4. CHAPTER IV: STUDY AREA

4.1. Physiographic Particulars

The study area, BLC is located in the central part of Peninsular Malaysia, in southwestern Pahang State and northeastern Negeri Sembilan State (Fig 4.1), between 2˚, 53′, 00″- 3˚, 10′, 00″ longitudes and 102˚, 30′, 30″-102˚, 47′, 00″ longitudes. This lake can be inversely trough as an island of water and surrounded by rain forest. Two very low but parallel mountain ranges [around 500 m high] flank Bera Lake into existence within a corridor. The mountain range the Bertangga/ Cermingat at east, and the Batu Beras/ Palong range at the west guides water within the lowland. The southern edge is a flat lowland gradually dominated the undulating "waves lands" of Johor.

As previously mentioned, the latest physiographic characteristics of study area were created using digital topographic maps of 1:25,000 scale (Series L8028) and a satellite image (Spot 5, 2009) of 10m spatial resolution and GIS media. The total catchment area was determined to be 593.1 km^2 with the area of cleared land, rubber and oil palm plantations covering some 340 km^2, and open water about 1.11 km^2 (Fig. 4.2). The remaining area is covered by wetlands and pristine (forest and reed swamps) lowland rain forests. The highest hills in BLC are up to 140 m above sea level and the lowest elevation is 7 m at the outlet point of Bera Lake (Fig. 4.3). River valleys mostly have developed from elevation of 40 m and mean water level of 7 m. Digital elevation model was developed in order to draw BLC slope map. Resultant slope map (Fig. 4.4) in degree shows that up to half of study area is composed of low land area with slope of 0 to 2 degree.

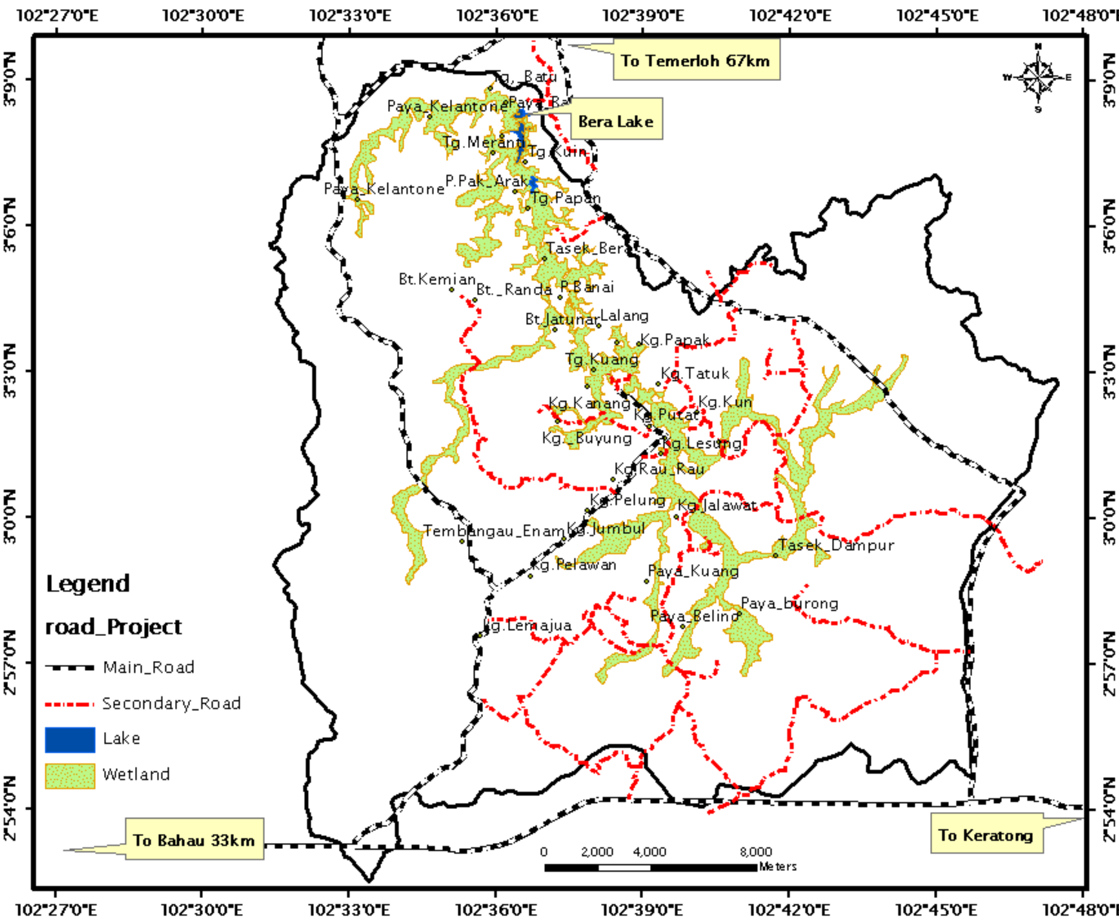

Figure 4.1: Geographical position of BLC in Peninsular Malaysia

Geomorphology of drainage pattern in Bera Lake is controlled by geological formation and topographic criteria. The common drainage pattern is dendritic (Fig. 4.4). A dendritic drainage pattern is the most common form in regions underlain by homogeneous material. That is, the subsurface geology has a similar resistance to weathering so there is no apparent control over the direction the distributaries take. Dendritic pattern is continued in wetlands and open waters as well. Several distributaries and elongate open waters have shaped the Bera Lake at northern part of catchment. Indeed, Bera Lake is topographically trapped body of water which has developed into the dendritic distributaries.

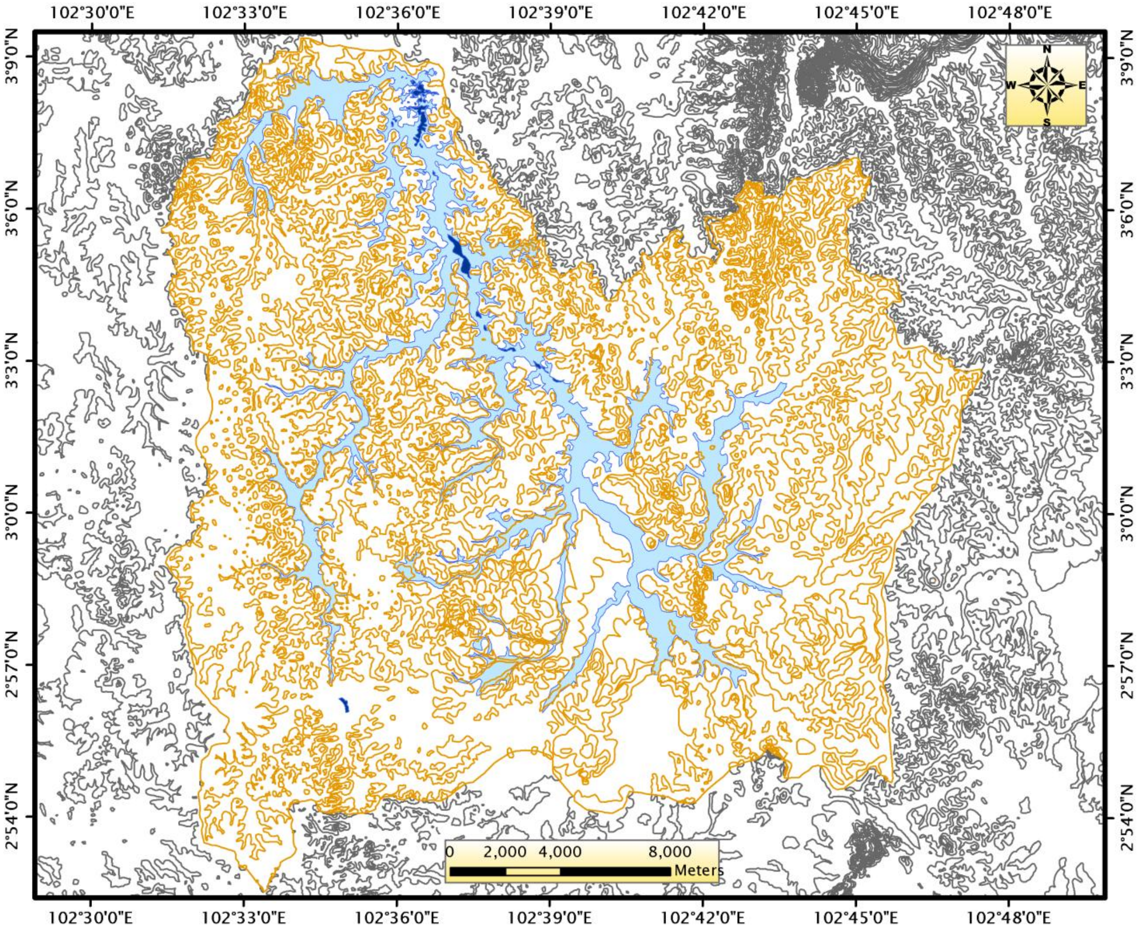

Figure 4.2: The topographic map of BLC and surrounding area

The total length of stream pattern in BLC area and drainage density were obtained 1316.84 km and 2.25 km km^{-2}, using geographical information system. The BLC has been separated into the 12 sub-catchments in which main open water is located at most northern part, at the third sub-catchment. Overall water flow is directed northward and stream patterns of the fourth to twelfth sub-catchments have been joined and ultimately connect and drain into the south of Bera Lake (Fig. 4.6). Two other streams from the first sub-catchment (Kelangton stream), and second, drain into the middle, and northern parts, of Bera Lake, directly. This leaves only one outlet - excess water over spilling into channels in the north where all join Bera River which ultimately ends into Pahang River.

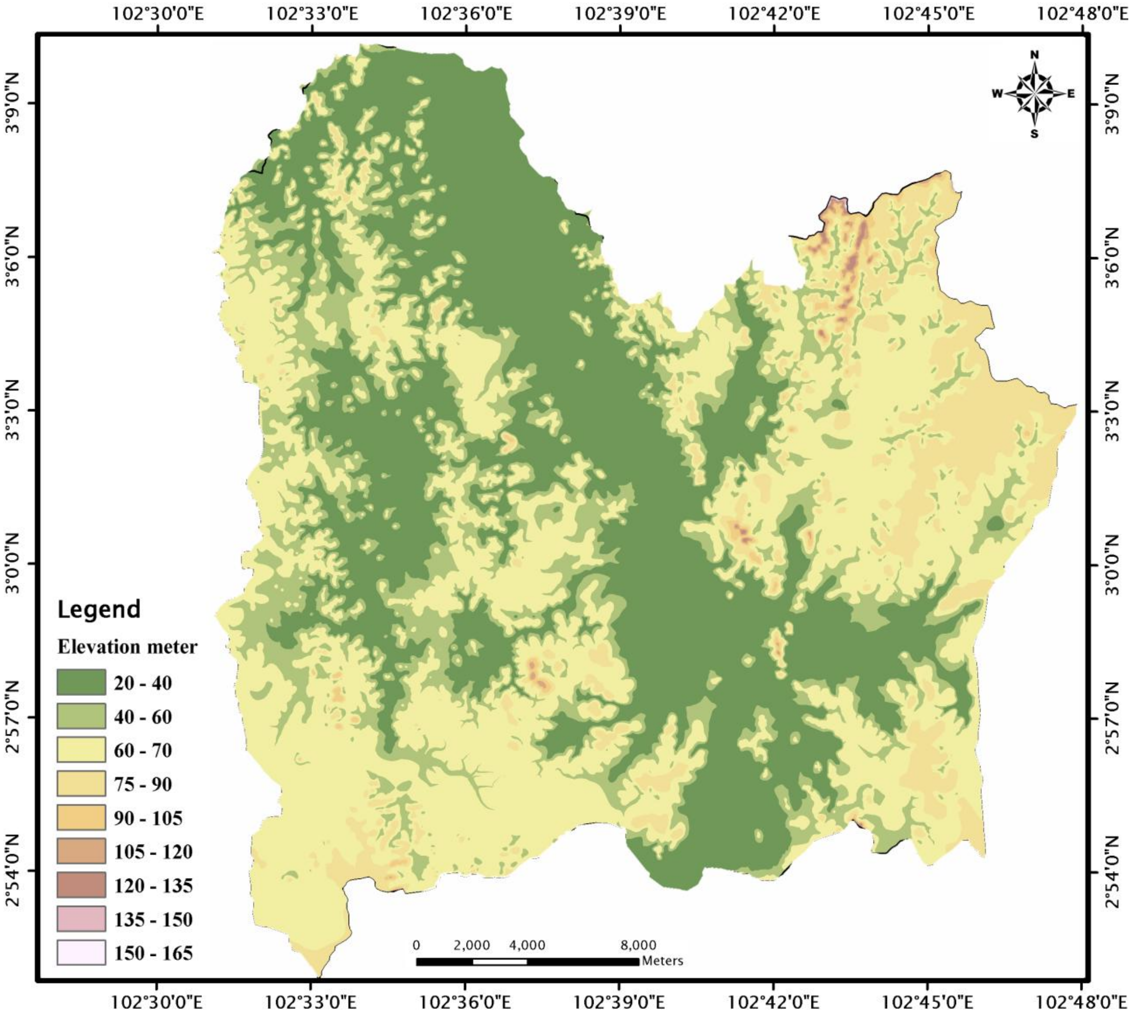

Figure 4.3: Digital elevation model of BLC

In addition, BLC and its sub-catchments were studied in order to calculate physiographic and drainage characteristics (Table 4.1). Catchment form is an essential factor which controls hydrological parameter like time of concentration and water discharge. As a result, the round shape catchments drain faster than elongate shape ones. Therefore, catchment form has been studied using shape factor, Gravelius coefficient (Gravelius, 1914), and Horton form factor (Horton, 1932).

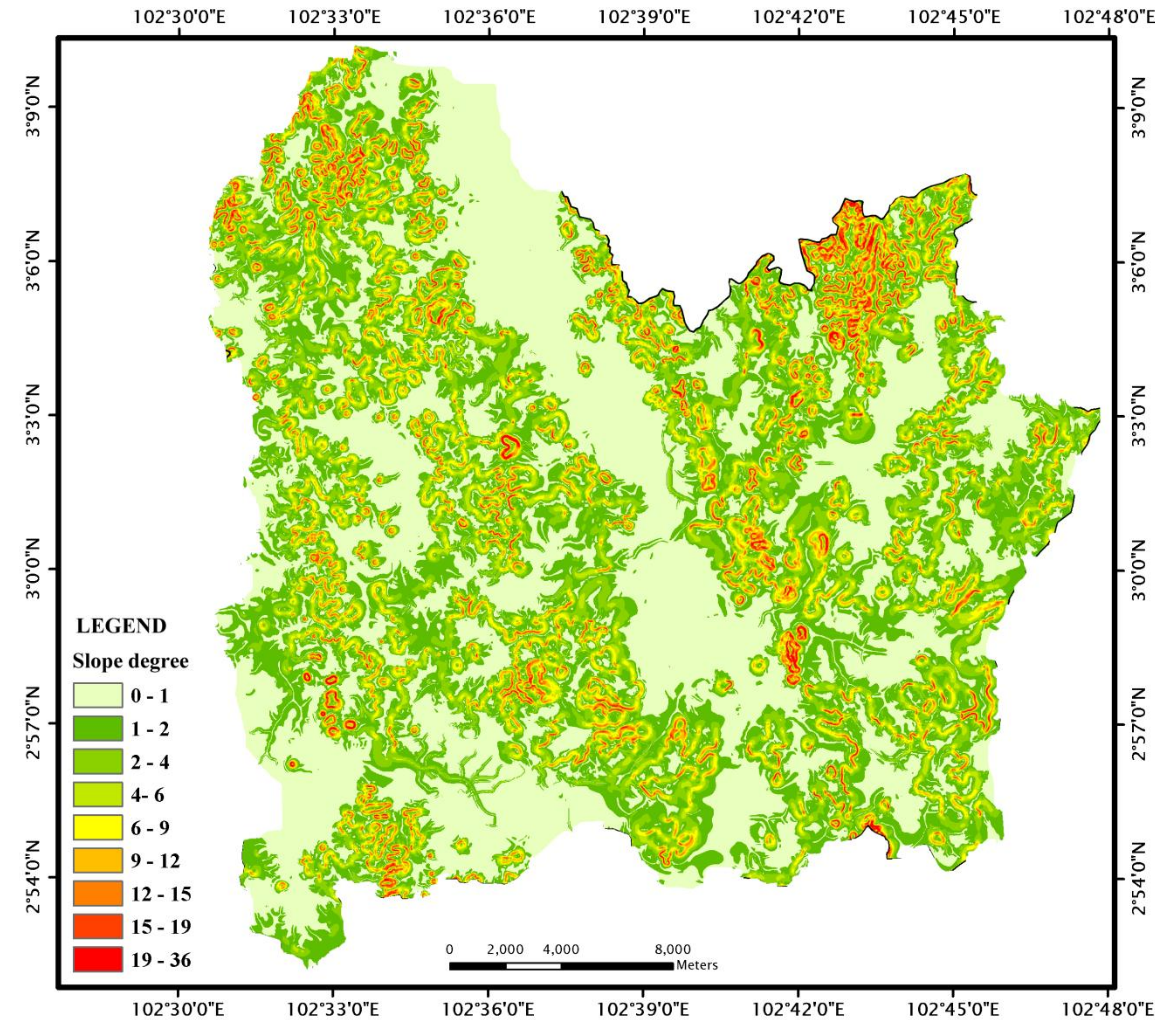

Figure 4.4: Slope categories at BLC

Table 4.1: Physiographic and drainage characteristics of Bera Lake watershed

Parameter	Bera Lake sub-catchment												Whole Catchment
	1	2	3	4	5	6	7	8	9	10	11	12	
Area (km2)	50.4	18.18	29.9	125.93	28.13	12.93	12.42	60.11	25.56	38.97	49.49	141.1	592.84
Perimeter (km)	39.9	23.53	33.4	69.95	28.65	20.2	17.61	37.31	27.83	44.45	38.2	65.8	138.195
Length (km)	9.58	7	10.33	21.28	8.97	4.96	3.25	10.9	8.85	6.8	3.74	17.86	23
Gravelius Coefficient	1.57	1.55	1.71	1.75	1.51	1.61	0.14	1.35	1.54	1.99	1.52	1.55	1.59
Horton form factor	0.55	0.37	0.28	0.28	0.35	0.5	1.18	0.51	0.33	0.84	3.54	0.44	1.12
Concentration time (hr)*	3.11	2.45	3.38	7.79	2.9	1.45	0.89	3.61	2.84	2.09	1.05	6.42	8.53

Gravelius Equation [Kc=28P/A^0.5) A: area (km2), P: perimeter (km)]

Form Factor in Horton Equation (F=A/L^2) A: area (km2), L: Length (km)]

*Kripich Equation [Tc(hr)=0.0003L^0.77*S^-0.385) L: Length of main stream (km)

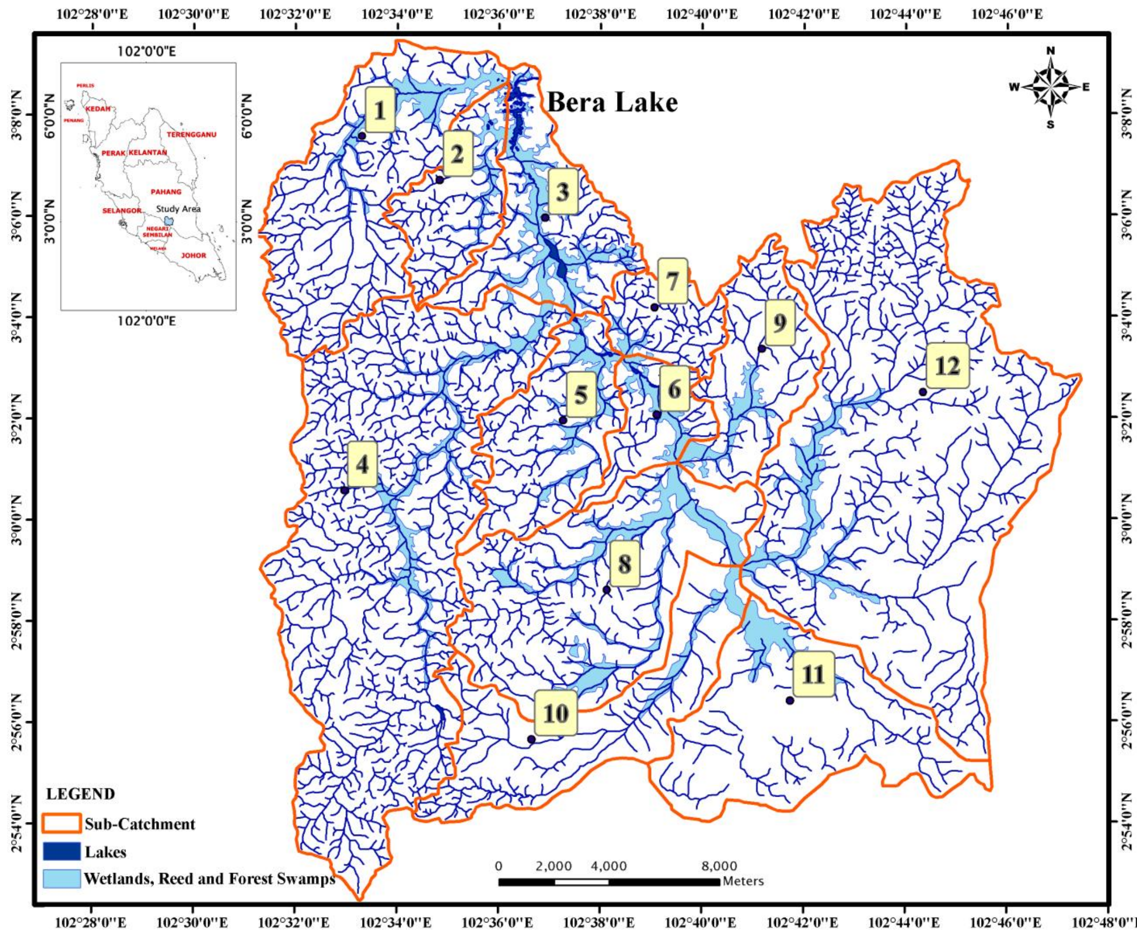

Figure 4.5: Stream pattern and sub-catchment of Bera Lake watershed

The highest and lowest Gravelius values were obtained 1.99 and 0.14 for the tenth and seventh sub-catchment, respectively. Gravelius coefficient of BLC was obtained 1.57 which illustrates its semi-elongate shape. Horton form factor is also an indicator of watershed circulatory representing form factor of 1 for circular shape and values less than 1 show diversion from roundness. Horton form factor was calculated for BLC is 1.12, points out a basin with a semi-elongate shape.

Time of concentration is a fundamental watershed parameter, which is the longest time required for a particle to travel from the watershed divide to the watershed outlet. It is used to compute the peak discharge for a watershed. The peak discharge is a function of the rainfall intensity, which is based on the time of concentration. Time of concentration of Bera Lake basin was calculated 8.53 hours based on the Kirpich equations (Kirpich, 1940). In addition, this value is decreasing in 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. Resultant time of concentrations is in accordance to shape of sub-catchment where the most circulate has been the seventh one, indicating the lowest time of concentration 0.89 hour.

4.2. Geology

Geological setting is one of the most important characteristics of BLC in terms of its contribution in sedimentary processes and evolution of basin. BLC is located in the geological central belt of Malaysia. The central belt significantly is different with western and eastern belts in terms of historical evolution, tectonic and structural, and stratigraphy settings (Hutchison & Tan, 2009). Figure 4.6 illustrates the Lebir fault and Bentong Suture as a boundary between eastern and western margin of the Central Belt, which covers the entire state of Kelantan, the western and central parts of Pahang, the eastern part of Negeri Sembilan, and the western part of Johor (Ismail et al., 2007). Central Belt involves the Kepis, Lop, Bera, Kaling, Paloh, Ma'Okil, Gemas, Semantan, Tembeling and Koh Formations, and the Gua Musang Group and the Bertangga Sandstone, which range in age from Permian to Cretaceous (Ismail et al., 2007) (Fig. 4.7).

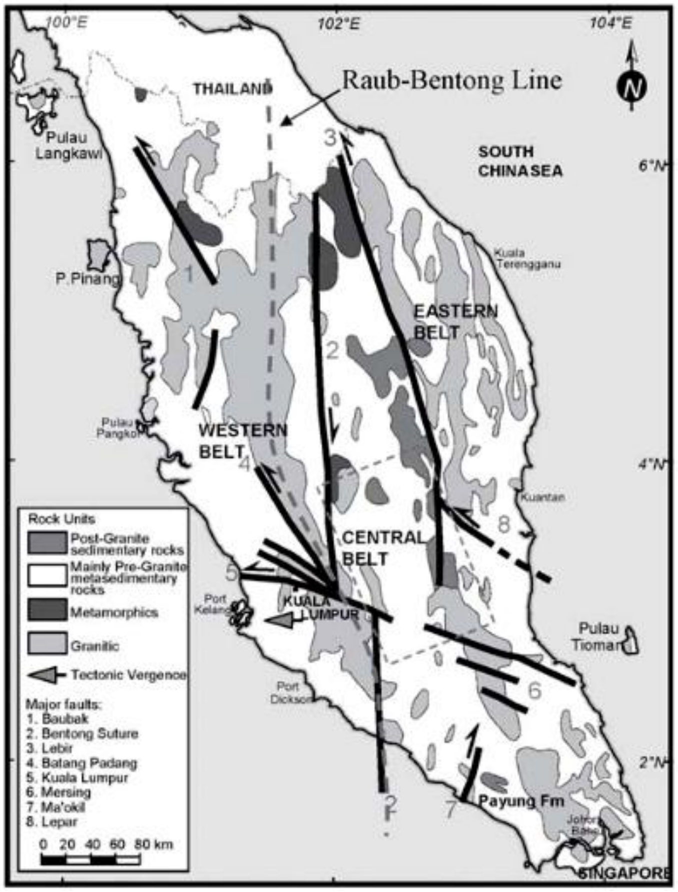

Figure 4.6: Geological map of Peninsular Malaysia after (Hutchison & Tan, 2009)

Age		CENTRAL BELT			
		South Kelantan		Pahang	Johor
Cretaceous	Upper	Non Deposition			
	Lower	Gagau group		Koh Formation Tembeling Group	Ulu Endau Formation / Panti Sst Tebak Formation
Jurassic	Upper				
	Middle	Non Deposition		Non Deposition	Non Deposition
	Lower				
Triassic	Rhaetian				
	Norian			Kaling Formation (Lipis Group)	
	Carnian	Gunung Rabong Formation	Telong Formation	Semantan Formation	Gemas/Ma'Okil Formation
	Ladinian	Gua Musang Formation			
	Anisian		Non Deposition		
	Scythian		Aring Formation	Non Deposition	Non Deposition
				Palaeozoic	Upper Palaeozoic

Figure 4.7: Mesozoic stratigraphic column of Central Belt. (In Ismail et al., 2007)

4.2.1. Stratigraphy

4.2.1.1. Bera Formation

The Bera Formation was introduced by Sone and Shafeea (2000) as recently exposed Permian layers on the eastern side of Bera Lake (Fig. 4.8). Bedding strata of the Bera Formation was recorded at N130˚ (NE-SE), 60˚SW in the twelfth sub-catchment, east of Bera Lake (Figs. 4.9, and 4.10).

The lithology of Bera Formation is composed of massive mudstone (Fig. 4.10), thick to massive tuffaceous sandstone, siltstone, and thin-bedded siliceous mudstone in its lower part, and thin-bedded shale, siltstone sandstone and subordinate conglomerate in its upper part. Several fossiliferous horizons give general middle Permian (Roadian to Capitanain) age (Sone & Shafeea, 2000). Field observation showed the deep weathering and some undifferentiated intrusions, probably the Triassic igneous rocks.

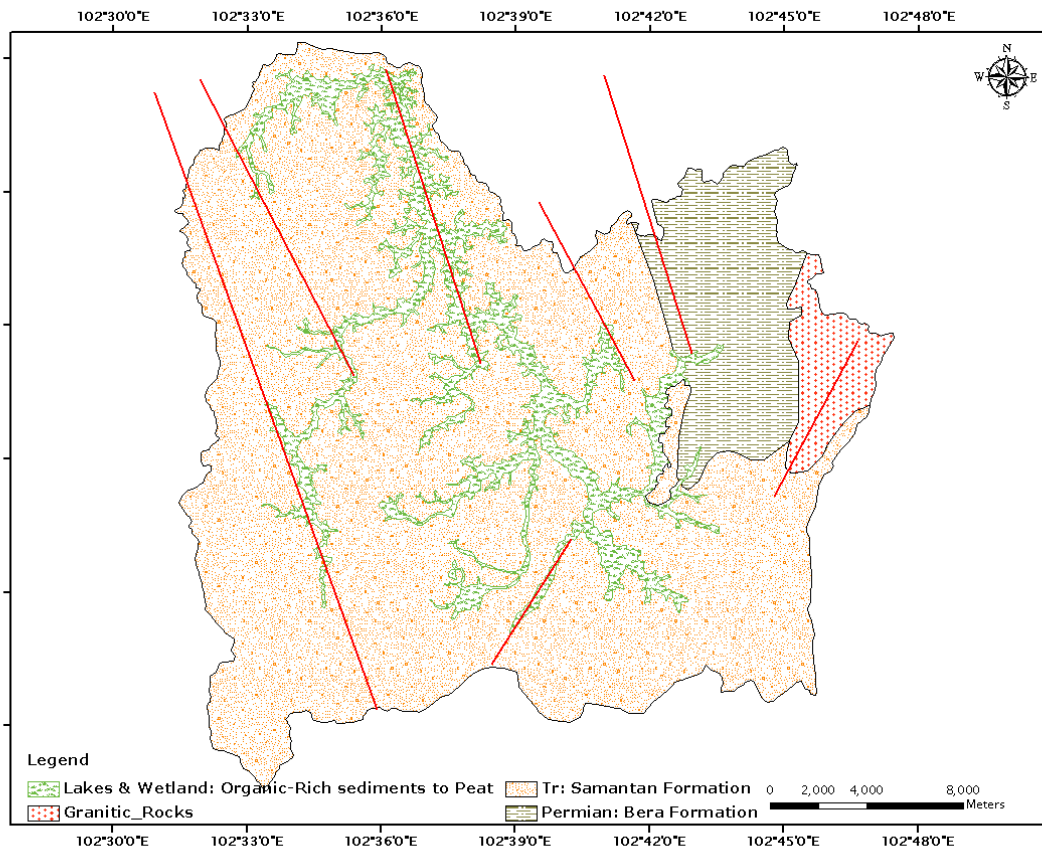

Figure 4.8: Geological map of BLC

Figure 4.9: Bera Formation bedding and lithology in the east of the study area

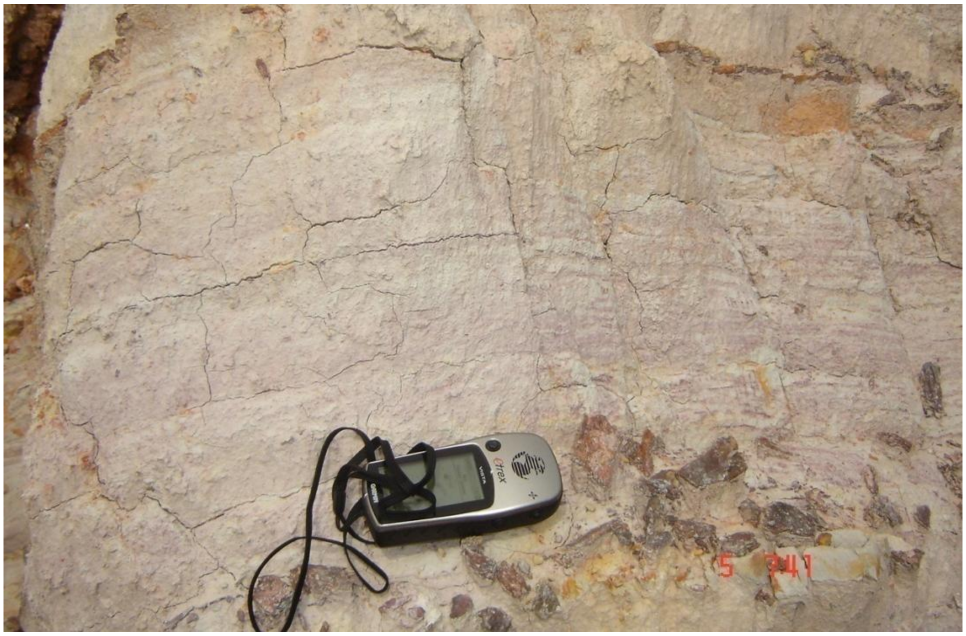

Figure 4.10: Thick outcrop of mudstone, Bera Formation at the twelfth sub-catchment

Iron oxide nodules appear as Gusan Zone is common product of highly chemical weathering of igneous rocks in study area which represents position of previous original rocks. Another source of iron-rich strata in the Bera Formation probably came from the final and dilute intrusion phases of igneous rocks which have been penetrated between sedimentary layers. Hutchison and Tan (2009) stated that the Bera Formation sediments were initially deposited in a shallow marine environment within a closed basin, with rapid sedimentation rate and volcanic input from the surrounding area. Overall sequence of the Bera Formation has been accumulated at a shallow upward to a littoral basin.

4.2.1.2. Semantan Formation

The Semantan Formation is one of the Paleo-Tethyan deposits which have been reported as Middle to Upper Triassic in age. Convergence between of the Eastmal/Indosinia and Sibumasu blocks resulted in closure of the Paleo-Tethys ocean in Late Triassic times (Hutchison and Tan, 2009) (Fig. 4.11).

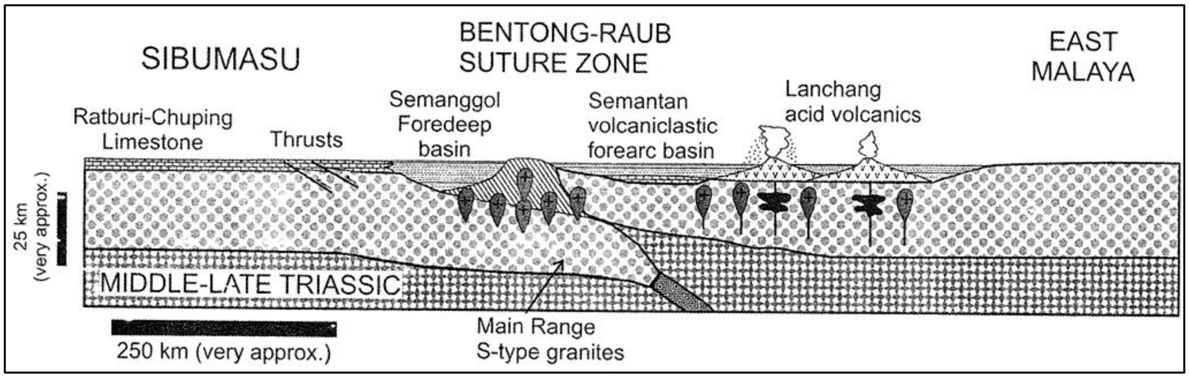

Figure 4.11: Structural setting of Semantan Formation (Hutchison & Tan, 2009)

The upper and lower contacts of the Semantan Formation are not exposed at the type locality. Lower boundary in BLC is not exposed and overlaid with an unconformity by Redbeds formation and quaternary deposits. The lithology of Semantan Formation comprises a rapidly alternating sequence of carbonaceous shale, siltstone and rhyolite tuff with a few lenses of chert, conglomerate and recrystallized limestone.

The best outcrops of Semantan Formation at BLC was found at the third sub-catchment where a sequence of fine sandstone with medium bedding layers interbedded with gray calcareous shale thin bedded layers (Fig. 4.12). Hutchison and Tan (2009) introduced basal as red beds from Karak to Cheroh along the foothills of the Main Range with an age of pre-Triassic, specifically pre-Anisian or pre-Semantan. Disconformity at the top surface has pointed out the unknown time period of erosion or situation without any deposition. It seems thickness of the Semantan Formation in study area remarkably has been reduced because of severe erosion. Several acidic to intermediate igneous intrusion are reported in this formation (Hutchison & Tan, 2009). Mohamed (1996) stated that Semantan formation appears as inter-fingering outcrops and is comparable with other formations; Raub Series; Calcareous Formation; Calcareous Series; Younger arenaceous

Series; Raub Group; Jengka Pass Formation; Kerdau Formation; part of Jelai Formation; Gemas Formation; Jurong Formation; Pahang Volcanic Series in the different areas.

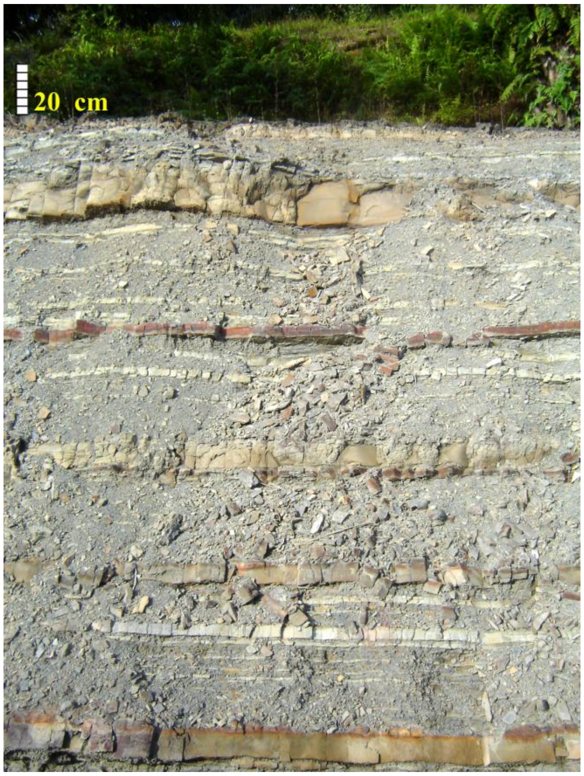

Figure 4.12: Lithological sequence of Semantan Formation in BLC

4.2.1.3. Post-Semantan Formation Redbeds

One stratigraphic unit with a wide distribution in the Central Belt is the Redbeds Formation which forms large km-sized folds. It is composed of conglomerate, pebbly sandstone and sandstone whereas the upper part is dominantly comprised by mudstone with subordinate sandstone (Hutchison & Tan, 2009). Redbeds Formation outcrop seems to be lenticular and it is not in the form of thick continues beds. The texture is composed of rounded quartz, schist, chert, volcanic fragments and iron oxide phenoclasts, size is varying between 2 and 20 mm. Grain supported texture with different portion of sandy to muddy sand matrix was obtained in the grain size analysis. Redbeds Formation strata have cemented with silica and yellow to red iron oxide cements. Field observations suggest that the Redbeds Formation were directly deposited on the Bera Formation with an erosional contact especially in fourth and twelfth sub-catchments, east and west of study area, respectively

Hutchison and Tan (2009) provide several discussions about the source and age of the Redbeds Formation. As the Semantan basin shoaled upwards during Late Triassic, the terminal phase of its shallow-water deposition passes transitionally into the Kerum Formation.

4.2.1.4. Granitic rocks

Granitic rock of BLC indeed is located at the outer part of Eastern Belt granite which is separated from sedimentary rocks by fault. K-Ar cooling ages, Rb-Sr whole rock and U-Pb zircon ages reveal intrusion of the Eastern Belt granites broadly dated as Permian to Triassic, in agreement with age of surrounding sedimentary rock units (Azman, 2009). Small batholiths comprising zoned and unzoned plutons in terms of their compositions are common character of the Eastern Belts granites. In addition, common rock types are ranging from monzogranites to granodiorite with minor gabbro and diorite.

Granitic rocks in BLC have been exposed in the twelfth sub-catchment at the eastern part. This rock unit has been well studied by MacDonald (1970) especially at Bukit Pandan which is close to BLC with a cliffy morphology and a steep valley. Their topography seemingly shaped by faulting and uplifting mechanisms. The main granite body of BLC has appeared at few outcrops. Field observations especially in the twelfth sub-catchment and soil analysis has been confirmed the granitic character of the plutonic rock from which it is derived. It appears that at the twelfth sub-catchment the granite body is located at a shallow depth beneath the capping of sedimentary strata. The common feature of few exposed granites bodies has been deeply altered and sericitiezed surface. MacDonald (1970) also has reported hornblende in a minor constituent, and epidote, garnet, pyrite, and clinozoisite as accessories.

4.2.1.5. Quaternary Deposits

There is a long history into investigation of quaternary deposits in BLC. The geological setting and evolution of the Bera Lake basin as well as deposition of peat and more recent palynological aspects have been studied (Morley, 1981; Wüst and Bustin, 1999; Phillips et al., 1998; Wüst et al., 2001, 2002, 2003, 2004, and 2008). Several boreholes which have been analyzed by Morley (1981) and Wüst and Bustin (2004) revealed sequence of inorganic and organic deposits in wetlands and open waters. According to the longest borehole log description; basal deposits is composed of detritus sands and coarse debris which may have been deposited at a time when river current flowed in a steep valley. Contribution of forest taxa in the basal deposits has been maximum between other organic taxa which approved by pollen records. Morley (1981) believed that inorganic alluvial sediments have been deposited only during the mid-Holocene; ca. 4,500 radiocarbon years BP. Wüst and Bustin (2004) represented a core in which stated that deposition of detritus sediments have been occurred before 5,500-6,500 yrs BP by a wet world season and heavily precipitation and runoff. They have introduced organic-rich lake sediments with an age of 20,480±190 yrs BP. In the other word, they believed that accumulation of organic matter occurred in local lakes during the LGM, but widespread peat deposition did not start until 5,300 BP when climatic changes led to the evolution of a wetland system. According to Morley (1981) contribution of non-forest and swampy pollens and spores have remarkably increased and preserved in sediments since 660±75 yrs BP. Transition to swampy condition has been rapid and is thought to have been caused by a reduction in gradient of the stream resulting from minor tilting of the area by tectonic movements.

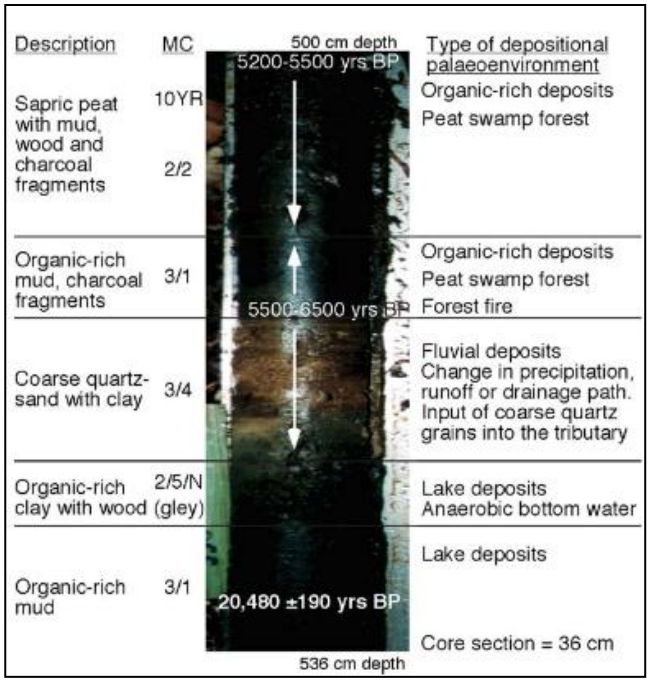

Figure 4.13: Historical sedimentation profiles in Bera Lake, after Wüst & Bustin (2004)

4.2.2. Structural Geology

Peninsular Malaysia has been structurally divided into three major belts with a less clearly defined fourth domain in the NW direction. The tectonic developments in the Mesozoic have been responsible for configuration of structural belts. BLC is located in the central belt and close to eastern belt. The boundary between the central and eastern Belts is marked by the Lebir Fault Zone (Hutchison & Tan, 2009) (Fig. 4.14). The structural geology of study area has been partially studied by MacDonald (1970) which divided the tectonic activities into three consecutive phases:

1) Folding due to earth movements along NW-SE lines, and minor faulting along axial planes.
2) East-West trend folding and emplacement of the granites bodies
3) Major north-south faulting

MacDonald (1970) has stated a major fold structures which are open anticlines and synclines with a northwest-southeast trend, and pitching gently to the southeast. Bera and Semantan Formations outcrops in BLC reveal significant effects of granites mass emplacement in the folding of Permian and Triassic rock units. Overall orientation of recorded bedding showed that rock units at BLC are located at right flank of a wide syncline, trending NW-SE and layers inclined 45-60˚ SE. Bera Fault (Hutchison & Tan, 2009) as a Jurassic-Cretaceous faulting system (Fig, 4-8) which developed between Mersing and Lepar fault zones, that has been active mid-Holocene as quaternary fault in terms of reshaping of Bera Lake basin. Faulting has played remarkable role in the final configuration of BLC.

As shown in Figure 4-8 there are five faults trending NW-SE and two faults are in NE-SW direction. Faults were recognized from aerial photos, stream pattern and confirmed using digital topographic maps. Evidences support the effects of strike-slip faults in shaping BLC valleys and controlled elongate shape of wetlands and open waters.

Probably, accumulation of detritus sediments at the depths of 8-9 m of Bera Lake had taken place 5,500-6,500 yrs BP due to a tilting and rapid steepness of the main valley. In addition, forest and reed swamps have developed mainly along depressions which already created by the strike-slip faults especially in the first, third, fourth, sixth, and the twelfth sub-catchments. Intensive chemical weathering of rock units resulted in coverage of fractures and joints in study area except at Semantan Formation where exposed with semi-fresh layers at northwest of catchment (Figs. 4.15 and 4.16).

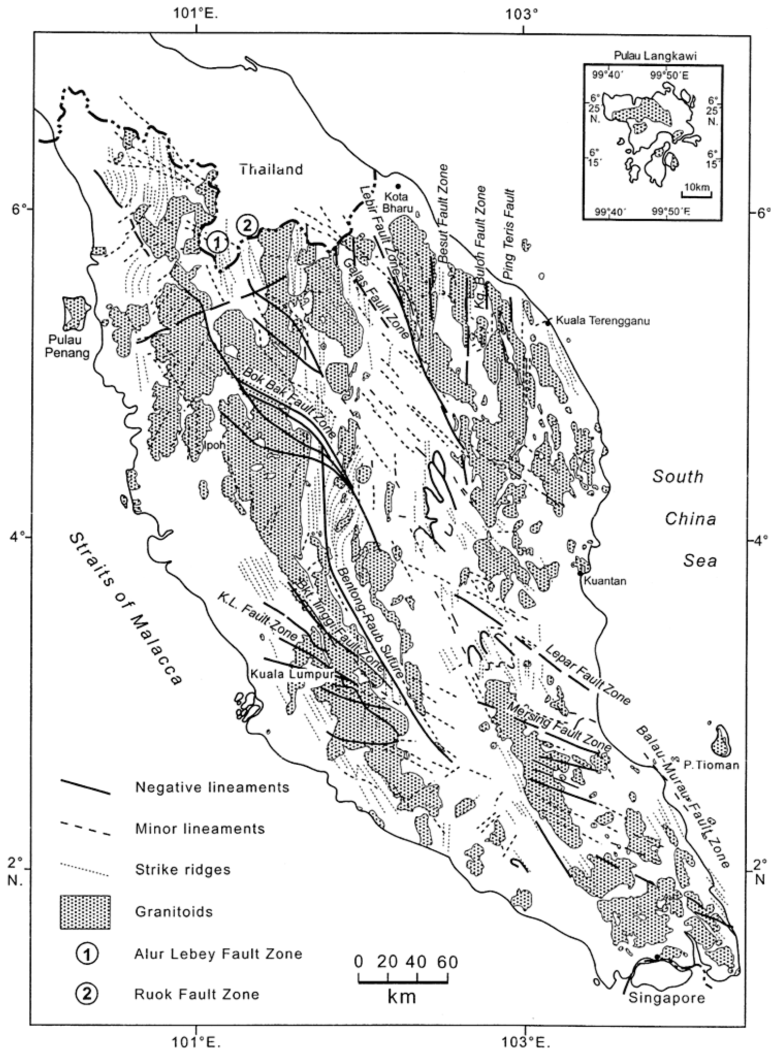

Figure 4.14: Structural zones of Peninsular Malaysia (Hutchinson & Tan, 2009)

Join and fractures were studied in order to find contribution of major fault system in the development of failure surfaces, and faults. Joint studies (Fig. 4.17) showed that the main faults and joints trends can be classified in four groups of N350˚, N60˚, N90˚, and N110˚, with 5, 25, 30, and 35 % of frequency respectively. Geological map (Fig. 4.8) and field observation demonstrated that N350˚ fault system has played a vital role in the development of fractures even though the maximum frequency of joint trend was appeared at N110˚. This maximum joint trend (N110˚) can be part of the Mersing Faulting Zone while main faults are representing effects of major faults which separated Central and Eastern Belts (Bentang-Raub).

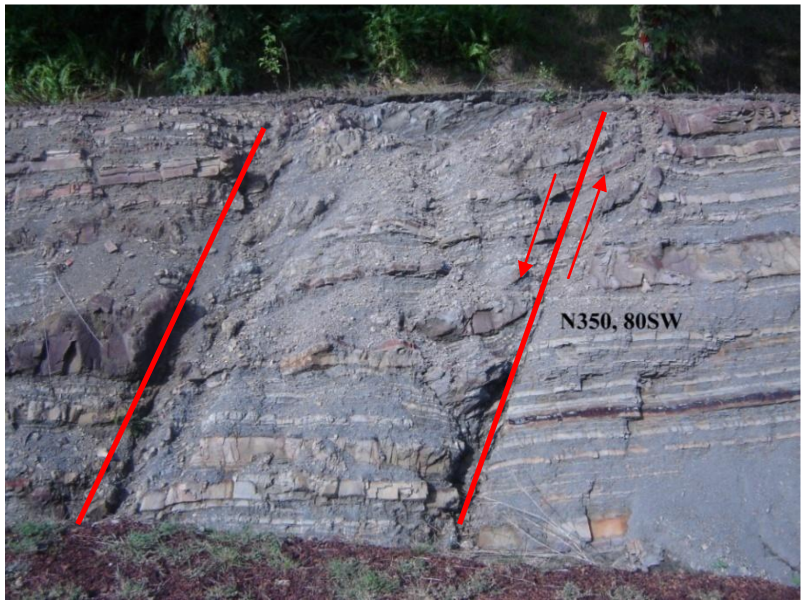

Figure 4-15: Major fault trends in catchment with 5% frequency

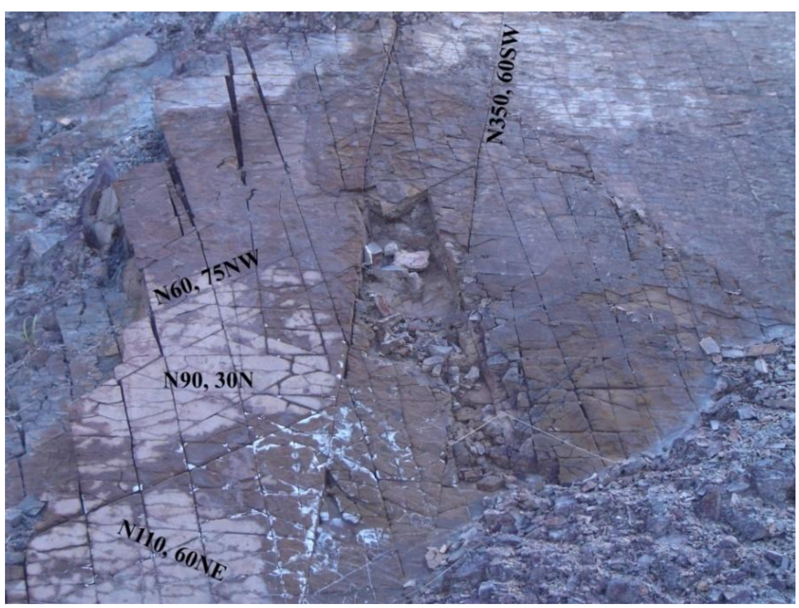

Figure 4.16: Joint system appeared in the Semantan Formation

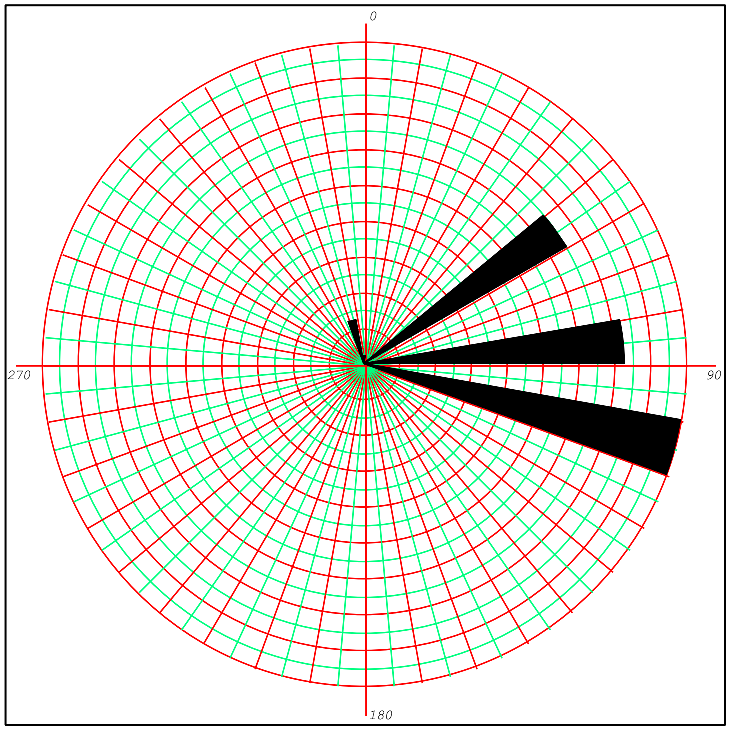

Figure 4.17: Rose diagram showing direction of joints and fractures in study area

4.3. Climatology

The climate of Peninsular Malaysia, can be distinguished by four seasons namely, the southwest monsoon, northeast monsoon and two shorter periods of inter-monsoon seasons. The southwest monsoon season is usually established in the latter half of May or early June and ends in September. The prevailing wind flow is generally southwesterly and light, below 15 knots (MMD, 2011).

The northeast monsoon season usually commences in early November and ends in March. During this season, steady easterly or northeasterly winds of 10 to 20 knots prevail. The winds over the Penang state may reach 30 knots or more during periods of strong surges of cold air (cold surges) from the north (MMD, 2011). During the two inter-monsoon seasons, the winds are generally light and variable. During these seasons, the equatorial trough lies over Malaysia. As Malaysia is mainly a maritime country, the effect of land and sea breezes on the general wind flow pattern is very marked especially during days with clear skies. On bright sunny afternoons, sea breezes of 10 to 15 knots very often develop and reach up to several tens of kilometers inland. On clear nights, the reverse process takes place and land breezes of weaker strength can also develop over the coastal areas (MMD, 2011).

The mean monthly relative humidity is between 70 to 90%, varying from place to place of study area and from month to month. The minimum range of mean relative humidity is varying from a low 80% in February to a high of only 88% in November. It is observed that in Peninsular Malaysia, the minimum relative humidity is normally found in the months of January and February. The maximum is however generally found in the month of November (MMD, 2011).

Mean annual temperature is approximately 30°C, varying from 25°C to 38°C (Chee & Peng, 1998). A number of occasions have been recorded on which the temperature did not rise above 24°C which is quite frequently the lowest temperature reached during the night in most areas. Night temperatures do not vary to the same extent, the average usually being between 21°C to 24°C. Individual values can fall much below this at nearly all stations, the coolest nights commonly followed some of the hottest days (MMD, 2011). Rainfall records from 1970 to 2009 at the Pos (Fort) Iskandar station, which is located at the mid-point of the BLC, show that minimum, and maximum, annual rainfall is in the range of 1,000, and 2,602, mm.

Available rainfall data of the eight nearest rainfall stations (Fort Iskandar, Triang, Gambir, Kemayan152, Buto CGA Mak, Kuala Bera86, Chenor 88, Bukit Imbam) were evaluated in order to find the most reliable and complete one. The nearest rainfall station to the Bera Lake is Triang station which has the most complete rainfall data particularly during the land development projects 1966-1996 (Fig. 4.18, and 4.19).

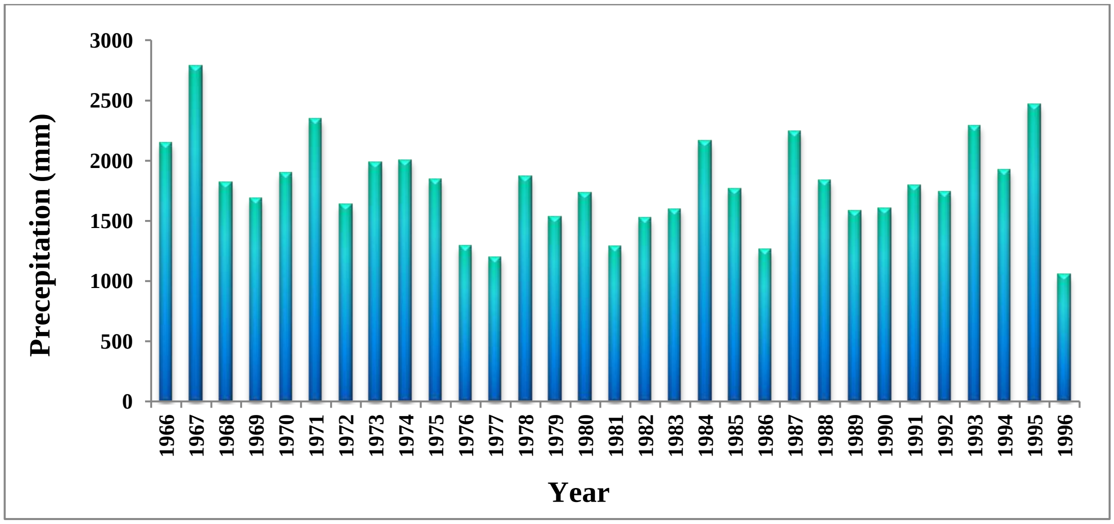

Figure 4.18: Annual precipitation of Triang station 1966-1996

The regulative effect of the forest canopy results in a lower evapotranspiration net water loss (Wüst & Bustin, 2004). Potential evapotranspiration of the Pahang state as estimated by Penman Method was 1515 mm y^{-1}, ranging from 1449 to 1509 mm (Nik, 1988). In addition, evapotranspiration rate in the study area is reported 4-4.5 mm per day (Nik, 1988).

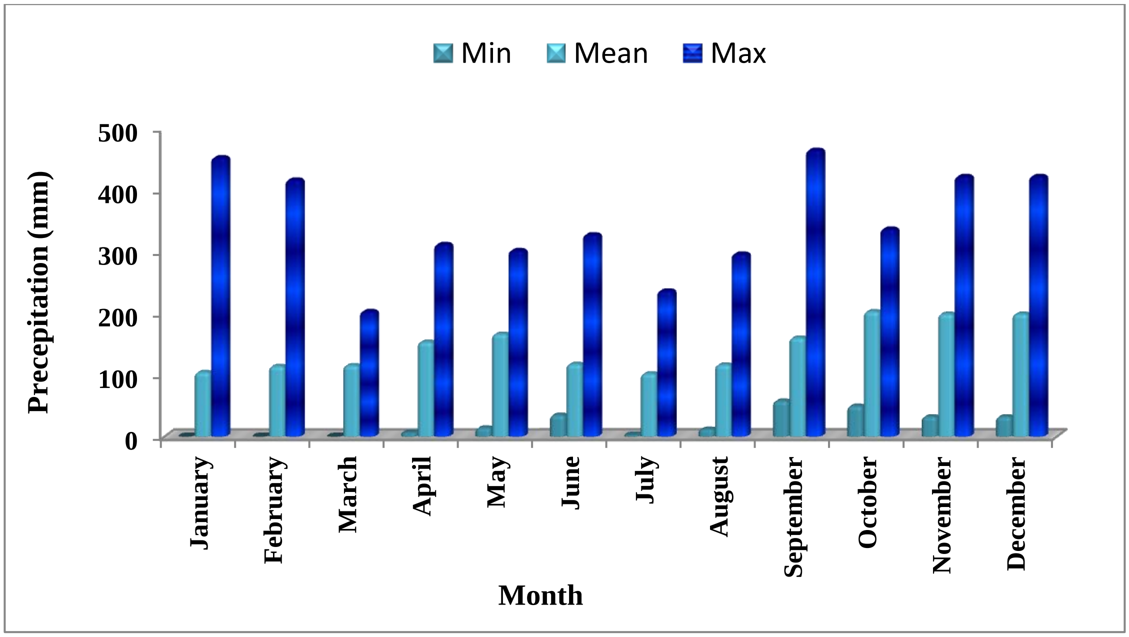

Figure 4.19: Long-term mean monthly rainfall between 1966 to1996 in Triang station

4.4. Land Use

Land use is an essential characteristic of each catchment which determines physical and chemical properties and rate of sediment delivery in empirical models and assigns rate of soil loss in radioisotopes conversion models. Investigate and updating of land use data was one of current research objectives.

The BLC is located in Pahang State, Malaysia which has experienced the most extensive land use change in the last four decades. FELDA was the main executive for land use change in Malaysia and has implemented 164 schemes in Pahang State which has 40% of all the land development in the country until 1990 (Henson, 1994). During five FELDA (MPOC, 2007) land development programmes from 1970 until 1995, some 292.86 km^2 of original forest was converted to oil palm and rubber plantations in the BLC area. FELDA land development districts maps were derived from the digital topographic maps of series L8028 (1:25,000 scale) which could be find in the Appendix 1. Bera Lake was designated under the Convention of Wetlands as the first RAMSAR site in Malaysia in November 1994 with the FELDA districts being known as Buffer Zone.

A new land use map of the BLC area has been developed using GIS, a satellite image (Spot5, 2009) of spatial resolution 10 m and an on-screen digitizing method. New land use map has remarkably revealed continues land use change and encroachment into the Bera Lake RAMSAR site. Between 1994 and 2009 the oil palm and rubber plantations and newly opened lands has been increased 47.14 km^2 and some 340 km^2 area has been established for forested lands (Fig. 4.20). Land use types and natural land covers is presented in Table 4.2. In this study, mature and immature oil palm plantations nominated developed and developing lands, respectively.

Table 4.2: Land use and natural land cover of BLC

Land use	Area (ha)
Dried Forest	17.93
Dried Pandanus	73.58
Dried Reed Swamp	132.12
Forest Swamp	4269.97
Reed Swamp	613.60
Pandanus	197.24
Lake	344.15
Developed Oil Palm/Rubber	23954.03
Developing Oil Palm/Rubber	8667.32
Cleared Lands	1406.35
Original Forest	19576.04
Residential	52.30

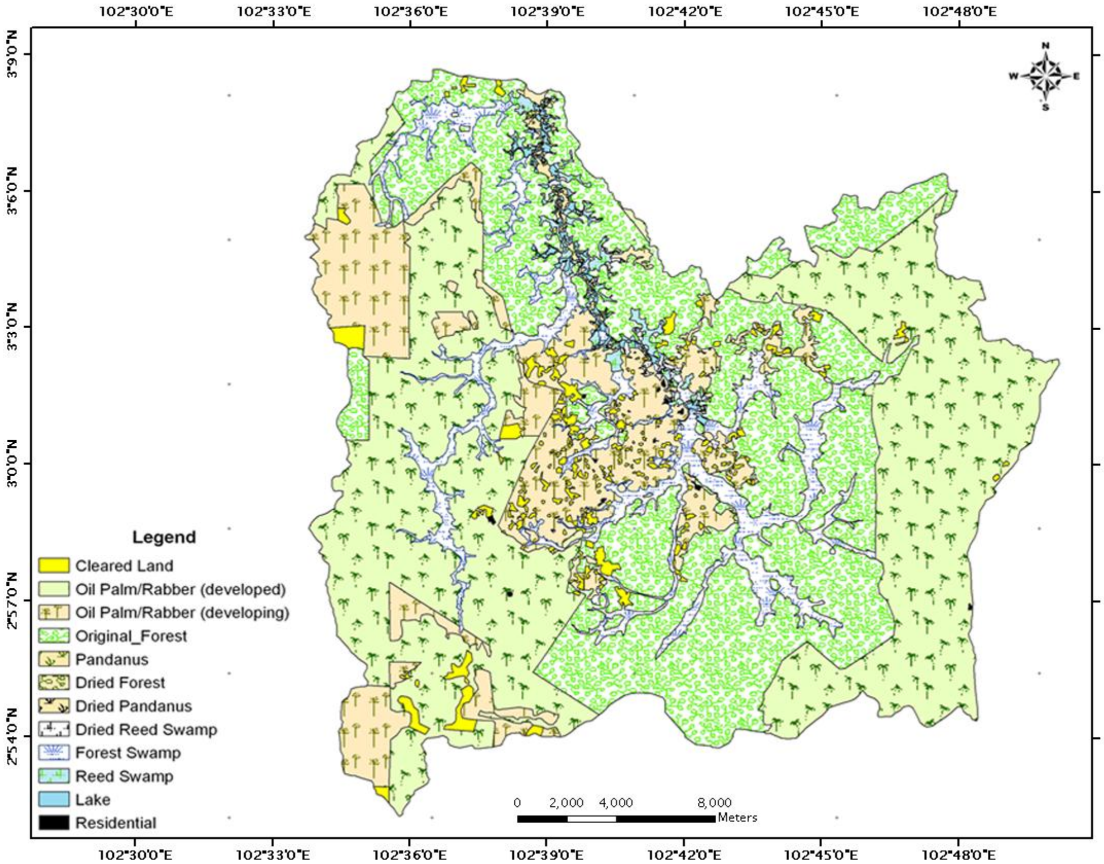

Figure 4.20: Land use map of BLC

4.5. Soil Type

The soil type of eastern BLC has been surveyed by Tharamarajan (1980). His study revealed 26 mapping units which have been implemented before FELDA land development projects which are not available. Several soil types and soil texture have been classified in BLC. Classified soil texture and soil map are presented in Table 4.3 and Figure 4.21, respectively. A significant correlation between the soil texture and land use was found at some sub-catchments. Similar soil texture classification in the adjacent land uses and sub-catchments resulted in a selective method in which similar soil texture districts were polygonized. Current soil texture (Fig. 4.21) indeed has been revealed the effects of land use change and conversion of original forests to oil palm and rubber plantations. The dominant soil texture in natural rainforest is Loamy to Silt loam which has changed to Sandy loam and Loamy sand after the development of oil palm plantations. Furthermore, substrate rocks have dictated soil texture in the northeast catchment where granite rocks are controlling distribution of sandy grain size particles and Loamy sand soil texture.

Field observations and laboratory analysis showed the soils of the BLC to be Ferralsols; the soils with brownish yellow, yellow and red colors, having developed on Permian, and Triassic sedimentary and igneous rocks. Post-Semantan Redbeds Formation has significantly dictated soil characteristics in terms of texture and color especially in the fourth sub-catchment. Ferrasols have been appeared with maximum, and average, thickness of 1, and 0.2 m, respectively. Organic-rich clays and peat are also found in the central part, and along the main channel, of Bera Lake.

Table 4.3: Soil particle size distribution at different land use areas

Sample ID	Land Use	Clay %	Silt %	Sand %	Classification
1	Oil Palm	3.58	30.74	65.68	Sandy loam
2	Oil Palm	7.15	34.94	57.91	Sandy loam
3	Oil Palm	7.27	48.34	44.40	Loam
4	Oil Palm	10.46	54.14	35.40	Silt loam
5	Oil Palm	4.84	24.19	70.97	Sandy loam
6	Oil Palm	6.31	43.09	50.60	Sandy loam
7	Oil Palm	3.14	20.04	76.82	Loamy sand
8	Oil Palm	3.34	30.67	65.99	Sandy loam
9	Oil Palm	3.46	26.08	70.45	Loamy sand
10	Oil Palm	5.11	28.47	66.42	Loamy sand
11	Oil Palm	7.36	60.08	32.56	Silt loam
12	Oil Palm	6.80	39.46	53.74	Sandy loam
13	Rubber farm	6.70	51.84	41.47	Silt loam
14	Oil Palm Developing	18.25	58.97	22.78	Silt loam
15	Oil Palm Developing	8.35	11.03	80.62	Loamy sand
16	Oil Palm Developing	7.56	47.31	45.13	Loam
17	Oil Palm Developing	7.10	48.07	44.83	Loam
18	Oil Palm Developing	8.03	48.39	43.58	Loam
19	Oil Palm Developing	7.60	46.61	45.79	Loam
20	Oil Palm Developing	5.04	32.53	62.44	Sandy loam
21	Oil Palm Developing	7.45	53.26	39.30	Silt loam
22	Cleared Land	11.05	40.88	48.07	Sandy loam
23	Cleared Land	11.67	60.46	27.87	Silt loam
24	Cleared Land	4.17	38.21	57.62	Sandy loam
25	Cleared Land	8.52	48.76	42.72	Loam
26	Cleared Land	6.03	43.82	50.15	Sandy loam
27	Reference	4.50	35.79	59.71	Sandy loam
28	Reference	6.44	45.88	47.69	Sandy loam
29	Reference	7.14	36.73	56.12	Sandy loam
30	Reference	8.04	52.55	39.41	Silt loam
31	Reference	4.12	29.42	66.46	Sandy loam
32	Reference	8.53	53.41	38.05	Silt loam
33	Reference	7.36	60.89	31.75	Silt loam
34	Reference	9.38	53.13	37.50	Silt loam
35	Reference	9.78	50.10	40.12	Silt loam

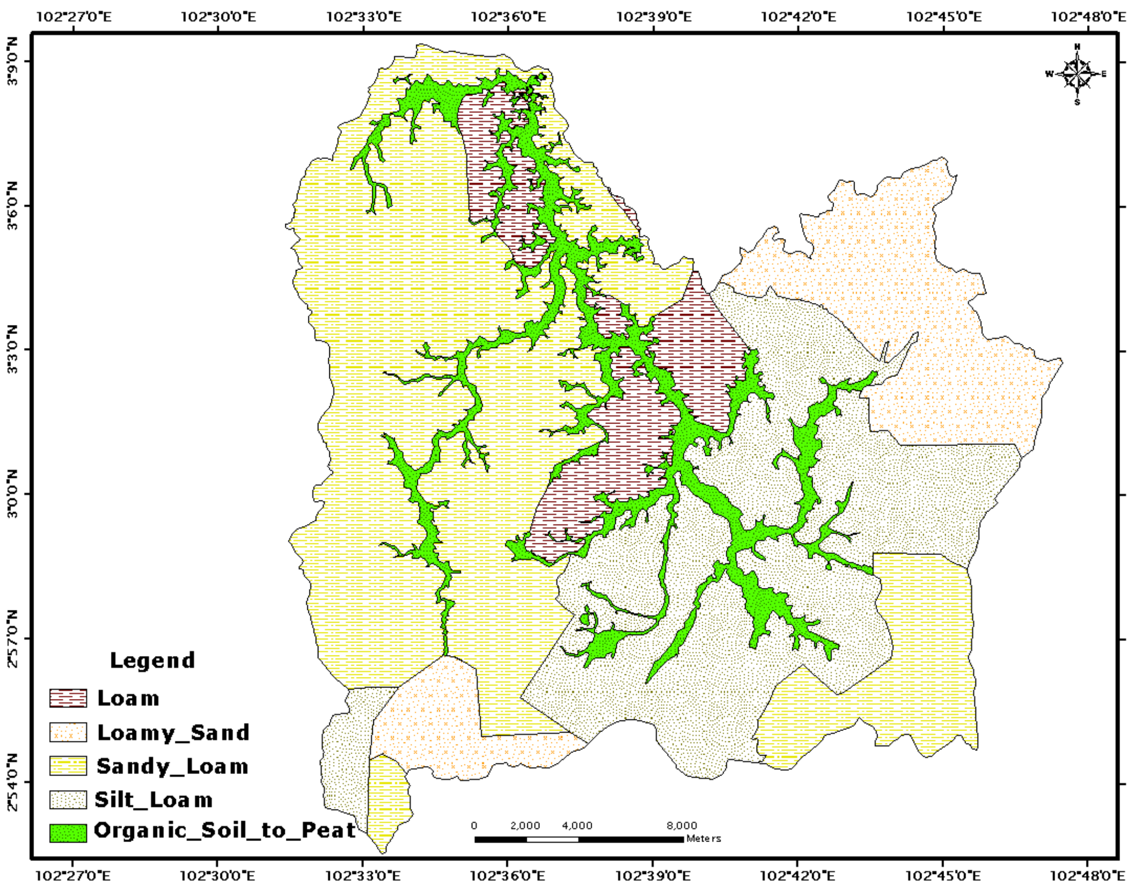

Figure 4.21: Soil texture classification at BLC

4.6. Hydrology

Lake hydrology is an essential knowledge for a proper sedimentary regime study. Hydrology of a lake can serve as wide range of data from current discharge into and from the lake, water level and balance, efficiency trap, flood retention, and determine agricultural water balance in the catchment area.

Drainage pattern in study area drains into Bera Lake at most northern part of catchment at the third sub-catchment. Bera Lake hydrology reveals remarkable data about historical sedimentary events of catchment area and provides reasonable data for interpreting sedimentation rate in Bera Lake. However, hydrology data is the shortage and significant gap of data in BLC. As already mentioned in the Section 3.2.4, water and sediment discharge to and from the Bera Lake were measured in the two wet seasons (February and April, 2010) and one dry season (October, 2009), and result are presented in the Figures 4.22, 4.23, and 4.24, respectively. The total water discharge and total TSS were calculated based on sub-sections discharges and suspended load concentrations. The total water discharge was multiplied to total TSS to calculate the sediment discharge from each section.

A moderate correlation between wet and dry seasons and water balance was revealed at Bera Lake. The mean contribution of the south and north inlets in terms of water supply were obtained 75.87, and 6.44%, respectively. Water discharge survey was pointed out as minor contribution of streams and channels in water and sediment supply in the October. Results also showed that hydraulic slope in Bera Lake still tend to drains water into the Bera River even in dry seasons.

It was proved that 95.7 % for Bera Lake sediment supply was contributed by the south inlet in February, 2010. The mean contribution of the south and north inlets in terms of sediment supply were 87.38, and 7.73%, respectively. Whenever the water contribution of north inlet decreased to 1%, its contribution to sediment supply has increased to 10%, Table 4.4.

There is a significant correlation between water volume from the south inlet of Bera Lake and residual sediment. Furthermore, 30-40% of sediment during wet seasons has been drained from Bera Lake to the Bera River. Capability of Bera Lake for sediment trapping can be increase up to 70% in wet season especially from the south inlet. Elongate shape and abundance of distributaries are among the other reasons for increase of sediment residual in Bera Lake. Conversely, sediment discharge from Bera Lake could be remarkably increased during dry season, when about 15% of residual sediments drain in the compensate lack of sediment supply from the south inlet.

Table 4.4: Contribution of water and sediment entry points in Bera Lake

Water gates	Water contribution (%)			Sediment contribution (%)			Water discharge (m^3/s)			Sediment discharge (g/s)		
	Feb	**Apr**	**Oct**	**Feb**	**Apr**	**Oct**	**Feb**	**Apr**	**Oct**	**Feb**	**Apr**	**Oct**
South inlet	71.6	94.2	61.8	95.7	91.4	74.94	3.83	6.24	11.78	77.82	31	65.41
North inlet	12.5	5.82	1	4.3	8.56	10.35	0.669	0.386	0.115	3.45	7.53	9.04
Others (wetlands)	15.9	------	37.33	------	------	14.7*	0.841	------	7.11	------	------	------
Residual	0	12.6	0	72.61	59.7	0	------	------	------	------	------	------
Outlet	------	------	------	------	------	------	5.34	5.8	19.05	22.26	13.67	87.28

*minus balance of sediment in Bera Lake

Water level fluctuation is another hydrology character of Bera Lake that has recently recorded by RAMSAR site directory staff (Fig. 4.25). Results show that the highest water level has been recorded during December 2007, October 2008, January 2009, and January 2010, 8.21, 8.29, 9.2, 8.25 m respectively. On the other hand, the lowest water levels have been recorded 6.3, 6.0, 5.0, 5.8 m in March 2007, 2008 July, 2009 August, and March 2010, respectively. The mean Bera Lake water levels were calculated to be 7.19, 7.6, 7.33, 6.87 m in 2007, 2008, 2009, and 2010, respectively. The annual mean water level fluctuation in Bera Lake has been 2.7 m since 2007.

Available data are reliable except for a short period of time which a huge flood event that has happened in the December, 2007, when water level has dramatically rose 11 meter and whole wetlands and open waters of catchment has been drowned. This significant event is not recorded in that available data and reports due to its intense destructive effects.

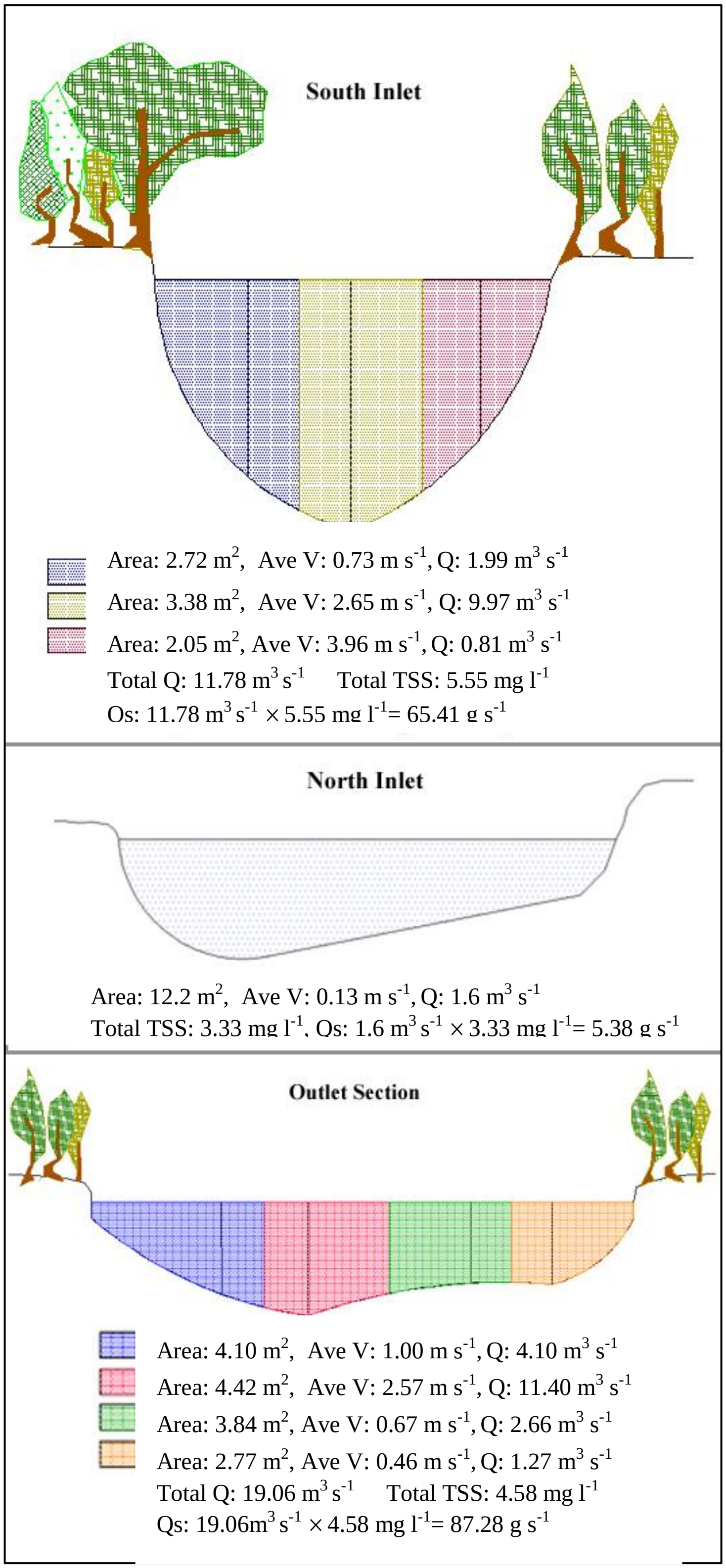

Figure 4.22: Water and sediment discharge into and from Bera Lake, October, 2009

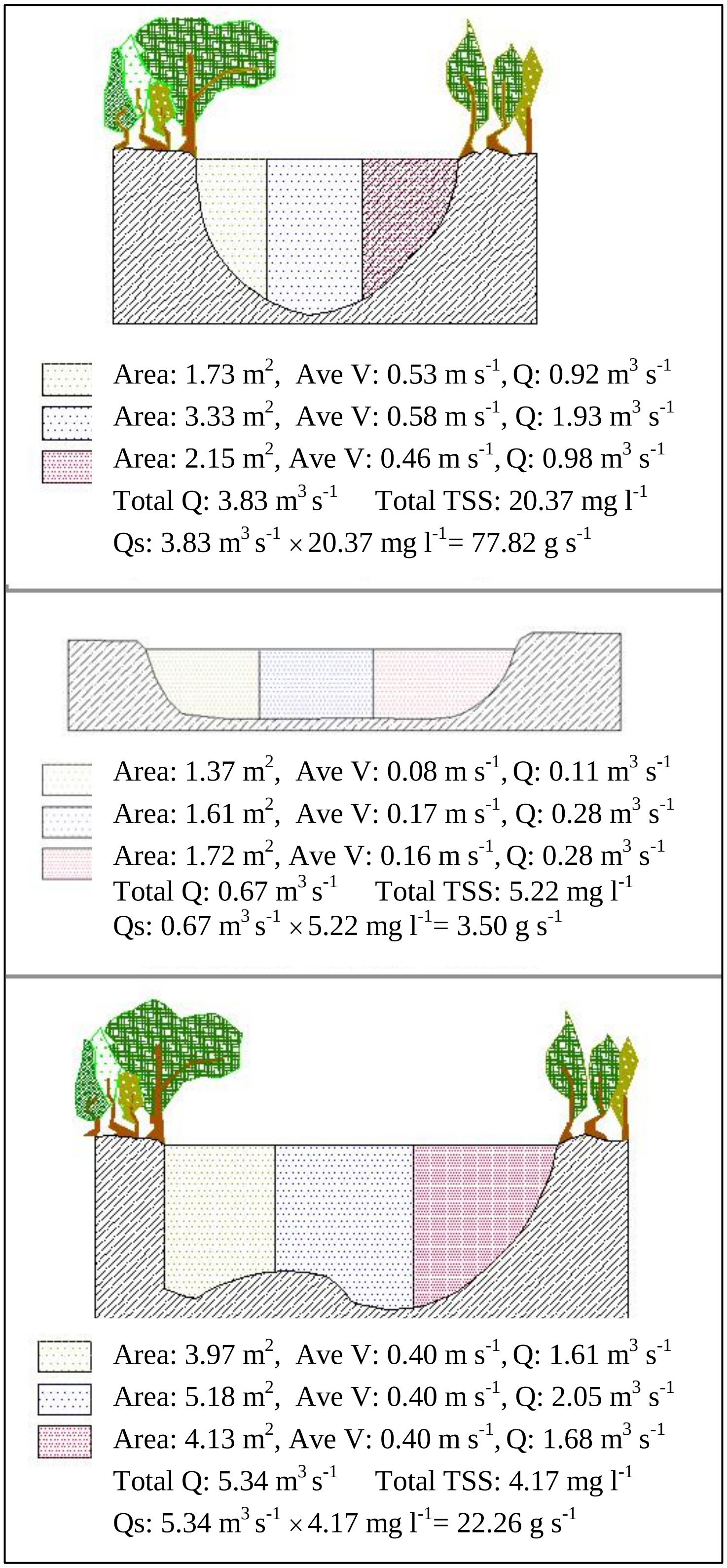

Figure 4.23: Water and sediment discharge into and from Bera Lake, February, 2010

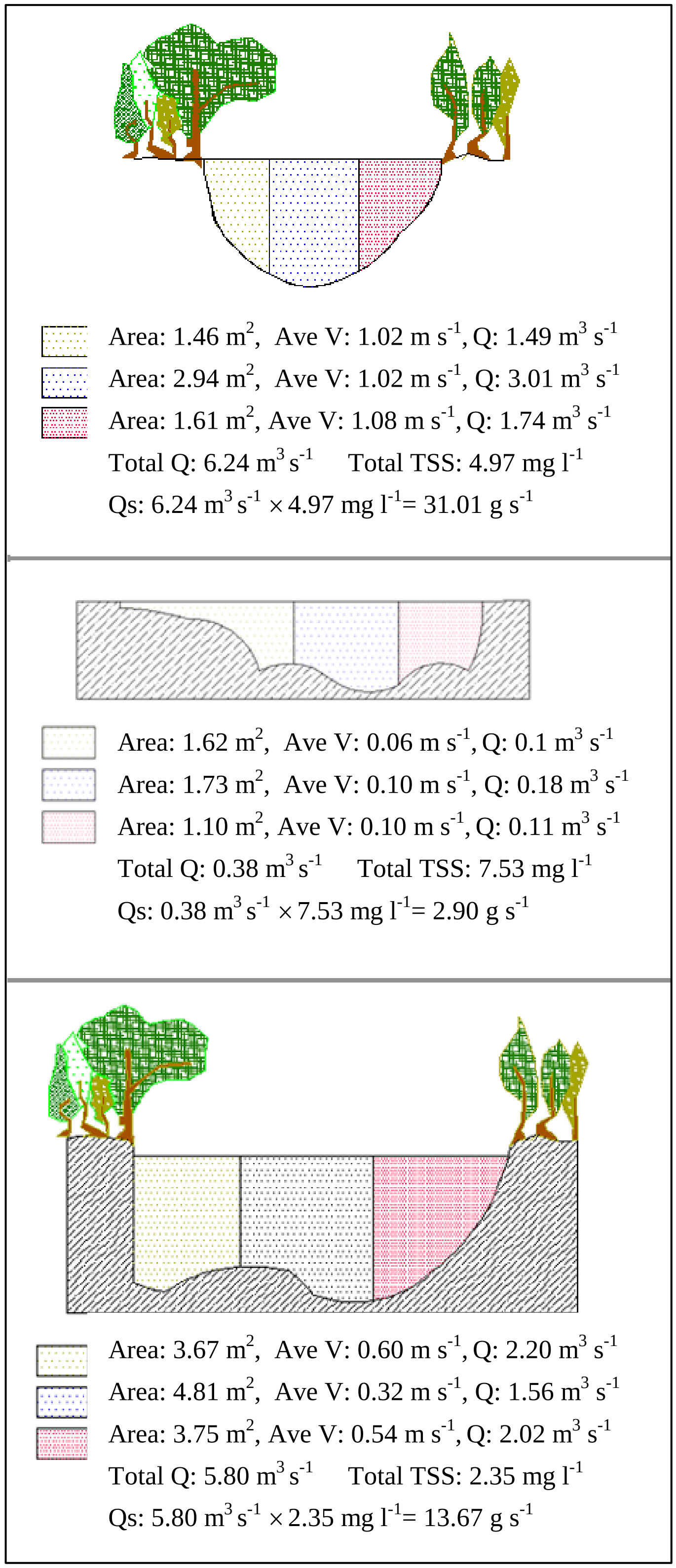

Figure 4.24: Water and sediment discharge into and from Bera Lake, April, 2010

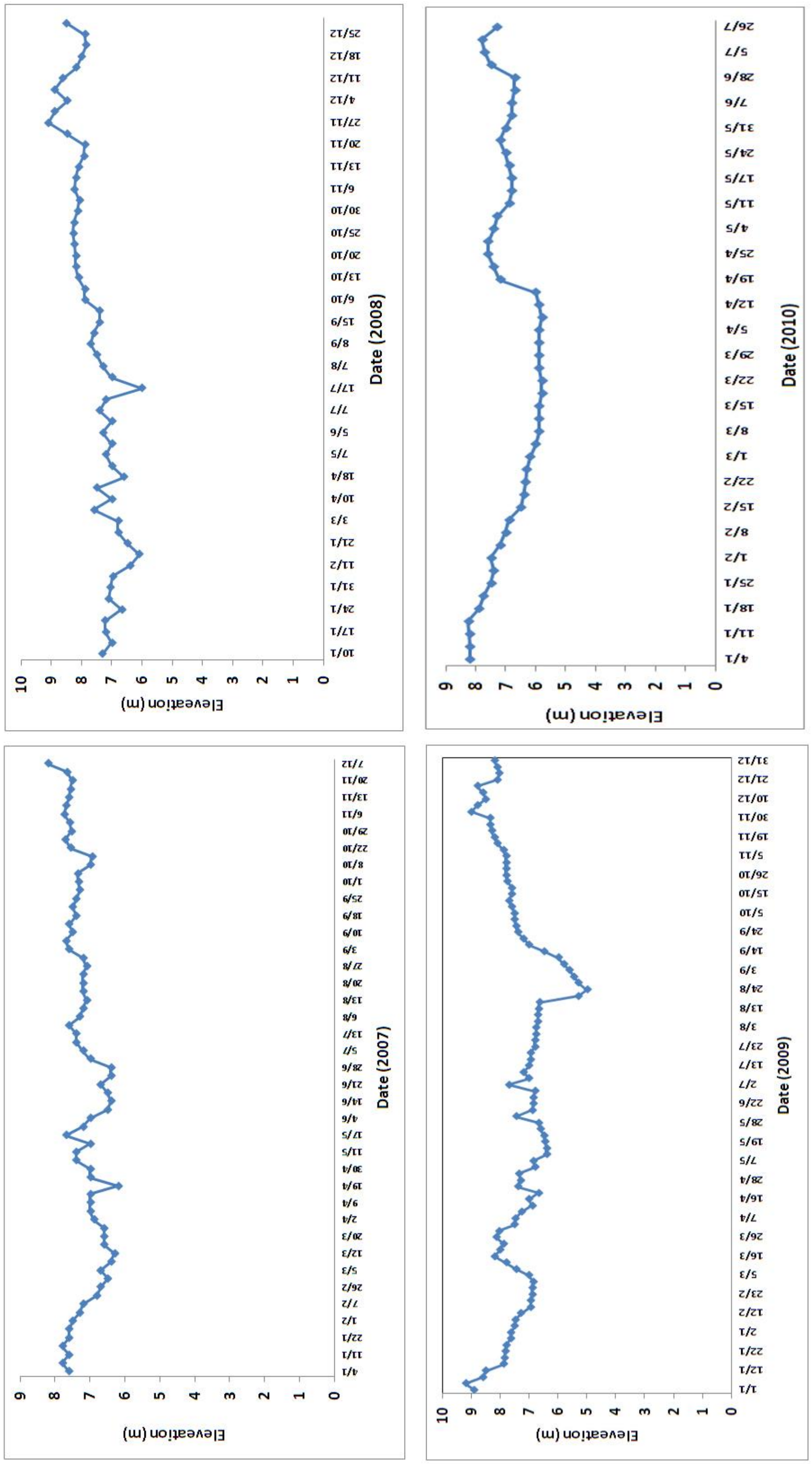

Figure 4.25: Bera Lake water level fluctuations since 2007

4.7. Bathymetry

Bathymetric map is an essential geo-spatial character of lakes and reservoirs which illustrates bed morphology and provides significant information about study area especially sampling site selection and sedimentary sub-basins. Bathymetric map is another geo-spatial data gap in Bera Lake although the AWB implemented multidisciplinary projects (DANCED, 1998) in order to complete geo-spatial data in study area. As already mentioned in section 3.4.1.4, bathymetric map of Bera Lake produced, is based on one thousand and three hundreds depth records which were taken in the February, 2010 by using Echosounder Model Garmin 400C.

Figure 4-26 depicts Bera Lake bed morphology, non-uniform bed surface and several troughs and obstacles especially at northern part of open water. Maximum depth was recorded 7 m at center middle of open water and along the main channel. Bera Lake bathymetric map (Fig. 4.27) appropriately showed sedimentary sub-basins in different parts of Bera Lake. Several distributaries represents shallow zone with depths of 0-1 m. Probably these branches are water storages with high capacity for wet seasons and have directly connected to wetlands, forest swamps, and reed swamps.

Bera Lake volume or storage capacity was calculated 2,995,998 m^3 (~3 km^3) according to equation (4-1) (Taube, 2000) in which sum of two sequential depth interval areas divided on 2 and multiply to depth difference between two surfaces (ΔE=1m).

$$V = \frac{1}{2} H (A_1 + A_2) \qquad (4\text{-}1)$$

Bera Lake trap efficiency was calculated based on Vörösmarty et al., (2003) equation (4-2, and 4-3).

$$\Delta\tau = \frac{V}{Q} \quad (4\text{-}2) \qquad TE = 1 - \frac{0.05}{\sqrt{\Delta\tau}} \quad (4\text{-}3)$$

where V is storage capacity (km^3) and Q is discharge at the mouth of basin ($km^3\ a^{-1}$) and $\Delta\tau$ is residence time of basin, and *TE* is trap efficiency. According to seasonal hydrological surveys, annual water and sediment discharge into the Bera Lake were calculated to be 24.2 ($km^3\ a^{-1}$) and 2042.58 (ton a^{-1}), respectively. Application of equations 4-2, and 4-3 residence time and trap efficiency of Bera Lake obtained were 0.124 (yr) and 86%, respectively.

Results show that Bera Lake is still capable to capture a large amount of sediments that are distributed into the basin. As a result, the annual sediment accumulation rate in Bera Lake could be 1756.6 tons. According to submerged density of the uppermost layer of Bera Lake sediment profile, annual accumulation rate could be 12,547.14 m^3. In conclusion, the relative sedimentation rate based on the 1,126,315 m^2 of Bera Lake area can be estimated 1.11 cm per year.

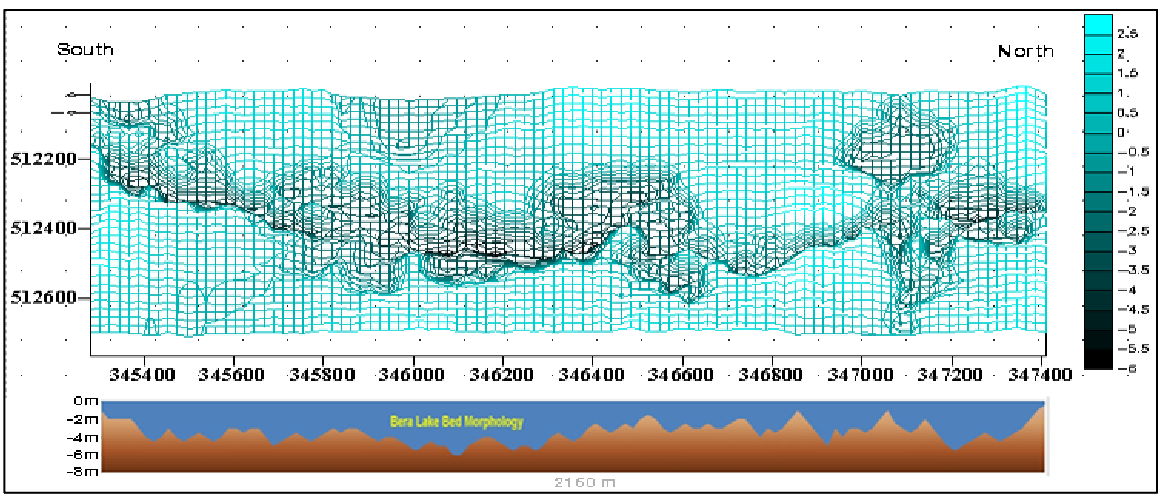

Figure 4.26: Bera Lake cross section and bed morphology

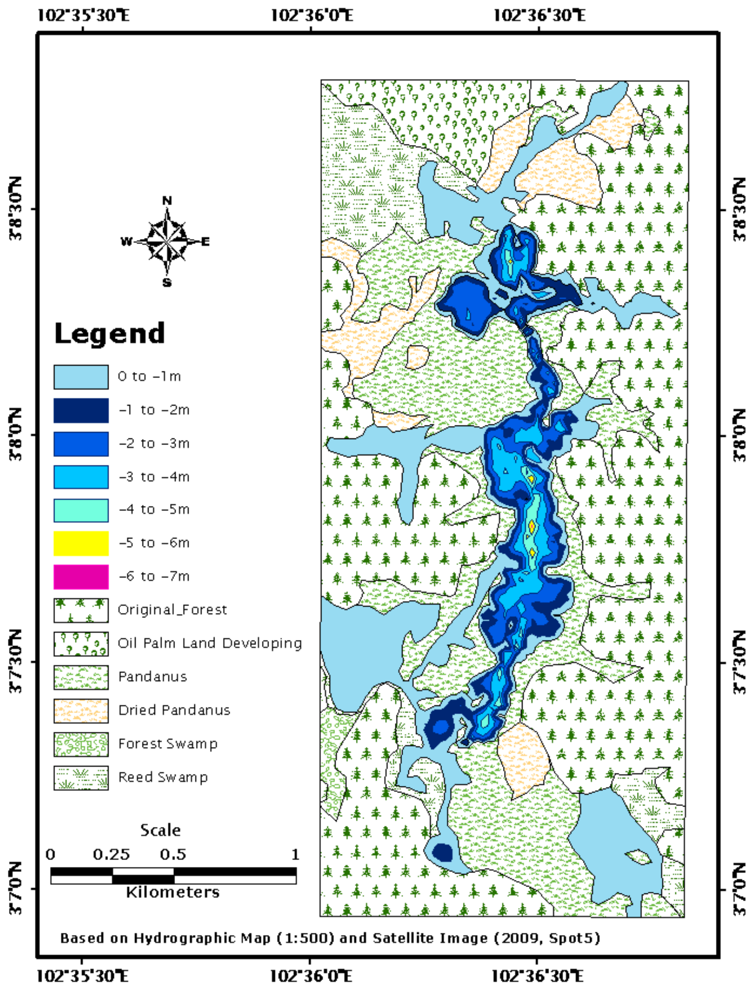

Figure 4.27: Bathymetric map of Bera Lake (accuracy1:500)

4.8. Water quality

Inland fresh water bodies play an important role in human, animals, and aquatic lives and has recognized as source of water for drinking and several activities like fishery, recreation, agriculture, industry, and navigation. Bera Lake is the largest natural fresh water reservoir in Malaysia and has vital environmental and ecological importance for human and wild lives. However, long-term water quality has not recorded in BLC. In addition, few records of water quality by RAMSAR site directory staff in the some cross sections along the Bera Lake are reported but not published.

The most reliable water quality data has published by Malaysian-Japanese committee prior to land development projects (IBP, 1972). This water quality analysis revealed that the area of open water adjacent to Pos Iskandar at the center of catchment is degraded. The brief available results presented in Tables, 4-5. According to IBP (1972) the mean TN, NO_3^{2-}, NO_2^{-1}, NH_4^{+1} and organic nitrogen have been 1.12, 0.11, 0.008, 0.33, and 0.58 mg l^{-1}, respectively. The mean PO_4 concentration was reported 0.021 (0.00-0.065). The ratio of reactive to un-reactive phosphorus has been 1/21 on the average.

Table 4.5: Water quality characters of Pos Iskandar open water, IBP, 1972

Depth (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ph	4.8	4.9	4.7	5.0	4.8	5.0	5.1	5.0	4.8	4.9	4.8	4.8
Transparency (m)	1.2	1.5	1.6	1.7	2.0	1.9	2.1	1.8	2.7	2.5	2.2	2.1
Do (mg/l)	1.1	1.3	1.5	1.3	1.7	2.0	2.4	2.7	2.3	2.3	2.3	1.7

A comprehensive water quality assessment was implemented in order to a comparison of current water quality situation with the prior land development projects condition. The mean value of water quality characters are presented in Table 4.5 and graphical distribution of some important parameters are illustrated in Figure 4.28 to 4.34.

Table 4.6: Bera Lake *in-situ* water quality sampling results

Station No.	Temp C	Sal ppt	TDS mg/l	Turb NTUs	pH Units	NH4+ mg/l-N	NO3- mg/l-N	Cl- mg/l	LDO% Sat	LDO mg/l	SpCond mS/cm
1	28.9	0.000	23.20	1000	5.13	0.40	0.38	2.90	29.2	2.25	36.23
2	29.1	0.000	23.18	1000	5.18	0.35	0.58	3.39	31.9	2.45	36.25
3	29.5	0.000	23.20	1000	5.29	0.28	0.68	3.55	33.8	2.58	36.23
4	28.7	0.000	22.97	1000	5.88	0.33	0.38	4.16	28.0	2.17	35.90
5	28.8	0.000	23.13	1000	5.41	0.28	0.55	4.00	30.4	2.34	36.03
6	28.8	0.000	23.10	1000	5.37	0.27	0.69	3.77	29.7	2.29	36.03
7	28.8	0.000	23.07	1000	5.32	0.28	0.74	3.32	28.2	2.17	36.03
8	29.3	0.003	23.73	1000	5.39	0.31	0.78	3.12	36.1	2.77	37.17
9	29.0	0.000	23.57	1000	5.34	0.30	0.81	3.08	22.2	1.71	36.83
10	29.1	0.000	23.27	1000	5.39	0.29	0.78	3.13	28.9	2.22	36.33
11	28.9	0.003	23.63	1000	5.48	0.27	1.12	3.46	28.4	2.18	36.93
12	29.1	0.007	29.67	667	5.54	0.41	1.58	3.92	24.4	1.87	36.70
13	29.0	0.000	23.03	1000	5.44	0.26	1.29	3.43	34.5	2.65	35.93
14	28.9	0.000	23.30	1000	5.44	0.23	1.63	3.74	28.8	2.21	36.48
15	28.9	0.000	23.10	1000	5.48	0.23	1.39	3.90	34.6	2.65	36.03
16	28.9	0.000	23.03	1000	5.42	0.23	1.42	3.73	32.6	2.51	35.97
17	28.9	0.000	23.03	1000	5.36	0.23	1.59	3.49	31.0	2.38	36.10
18	28.8	0.000	23.03	1000	5.37	0.24	1.48	3.58	31.9	2.46	36.00
19	29.0	0.000	23.00	1000	5.31	0.24	1.49	3.32	33.8	2.60	35.97
20	29.0	0.000	23.23	1000	5.34	0.25	1.63	3.26	34.3	2.64	36.47
21	28.6	0.000	23.17	1000	5.38	0.25	1.71	3.15	27.0	2.08	36.17
22	28.9	0.000	23.10	1000	5.38	0.22	1.57	3.79	28.3	2.18	36.10
23	28.9	0.000	23.07	1000	5.32	0.23	1.58	3.29	31.5	2.43	36.00
24	28.9	0.000	22.97	1000	5.42	0.21	2.01	4.43	32.5	2.50	35.93
25	28.9	0.000	23.08	1000	5.43	0.22	1.78	3.76	32.8	2.53	36.08
26	28.9	0.000	23.07	1000	5.37	0.23	1.63	3.60	32.6	2.51	36.03
27	28.8	0.000	22.93	1000	5.35	0.24	1.40	3.11	28.3	2.18	35.80
28	28.8	0.000	23.33	1000	5.39	0.25	1.68	3.28	23.7	1.83	35.87
29	29.0	0.003	24.73	1000	5.40	0.29	1.82	3.58	29.1	2.23	38.70
30	29.0	0.000	23.07	1000	5.34	0.23	1.72	3.52	29.3	2.25	35.97
31	28.9	0.000	23.03	1000	5.45	0.22	1.64	3.56	32.0	2.47	36.03
32	26.6	0.007	26.17	1000	5.66	0.31	1.45	2.88	25.9	2.07	52.30
33	27.1	0.000	23.80	1000	5.47	0.34	1.19	2.47	31.6	2.50	37.15
34	28.9	0.000	23.03	1000	5.58	0.23	1.46	3.46	36.8	2.84	35.97
35	29.0	0.000	23.10	1000	5.42	0.19	1.99	3.88	31.4	2.42	36.10
36	29.0	0.000	22.93	1000	5.32	0.26	1.65	3.00	32.4	2.49	35.87
37	28.8	0.003	24.73	1000	5.42	0.24	2.27	4.07	27.8	2.14	38.33
38	29.0	0.000	22.90	1000	5.37	0.26	1.79	3.30	34.0	2.61	35.87
39	28.8	0.003	25.63	1000	5.43	0.24	2.61	3.43	26.5	2.04	39.43
40	29.1	0.000	22.87	1000	5.38	0.25	2.00	3.00	36.4	2.80	35.93
41	29.0	0.000	23.10	1000	5.37	0.25	1.91	3.04	27.7	2.13	36.13
42	29.1	0.000	23.10	1000	5.34	0.26	1.57	2.74	34.5	2.64	36.10
43	28.9	0.000	23.13	1000	5.36	0.25	1.63	3.11	29.0	2.23	36.17
44	29.0	0.000	23.07	1000	5.39	0.24	1.89	3.29	34.0	2.61	36.00
45	29.1	0.000	23.10	1000	5.33	0.26	1.65	2.60	32.9	2.53	36.10
46	29.0	0.000	23.17	1000	5.33	0.26	1.53	2.75	27.9	2.15	36.17
47	28.9	0.000	23.17	1000	5.27	0.25	1.67	2.85	28.9	2.22	36.23
48	29.4	0.000	23.02	1000	5.33	0.23	1.93	3.07	37.7	2.88	35.92
49	29.4	0.003	24.47	1000	5.47	0.26	2.13	3.32	29.5	2.24	38.23
50	29.3	0.000	23.20	1000	5.40	0.32	2.07	2.74	35.2	2.69	36.23
51	29.2	0.000	23.10	1000	5.31	0.25	1.88	2.93	35.1	2.69	36.10

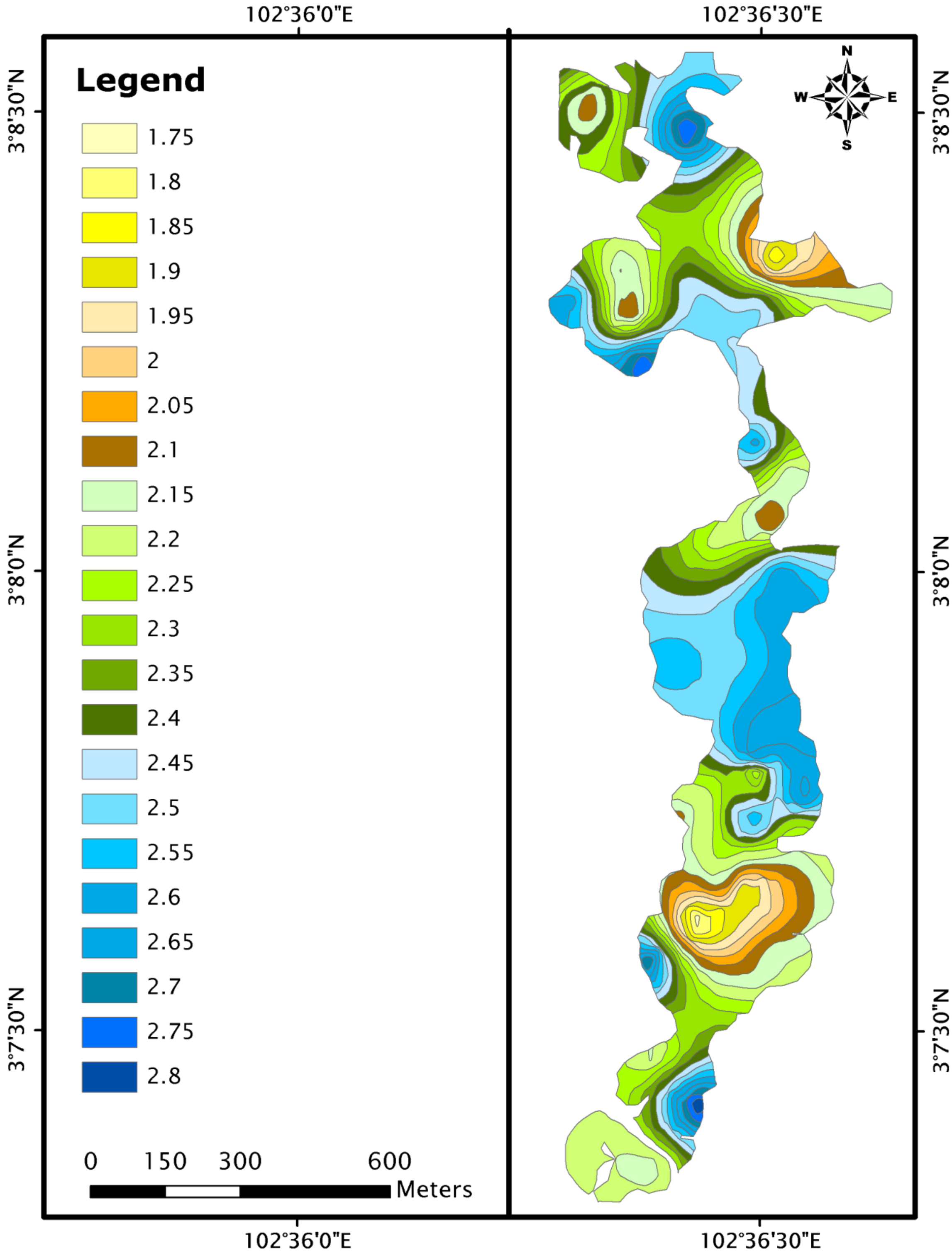

Figure 4.28: Distribution of DO (mg l^{-1}) in Bera Lake, February, 2011

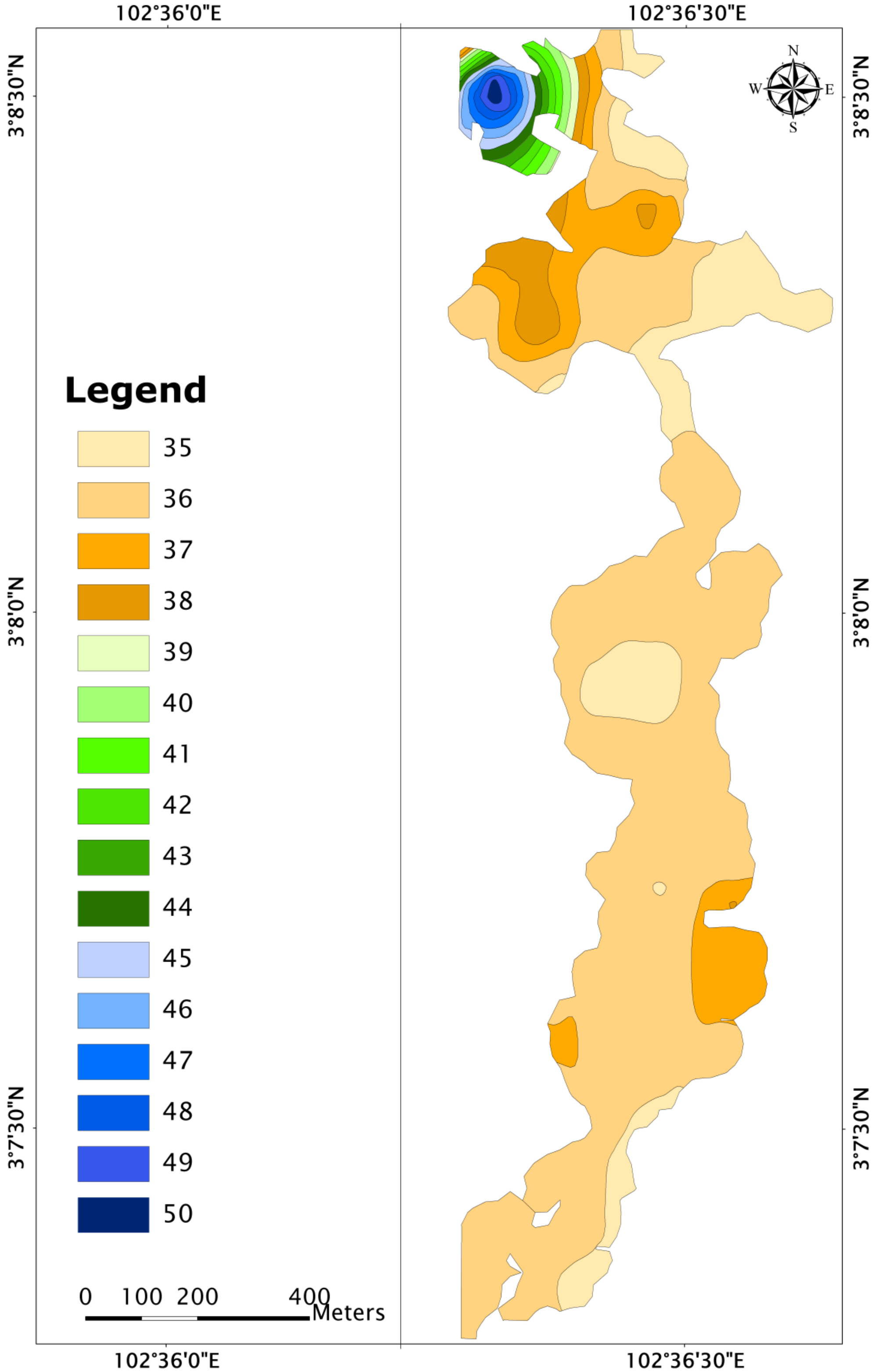

Figure 4-29: Distribution of EC (mS cm^{-1}) in Bera Lake, February, 2011

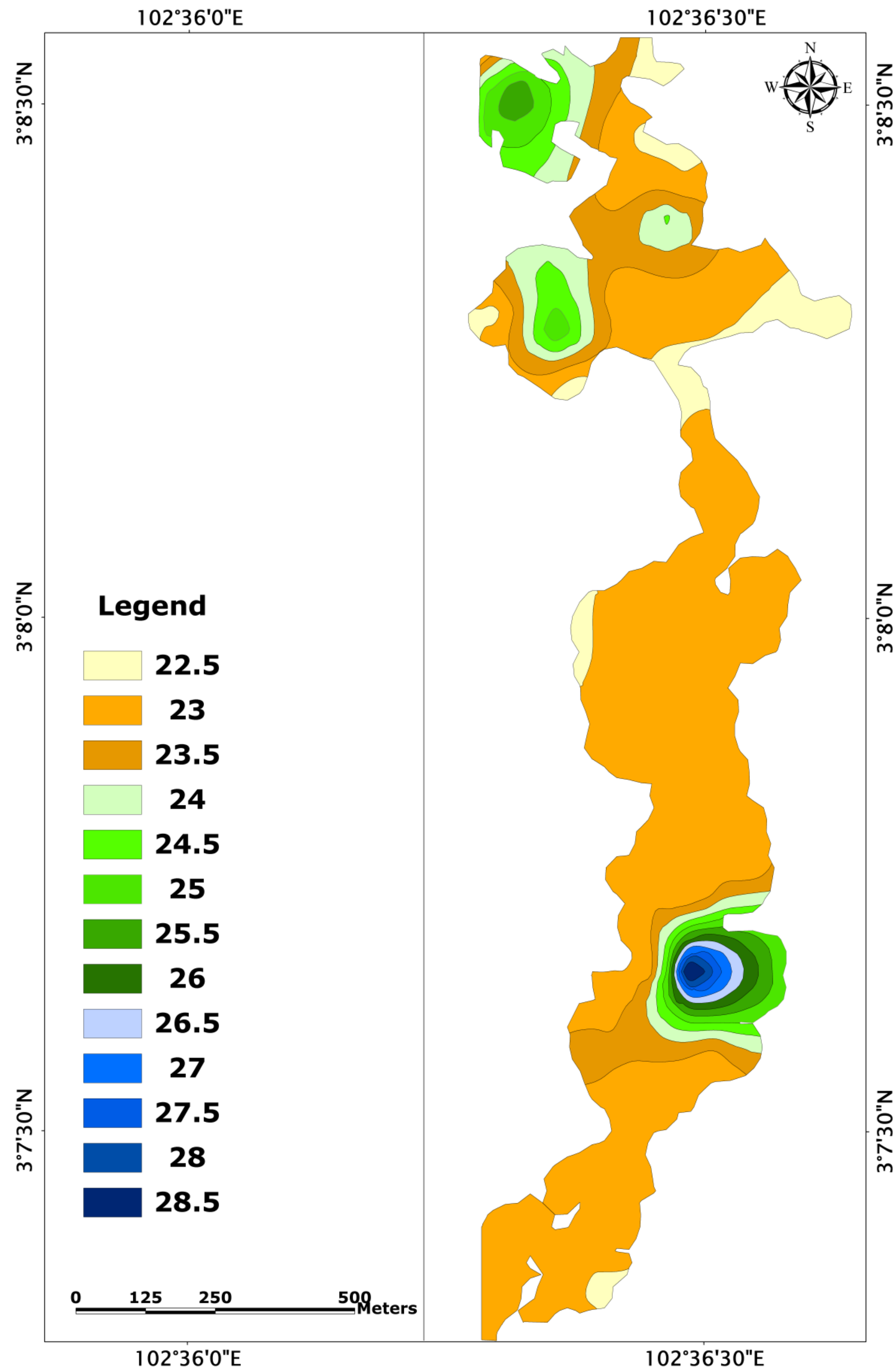

Figure 4.30: Distribution of TDS (mg l^{-1}) in Bera Lake, February, 2011

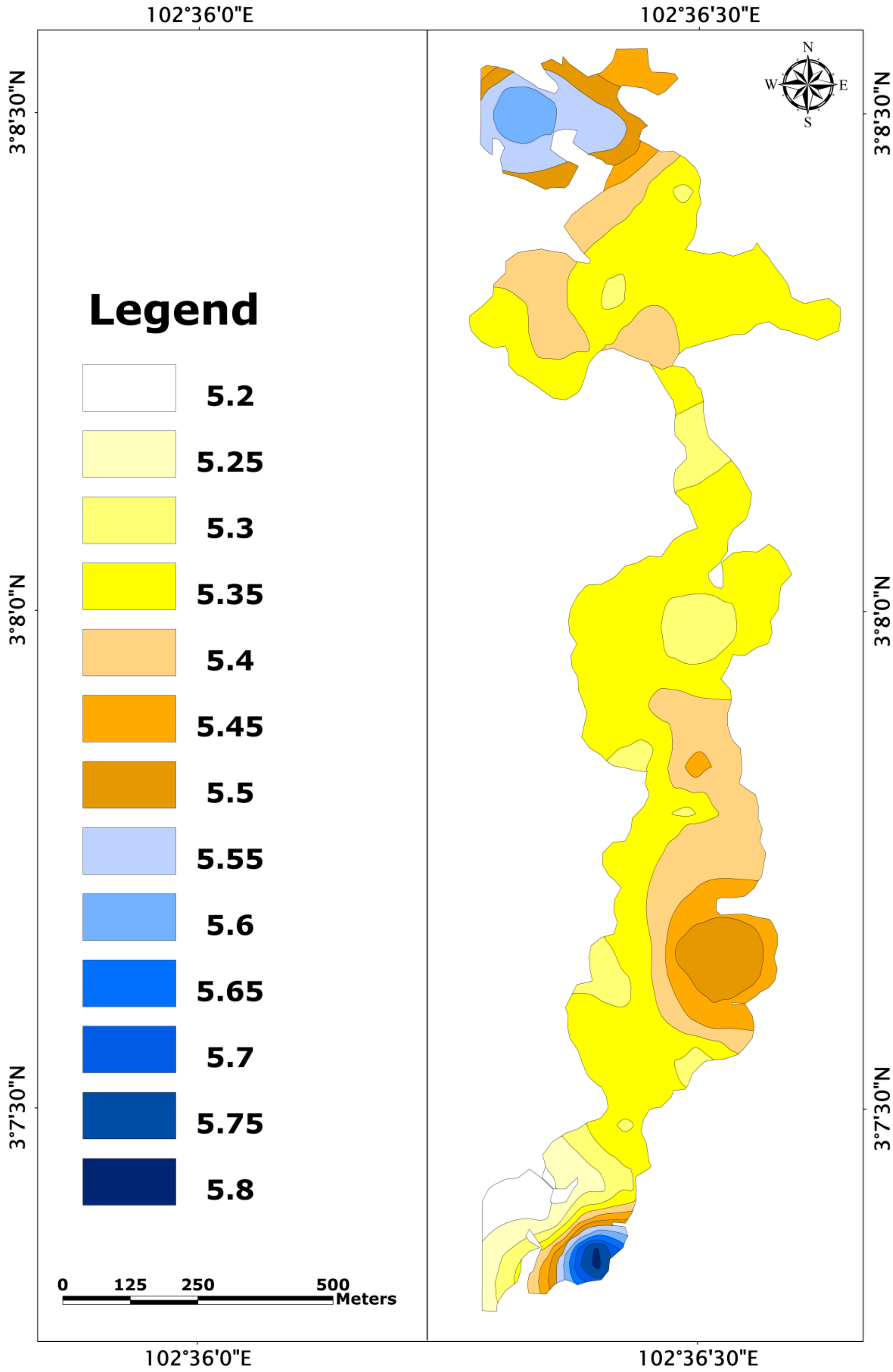

Figure 4.31: Distribution of acidity (pH) in Bera Lake, February, 2011

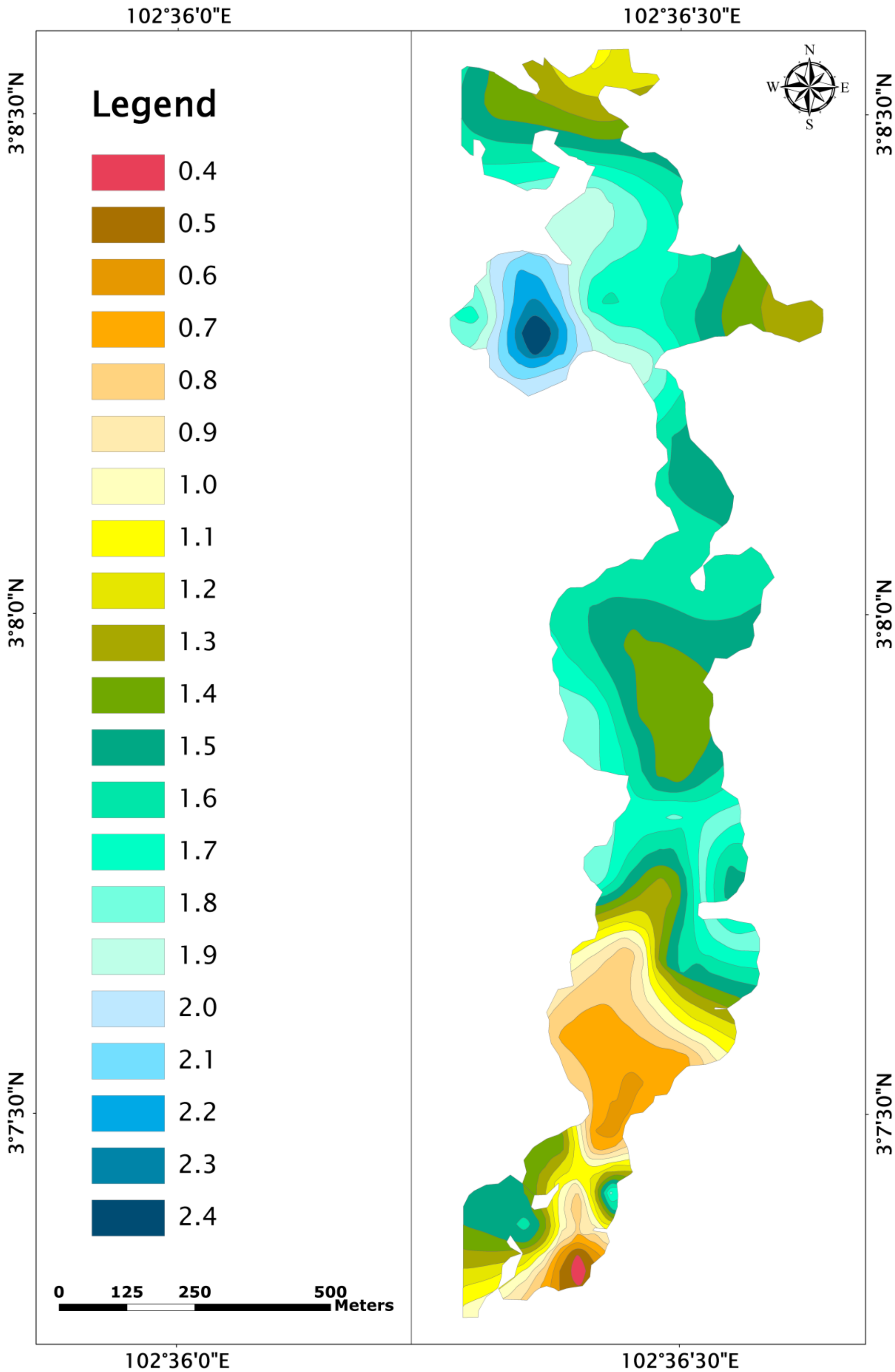

Figure 4.32: Distribution of NO_3^{2-} (mg l^{-1}) in Bera Lake, February, 2011

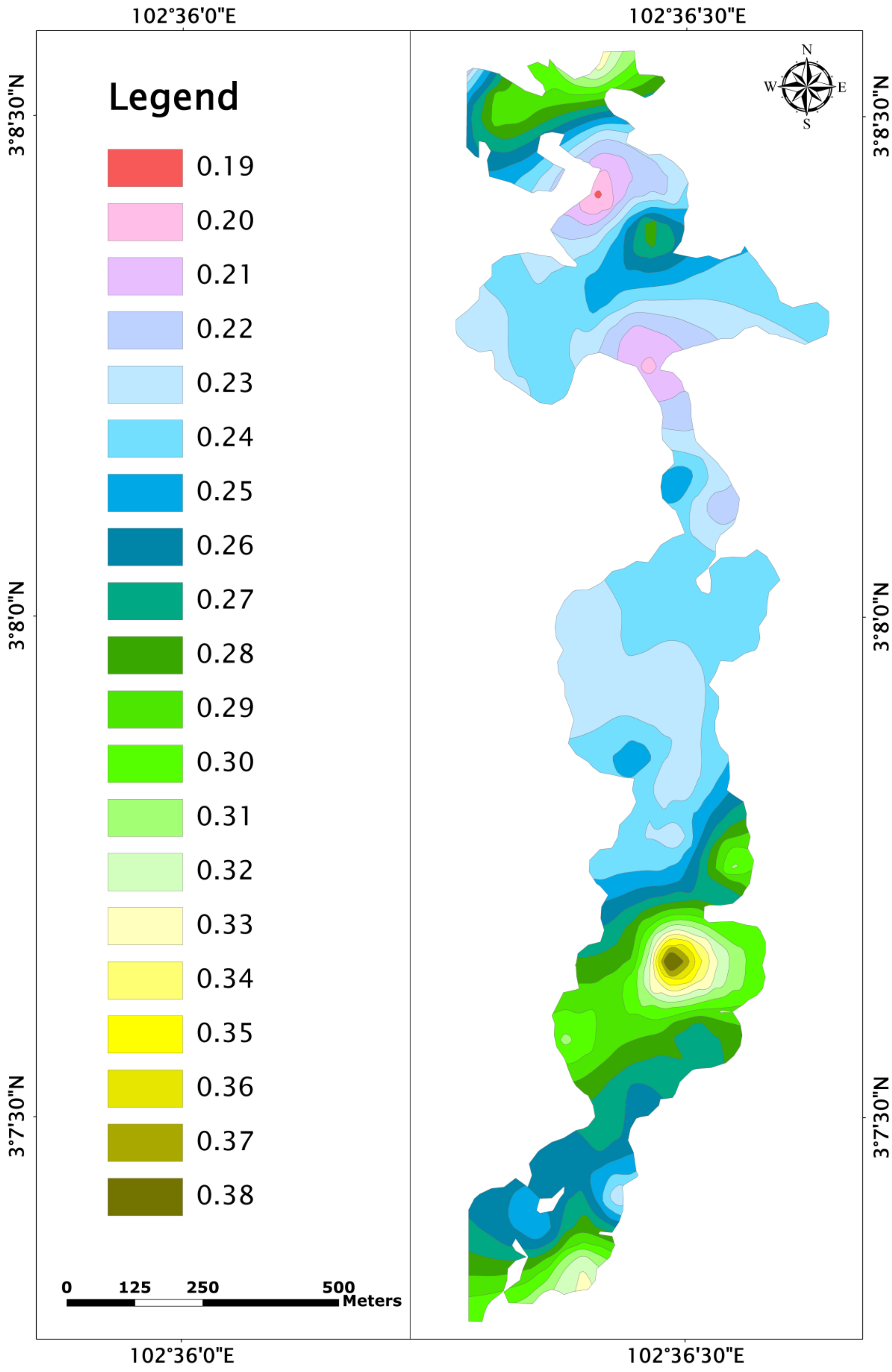

Figure 4.33: Distribution of ammonium (mg l^{-1}) in Bera Lake, February, 2011

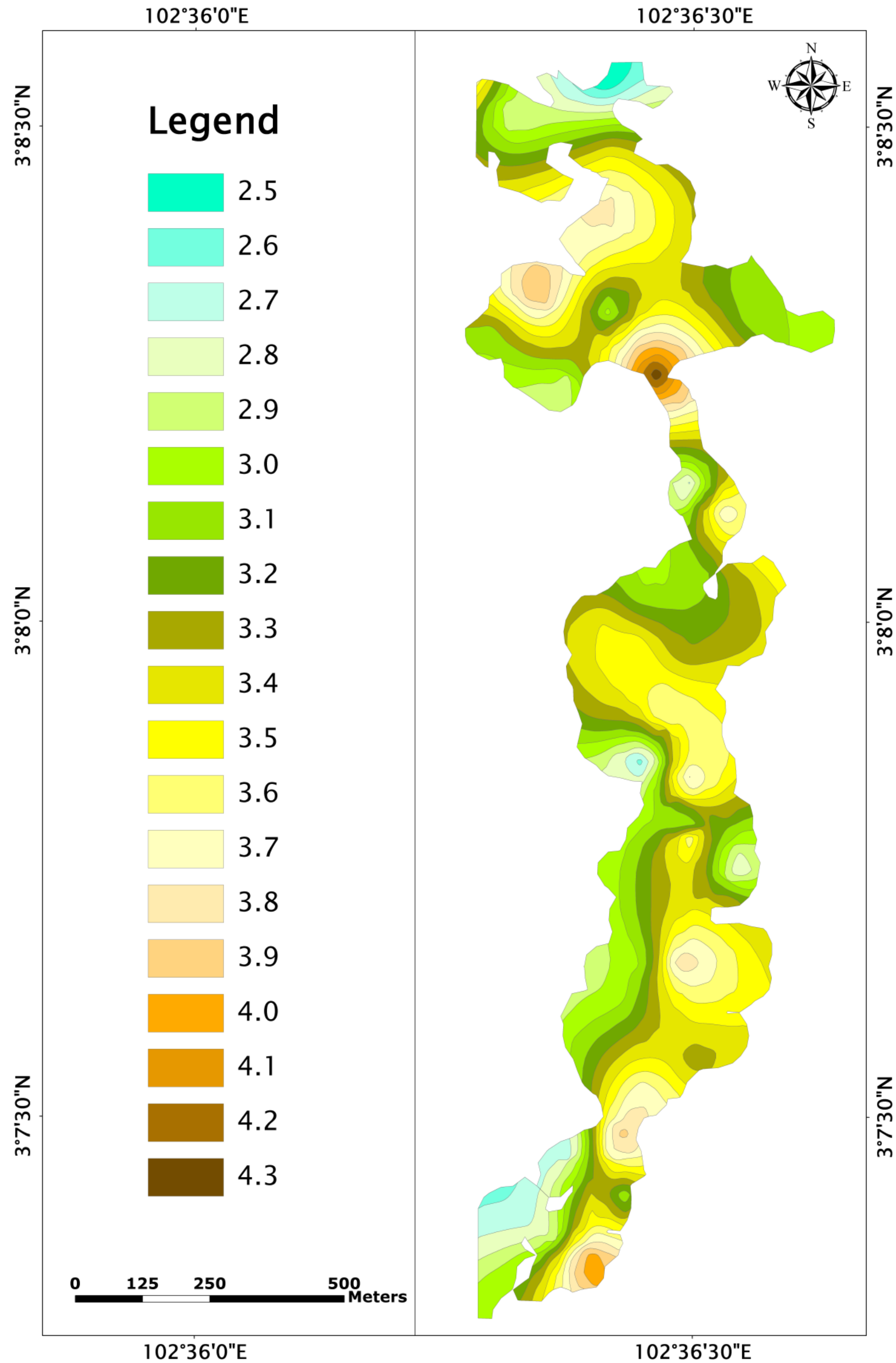

Figure 4.34: Distribution of chloride (mg l^{-1}) in Bera Lake, February, 2011

National Water Quality Standards for Malaysia (NWQS) (DOE, 2006) and Water Quality Index (Brian, 2010) were used to evaluate Bera Lake water quality (Table 4.6). Overall classification of Bera Lake water quality before and after land development project is classified IV and V which is suitable for irrigation only and requires extensive treatment for drinking.

Table 4.6: Bera Lake water quality based on NWQS and WQI guidelines

Sampling	Parameter								WQI	
	Salinity	**TDS**	**pH**	**No_3^-**	**Cl^-**	**DO**	**EC**	**Turbidity**	**Brain 2010**	**DOE 2006**
IBP1972	------	------	III	V	------	IV	-----	II	39	41
Current Study	I	I	IV	V	I	IV	III	IIA	Very Bad	Polluted

Water temperature is significantly affects all kinds of aquatic life, regulates the DO in water, and influences the rate of chemical and biological reactions. Seasonal water temperature dictates organism age and life stage and higher biological and chemical reactions expect in the higher water temperature (Brian, 2010). *In-situ* water analyzes showed that Bera Lake mean water temperature is similar to mean temperature at various sites in Malaysia and the mean annual Bera Lake water temperature is excepts to vary less than 5˚C. In other word, annual Bera Lake chemical and biological reactions happening in limited variation and seasonal water quality represents minor differences.

Vertical water quality analysis revealed a clear stratification in Bera Lake water profile in terms of temperature, DO, Cl^{1-}, NO_3^{2-}, pH, and EC parameters. Clear downward reduction of DO profile indicates the effects of temperature. Maximum coefficient of variation of 0.5 was obtained for vertical variation of DO. Dissolved oxygen concentrations vary remarkably (Fig. 4.28) as well as its variation with depth. The lowest DO values were recorded at the south and northeast open waters which probably have a weak water circulation and partially restricted by some plant species such as *Pandanus*. These areas were recognized as the worst locations for biological activities. The mean Do value was 2.38 mg l^{-1} which is low and can adversely affect the functioning and survival of biological communities. The microbial activity (respiration) enhanced during the degradation of the organic and nutrients rich waste water, resulted in DO values reduction (Chapman, 1996).

Figures 4.29 and 4.30 depict that Bera Lake water is moderately homogenous in terms of electrical conductivity and total dissolved solids except at the northwest part or Kelantong water entry point. A significant correlation between TDS and EC values was observed in Bera Lake. The minimum variations in EC and TDS values were recorded in the vertical water profile. Dramatic increment in EC and TDS should indication polluted water (Chapman, 1996). In addition, semi-closed water bodies and reed swamp at the northwest of Bera Lake represent high evaporation and increase of total dissolved solids as well as electrical conductivity.

The acidity of water depends on weak acids such as carbonic, humic and fulvic, and hydrolyzing salts of metals (e.g. iron, aluminum), as well as strong acids. Bera Lake represents acidic condition with mean average pH of 5.39. In such condition bottom-dwelling decomposing bacteria begin to die off and leaf litter and dead plant and animal materials begin to deposition. With regards to heavy metals, the degrees to which they are soluble usually determine their toxicity. The lower the pH, the more toxic the metal as they are more soluble then. Solubility refers to the amount that can be dissolved in water (Chapman, 1996).

A minor depth-wise increase in water acidity with CV of 0.02 observed at Bera Lake. The distribution of acidity in Bera Lake is uniform except at the southern and northern part and at sediment entry points while slightly increased at the eastern of the south of basin (Fig. 4.31). A clear correlation between pH and EC was obtained at the south of Bera Lake, which indicate an effluent plum or discharge into the open water. Similar to DO, increase of acidity at surface water must be controlled by higher temperature and photosynthesis.

Another important water quality parameter is NO_3^- which is the common form of combined nitrogen found in natural waters. Natural sources of NO_3^- to surface waters include igneous rocks, plant and animal waste debris. In lakes, concentrations of NO_3^- in excess of 0.2 mg l^{-1} NO_3^- tend to stimulate algal growth and possible eutrophic conditions (Chapman, 1996).

The mean average of NO_3^- was 1.49 mg l^{-1} which is indicator of a moderate eutrophication in Bera Lake. Chapman (1996) stated that land clearing and plough for cultivation has increased soil aeration, resulted in enhancement of nitrifying bacteria action and production of soil NO_3^-. Furthermore, burning of felled tress could release a large amount of nitrogen especially after the first heavy storm to the sink areas (Field, 2000). Both mechanisms happened in BLC since 1972 in which half of study area was cleared, disturbed and felled tress burned. The highest concentration of NO_3^- was recorded at one of semi-closed open waters at the northwest of Bera Lake (Fig. 4.32). The rest of the lake represents an acceptable range of NO_3^- concentration between 0.4-1.9 mg l^{-1}. Bera Lake water column experienced stratified and upward increasing in NO_3^- concentration is obvious. According to Chapman (1996), natural occurrence of ammonia in water bodies is attributed to the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion by biota, reduction of the nitrogen gas in water by micro-organisms and from gas exchange with the atmosphere. The mean average of ammonia was 0.26 mg l^{-1}. Bera Lake water profile represents clear reduction downward in ammonia with a coefficient of variation of 0.51 in which ammonia value deplete two times with depth. Chapman (1996) stated that ammonia plays an important role in the creation of toxic condition for aquatic life and being detrimental for the ecological balance of open waters at certain pH levels. Higher concentration of ammonia and pH was observed at surface water in the Bera Lake. The average of mean value of ammonia content is an indication of organic pollution by agriculture or industrial sewages, and fertilizer run-off at BLC area.

The chloride enters surface waters with the atmospheric deposition of oceanic aerosols, by the weathering of some sedimentary rocks (mostly rock salt deposits) and from industrial and sewage effluents, and agricultural and road run-off (Chapman, 1996). Minimum Cl^{-1} value was recorded at the south water entry point and at the departure point of Bera Lake. Conversely, the highest value of Cl^{-1} was obtained at the north open water especially at the end of connection channel. There is a vivid increment downward in Cl^{-1} concentration with coefficient of variation of 0.25. Probably the downward increases of Cl^{-1} and NO_3^- in Bera Lake water column, indicates a significant correlation with anoxic condition at low DO.

4.9. Physical Properties of Bera Lake Sediment

Physical properties of a lake can imply properly about current and long-term physical condition of depositional system. Sediments in all sedimentary media involves signature of natural events and anthropogenic changes in source and sink areas. Bera Lake as other fresh water lakes around the world has experienced several changes in sediments physical properties over the last decades. Determination of physical properties of Bera Lake sediments is an objective of this study. As mentioned in the Section 3.2.2, ten undisturbed cores were collected from Bera Lake sediments based on a deterministic sampling strategy. The sample preparation and analysis are described in the sections 3.3.1 and 3.3.5, respectively.

Detailed physical properties of Bera Lake sediment column represented by 350 subsamples were analyzed at every 2±0.2-cm depth intervals. Consequently, five distinct layers were identified in the first one meter thickness of Bera Lake sediment profile (Fig. 4.35). These layers with different thickness differentiated along all cores or at whole lake area. The identified layers were confirmed after analysis of subsamples for grain size, bulk density, porosity, and organic matters.

Description of Bera Lake physical properties are continued by introducing stratigraphic layers of sediment column. Core 7 is recognized as a master core to analyze grain size distribution in Bera Lake sediment profile. Additionally, some samples from individual layers of Cores 5 and 6 were analyzed as control samples in order to verify the results of master core. Core 7 is the longest among all the collected cores. Detailed grain size distribution and relevant statistical parameters for each sample are presented in Figure 4.36 and Table 4.7. Bulk density and porosity are crucial physical properties of sediments in a sedimentological study of each basin. Bulk density is necessary for estimating sedimentation rate using radioisotopes techniques (Appleby & Oldfield, 1978).

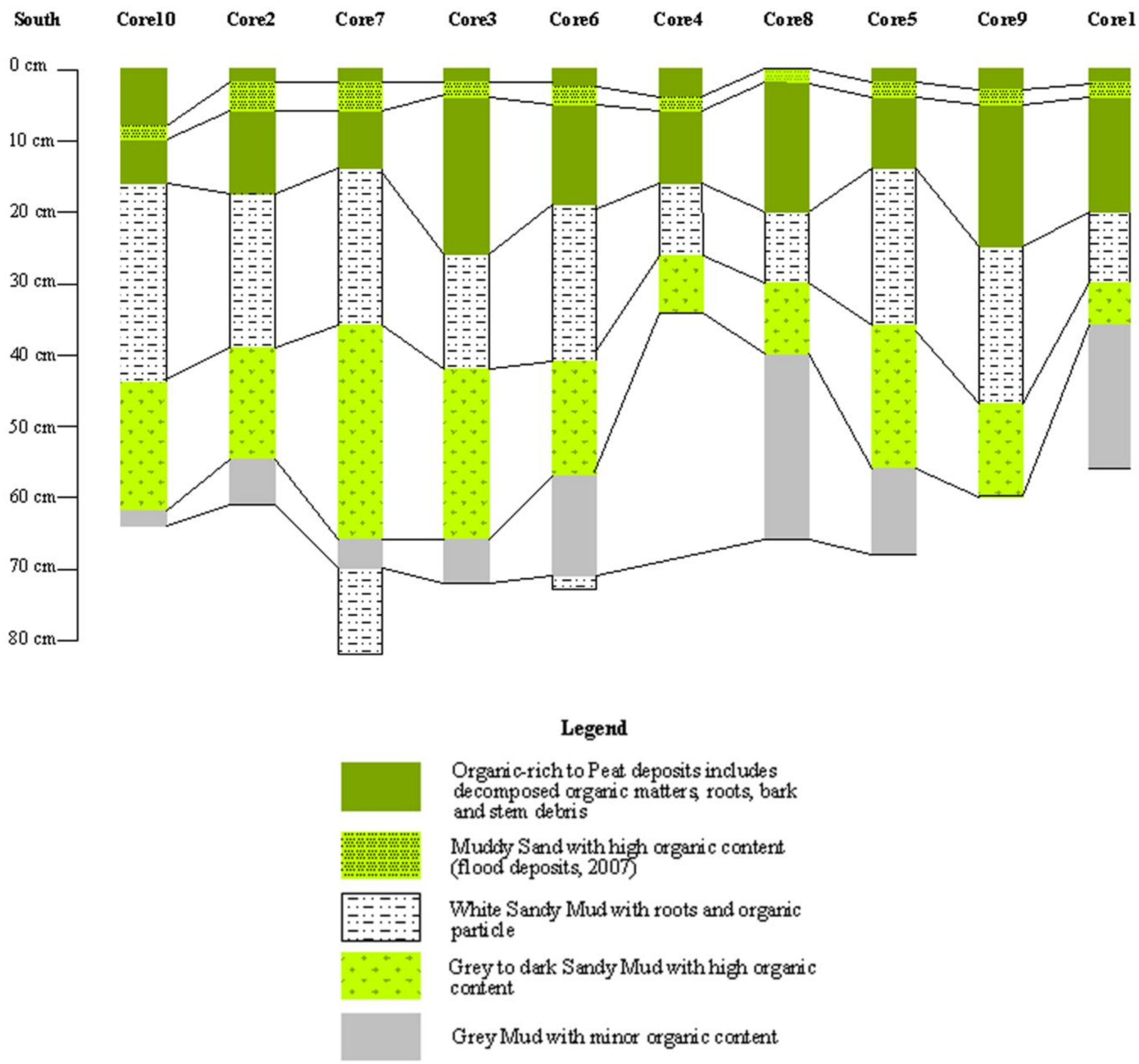

Figure 4.35: Stratigraphic layers of Bera Lake sediment profile

Minerals and coarse grain particles contribute to a higher bulk density. However, fine grain size sediments, organic matters and porosity tend to decrease bulk density values. Therefore, bulk density and porosity were used as indicators of environmental changes which have occurred over the last decades in BLC. Variations of bulk density and porosity values with depth have presented in Figures 4.37 and 4.38, respectively.

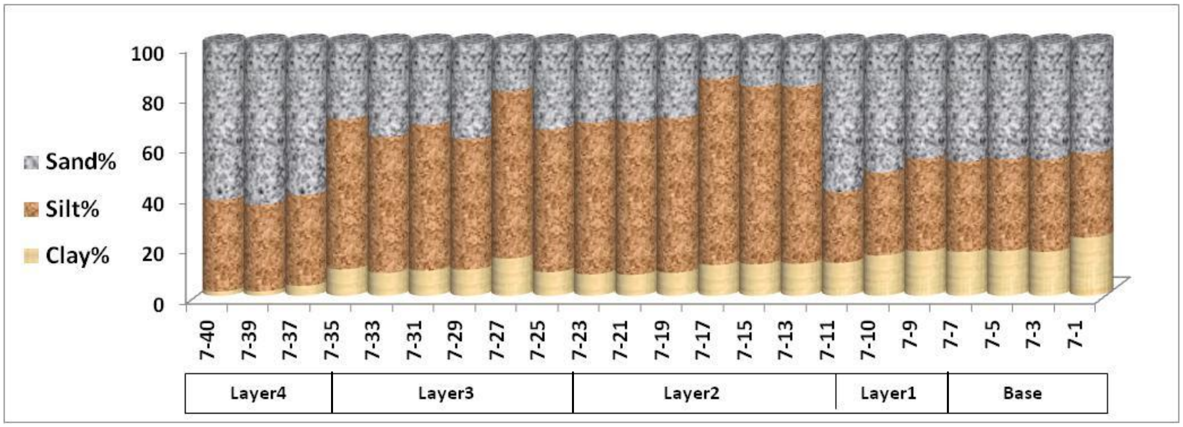

Figure 4.36: Grain size distributions along the master core 7

Table 4.7a: Sediment size distribution in master core 7 and statistical parameters

		7-1	7-3	7-5
SAMPLE STATISTICS PARAMETERS	SAMPLE TYPE:	Polymodal, Very Poorly Sorted	Polymodal, Very Poorly Sorted	Polymodal, Very Poorly Sorted
	TEXTURAL GROUP:	Sandy Mud	Sandy Mud	Sandy Mud
	SEDIMENT NAME:	Coarse Sandy Mud	Coarse Sandy Very Coarse Silt	Coarse Sandy Very Coarse Silt
FOLK AND WARD METHOD (f)	MEAN $(\bar{x}_a)$:	5.392	4.946	4.965
	SORTING (σ_I):	3.956	3.589	3.612
	SKEWNESS (Sk_I):	0.211	0.200	0.199
	KURTOSIS (K_G):	0.719	0.728	0.722
FOLK AND WARD METHOD (Description)	MEAN:	Coarse Silt	Very Coarse Silt	Very Coarse Silt
	SORTING:	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
	SKEWNESS:	Fine Skewed	Fine Skewed	Fine Skewed
	KURTOSIS:	Platykurtic	Platykurtic	Platykurtic
Mode (mm)	MODE 1 (mm):	816.5	816.5	816.5
	MODE 2 (mm):	0.985	0.985	152.176
	MODE 3 (mm):	8.359	1.558	0.985
Grain Size	% GRAVEL:	0.0%	0.0%	0.0%
	% SAND:	43.4%	45.9%	45.8%
	% MUD:	56.6%	54.1%	54.2%

Table 4.7b: Sediment size distribution in master core 7 and statistical parameters

		7-7	7-9	7-10
SAMPLE STATISTICS PARAMETERS	SAMPLE TYPE:	Polymodal, Very Poorly Sorted	Polymodal, Very Poorly Sorted	Trimodal, Very Poorly Sorted
	TEXTURAL GROUP:	Sandy Mud	Sandy Mud	Muddy Sand
	SEDIMENT NAME:	Coarse Sandy Very Coarse Silt	Coarse Sandy Very Coarse Silt	Very Coarse Silty Coarse Sand
FOLK AND WARD METHOD (f)	MEAN $(\bar{x}_a)$:	4.898	4.974	4.647
	SORTING (σ_I):	3.607	3.601	3.600
	SKEWNESS (Sk_I):	0.217	0.200	0.301
	KURTOSIS (K_G):	0.726	0.732	0.771
FOLK AND WARD METHOD (Description)	MEAN:	Very Coarse Silt	Very Coarse Silt	Very Coarse Silt
	SORTING:	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
	SKEWNESS:	Fine Skewed	Fine Skewed	Very Fine Skewed
	KURTOSIS:	Platykurtic	Platykurtic	Platykurtic
Mode (mm)	MODE 1 (mm):	1.0	177.3	816.5
	MODE 2 (mm):	8.359	0.985	0.985
	MODE 3 (mm):	11.345	9.738	3.895
Grain Size	% GRAVEL:	0.0%	0.0%	0.0%
	% SAND:	46.7%	45.6%	51.0%
	% MUD:	53.3%	54.4%	49.0%

Table 4.7c: Sediment size distribution in master core 7 and statistical parameters

		7-12	7-15	7-17
SAMPLE	SAMPLE TYPE:	Trimodal, Very Poorly Sorted	Unimodal, Very Poorly Sorted	Unimodal, Very Poorly Sorted
STATISTICS	TEXTURAL GROUP:	Muddy Sand	Sandy Mud	Sandy Mud
PARAMETERS	SEDIMENT NAME:	Very Coarse Silty Coarse Sand	Very Fine Sandy Very Coarse Silt	Very Fine Sandy Very Coarse Silt
FOLK AND	MEAN $(\bar{x}_a)$:	4.110	6.023	6.100
WARD METHOD	SORTING (σ_I):	3.458	2.311	2.211
(f)	SKEWNESS (Sk_I):	0.396	0.276	0.283
	KURTOSIS (K_G):	0.860	1.050	1.055
FOLK AND	MEAN:	Very Coarse Silt	Medium Silt	Medium Silt
WARD METHOD	SORTING:	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
(Description)	SKEWNESS:	Very Fine Skewed	Fine Skewed	Fine Skewed
	KURTOSIS:	Platykurtic	Mesokurtic	Mesokurtic
	MODE 1 (mm):	816.5	44.8	38.5
Mode (mm)	MODE 2 (mm):	0.985		
	MODE 3 (mm):	3.344		
	% GRAVEL:	0.0%	0.0%	0.0%
Grain Size	% SAND:	58.7%	16.9%	13.8%
	% MUD:	41.3%	83.1%	86.2%

Table 4.7d: Sediment size distribution in master core 7 and statistical parameters

		7-19	7-21	7-23
SAMPLE	SAMPLE TYPE:	Unimodal, Very Poorly Sorted	Unimodal, Very Poorly Sorted	Unimodal, Very Poorly Sorted
STATISTICS	TEXTURAL GROUP:	Sandy Mud	Sandy Mud	Sandy Mud
PARAMETERS	SEDIMENT NAME:	Very Fine Sandy Very Coarse Silt	Very Fine Sandy Very Coarse Silt	Very Fine Sandy Very Coarse Silt
FOLK AND	MEAN $(\bar{x}_a)$:	5.325	5.218	5.246
WARD METHOD	SORTING (σ_I):	2.335	2.270	2.303
(f)	SKEWNESS (Sk_I):	0.281	0.290	0.288
	KURTOSIS (K_G):	1.109	1.108	1.089
FOLK AND	MEAN:	Coarse Silt	Coarse Silt	Coarse Silt
WARD METHOD	SORTING:	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
(Description)	SKEWNESS:	Fine Skewed	Fine Skewed	Fine Skewed
	KURTOSIS:	Mesokurtic	Mesokurtic	Mesokurtic
	MODE 1 (mm):	44.8	52.2	52.2
Mode (mm)	MODE 2 (mm):			
	MODE 3 (mm):			
	% GRAVEL:	0.0%	0.0%	0.0%
Grain Size	% SAND:	29.4%	31.0%	31.2%
	% MUD:	70.6%	69.0%	68.8%

Table 4.7e: Sediment size distribution in master core 7 and statistical parameters

		7-25	7-27	7-29
SAMPLE	SAMPLE TYPE:	Unimodal, Very Poorly Sorted	Bimodal, Very Poorly Sorted	Unimodal, Very Poorly Sorted
STATISTICS	TEXTURAL GROUP:	Sandy Mud	Sandy Mud	Sandy Mud
PARAMETERS	SEDIMENT NAME:	Very Fine Sandy Very Coarse Silt	Very Fine Sandy Very Coarse Silt	Very Fine Sandy Very Coarse Silt
FOLK AND	MEAN $(\bar{x}_a)$:	5.198	6.096	5.239
WARD METHOD	SORTING (σ_I):	2.379	2.452	2.505
(f)	SKEWNESS (Sk_I):	0.350	0.325	0.325
	KURTOSIS (K_G):	1.120	0.958	1.035
FOLK AND	MEAN:	Coarse Silt	Medium Silt	Coarse Silt
WARD METHOD	SORTING:	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
(Description)	SKEWNESS:	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed
	KURTOSIS:	Leptokurtic	Mesokurtic	Mesokurtic
	MODE 1 (mm):	60.9	52.2	60.9
Mode (mm)	MODE 2 (mm):		0.459	
	MODE 3 (mm):			
	% GRAVEL:	0.0%	0.0%	0.0%
Grain Size	% SAND:	33.8%	18.8%	34.7%
	% MUD:	66.2%	81.2%	65.3%

Table 4.7f: Sediment size distribution in master core 7 and statistical parameters

		7-31	7-33	7-35
SAMPLE STATISTICS PARAMETERS	SAMPLE TYPE:	Unimodal, Very Poorly Sorted	Unimodal, Very Poorly Sorted	Unimodal, Very Poorly Sorted
	TEXTURAL GROUP:	Sandy Mud	Sandy Mud	Sandy Mud
	SEDIMENT NAME:	Very Fine Sandy Very Coarse Silt	Very Fine Sandy Very Coarse Silt	Very Fine Sandy Very Coarse Silt
FOLK AND WARD METHOD (f)	MEAN $(\bar{x}_a)$:	5.309	5.087	5.437
	SORTING (σ_I):	2.436	2.386	2.422
	SKEWNESS (Sk_I):	0.319	0.346	0.322
	KURTOSIS (K_G):	1.064	1.073	1.038
FOLK AND WARD METHOD (Description)	MEAN:	Coarse Silt	Coarse Silt	Coarse Silt
	SORTING:	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
	SKEWNESS:	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed
	KURTOSIS:	Mesokurtic	Mesokurtic	Mesokurtic
Mode (mm)	MODE 1 (mm):	52.2	70.9	52.2
	MODE 2 (mm):			
	MODE 3 (mm):			
Grain Size	% GRAVEL:	0.0%	0.0%	0.0%
	% SAND:	32.1%	36.9%	29.9%
	% MUD:	67.9%	63.1%	70.1%

Table 4.7g: Sediment size distribution in master core 7 and statistical parameters

		7-37	7-39	7-40
SAMPLE STATISTICS PARAMETERS	SAMPLE TYPE:	Unimodal, Poorly Sorted	Unimodal, Poorly Sorted	Unimodal, Poorly Sorted
	TEXTURAL GROUP:	Muddy Sand	Muddy Sand	Muddy Sand
	SEDIMENT NAME:	Very Coarse Silty Fine Sand	Very Coarse Silty Fine Sand	Very Coarse Silty Fine Sand
FOLK AND WARD METHOD (f)	MEAN $(\bar{x}_a)$:	3.777	3.657	3.739
	SORTING (σ_I):	1.920	1.730	1.703
	SKEWNESS (Sk_I):	0.321	0.371	0.346
	KURTOSIS (K_G):	1.123	1.046	1.051
FOLK AND WARD METHOD (Description)	MEAN:	Very Fine Sand	Very Fine Sand	Very Fine Sand
	SORTING:	Poorly Sorted	Poorly Sorted	Poorly Sorted
	SKEWNESS:	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed
	KURTOSIS:	Leptokurtic	Mesokurtic	Mesokurtic
Mode (mm)	MODE 1 (mm):	206.5	177.3	177.3
	MODE 2 (mm):			
	MODE 3 (mm):			
Grain Size	% GRAVEL:	0.0%	0.0%	0.0%
	% SAND:	60.0%	63.9%	62.0%
	% MUD:	40.0%	36.1%	38.0%

Table 4.8: Mean bulk density (g cm^{-3}) of Bera Lake sediment layers

Layer	Core Number									
No.	1	2	3	4	5	6	7	8	9	10
4	0.23	0.36	0.27	0.28	0.35	0.45	0.20	0.27	0.40	1.09
3	0.88	1.01	0.71	0.40	0.88	1.16	0.75	0.73	0.32	1.37
2	0.78	1.18	0.58	0.85	1.40	1.06	0.52	0.88	0.41	2.12
1	1.58	0.90	1.20	NR	1.40	0.87	1.47	0.53	NR	2.57
base	NR	NR	NR	NR	NR	0.99	1.47	NR	NR	NR

NR: Not recorded in collected core

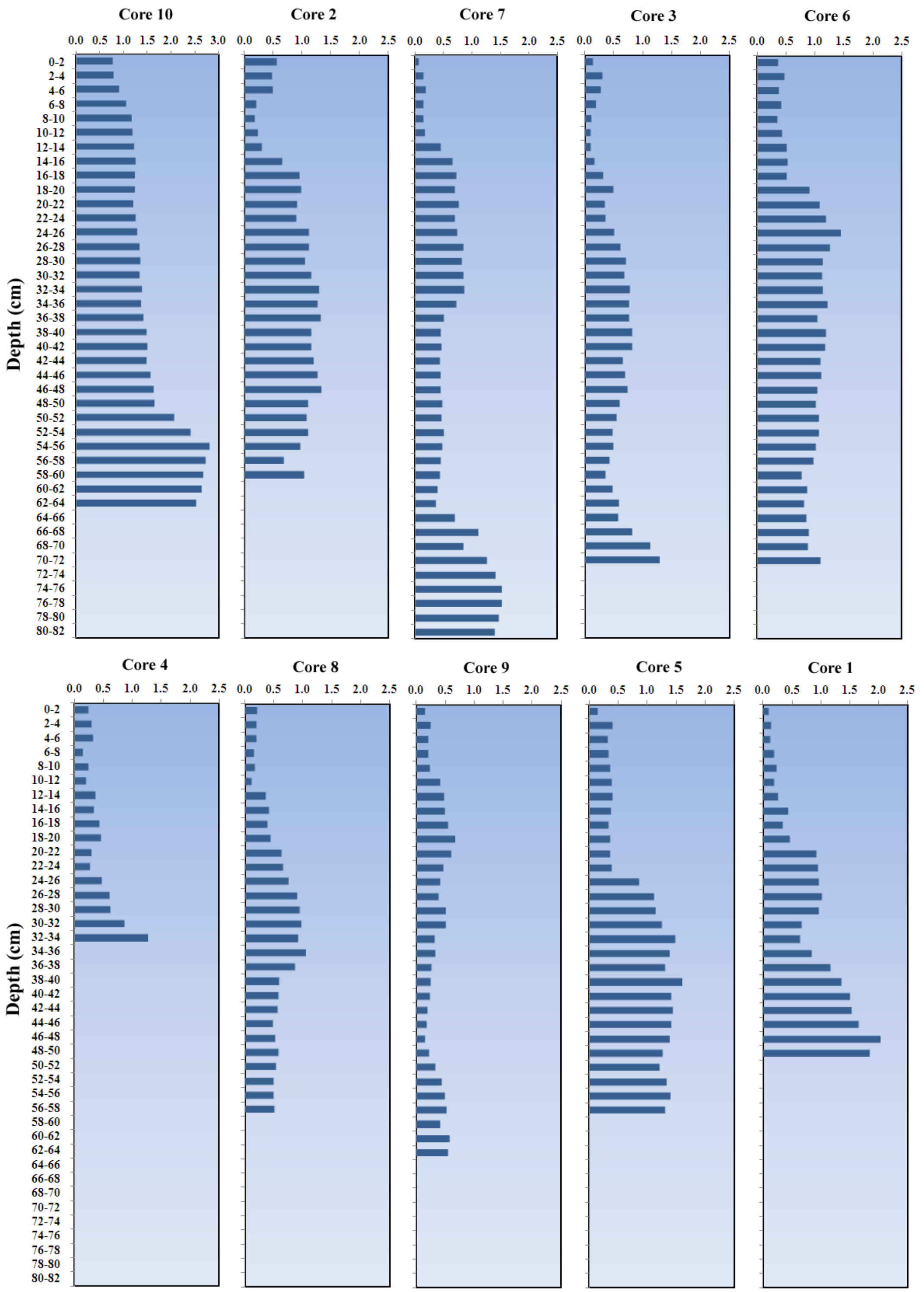

Figure 4.37: Northward bulk density variations in Bera Lake sediment profile

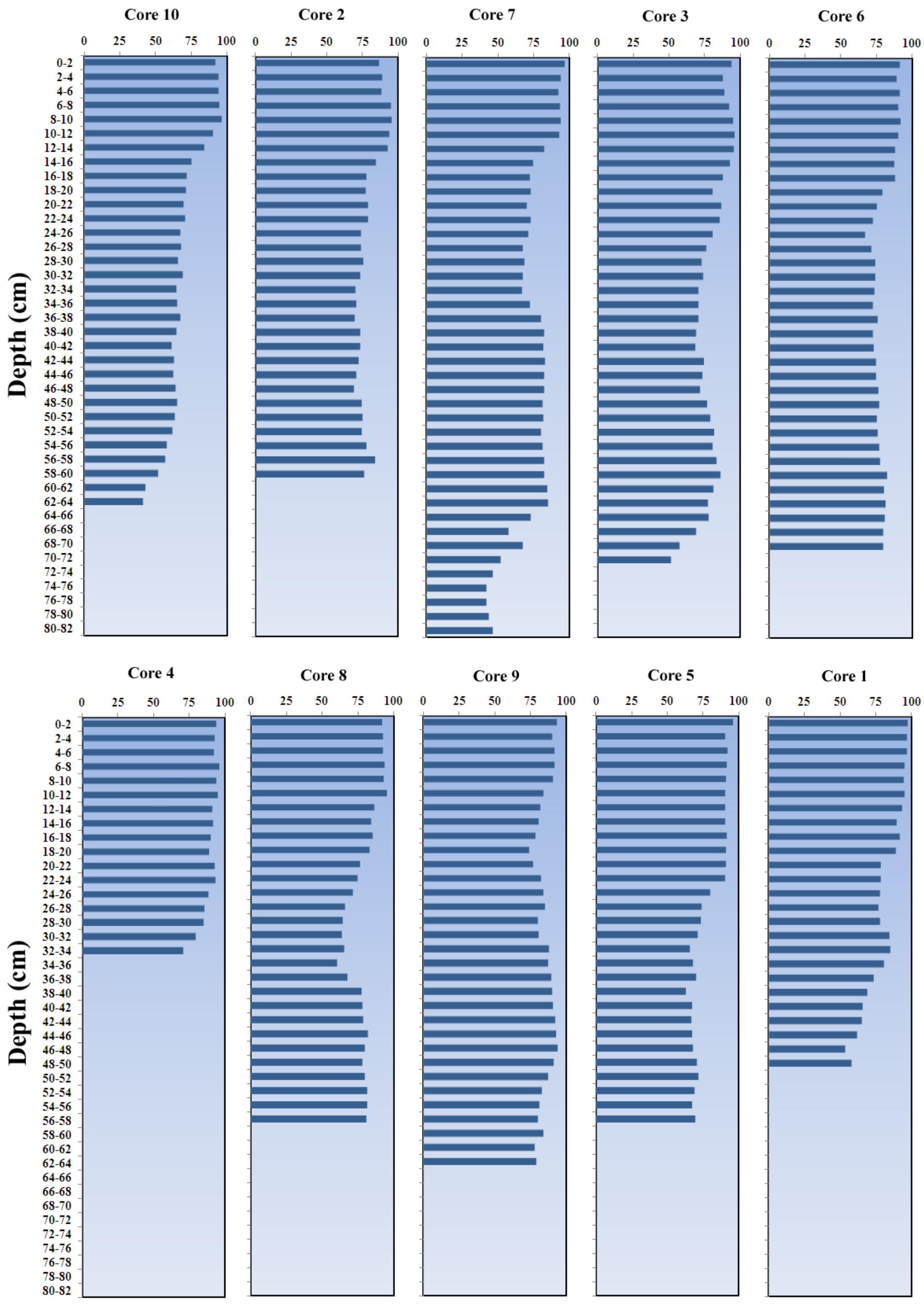

Figure 4.38: Northward porosity variations in Bera Lake sediment profile

4.9.1. Sediment Layers Stratigraphy

4.9.1.1. Gray Mud to Sandy Mud (Layer 1)

The first layer from base in Bera Lake sediment profile represents gray color and muddy texture with 20-cm average thickness. The maximum thickness was recorded in Cores 1 and 8. The lower contact is white sandy mud in Cores 7 and 6 and unknown at others cores. Layer 1 overlaid by grey to dark grey sandy mud in all studied cores. Clay, silt and sand size grains made up 18±2.5, 35±1.7, and 48±2.5 %, of the muddy texture. Contribution of clay mineral in layer 1 at the middle and the north of Bera Lake sediment column decreased to 10% while silt size grains portion has been increased to 62 %. Mean grain size represents coarse to very coarse silt with a very poorly sorted texture. Layer 1 at the south of Bera Lake is composed of polymodal sediments while it comprises unimodal sediments at the middle and the north of basin. Its cumulative curve skewed to fine grains which illustrate its platykurtic to mesokurtic shape. Grain size description of cores indicates existence of roots, barks, and charcoals in some sub-layers. The highest lithogenic content in layer 1 caused an increase of bulk density to 2.57 g cm^{-3} in Core 10. The bulk density values were 1.58, 1.47, 1.4 g cm^{-3} in layer 1 at cores 2, 7, and 5, respectively. Porosity values showed a downward decrease with depth especially in Cores 1, 3, 4, 7, and Core 10. The lowest porosity value in Bera Lake sediment column were 42 and 41.5% respectively in layer 1 of cores 7 and 10. The mean porosity value of layer 1 was 75±0.06 %.

4.9.1.2. Gray to Dark Sandy Mud (Layer2)

This section of sediment profile with 25cm average thickness, characterized by medium size matrix, abundance of partly decomposed roots, barks, stems, charcoal and organic debris, and gray to dark gray color. Lithology in Layer 2 gradually changed from grey to grey dark sandy mud and then to muddy sand deposits. Muddy matrix and clay size grain portion has decreased in Layer 2. Clay, silt and sand size grains have been contributed with an average of 11±2, 61±15, and 28±15 %, respectively. The mean size is comparable to coarse silt, very poorly sorted texture and platykurtic shape of cumulative curve. Bulk density in the most of studied cores was reduced because of organic contamination especially in Cores 1, 3, 4, 7, 8, and 9. Minimum, maximum and average of bulk density in Layer 2 was calculated to be 0.41, 2.12, and 0.98±0.5 g cm^{-3}, respectively. The minimum, maximum, and mean porosity values for layer 2 calculated to be 69.83, 79.53, and 76±0.06 %, respectively. The maximum porosity in Layer 2 observed in Cores 9, 4, 1, and 7 which are in positive correlation with the lowest bulk density values.

4.9.1.3. White Sandy Mud (Layer 3)

Erosion-induce deposits accumulated in Bera Lake as white sandy mud sediments in Layer 3 during and after maximum deforestation activities. It overlaid on Layer 2 with a sharp contact. Contribution of silt size grains was increased to 58±5 % while clay and sand portions were reduced to 11±2 and 32±7 % on the average. Although, analyzed samples in this layer represent a mesokurtic and unimodal cumulative curve, but they are very poorly sorted sediments. The mean grain size is in the range of coarse silt and the sedimentological name is very fine sandy very coarse silt. Analyzed samples from same layer in Core 5 and 6 represented similar kind of statistic parameters. Contribution of clay, silt and sand size grains at the middle and north of study area were calculated to be 15, 68, and 17%, respectively. A remarkable charcoal horizon was recognized at lower contact of Layer 3, signals of maximum land preparation by burning of fallen trees. This horizon has significantly reduced bulk density values to 0.5 g cm^{-3} in Cores 1, 4, and 9. Lithogenic contents in Layer 3 have contributed to increase bulk density especially in Cores 1, 3, 6, and 7. Minimum, maximum and mean bulk density values in Layer 3 calculated to be 0.32, 1.37, and 0.82±0.31 g cm^{-3}, respectively. Scatter roots, barks, charcoals were found along this layer. The highest porosity of Layer 3 was observed in Cores 4, 9, 5 and 6. These cores seem to be more contaminated by organic matters than others. The maximum, minimum, and mean porosity values for white sandy mud layer calculated to be 91, 72, and 78±0.07%, respectively.

4.9.1.4. Organic-Rich Deposits (Layer 4)

General upward decrease in lithogenic mineral and bulk density value has been continued with deposition of organic-rich sediments at top of Bera Lake sediment column. Layer 4 was characterized by very low matrix content, abundance of partially decomposed roots, barks, stems, charcoal and organic debris, and dark color, and 25-cm thickness of average. It overlaid on white sandy mud deposits with a gradual contact. Contribution of clay and silt size grains has reduced dramatically to 2.7 and 35.5% of the average. Coarse grains mainly composed of organic particles in different size. Therefore, this sediment represents very poorly sorted texture. Detailed organic matters include TOC and POC will present at section 5-4.

Minimum, maximum, and mean bulk density values in Layer 4 obtained 0.2, 1.09, and 0.39±0.25 with coefficient of variation of 0.66. General upward increasing in porosity value has reach to maximum content in Layer 4. Minimum, maximum and average porosity values were calculated to be 91, 95.5, and 85±0.1%, respectively.

An interruption recorded in general upward decrease in bulk density by deposition of thin layer muddy sand sediments at the depth of 0 to 4 cm in all parts of Bera Lake. This Layer (5) is an indicator of a hiatus event in which catchment area flooded extensively at December, 2007. This event has been occurred in study area, when 1,200 mm rain precipitated during 11 days.