents in the sediment profiles significantly controlled the rate of nutrient supply and physico-chemical conditions at Bera Lake.

Table 7.6: POC (dry weight) content in analyzed samples of master Cores 2, 5, and 6

Depth	Particulate Organic Carbon % Drywt		
cm	Core2	Core 6	Core5
0-3	0.00	4.92	0.00
3-5	0.00	6.61	0.00
5-7	9.44	2.88	0.00
7-9	47.51	0.00	7.47
9-11	62.45	0.00	7.70
11-13	45.59	0.00	0.00
13-15	17.34	0.00	0.00
15-17	0.00	0.47	0.00
17-19	0.00	0.00	0.00
19-21	0.00	0.00	0.00
21-23	8.39	0.38	0.00
23-25	6.27	0.53	0.00
25-27	1.13	0.58	0.00
27-29	2.54	0.69	0.00
29-31	2.58	0.67	0.00
31-33	0.76	0.00	0.00
33-35	0.47	0.00	0.00
35-37	0.00	3.59	0.00
37-39	0.00	11.21	1.36
39-41	0.37	1.43	0.75
41-43	4.16	0.00	0.43
43-45	1.17	0.00	0.44
45-47	2.77	0.00	0.33
47-49	0.00	0.00	0.00
49-51	0.00	0.00	0.53
51-53	0.00	0.66	0.09
53-55	0.00	0.00	0.10
55-57	0.00	4.03	1.62
57-59	0.00	2.20	0.00
59-61	0.00	14.11	0.00
61-63	0.00	0.71	0.00

While Ca, Mg, and K contents are significantly sensitive to physico-chemical conditions of the basin, TOC and TN contents indicate more the rate of nutrient supply from source areas. Hierarchal cluster analyses indicate good similarities in chemical conditions in which nutrients and metals were deposited in the Bera Lake sediment column (Figs. 7.14 and 7.15).

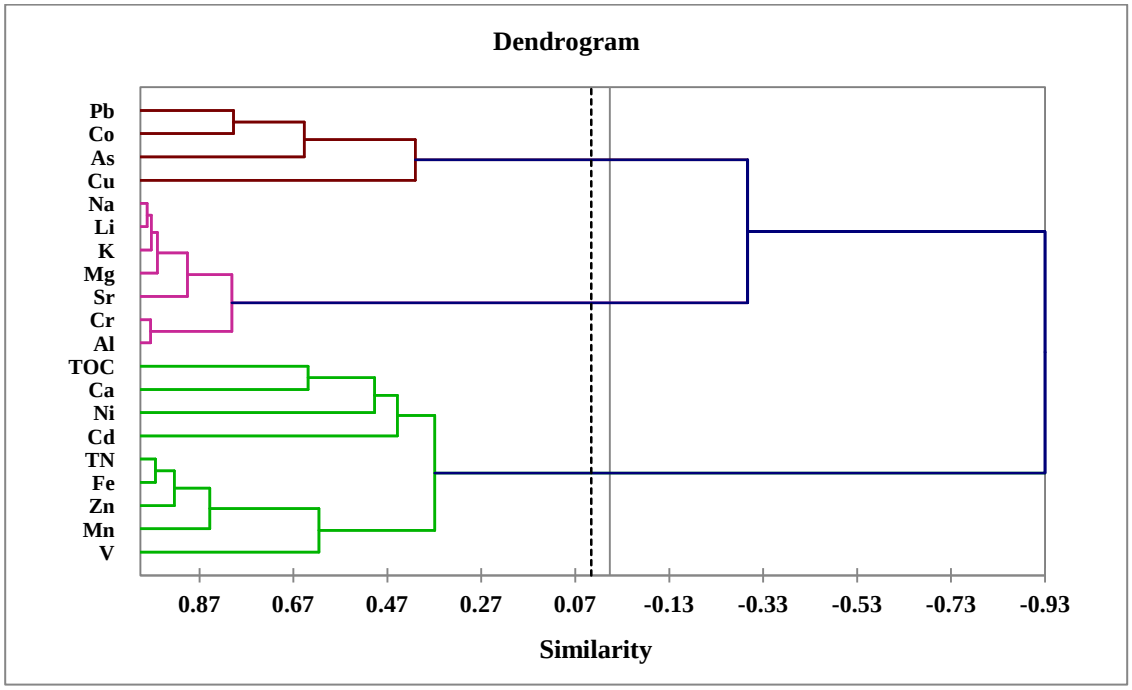


Figure 7.14: Similarities in chemical media of elements and TOC and TN at Core 6

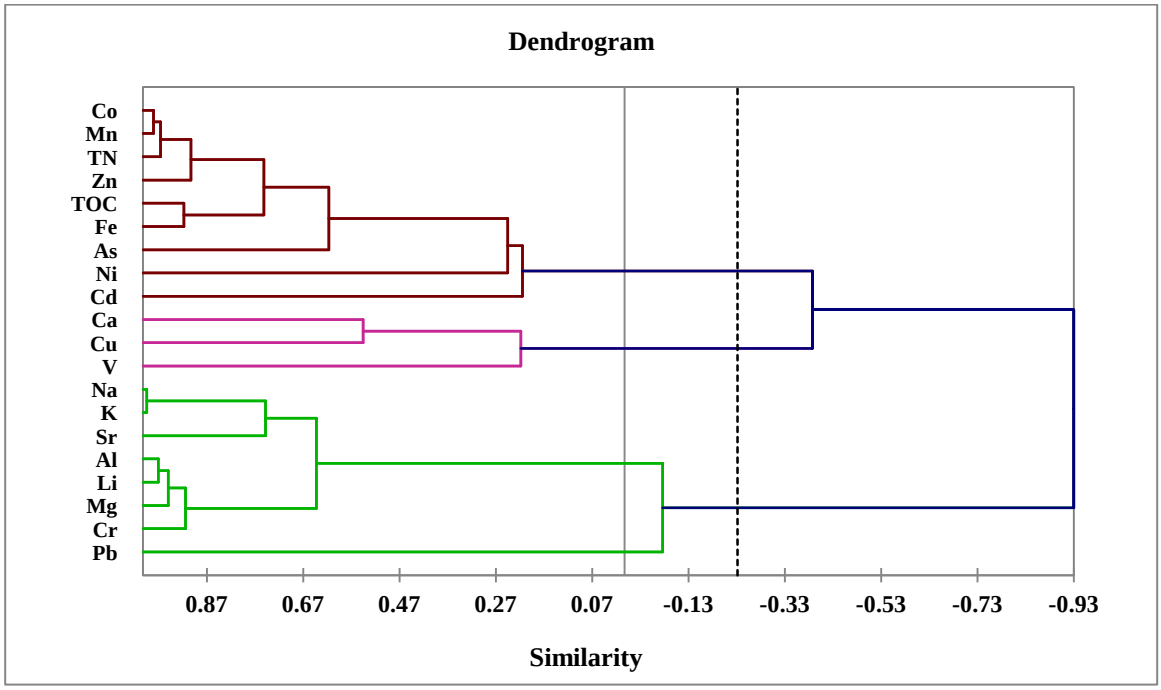


Figure 7.15: Similarities in chemical media of elements and TOC and TN at Core 5

Figure 7.15 illustrates a significant correlation between TOC content with Ca, Ni, and Cd metals. Maximum similarities are seen between the accumulation of TC and Fe, Zn, Mn, and V metals. Class 3 is also indicator of metals bounded to the organic matters and which mostly enriched with existing of them.

At the north of Bera Lake, organic-bond metals as well as Cu cluster in classes 1 and 2. A significant positive correlation also appears between TOC and Fe, and between TN with Mn, and Co. These groups show high similarities in accumulation media with As, Ni, Cd, Ca, Cu, and V metals. Metals which cluster with nutrients, however, show minimum similarities with lithogenic metals in terms of chemical conditions during accumulation. This trend appears clearly in Figures 7.14 and 7.15 in which there is a negative correlation between Mg and K concentrations and TOC and TN values. Three influxes of organic carbon into the middle of Bera Lake were recorded at depths of 68, 40, and 20 cm, respectively in 1948, 1970, and 1991. The deepest peaks are related to a natural event or an artificial one when large amounts of POC and organic rich deposits settled. The second peak showed the remarkable contribution of maximum deforestation at the start of the FELDA projects with accumulation of a certain charcoal horizon. The youngest peak represents a remarkable change in chemical media of the basin and the commencement date of organic-rich deposition in layer 4. The TN content has also increased coinciding with the accumulation of organic-rich deposits. Therefore, the C/N ratio as an indicator of eutrophication decreased significantly and showed an upward decreasing trend in the middle of the Bera Lake sediment column. This shows that in situ vegetation and algae play minor roles in the production of organic carbon. On the other hand, the contribution of

forest burning and land preparation has been earlier explained. These continuous processes have promoted TN content in the sink area.

Different variation trends in nutrient content were recorded in the north of Bera Lake in comparison with the other parts of the basin. A sharp and significant variation was recorded in nutrient content prior to, and after, land development projects. In this part of the basin, eutrophication increased in two remarkable steps. These steps appear clearly in the upward decrease of K and Mg as lithogenic-bond nutrients. An upward increase in eutrophication, started from 1973 in the sediment column at the north of Bera Lake. This trend reached a maximum level which coincided with the third FELDA land development project in 1985. A constant rate of nitrogen influx has been recorded from 1985 until the present-day, indicating continuous deforestation and nitrogen release to the sink areas. Reworked of ^{137}Cs shows two peaks in agreement with influxes of nutrients into the north of the basin especially in 1975 and 2001, respectively. A clear correlation in TOC, TN, and Ca values appeared especially from at 24 cm depth, and from 1985. An increasing upward trend in the C/N ratio has dominated the north of Bera Lake. There is therefore, a negative correlation between the middle and the north of the basin. Evidence indicates that chemical media in the north of Bera Lake created a condition where nutrients were significantly preserved in contrast to the middle of basin. According to the US Taxonomy, Bera Lake sediment would be classified as being high organic nitrogen sediment because of nitrogen enrichment.

7.7. Discussion

The literature review (Section, 2.4.4) has revealed that the influx of contaminates can indicate an environmental changes and an independent time marker for reconstructing the history of lakes over the past few decades. Literature also shows that the long-term investigation of pollution can be separated into pre-, and post-, 1950 industrialization period. Long-term variations in concentrations of heavy metals in a lake sediment profile can be investigated by using radioisotopes. A remarkable gap in the study area (Section, 2.4.5) was identified to be the medium-term sediment quality and ecological risk assessment. The multidisciplinary importance of Bera Lake especially in terms of aquatic life and related human health also encouraged this research to define and determine the Bera Lake sediment quality assessment as one of the main objectives of study. The research also intended to correlate environmental impacts of land use change to heavy metal fluxes into the Bera Lake. It was initially thought that the influx of heavy metals involved contaminants but this was not so when compared with sediment quality guidelines to determine threshold of pollution. In other words, contaminants may not harmful to human health when compared with the existing standard limits of pollution and toxins. A wide range of sediment quality standards and ecological risk assessment indices were used to achieve the study objectives.

The contribution of natural and anthropogenic events has been evaluated in terms of their effects on the creation of dissolved loads and accumulation at Bera Lake based on resultant data. The sediment compositions at Bera Lake remarkably reveal the overall parent rock compositions. There are apparently Al-bearing deposits in the Bera Formation (Permian) and Triassic granite intrusion. These rock units have been deeply weathered

with a thick pale, bleached layer and in situ secondary minerals. In addition, there are outcrops of the Redbeds Formation (Jurassic), especially in the west and northwest of the study area. This formation is mainly responsible for promoting Fe contents in the soil and sediment profiles of the area. Macdonald (1970) identified iron-rich strata as being mineral ores in the Bera Lake catchment thus indicating them as iron-bearing sources for increasing Fe contents in the sink areas.

Deposition of erosion-induced sediments in the Bera Lake basin started with deposition of a massive white sandy mud (Layer 3). There is a good agreement with the results of the cluster analyses and the vertical variations in sediment composition in layer 3. The first population of elements which was associated with deposition of the white sandy mud involves lithogenic Na, K, Sr, Al, Li, Mg, Cr, and Pb. A deep positive correlation with a significant Pearson coefficient r-value existed for this metal group in all sections of Bera Lake. Cluster analyzing properly revealed their relationships and classified them in a nearest distance and similar group. Correlation of ^{210}Pb dates in the Bera Lake sediment column and heavy metal enrichment, implied effects of land clearing in FELDA projects in aggressive chemical weathering and sediment supply of exposed rocks.

Based on the resultant dates, the south and main entrance to Bera Lake has experienced two major enrichments of heavy metals in 1986, and in 1994-1995 during the fourth and fifth FELDA projects, and two minor influxes of heavy metals between 1971 and 1979, and in 1991, due to the first to third, and fifth, FELDA land development projects, respectively. Thus, the fourth and additional fifth FELDA land developments projects played a major role in exposure of weathered bed rock and the moderate to

significant enrichments of Ni, Cu, Cr, and Zn heavy metals in the southern part of Bera Lake.

Low contamination degrees and EF were obtained from cores in the deepest part of Bera Lake where the minimal to moderate EF of heavy metals especially Zn, Fe, Ni, Cu, Cr, and Pb is in agreement with the influx of ^{137}Cs recorded in 1964, 1983, 1993, and appears to be controlled by anoxic conditions due to re-dissolution of heavy metals combined with horizontal transport to adequately oxygenated parts of the Bera Lake. Similar conditions of re-dissolution of major elements and ^{210}Pb has been reported by Robbins et al., (1978) for Lake Erie. Minor peaks of enrichment of heavy metals in the middle part of Bera Lake are also in agreement with the dates of the third, fifth FELDA land development projects.

There is a distinct difference between the degree of contamination, EF and ecological risk index during both pre- and post-, FELDA land development projects in the northern part of Bera Lake. Contamination factors prior to land use changes in the catchment area were in a non-contaminated mode with the EF for all major and minor elements being under the factor of 2 or minimal contamination. On the other hand, three main influxes of heavy metals occurred in the northern Bera Lake sediment profile between 1971 and 1974, between 1981 and 1983, and between 1986 and 1994, during the first to fourth FELDA land development phases. Enrichment of heavy metals mainly occurred during deposition of white sandy mud sediments where Zn, Fe, As, Mn, V and Co has been moderately to significantly enriched. The strong affinity of As, Cr, Cu, and Ni for aquatic particles, particularly iron and manganese oxides is also demonstrated in their deposition at Bera Lake in association with these materials. This fact can be clearly

correlated with the significant increase of Fe and Mn concentrations in the Bera Lake sediment profile since 1972 after land use change.

Sediment profile interpretation of Bera Lake and its ^{210}Pb dating has emphasized the accumulation of organic-rich to peaty sediments in the top 20-cm (uppermost layer) of the sediments since 1993 due to high organic waste production associated with oil palm plantations. Layers with as much as 20% organic matter include roots, bark, stems, charcoal, and other organic debris.

Although many local land developments have occurred during the last two decades, most of the original FELDA districts have been in place for quite some-time, and the present runoff thus mostly contains organic materials. Agricultural development in the catchment areas has thus dictated that the Bera Lake sediments in the wetlands will be biomass and other organic matter after stabilization of mature oil palm plantations. Organic-rich sediments are a well-known sanctuary for microorganisms to absorb inorganic heavy metals, which they then transform to organic forms. Cluster analyses revealed a clear correlation between the deposition of organic-rich sediments and a specific group of metals involving Fe, Mn, As, Zn, Cu, Ni, V, Co, Ca and Cd.

Vanadium, which is known as an indicator of oil pollution (Anke et al., 2005) also falls into this cluster and agrees with the spread of organic-bond heavy metals. The results revealed that the level in sediment samples is close to its concentration in shales (100-130 mg kg^{-1}) which are one of the dominant lithologies in the catchment area. The clear increase in concentration of V coincided with the start of the FELDA land development phases. Fuel consumption is an unavoidable item for machinery during land preparation and plantation stages and this has released large amounts of V to the soil and sediments.

Arsenic is significantly associated with contamination in the Bera Lake sediments. Agronomic projects and the geological setting of the study area as nonpoint sources have mainly contributed to the arsenic present. Burning of biomasses land during land preparation is apparently responsible for the oil palm plantations promoting the arsenic content of Bera Lake deposits. Arsenic is present naturally in the aquatic and terrestrial environments owing to weathering of rock and soil. Further study, however, is needed to estimate the real distribution of arsenic in the Bera Lake large catchment. Arsenic appears in the organic-bond group of metals in Bera Lake and indicates the importance of organic matter in the enrichment of this metal.

Iron and manganese oxides are well known for their ability to absorb and enrich other metals like As, Cr, Cu, and Ni. They play an important role in encouraging deposition of the other metals in the bed sediments. The fate and persistence of As, Cr, Cu, and Ni is also intricately connected with the fate and persistence of iron oxides. The Mn/Fe ratio values for Cores 1, 2, 4, 5, and 6 revealed the important role of iron oxide at Bera Lake. These values are also influenced by redox conditions, pH, and microbial activity in the sediments. The sediments therefore, act as an important route of exposure to aquatic organisms for As, Cr, Cu, and Ni. These metals account for adverse biological effects in the organic-rich sediments of Bera Lake. For instance, the many expected adverse effects by Arsenic include a decline in benthic invertebrates, mortality expansion, and behavioral changes (CCME, 1995). Benthic organisms are exposed to both particulate and dissolved forms of the metals in interstitial and overlying waters. They also exposed to sediment-bound As through surface contact and ingestion of sediment. Inorganic heavy metals are the predominant form in the sediment, the water column, and interstitial water.

Microorganisms in the sediments can transform inorganic forms of heavy metals into organic forms, which can perfectly collect in aquatic organisms. Microorganisms provide the biochemical link in the cycling of metals in aquatic systems. The methylated forms found in interstitial waters are by-products of microbial action (CCME, 1995).

Dose-response models expressed on the metals exposures at a particular site as main reason for their adverse effects. In addition, the sensitivity of individual species of aquatics account for adverse effects of metals. Bera Lake is a sink area which provided progressively enriched metals with maximum exposure to aquatics.

A previous study (Wüst et al., 2002) and field tests indicated that the pH values of Bera Lake sediments and water column are between 4.4 and 5. The acidic condition may be the result decomposition of organic matters (release of carbon dioxide) and the incremental addition of SO_4 (sulfate) and NO_3^{2-} ions, leading to a reduction in the exchangeable cations ratio, i.e., (K+Na)/(Ca+Mg), and organic matter preservation in the uppermost layer of the sediment profile (Wüst et al., 2002). In such conditions, bottom-dwelling decomposing bacteria begin to die off and leaf litter and dead plant and animal materials begin to accumulate (CCME, 1995). With regards to heavy metals, the degree to which they are soluble usually determines their toxicity. A rule of thumb indicates that the lower the pH, the more toxic the metal as they are more soluble and enter to the food chain.

The first contribution of this research to knowledge was the introduction of the background values (Table 7.1) of each individual metal which can be used for ecological risk assessments at any natural and artificial lake in Malaysia. Normalizing metals using the Al value is recognized as being much better than using the Li. Background values were calculated for individual metals with minor uncertainty. The validity of background values

was well confirmed by ecological risk assessment indices in which they successfully revealed any anomalies and variations in the Bera Lake sediment columns.

In addition, the results have confidently supported the capability of the selected methods in achieving the research objectives. The research has remarkably contributed to knowledge in terms of the emphasizing of EF and the exchangeable cation ratio between other contamination factors as the best indicators of anthropogenic activities at any lake sediment profiles. The lowest capability in order to show effects of land use changes or influx of heavy metal was recognized for Index of geoaccumulation.

Identification of the most toxic metals between the analyzed major and minor elements has been another achievement of the present research. Places in Bera Lake where contamination was above the upper pollution threshold were revealed in this research project. The study also remarkably emphasized that Fe, Mn, Co, Ni, Cd, Cu, Ca and Zn are the best indicators of organic matter enrichment under acidic conditions. On the other hand, lithogenic K, Na, Sr, Al, Li, Mg, and Pb metals can be used as indicators of land use change in further studies especially in Malaysia. This study therefore, has appropriately introduced the best materials and methods for further ecological risk assessments in Malaysia and in so doing has achieved one of the objectives of the project. Decision makers at the RAMSAR site can therefore, now find answers to their questions on why the fish population has dramatically decreased in Bera Lake and why seasonal emigrant birds do not choose the wetlands and open waters of the area.

Land use changes have seriously affected the nutrient cycle in the wetlands and open waters. Interruption in natural accumulation trends has been remarkably illustrated in the historical study of nutrient contents in the Bera Lake sediment columns. Different rates

of eutrophication in the middle and north of Bera Lake have also emphasized the effects of morphological and hydrological factors in creating semi-closed areas and increasing nitrogen enrichment.

In the tropics, intense chemical weathering and leaching of minerals leads to a shortage of nutrients. Nutrients are therefore, limited and plants adopt ability for strong nutrient recycling (Reading, 1995). Land development projects at Bera Lake catchment have significantly promoted nutrient release and redistribution. The upward decreasing trend in the C/N and exchangeable cations (K+Na)/(Ca+Mg) ratios at the middle of Bera Lake clearly emphasizes the effects of land development projects in upward increasing eutrophication. A similar C/N ratio trend has been reported by Wüst and Bustin (2001) from areas in the south of the Bera lake catchment where water discharge is relatively proper. Wüst and Bustin (2001) have stated that low C/N values indicates low bacterial activity and low organic matter decomposition.

On the other hand, nutrients like TOC, particulate organic carbon and nitrogen were properly conserved after the onset of land development projects. Two clear shortages in nitrogen contents have been appeared during the first and third FELDA projects. The overall chemical results like exchangeable cation ratio, dissolved oxygen and pH have demonstrated a good media for conservation of nutrients at the north of Bera Lake since 1980 (Fig. 7.16). In addition, the increased production of biomass from clear-cutting of existing forests and after establishment of mature oil palm plantations has resulted in an influx of organic carbon into wetlands and open waters. The results showed that significant conservation of nutrients in the south and middle of the study area only commenced later from 1991 (Fig. 7.17).

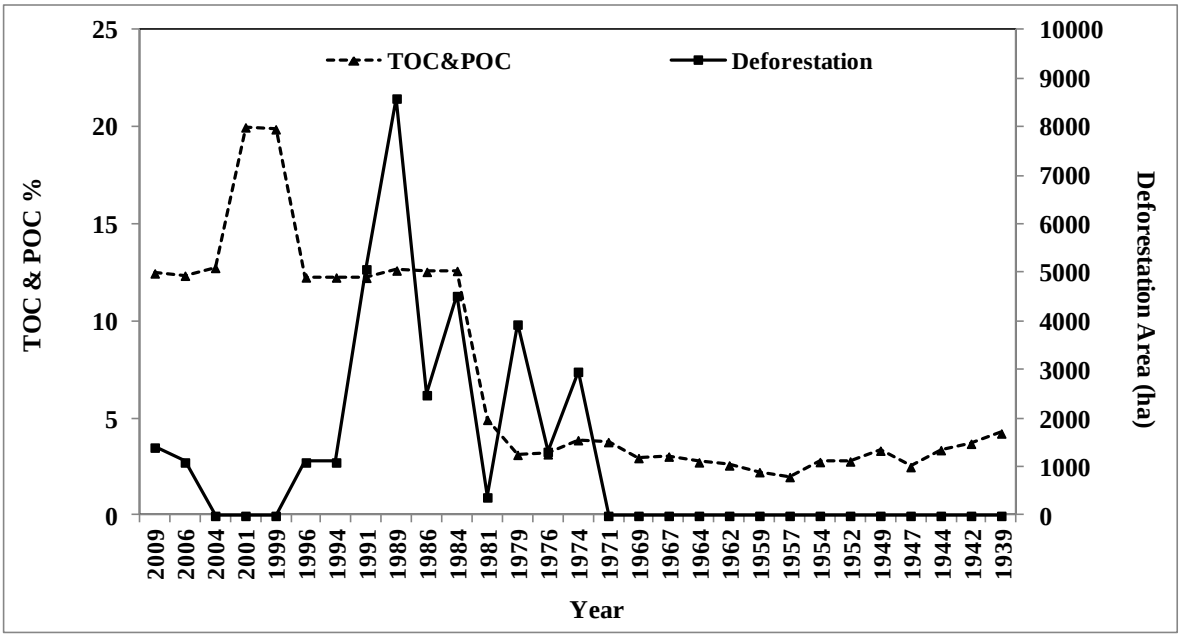


Figure 7.16: Clear increment of organic carbon at the north of Bera Lake since 1980

The C/N ratio has increased to a value of 24; a value similar to that at Paya Belinau in the south of the study area as reported by Wüst & Bustin (2001). The lower hydrological circulation in those semi-closed basins seemingly leads to minor DO and more anoxic and acidic depositional media. Cluster analyses revealed a negative association of lithogenic metals in the organic-rich mud in the uppermost layer of the Bera Lake sediment column. Low mineralization of organic material is an expected process in this part of the Bera lake sediment profile. The fixation of potassium (K) and sodium (Na) entrapment at specific sites between clay layers tends to be lower under acid conditions. In such situations, calcium (Ca) which is known as an organic bound element can exchange potassium position. This means that after the onset of land development projects, the potassium availability has increased and led to increases in vegetation cover especially *Pandanus* over the Bera Lake wetlands and open waters.

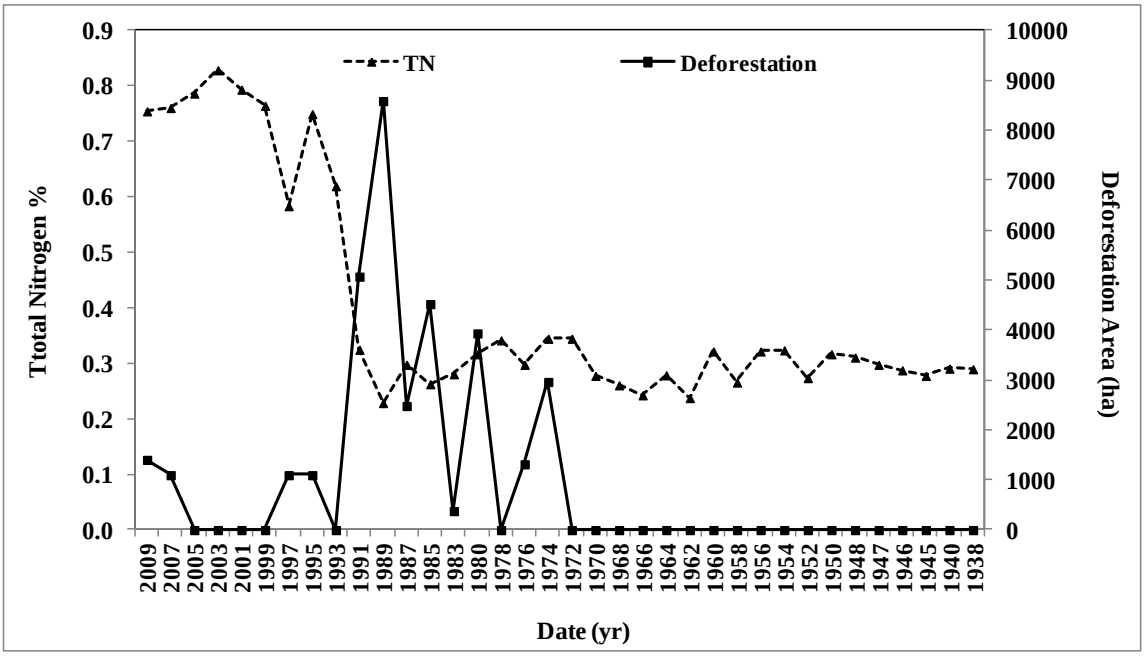


Figure 7.17: Nitrogen content in Bera Lake and deforestation phases

This process is more common in the north of the study area than in other parts. The Bera Lake water quality analyses furthermore, showed a remarkable northward increase in NO_3^- contents which indicate eutrophication. ^{210}Pb dates using the CRS model have been verified by the stratigraphic nutrient dates and charcoal horizons. The overall dept-wise variation in nutrient contents also appears to be in good agreement with anthropogenic activities in the catchment area. Thus present study has adequately answered questions about the environmental impacts of land use changes on nutrient redistribution. The unique destiny of nutrients which have been released from source areas during and after FELDA projects have been shown in this research. Significant recycling of nutrients is found in the uppermost layer of the Bera Lake sediment column as organic-rich deposits.