

Chapter 11

Climate, C/N Ratio and Organic Matter Accumulation: An Overview of Examples from Kashmir Himalayan Lakes



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Abstract This present study provides an overview of the C/N ratio and organic matter (OM) contents in surface sediments of four lakes that occur in the Kashmir Valley. Valleys are depressed areas of land that influence climate and weather at both global and local scales. The oval-shaped intermontane valley is dotted with numerous freshwater lakes of various shapes and depths. These lakes represent the remnants of a substantial Karewa Lake body that extended across the valley floor currently occupied by the modern lakes. The study presented is based on analysis of the organic material deposited on the lake basin floors, transported via both natural and anthropogenic sources. The present deposition of terrestrial organic material in the lake sediments has apparently altered the trophic status of these lakes from oligo- to eutrophic conditions. Analysis of the C/N ratio in the Holocene lake sediments suggests that these lakes are dynamic ecosystems the accumulation of organic material being sources and depositional processes occurring within these lake basins. The report reviews the accumulation of organic material and the C/N ratio of the surface sediments, and discusses their potential value in palaeoclimatic interpretation of fossil sediments in these lake basins to serve as an analogue with older materials. The organic material deposited in these lakes is predominantly a function of climatic conditions in the valley. The organic and isotopic composition of the lake sediments can potentially provide important information of past lake nutrient dynamics, palaeoenvironmental changes and depositional sources influencing the basins through time.

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11.1 Introduction

Fresh water bodies constitute only 3% of the total volume of water on earth. These water bodies have a bearing on the economy as they provide potable water, fish and fodder for the people. The fresh water lakes are however, the most vulnerable habitats as they act as sinks for sewage and waste disposal. Limnological study has now firmly entrenched itself as an important branch of geo-environmental study. Physical and chemical characteristics of lake sediments are potential proxies, which offer important information on the long-term climate variability of the past. The lakes being relatively small bodies of water in comparison with the ocean, can respond relatively quickly to an external forcing variable. Changes in air temperature or regional landuse can be reflected within months to decades in the inputs to the lake's sedimentary record. The rapidity of this response varies both within a lake, for example from near shore to offshore environments, and between the lakes.

The organic content of the sediments reflects the amount of living organisms in and around the lake, i.e. the level of productivity and leaching from humus-rich catchment soils (Meyers and Teranes 2001). The lakes also have properties that allow us to use them as sentinels of stress in the terrestrial and wetland ecosystems that are found in their catchments. Changes to watersheds caused by climate warming can in turn affect the properties of lakes to which they drain. Examples include changes to nutrient inputs, the balance between base cations and strong acid anions, carbon cycles, and mercury, in some cases associated with insect outbreaks and forest fires.

Sedimentary organic matter (OM) is one of the most important components of terrestrial and marine lake sediments generally derived from in situ (autochthonous) and/or terrestrial (allochthonous) sources (Meyers and Ishiwatari 1993). Lake sediments play an important role as an efficient natural trap for organic rich sediments and hence act as a natural regulator of the various processes that occur inside the lake ecosystems (Burone et al. 2003). The particulate detritus of plants that grow in and around the lake catchment areas comprises the primary source of OM to the lake deposits. The relative contribution of OM from these two sources is strongly controlled by lake morphology, watershed topography and the relative abundances of lake and watershed plants (Meyers and Ishiwatari 1993). However, lake sediments are strongly influenced by the natural and human settlement characteristics around the catchments. While human induced changes in nutrient loads have had a marked effect on Kashmir Himalayan lakes, changes in climate also play a vital role. The key processes of climate variability are solar radiation and water balance (water level, retention time, stratification) and related factors (snow, wind). Thus, natural proxy signals preserved in lake sediments can be used for reconstruction of high-resolution Late-Quaternary-Holocene climatic variabilities.

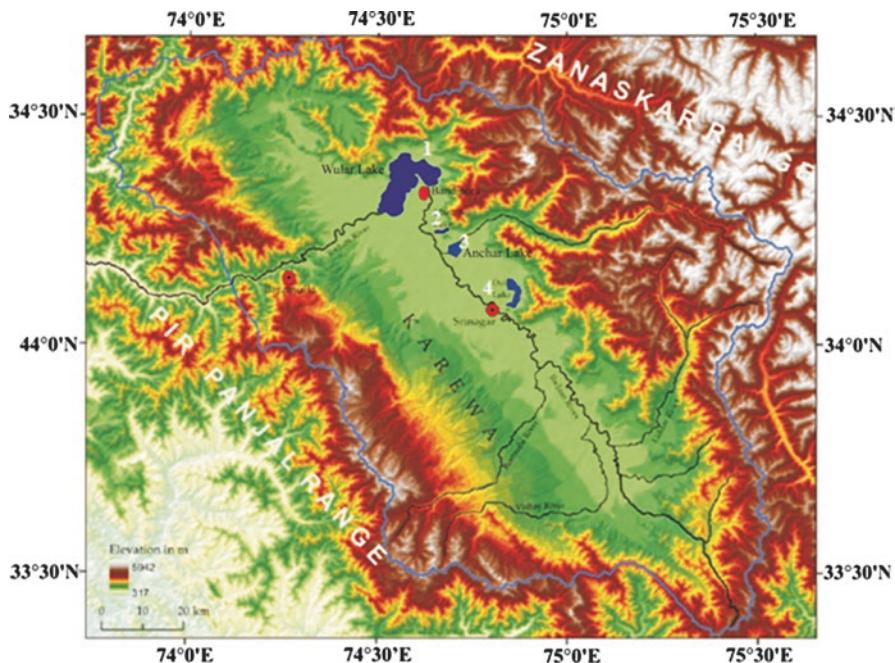


Fig. 11.1 DEM map of the Kashmir Valley along with location of four lakes (1) Wular, (2) Manasbal, (3) Anchar and (4) Dal Lake. Different colours indicate elevation in meters (Ganjoo 2014)

11.2 Climate and Geology of Kashmir Himalayan Region

The Kashmir Himalayas (Fig. 11.1) are extremely important because of their position and for the role; they play in the climate and weather phenomena and economy of the state. It is believed that the valley originated from the draining of the Karewa Lake, which was formed as a result of tectonic upheaval and subsequent tectonic uplift of the Pir Panjal and Zanskar Ranges. It is an intermountain valley fill, comprising of unconsolidated gravel, pebble, boulder and mud. A succession of plateaux is present above the plains of Jhelum and its tributaries. These plateaux-like terraces are called ‘Karewas’ or ‘Vudr’ in the local language. Due to the rise of the Pir-Panjal, the drainage was impounded, a lake of about 5000 km² area was developed, and thus a basin was formed.

The climate of the study area is characterized by warm summers and cold winters and varies between -5 and > 30 °C. According to Bagnolus and Meher-Homji (1959), the climate of Kashmir falls under Sub-Mediterranean type with four seasons based on mean temperature and precipitation. The precipitation is highly variable round the year with more rains occurring during the summer and snowfall

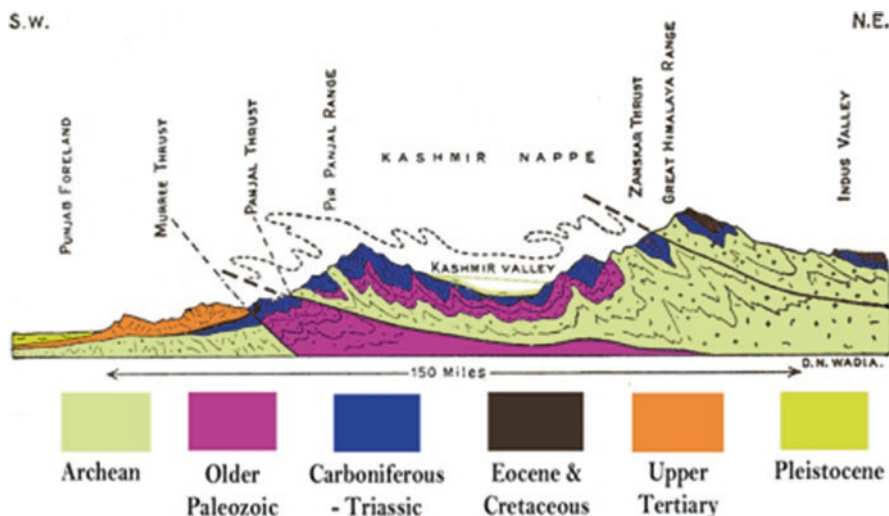


Fig. 11.2 Diagrammatic cross sections across the Kashmir Himalaya, showing broad tectonic features along with the Kashmir Nappe zone. (After Wadia 1976)

during winter. Western disturbances are mainly responsible for causing rainfall and snowfall from January to May. Both the daily minimum and maximum temperatures start rising and falling by April and September respectively, and are at their peak in July and January.

Kashmir Valley encompasses a very important place in the geo-tectonic framework of Kashmir Himalaya (Fig. 11.2). The geology of the Kashmir region displays a chronological record of the Great Alpine Orogeny, including sedimentation, tectonics and volcanic activity, that followed the Himalayan Orogeny. The valley is bounded on the southwest by the Pir Panjal and by the Greater Himalayas on the northeast. The bowl-shaped basin is represented by the Precambrian basement overlain by a thick succession of fossiliferous Palaeozoic and Triassic rocks with thrust contacts in the north with the Great Himalayan Range and in the south with Pir Panjal Range (Ganjoo 2014). Panjal Volcanic Complex and the Triassic Limestone form the two main geological formations, underlain by the Archean metasedimentary rocks (Salkhala Formation). Salkhala formation constitutes carbonaceous slate, graphitic phyllite and schist associated with carbonaceous grey or white limestone, marble, calcareous slate and calcareous schist (Alam et al. 2015). Plio-Pleistocene glacio-fluvio-lacustrine sediments (approximately 1300 m thick) in turn overlie the Precambrian to Mesozoic basement rocks and constitute the Karewa Group. The Karewa Group of sediments is mostly composed of sand, silt, clay, shale, mud, lignite, gravel and loessic sediments (Alam et al. 2015; Babeesh et al. 2017). The landuse and land cover of the area may be divided into agricultural land with various types of crops and trees, forests, Karewa deposits, built-up, barren land and horticulture areas. The landuse and land cover classes along the lake catch-

ment areas has been substantially modified by human population over the past few decades (Lone et al. 2017; Lone et al. 2018a, b, c).

11.3 The Karewa Lakes

One of the unique geomorphic features present in the Kashmir valley are the thick Quaternary Karewa deposits. These deposits are dominantly lacustrine, fluvial, glacial and aeolian in origin. The past existence of Karewa Lake, is thought to be an intermittent one attaining maximum extent during warmer interglacial periods and succeeded by periods of minimum extent. Nearly half of the present Kashmir Valley is covered by deposits of Karewa sediments and contain detailed systematic records of ice ages over western Himalayas (Wadia 1941). The important freshwater lakes (Anchar, Dal, Manasbal and Wular Lakes) found in the Kashmir Valley (Fig. 11.3) are the remnants of the great Karewa Lake and thus represent the present day geomorphic landscape of the region.

In this chapter we present an overview of OM accumulation and C/N ratio from four Kashmir Himalayan lakes. This study was carried out to understand the accumulation and source of OM in surface sediments and the controlling factors that modulate the deposition of OM in recent surface sediments. The four lakes although located in the same climatic conditions prevailing in the valley display changes in the sources and depositional pattern of allochthonous and terrestrial OM contents.



Fig. 11.3 Google earth map (2017) showing location of important lakes in Kashmir Valley

This study was also aimed to understand the factors such as type of the lake (open or closed), catchment area changes and further, the paleoclimatic potential of the above two proxy records were also discussed for future references. The water in these lakes is added from in situ springs, drainage inlets from the upland catchment such as Jhelum river, Sindh river besides other small tributaries which bring in diverse type of sediments rich in OM (Sarkar et al. 2016). This study investigates the distribution and sources of organic matter within four Kashmir Himalayan lake basins and illustrates the usefulness of C/N ratio as a biomarker approach in discriminating organic matter sources within lacustrine environments.

11.3.1 *Wular Lake*

The Wular Lake (34°22'10.56"N and 74°33'28.8"E) located in the Bandipora district of north Kashmir is an oxbow type mono-basined lake (Fig. 11.4). The lake is situated nearly 34 km to the northwest of Srinagar city at an altitude of 1530 m a.s.l. The average surface area of the Wular lake is 189 km² and the water remains alkaline throughout the year and pH changes from 7.5 in summer to 8.8 in winter season (Shah et al. 2017). The average depth of the lake is 5 m. Based on its high biological, hydrological and socioeconomic value, the lake was declared as a wetland of National importance under the wetlands programme of the Ministry of Environment and Forests, Government of India, in 1986 and has been subsequently declared as a Ramsar Site in 1990 to give it the status of wetland of International importance.

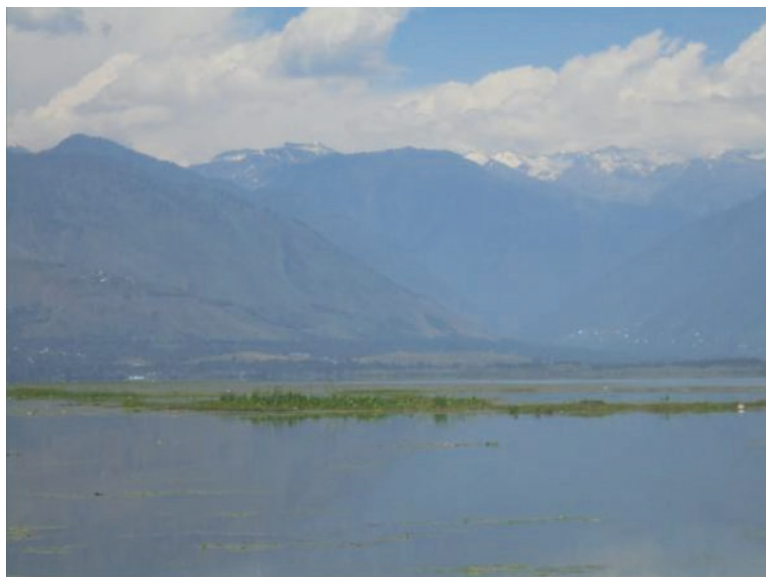


Fig. 11.4 A view of the Wular lake, Bandipora Kashmir

Wular Lake, the largest freshwater lake in Asia within the Jhelum river basin, plays an important role in the hydrographic system of the Kashmir valley by acting as predominant absorption basin during the flood events besides playing a vital role in sustaining agriculture. The shrinkage in lake area is mainly because of a continuous siltation brought by the various tributaries besides River Jhelum. The lake is an open drainage type and hence experiences moderate eutrophication (Pandit 2002).

11.3.2 *Manasbal Lake*

The Manasbal Lake 34°14'47.66" N and 74°41'20" E is one of the deepest, mesotrophic freshwater lake, located in the Safapora area (Ganderbal district), at an altitude of about 1585 m a.s.l (Fig. 11.5). The lake is semi-drainage type, oblong in outline and covers an area of 2.80 km² with a maximum depth of 12.5 m (Maqbool and Khan 2013; Rashid et al. 2013; Lone et al. 2017; Lone et al. 2018a, b, c). The lake is surrounded by the Karewa deposits of Plio-Pleistocene age on the northeast and northwestern side. On the eastern side are the Panjal traps of Permian age overlain by the Triassic limestone extending to the southeast. The lake inflow is chiefly derived from the underground springs, local precipitation in addition to which a small irrigation stream (Laar Kul) on the eastern side also drains water into the lake during the rainy season from the higher catchment areas. The Laar-kul stream brings in diverse types of terrestrial organic and inorganic material into the lake, including major and minor nutrients and other materials. An outflow channel called Nunnyar Nalla drains excess water from the western side of the lake into the Jhelum River.



Fig. 11.5 Panoramic view of the Manasbal Lake with the Ahtung hills in the background



Fig. 11.6 A view of the Anchar Lake, Srinagar Kashmir Valley

11.3.3 Anchar Lake

Anchar Lake ($34^{\circ}08'37.58''\text{N}$ and $74^{\circ}47'10.89''\text{E}$) located in the urban area, is a fresh water lake, situated about 25 km northwest of Srinagar city at an average elevation of ~ 1583 m a.s.l. with an average depth of about 4 m (Fig. 11.6). Presently, the lake occupies an area of 6.80 km^2 of which about 1.69 km^2 correspond to open-water and the remaining portion has been transformed into a marshland because of increased human impact on the lake ecosystem. The lake catchment covers a surface area of about 5.8 km^2 . The lake surface is a single basined, open drainage type water body fed by a network of channels including local catchment watersheds, open springs and Sindh River (Ganaie et al. 2015). The Sindh River constituting one of the largest basins in the Kashmir Himalayas drains major part of its water into the Anchar Lake. Further, a number of channels from agricultural fields, effluents from the settlements around the Anchar Lake and surface runoff from the catchment area directly drain into the lake throughout the year (Lone et al. 2017; Lone et al. 2018a, b, c). Much of the excess water from the Anchar Lake drains through the Shalabugh wetland into the Jhelum River (Khanday et al. 2016).



Fig. 11.7 A view of the Dal Lake Srinagar, Kashmir Valley

11.3.4 Dal Lake

Dal Lake (Fig. 11.7), situated in Kashmir Himalaya, is a multi-basin drainage lake covering an area of 24 km² with the open water spread of about 10.5 km² and a water holding capacity of 15.45×10^6 m³. The lake lies between 34°5′–34°9′N and 74°49′–74°53′E at a mean altitude of 1585 m a.s.l. The average depth of the Dal Lake is 1.42 m. Being a major tourist attraction in Kashmir, the lake is socio-economically important as the livelihood of a large section of population of Srinagar city is dependent on the services and products provided by the lake. The lake is an important source of vegetables, fisheries, recreation and drinking water to the people of Srinagar city. The catchment area, spread over 337 km², is geologically composed of Panjal Traps, agglomeratic slates, alluvium and Karewa deposits (Wadia 1976). As per Bagnolus and Meher-Homji (1959), climate of the area is sub-Mediterranean with four seasons. The total annual precipitation and average temperature recorded at the nearest metrological station (Srinagar) is 870 mm and 11 °C respectively.

11.4 Organic Matter Accumulation, C/N Ratio and Paleoclimate Inferences

Understanding the OM accumulation and diagenesis is one of the important parameters to distinguish between various depositional environments of the past as well as recent lake sediments. Terrestrial run off and organisms present within the water column generally contribute OM and calcium carbonate to the lake basins. The

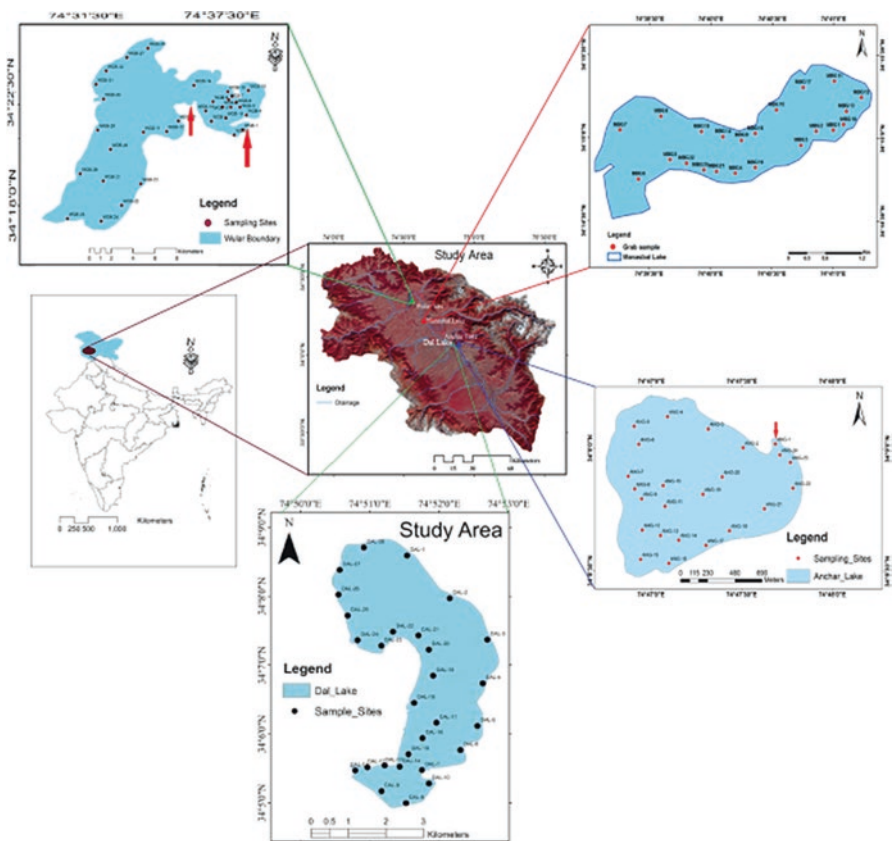


Fig. 11.8 Location map of the study area and the site location of the four freshwater lakes with sampling stations

concentration of OM and CaCO_3 varies within the lake basins (Dean 2006). This variation is owing to the changes in water chemistry, catchment geology, climate, lake-flora and fauna, anthropogenic influences along the catchments etc.

The sediment grain size variations, its sorting under hydraulic conditions and its distribution both spatially and temporally largely controls the distribution pattern and behaviour of organic matter in the lakes (Xiao et al. 2013). The modern surface sediment samples were collected from all the four lakes (Fig. 11.8). The sampling stations were carefully selected and these sampling sites represent the modern sediments that accumulate within these lake basins. Sediment texture of these lakes is dominantly fine fractions such as clay and silt reflecting that the source area catchment is contributing finer fractions into these lake basins (Lone et al. 2017). This also reflects the weathering conditions prevailing in the catchment area. Generally, coarser components such as sand fractions are higher along the lake margins supporting shallow water column and along the sites influenced by inlet streams. Further, it is noted that the small and large watershed drainage inlets also carry large

volumes of coarser sediment from the upper catchment areas and deposit them along the lake margins. Higher clay contents reflect the deeper bathymetry of the lake-basin and the relatively stagnant depositional environment, which allows finer fractions to settle down.

The lakes in Kashmir Valley are the potable sources of freshwater for the region but unfortunately, due to their exploitation for various purposes like drinking, domestic, agriculture, hydropower, these freshwater ecosystems are getting eutrophicated and subsequently shrinking in area. These lakes are located within the intermountain settings and receive large amounts of weathered sediments from the nearby surrounding catchment areas, which consist of diverse lithological formations suggesting a variety of provenance with variable geological settings. Panjal traps and the Agglomeratic slates, granites and metamorphic schists, Quartzites, Triassic limestone and recent Alluvium represent the exposed lithology. These rock types form the important source of weathered sediments that are redeposited into these lakes. The unique climate of the valley (cold winters) and the steep slopes enhance the physical weathering of the exposed surfaces resulting in increased erosion and subsequent deposition of sediments into these lake basins. The sedimentation rate and pattern in these lakes vary spatially and temporally. The sedimentation rate in each Himalayan lake differs due to catchment lithology, slope, vegetation cover and energy of transporting media (inlet stream, rainfall and wind) causing differential erosion. The sedimentation rate reported from few of the Himalayan lakes reveals contribution of sediments due to both natural and human interference. Sarkar et al. (2016) reported sediment rates from the Kashmir Himalayan lakes and revealed that the Manasbal Lake shows a sedimentation rate of 0.44 cm/year while the average sedimentation rates of the Dal and Mansar lakes were measured and observed to be 0.93 and 0.23 cm/year, respectively.

The lake basins in the Kashmir Valley lie in the temperate zone, characterized by wet and cold winters driven by westerlies and relatively dry and moderate hot summers (subdued SW monsoon). Most of the precipitation falling in the area is owing to the western disturbances (westerlies) during the winter and early spring seasons. Additionally water from the local catchment streams, melting glaciers and insitu springs also add water to these lakes. The water and the sediment chemistry of these lake basins are comparable to catchment rock lithology as such the geochemical characteristics of the lake water is mostly influenced by the weathering of the catchment (carbonate and silicates) (Jeelani and Shah 2006; Rashid et al. 2013).

The C/N ratio and OM contents displayed a distinct spatial variation in all the four lakes (Fig. 11.9; Table 11.1). The C/N ratio of the Manasbal Lake sediments (Fig. 11.9a) showed a wide variation in the C/N ratio with an average value of 15, minimum of 7.73 and maximum value of 33.83. The OM in the lake sediments ranges between 3.2 and 29.6% with an average value of 16.89%. Wular Lake sediments (Fig. 11.9b) exhibited an average C/N value of 11.86 with a minimum and maximum value of 9.04 and 22.03. The OM percentage of the lake bottom samples showed a minimum value of 1.42% and maximum value of 14.89%. A lowest C/N value of 5.49 and a highest value of 27.27 were observed for Anchar Lake sediments (Fig. 11.9c). The overall concentration of OM varies along different sampling

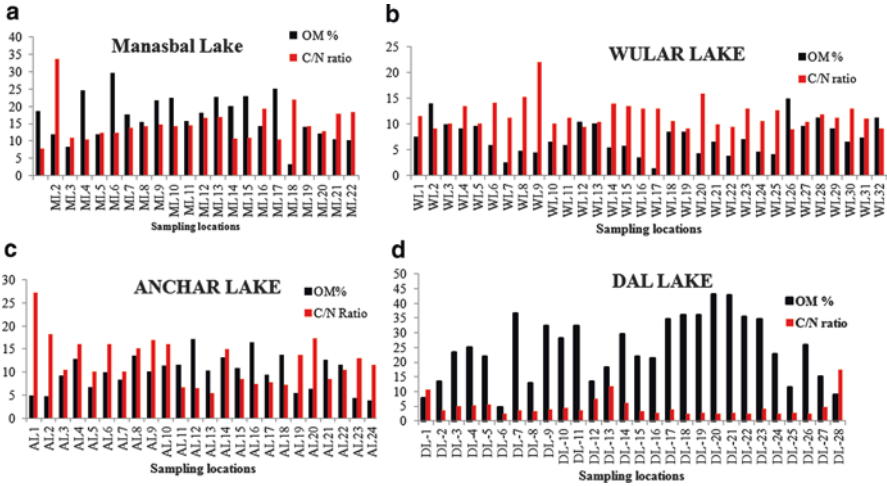


Fig. 11.9 An overview of C/N ratio and OM concentration in lake surface sediments from the four lakes

stations. The OM content ranges between 3.88 and 17.22% with an average value of 9.95%. Further, Dal Lake a hotspot centre for tourism reveals low C/N ratio indicating high N input due to anthropogenic contributions into the lake (Fig. 11.9d). The OM was determined by titration method and it was observed that 19 samples yielded more than 20% of OM contents. The OM in Dal lake sediments exhibited an average concentration of 24.70%, which is highest among all the four lakes. The overall the higher content of OM is concentrated in the lake towards western sampling sites, compared to the eastern and it could be the result of high household output due to large urbanization towards western fringe and addition of untreated municipal wastes directly drained into the lake. The highest value of C/N ratio was recorded to be 17.44 in the station DL-28 and the lowest value was recorded as 2.37 in station DL-6. Most of the sampling station shows C/N value of less than 4 pointing towards the secondary deposition of nitrogen to the lake sediments in addition by the lake vegetation. It is often noted that higher OM content and lower C/N ratio indicate higher productivity of algae and intense wetter conditions associated with high lake bathymetry.

The present-day landscape of the Kashmir Valley came into existence through various tectonic and climatic events. These changing climate conditions and tectonic pulsations have been instrumental in changing sediment transportation and accumulation rates in the Kashmir Himalayan lakes. Thus, the sediment and OM dynamics in Kashmir Himalayan lakes are governed by the presence of riverine and other terrestrial sources and later are accumulated towards the shallow margins of the lake. The amount of OM found in lake sediments is a function of the input of various sources reaching the sediment-water interface and the rate at which OM is degraded by microbial processes during burial (Hedges and Keil 1995). Aquatic flora and fauna, weeds growing within the lake, terrestrial vegetation growing along

Table 11.1 Concentration of OM (%) and C/N ratio in surface sediments of the (a) Manasbal, (b) Wular, (c) Anchar and (d) Dal Lakes

(a) Manasbal Lake			(b) Wular Lake			(c) Anchar Lake			(d) Dal Lake		
S. no.	OM %	C/N ratio	S. no.	OM %	C/N ratio	S. no.	OM%	C/N ratio	S. no.	OM %	C/N ratio
ML-1	18.6	7.73	WL-1	7.54	11.5	AN-1	4.98	27.27	DL-1	7.73	10.68
ML-2	11.8	33.83	WL-2	14	9.18	AN-2	4.77	18.2	DL-2	13.64	3.51
ML-3	8.4	11.03	WL-3	9.98	10.18	AN-3	9.16	10.48	DL-3	23.30	5.01
ML-4	24.6	10.49	WL-4	9.09	13.53	AN-4	12.9	15.99	DL-4	25.04	5.40
ML-5	11.8	12.31	WL-5	9.69	10.17	AN-5	6.68	10.11	DL-5	21.95	5.65
ML-6	29.6	12.32	WL-6	5.83	14.15	AN-6	9.92	16.15	DL-6	4.67	2.37
ML-7	17.6	13.75	WL-7	2.55	11.26	AN-7	8.34	10.15	DL-7	36.65	3.60
ML-8	15.6	14.39	WL-8	4.76	15.31	AN-8	13.49	15.11	DL-8	12.92	3.45
ML-9	21.8	14.81	WL-9	4.38	22.03	AN-9	10.12	16.9	DL-9	32.31	3.99
ML-10	22.4	14.23	WL-10	6.54	10.15	AN-10	11.31	16.15	DL-10	28.12	4.45
ML-11	15.8	14.43	WL-11	5.91	11.28	AN-11	11.63	6.67	DL-11	32.55	3.51
ML-12	18.2	16.79	WL-12	10.4	9.42	AN-12	17.22	6.56	DL-12	13.43	7.68
ML-13	22.8	16.9	WL-13	10.1	10.41	AN-13	10.35	5.49	DL-13	18.21	11.72
ML-14	20	10.61	WL-14	5.47	14.01	AN-14	13.12	14.92	DL-14	29.49	6.11
ML-15	23	10.93	WL-15	5.78	13.49	AN-15	10.91	8.55	DL-15	21.94	3.43
ML-16	14.4	19.23	WL-16	3.47	13.04	AN-16	16.45	7.36	DL-16	21.35	2.84
ML-17	25.2	10.51	WL-17	1.42	13.09	AN-17	9.46	7.69	DL-17	34.76	3.99
ML-18	3.2	22.02	WL-18	8.48	10.63	AN-18	13.82	7.25	DL-18	36.18	2.55
ML-19	14	14.37	WL-19	8.43	9.2	AN-19	5.47	13.68	DL-19	36.14	2.67
ML-20	12.2	12.83	WL-20	4.29	15.96	AN-20	6.27	17.4	DL-20	43.20	2.56
ML-21	10.4	17.99	WL-21	6.56	9.88	AN-21	12.64	8.45	DL-21	42.97	2.78
ML-22	10.2	18.47	WL-22	3.83	9.47	AN-22	11.61	10.49	DL-22	35.68	2.40
			WL-23	7.06	13.01	AN-23	4.38	13.06	DL-23	34.66	4.30
			WL-24	4.65	10.59	AN-24	3.88	11.59	DL-24	22.77	2.39
			WL-25	4.17	12.7				DL-25	11.64	2.89

(continued)

Table 11.1 (continued)

(a) Manasbal Lake			(b) Wular Lake			(c) Anchar Lake			(d) Dal Lake		
S. no.	OM %	C/N ratio	S. no.	OM %	C/N ratio	S. no.	OM %	C/N ratio	S. no.	OM %	C/N ratio
			WL-26	14.89	9.04				DL-26	25.98	2.57
			WL-27	9.57	10.5				DL-27	15.18	4.73
			WL-28	11.31	11.89				DL-28	9.00	17.44
			WL-29	9.22	11.17						
			WL-30	6.59	13.05						
			WL-31	7.37	11.04						
			WL-32	11.22	9.13						

the lake catchments and anthropogenic influences are the primary sources that control the quantity and purity of organic material delivered to the lakes. The amount and type of OM deposited within the lake reflect the ecology and environmental conditions of that ecosystem (Meyers and Lallier-Vergès 1999). The low to moderate content of OM in the lake sediments is attributed to the mixed contributions from both in situ lake flora and fauna and terrigenous detrital sources available along the lake catchment.

The C/N ratio is primarily controlled by the availability of organic material and fine fractions accumulating with a sedimentary basin. However, early diagenesis can lead to both, a decline of C/N ratio inland derived material and an increase of C/N ratios in the planktonic OM. Nevertheless, the C/N ratio provides an important idea about the relative source contribution of terrestrial plants vs. planktonic OM in the sedimentary basins. Algae usually has a C/N ratio ranging from 4 to 10 because algae is rich in proteins and devoid of cellulose (Meyers and Teranes 2001; Meyers 1994). C/N ratios between 10 and 18 suggest that the source of OM was a combination of algae and vascular land-plants.

The C/N ratio of lake sediments reflects intermediate to moderately value of the C/N ratio for all the lake systems which suggest that the primary source of OM is governed by the mixing of both autochthonous algal matter and terrestrial OM. However, the high C/N ratio along certain sampling stations is attributed to the increased particulate matter loads and wastewater discharges from the upper catchments through the ephemeral channels and direct inflow of sewage from the households near the lake margins. This suggests that the increased utilization of the lake catchment for urbanization, tourism, water discharge and agricultural activities in recent years is the primary source contributing OM to the lake sediments.

The small and large watershed drainage inlets carry large volumes of organic rich sediment from the upper catchment areas and deposit them along the lake margins. Further, sediment texture within the lakes also controls the transport and deposition of OM accumulation and that the sediment OM acts as a source of recycled nutrients for lake productivity upon degradation and thereby decreasing the biological oxygen demand (BOD) and support large algal blooms and other aquatic plants in lake waters. Increased catchment soil erosion during the rainy season and the steep slopes of the catchment areas support the high influx of catchment derived organic rich materials into the lake basins. Further, in situ nutrient sources around the lake margins and macrophytes growing in the shallow parts contribute to local OM productivity thus augmenting OM sedimentation.

Paleoclimatic inferences based on OM accumulation and C/N can be deduced using sediment cores retrieved especially from the lake margins, as these margins are dynamic areas and are often subjected to the high and low lake level variations. Any change in the paleo-hydrology of the lake is reflected and preserved in sediments, and thus careful and high-resolution analyses of these sediments using OM and C/N ratio can help in reconstructing the paleo-environmental and vegetation changes around the lake catchments. Further, any anthropogenic impact such as deforestation, over exploitation of lake waters due to unplanned agricultural practices, application of pesticides around the lake catchment areas can be easily detected using these proxy records. A compilation of the C/N ratios in surficial sediments (Table 11.2) for different lakes over the world suggests that these bulk parameters retain source information despite large decreases in the total amount of organic matter during sinking. Considerable variation is evident, in the C/N values in the surface sediments. These changes in the C/N ratios reflect variations in the sources and accumulation of terrestrial and autochthonous organic inputs and prevailing climate. These variations also apparently reflect different diagenetic processes occurring at different water depths. The changes in C/N ratios is sensitive to collective input of OM from different sources along with its selective diagenesis within the lake basins. The two significant factors governing the amount of organic matter in surface sediments of these lake basins are (a) input of OM into the lake basin and (b) detrital sedimentation rates. As such, high sedimentation rates tend to dilute the OM whereas low sedimentation rates allow the OM to be oxidised (Hyne 1978).

From the above discussion, it is reiterated that the distribution of sediments, OM and C/N ratio in lake sediments from Kashmir Valley indicates that the catchment processes in context with present climate provides an important preliminary record of the factors governing the deposition and distribution of organic and inorganic sediments in lakes. Thus, the study suggests that the depositional processes in these lakes are controlled by OM influx, catchment geomorphology coupled with anthropogenic impacts. Further, recent eutrophication of these lakes is essentially simultaneous with large-scale human settlements and the application of agricultural and horticulture fertilizers in the catchment areas.

Table 11.2 A compilation of the present C/N ratio and OM content with other national and international studies

S. no	Lake	Location	Sediment type	C/N ratio	References
1	Bohai Bay	China	Surface sediments	21.3	Gao and Chen (2012)
2	Daihai Lake	China	Surface sediments	8.2–12.1	Hou et al. (2013)
3	Lake Michigan	N America	Surface sediments	9	Meyers and Ishiwatari (1993)
4	Lake Baikal	Russia	Surface sediments	11	Meyers and Ishiwatari (1993)
5	Lake Ohrid	Macedonia	Surface sediments	3–14.5	Vogel et al. (2010)
6	Mangrove Lake	Bermuda	Surface sediments	13	Meyers and Ishiwatari (1993)
7	Naples Harbour	Italy	Surface sediments	0.39–68.8	Rumolo et al. (2011)
8	Taapei Basin	Taiwan	Surface sediments	6.1	Ku et al. (2007)
9	Varthur Lake	India	Surface sediments	23–33	Mahapatra et al. (2011)
10	Walker Lake	Nevada	Surface sediments	8	Meyers and Ishiwatari (1993)
11	Welwich Marsh	England	Surface sediments	14.7	Lamb et al. (2007)
12	Lake Biwa	Japan	Surface sediments	6	Meyers and Ishiwatari (1993)
13	Karlad Lake	India	Surface sediments	9	Babeesh et al. (2016)
14	Berijam Lake	India	Surface sediments	10.95	Vijayaraj and Achyuthan (2016)
15	Kukkal Lake	India	Surface sediments	6	Vijayaraj and Achyuthan (2016)
16	Manasbal Lake	India	Surface sediments	15.0	Present study
17	Wular Lake	India	Surface sediments	11.86	Present study
18	Anchar Lake	India	Surface sediments	12.32	Present study
19	Dal Lake	India	Surface sediments	4.8	Present study
20	Lake Algae	–	–	4–10	Meyers and Ishiwatari (1993)
21	Terrestrial plants	–	–	>20	Meyers and Ishiwatari (1993)

11.5 Conclusions

In this chapter, a detailed overview was carried out on the changes in C/N ratio and OM content with paleoclimatic inferences of the modern lake sediments deposited in four freshwater lakes. The OM and C/N ratio content reveal that the sediments are organically moderate to highly productive (mesotrophic to eutrophic). The variation in C/N ratio and OM concentration of the lake sediments from the Manasbal, Wular and Anchar and Dal Lakes, revealed that sediment distribution, OM and, the C/N ratio in the lake is a function of both in situ and external sources. The C/N ratio reveals a mixed source of OM for all the four lakes suggesting both in situ production of OM by the lake biota and the allochthonous materials deposited by external sources. Anthropogenic impact, aided by landuse pattern changes and prevailing environment has resulted in the significant increase in the amount of OM accumulation in these lakes. More detailed and simultaneous analysis C/N and OM results from lake core sediments will help to better comprehend the past nutrient dynamics and palaeolimnological processes.

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