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S. I. – CEC FRAMEWORK

# Spectral characterization of sediment of two lake water bodies and its surrounding soil in Haryana, India

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**Abstract**
The study presents the physico-chemical and spectral characterization of soil and sediments of two lakes and the surrounding fields of Haryana state in India. The sediment analysis was carried out to assess its general characteristics for utilization as a part in agriculture, landfills and earthworks as well as safety for dumping; the soil analysis was done to determine its suitability for agriculture as well as discerning the existing conditions of lake ecosystem and the nearby area. The study also focusses on morphological details of soil and sediments obtained using scanning electron microscope (SEM) and X-ray diffraction (XRD) technique. The identification of the different elements was done using an energy-dispersive X-ray spectroscopy (EDS). The elements and ions are liable to accumulate in the soil and sediments over long duration of time leading to bio accumulation in the ecosystem and hence is of utmost importance for study. The physico-chemical parameters for the soil and sediments of both the lakes were observed to be within permissible limits. The SEM and XRD results for soil and sediments showed clear differences in morphological properties. The elemental mapping of the soil and sediment along with its quantification done by EDS showed the interrelation amongst the elements of soil and sediments confirming the erosion from the watershed area being one of the major causes of high sedimentation rate in the lakes. The elements showed no serious threat to the environment from the existing data obtained and confirmed the safe utilization of sediments extracted from the lakes.

**Keywords** Scanning electron microscope (SEM) · Energy-dispersive X-ray spectroscopy (EDS) · X-ray diffraction · Index methodology

## Introduction

Soil in general is always in a dynamic system with contamination of fresh soil arising, due to the weathering action of the parent rocks (Antibachi et al. 2012). The nature of the pollutants contaminates the soil varying from natural to anthropogenic sources (Antibachi et al. 2012). The plant growth and the soil stability depend on various physical characteristics of soil including water retention, amount of oxygen, temperature and mechanical resistance which all have a direct impact on the soil. Other characteristics which indirectly affect soil properties are its texture, bulk density, aggregate stability and pore size (Letey 1958; Kar et al. 2020). In general, it has been observed that higher bulk densities and low porosity decreases the oxygen diffusion rates into the soil leading to a reduced plant growth (Rickman et al. 1966; Neira et al. 2015). Soil as a material has great complexities, with the nature and properties of soil varying with concentrations of minerals, oxides, organic matter, microorganisms, and other associated properties like particle size and densities (Cengiz et al. 2004; Owens et al. 2016).

Soil can be easily differentiated based on colour, textures and mineral characteristics with the variability in the soils depending on their topographical features, climate and microbial functions along with watering conditions and associated anthropogenic activities (Cengiz et al. 2004; Zhang et al. 2015; Wani et al. 2017). The change in the soil characteristics may lead to deterioration in the soil quality due to its degradation thereby leading to impacts on human welfare as well as the environment globally (Brundtland 1987; Pozniak 2015; Mishra et al. 2016). In actuality, the changes in the soil characteristics cannot be identified based on some pre-defined

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criteria, since there is no acceptable methodology to quantify its degradation. This often leads to a lack in formation of a meaningful and well-defined soil management strategy (Arshad and Coen 1992; Phillips 2017).

Soil erosion is recognized to be one of the most destructive form of soil degradation and heavily impacts various soil properties (Arshad and Coen 1992; Thomas et al. 2018). The increased agricultural activities, population explosion, urbanization and improper land use management system lead to accelerated soil erosion and runoff instead of rain water infiltration (Leh et al. 2011; Liu 2016). The soil erosion from the lake's terrestrial section leads to formation of fine particles which increases the suspended sediment load into a stream or lake with the vegetation from the surrounding vicinity. The addition of soil particles contributes to heavy metals and other chemicals including nitrogen and phosphorous leading to eutrophication and disturbance in lake ecosystem by increased silt inputs (Wilson et al. 2008; Bing et al. 2013). The increased pollution in the water bodies coupled with low productivity near the croplands can be attributed to excessive soil erosion from nearby sloping grounds of the watershed areas (Shi et al. 2012; Issaka and Ashraf 2017). Further, the weathering of nearby sedimentary and calcite rocks along with increased anthropogenic activities like mining, tillage of agricultural fields, rock cutting for form roads and tunnels and other associated activities leads to additional sediment loads (De Boer and Crosby 1995; Lin et al. 2015), which causes soil erosion and have long existed (Rahman et al. 2009). The study on East Lake in Wuhan, China, is one such effort put by researchers where the lake water quality degradation has been studied in detail through models and the major impacts determined are found associated with soil erosion and degradation. An attempt has therefore been made to study and assess the similar factors in the manuscript below.

The physical, chemical and biological processes of the deposited sediment in the water ecosystem can lead to the modification of the suspended particles thereby leading to varieties of organic and inorganics as part of the sediment load (De Boer and Crosby 1995; Wilkes et al. 2018). In this context, significant research focus has been associated with the determination of sediment characteristics to identify and evaluate the possible sources of sediment influx. The sediment along with increasing the sediment loads also changes the lake water characteristics which in turn affects its designated best use (DBU) based as per Central Pollution Control Board (CPCB) of India. Such changes also affect the existing flora and fauna of lake ecosystem.

In this context, the major aim was to develop efficient management systems and suitable tools for combatting the sediment influx through source recognition (Peters and Walling 1991; Wheatcroft 2000). The sediment characteristics such as morphology and its chemical characteristic also help in identifying the processes involved during transportation and settlement of sediments. (De Boer and Crosby 1995; Lin et al. 2015). In particular, the identification, classification and characterization of the sources of these pollutants require collection and processing of huge number of samples of soils and sediments, collected over long and continuous monitoring periods which might often be cumbersome and impractical over a long-term basis (Douglas et al. 1993; Owens et al. 2016). Further, increased costs of such continuous monitoring practises also render it impractical.

In this regard, microscopy techniques are one of the low-cost methods that are often used to overcome such practical difficulties (Pye and Croft 2007; Jantzi and Almirall 2011). Initially, the microscopic techniques were limited to description of shape and size of the particles but rapid advancement has led to development of new and improved techniques like scanning electron microscope (SEM), energy-dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD) which provides detailed characteristic analysis of the samples with just a small quantity (few micrograms) of samples collected (Maeda et al. 2014). Further, in this principle, microscopic techniques like SEM and EDS are used for data quantification of such samples wherein the XRD analysis focusses on the qualitative results (Kikkawa et al. 2019). In many studies, the focus has been on determination of characteristics based on the morphological studies relating to shape, size and texture as well as chemical characteristics such as elemental data (Pye and Croft 2007; Woods et al. 2014).

Considering the above, the major objective of the study was to determine the spectral characteristics of the soil and sediment through SEM, EDS and XRD to reveal its structure and elemental composition. Further, an attempt has been made to identify the sources of sediment either as natural or as anthropogenic and also to evaluate the role of the soil characteristics in the lake vicinity to determine its effects on the plants and humans. The sediment quality index has further been added as a small component to quantify the sediment properties and its effects on lake ecosystem and environment nearby.

## Site description

The lakes in the study area are located near Morni Hills at an altitude of 30° 42′ N 77° 5′ E in the district of Panchkula in the state of Haryana in India. Lake 1 has the dimensions of 560-m length and 460-m width having a depth of about 5 to 6 m at the centre of the lake. In particular, the depth of the lake has been significantly reduced year on year due to heavy sediment loads from around the watershed area of the lake. Earlier, the lake water used to be utilized for some minor activities like small-scale irrigation and for recreational activities like boating. However, in the actual DBU of this lake as per CPCB guidelines of India, its sediment characteristics and sources were unknown and hence have been undertaken for the study. The view of the lake as well as the sampling location is shown in Fig. 1.

**Fig. 1** View of lake 1 with sediment and soil sampling points located in Panchkula

Lake 2 lies in close vicinity of lake 1 but being smaller in dimension with 365-m length and width. Earlier, activities like pisciculture were carried out in this lake but is presently non-operational due to some associated governmental issues. Similar to the above condition of lake 1, the DBU, characteristics and other associated parameters of lake 2 is unknown presently. The view of the lake as well as the sampling location is shown in Fig. 2.

To summarize this, both the lakes might be considered a fresh water source primarily due to an influx of fresh water from a waterfall nearby which can be considered to be the main source of water and which primarily remains active from August to December of the year. Further as mentioned earlier, there has been a significant reduction in the depth of the lakes over the past few years due to constant erosion from the banks of the lake, the soil erosion from the watershed area which to a maximum extent is used majorly for the purpose of agriculture. Additional sediment deposit could also occur due to regular landslides from the nearby rocks surrounding the main water source, i.e., the waterfall section. The detailed assessment of the lakes and the nearby watershed area has not been conducted and reported anywhere therefore the present study has been undertaken.

## Materials and methods

The following section discusses the methodology involved in collection, preparation and testing of the samples of the sediments and soils and have been described below.

### Sample collection and preparation

#### Collection of soil samples

The soil samples were collected from the fields adjacent to the lakes at five different points in the case of both lakes and have been marked with *red coloured* points in Figs. 1 and 2 respectively. The soil samples were taken at a depth varying from 15 to 30 cm for the determination of various parameters (Motsara and Roy 2008). The top surface of the soil was cleaned from pebbles and dried leaves and a hand auger was used to dig up the soil and the top 1–2-cm layer was removed and discarded; the auger was then again dug and the sample was then collected; the collected sample was then put into a bucket, a clean cloth was then spread on the surface and the samples were

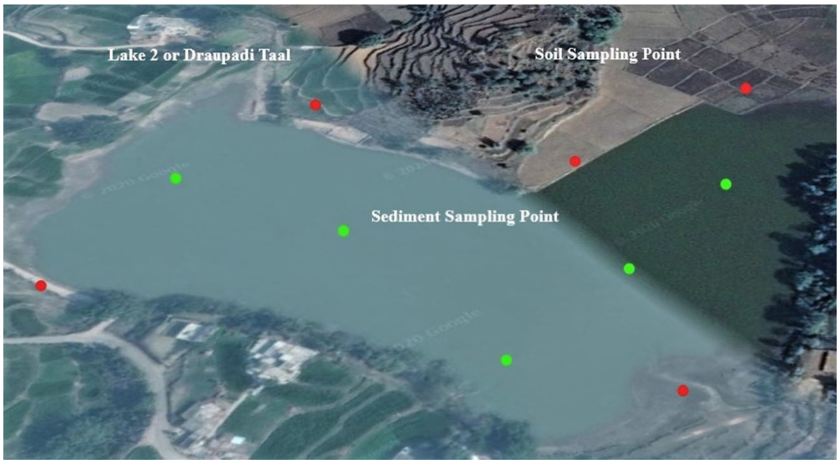


**Fig. 2** View of lake 2 with sediment and soil sampling points located in Panchkula

spread on the cloth for cleaning and removing any external impurities (Motsara and Roy 2008).

The composite samples for the testing purpose for the respective lake were prepared by mixing all the samples collected from the lake bottom together thoroughly and then dividing them into quarters for repetitive homogenization of the samples, by mixing each quarter thoroughly in all directions (EPA 2000). The soil samples were then filled into plastic containers using shovels by alternating sequence technique which includes putting spoonful of soil in the first container then second and likewise and then repeating the procedure again until all the containers are appropriately filled as shown in Figure S1 of the supplementary material. The containers were then sealed and labelled appropriately for testing in the laboratory.

### Collection of sediment samples

The sediment samples were collected from the bed of the lakes at 5 different points as shown in Figs. 1 and 2 respectively and have been marked with green coloured dots for reference purposes. The ideal sampling points for the lake sediments were decided to cover the entire lake bed. The elaborative samples help in determining the sediment properties accurately and precisely. In practise, the samples were collected using a Van Veen grab sampler (JN Sciencetech I.D. 20572517688, item code: 134833654) made from stainless steel material grade SS 304 with a weight of 5 kg in total and a dimension of 24-cm length and 22-cm width was used. It is a common sampler used for collection of fine grain up to a depth of 30 cm (EPA 2000) to avoid loss of fine grained sediments (ASTM 2000). Since the lakes have not been reported for any contamination, only the top layer of about 10–15 cm is of primary interest (EPA 2000); therefore, the first 30-cm layer was collected with the help of the sampler for determination of sediment properties. The volume of collected samples is dependent on the parameters to be determined. For the determination of the sediment parameters in our study, about 3 kg of sediment was collected in total similar to earlier reported literature (Klemm et al. 1990; PSEP 1997; WDE 1995).

A single composite sample was prepared from the collected samples and analysed to obtain the detailed analysis of the sampling area as well as to reduce the cost of the analysis (EPA 2000). Duplicate analyses were performed on at least 10% of the samples for obtaining satisfactory results (GLNPO 1994; USEPA/ACOE 1991; PSEP 1997; USEPA/ACOE 1998). Since there is no fixed rule for number of sampling durations, so field replicates were collected twice a month at an interval of every 15 days and analysed separately in triplicates of each sample to obtain the average of the results. The samples were then sealed and stored in a plastic container for appropriate laboratory testing.

### Preparation of soil and sediment samples

For performing chemical analysis, the samples were prepared differently for each of the chemical analyses to be performed and were based on the guidelines issued by USEPA 1998; APHA Edition 23rd Edition, 2017; USDA Soil Method Manual, 1996 and 2014; RC 353.08; USEPA 1640 and Oxide Conversion Chart etc. which have already been elaborated section-wise in Table 1 against each of the parameter to be determined under heading of method used. Figure S1 of the supplementary material shows the samples of soil and sediments collected from both the lakes.

For the purpose of spectral characterization, 200 mg of sediment and soil samples was heated in a laboratory hot air Memmert type oven (Item code: BTL-27, manufacturer: Bio Techno Lab, Mumbai) having a temperature range of 50 to 250 °C and capacity of 43 to 325 l (Sharma et al. 2019) at a temperature of about 110 to 120 °C for 2–3 h to evaporate excessive moisture (Cengiz et al. 2004). The samples were then removed from the oven and allowed to cool at a room temperature. The soil samples were then grounded with help of pestle and mortar for 15 min to a slightly powdered form keeping in mind not to break the natural structure of the soil and then sieved with a sieve of size less than 0.5-mm diameter having brass frame and stainless-steel mesh (catalog no. J-81, Jayant Test sieves). The 0.425-mm or 420 micron sieve based on Indian standard 469/1972 and having ASTM mesh no. as 40 was used to obtain a powdered form of soil samples whereas in the case of the sediment samples the sieving was done just to obtain a fine powder. The samples were then stored in microcentrifuge tube of Eppendorf company and labelled appropriately with month and location to avoid any anomaly in testing and analysis procedures.

## Sample testing and analysis

### Chemical analysis

The prepared samples were tested for texture, colour, organic matter, organic carbon, pH, cation exchange capacity (CEC), phosphorus, nitrate sulphur, calcium, magnesium, chloride, aluminium, silica and pesticide residues such as alpha BHC, beta BHC, gamma BHC, lindane, OP-DDT, PP-DDT, alpha endosulphan, beta endosulphan, malathion, aldrin, methyl parathion anilophos, chlorpyriphos, chlordane, DDD, DDE, dieldrin, endrin, heptachlor, nonylphenol, 2-methyl, acenaphthene, acenaphthylene, anthracene, benza anthracene, benza pyrene, chrysene, dibenza anthracene, fluoranthene, fluorene, naphthalene, phenanthrene, PCB1254, tPCB, PCDD/F and toxaphene. The samples were also tested for

**Table 1** Physico-chemical parameters and pesticide determination of soil and sediment. Samples collected from lake 1 and lake 2

| | | Lake 1 | | Lake 2 | | | |
|---|---|---|---|---|---|---|---|
| S. no. | Parameter | Soil | Sediments | Soil | Sediment | Method used | Suitable range |
| 1. | Texture | Clay | Fine sand | Clay | Fine sand | Hydrometer | None |
| 2. | Colour | 5YR63 (dull orange) | 7.5YR51 (brownish grey) | 7.5yr64 (dull orange) | 5yr51 (brownish grey) | Munsell System | None |
| 3. | pH | 7.72 | 7.82 | 7.70 | 8.3 | USEPA 1998, 9045 D | pH > 7 (alkaline)<br>pH < 7 (acidic) |
| 4. | Organic matter (%) | 0.34 | 0.68 | 0.16 | 0.24 | APHA 2540, Edition 23, 2017 | – |
| 5. | Organic carbon (%) | 0.19 | 0.39 | 0.09 | 0.14 | USDA Soil Method Manual, 1996 & 2014 | < 0.5% (low)<br>0.5–7.5% (medium)<br>> 7.5% (high) |
| 6. | Cation exchange capacity (meq./100 g) | 17.2 | 11.7 | 12.3 | 8.6 | USDA Soil Method Manual, 1996 & 2014 | 5 (sandy soils)–15 ( high organic content soils) |
| 7. | Phosphorous (mg/kg) | 15.7 | 8.6 | 14.6 | 7.6 | USDA Soil Method Manual 1996 & 2014 | < 10 (low) 10–24.6 (medium) > 24.6 (high) |
| 8. | Nitrate nitrogen (mg/kg) | 162 | 86 | 165 | 82 | USDA Soil Method Manual 1996 & 2014 | < 96 (low) 96–192 (medium) > 192 (high) |
| 9. | Sulphur (mg/kg) | 8.6 | 4.5 | 7.2 | 4.8 | RC 353.08 | < 2 (very low) 2–5 (low) 5–20 (medium) > 20 (high) |
| 10. | Calcium (mg/kg) | 106 | 250 | 40 | 216 | USDA | Only considered low for pH < 4 |
| 11. | Magnesium (mg/kg) | 56 | 95 | 18 | 105 | USDA | < 60 (low) 60–300 (medium) > 300 (high) |
| 12. | Chloride (mg/kg) | 15 | 10 | 10 | 40 | USDA Soil Method Manual 1996 & 2014 | 0–5 (very low) 5–10 (low) 10–20 (medium)<br>20–50 (high) > 50 (excessive) |
| 13. | Aluminium (mg/kg) | 0.04 | 0.02 | 0.03 | 0.03 | USEPA 1640 & Oxide Conversion Chart | – |
| 14. | Silica (%) | 31.5 | 63.5 | 28 | 66.9 | APHA 4500 $SiO_2$ C G $23^{rd}$ Edition, 2017 | – |
| 15. | Alpha BHC (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, $23^{rd.}$ edition 2017 | Not available |
| 16. | Beta BHC (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, $23^{rd.}$ edition 2017 | Not available |
| 17. | Gamma BHC (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, $23^{rd.}$ edition 2017 | Not available |
| 18. | Lindane (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, $23^{rd.}$ edition 2017 | Not available |
| 19. | OP DDT (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, $23^{rd.}$ edition 2017 | < 0.01 mg/kg |
| 20. | PP DDT (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, $23^{rd.}$ edition 2017 | < 0.01 mg/kg |
| 21. | Endosulphan (mg/Kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, $23^{rd.}$ edition 2017 | < 0.0004 mg/kg |
| 22. | Beta endosulphan (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | | < 0.0004 mg/kg |

**Table 1** (continued)

| | | Lake 1 | | Lake 2 | | | |
|---|---|---|---|---|---|---|---|
| S. no. | Parameter | Soil | Sediments | Soil | Sediment | Method used | Suitable range |
| | | | | | | APHA 6410 B & 6440 C, 23 rd. edition 2017 | |
| 23. | Aldrin (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | < 0.00003 mg/kg |
| 24. | Malathion (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | < 0.19 mg/kg |
| 25. | Methyl Parathion Anilophos (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 26. | Chlorpyriphos (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | 0.03 mg/kg |
| 27. | Chlordane (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 28. | DDD (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 29. | DDE (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 30. | Dieldrin (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 31. | Endrin (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 32. | Heptachlor epoxide (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 33. | Nonylphenol (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 34. | 2-Methyl (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 35. | Acenaphthene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 36. | Acenaphthylene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 37. | Anthracene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 38. | Benza anthracene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 39. | Benza pyrene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 40. | Chrysene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 41. | Dibenza anthracene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 42. | Fluoranthene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |
| 43. | Fluorene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23 rd. edition 2017 | Not available |

**Table 1** (continued)

| S. no. | Parameter | Lake 1 |  | Lake 2 |  | Method used | Suitable range |
|---|---|---|---|---|---|---|---|
|  |  | Soil | Sediments | Soil | Sediment |  |  |
| 44. | Naphthalene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23rd edition 2017 | Not available |
| 45. | Phenanthrene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23rd edition 2017 | Not available |
| 46. | PCB1254 (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23rd edition 2017 | Not available |
| 47. | tPCB (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23rd edition 2017 | Not available |
| 48. | PCDD/F (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23rd edition 2017 | Not available |
| 49. | Toxaphene (mg/kg) | Not detectable | Not detectable | Not detectable | Not detectable | APHA 6410 B & 6440 C, 23rd edition 2017 | Not available |

heavy metals namely arsenic, cadmium, copper, lead, chromium, zinc and mercury through procedures mentioned in APHA, 2012. The results were compared with standards prescribed by authorities for their suitability from agricultural and environmental point of view as well as to confirm the toxicity of soil and sediments.

The equations mentioned in a report on sediment characterization and parameter estimation (Trannum 2006) were used for determining some parameters in the case of sediments that cannot be measured *in situ*. The report mentions the suitability of the usage of these equations for depth less than 500 m of the water body. Since the depth of the lakes in our study was less than 500 m, these equations were deemed fit to be utilized for our study. In actuality, the parameters should preferably be measured onsite directly (Trannum 2006), but due to lack of resources, the following equations could be used as suitable substitute for the determination of grain size, percentage of Pelite and total organic matter (TOM) (Trannum 2006). The equations are summarized below.

$$\text{Grain size } (\mu\text{m}) = 229e^{-0.0054(m)} \tag{1}$$

$$\text{Pelite } (\%) = 1.19e^{0.012(m)} \tag{2}$$

$$\text{Total Organic Matter (TOM)} = 0.51e^{0.0072(m)} \tag{3}$$

where $(m)$ is the depth at which sediment sample was collected.

### Field emission scanning electron microscope and energy-dispersive X-ray spectroscopy

The soil and sediment samples were deployed to a voltage of 10 kV after sputter coating with gold (Au) to avoid the charging of the samples as well as for better dispersion of the electron beam. The double-sided carbon tape was used for sticking the samples and the readings were taken after necessary coating of the samples with Au. The image of soil and sediments were detected through Everhart–Thornley detector in a field free mode for SEM. The same instrument was used for determination of energy-dispersive X-ray spectroscopy (EDS) of the samples.

### X-ray diffractometer

The atomic and molecular structure of crystal and other inorganic materials can be evaluated through X-ray diffraction (XRD) which in principle detects X-ray beams which gets diffracted in particular directions with each X-ray diffraction denoting the plane of crystal (Manohara and Belagali 2017). The samples were compressed into powdered form and the spectra of the samples were obtained through Rigaku Corporation's Smart lab 9 Kw rotating anode X-ray diffractometer with counter detection system (Kakoria et al. 2018). The target material is copper and the fine focus filament material is used as cathode (Kakoria et al. 2018). A small-angle X-ray scattering unit is also attached to the system.

### Sediment Quality Index

The Canadian Council of Ministers of the environment (CCME) coded SEQI 1.0 as a user-friendly excel model that can be used for the calculation of sediment quality of the freshwater and marine systems (CCME 2007). The data tool is used for inserting the data for calculation of index on both site specific as well as average basis for sites. The Sediment Quality Index (SeQI) results obtained from the CCME methodology conforms to the guidelines for freshwater standards as prescribed by the Interim Sediment Water Quality Guidelines (ISQG) and probable effect levels (PELs). However, to expand the application of the model, users can upload specified set of guidelines for studying specific cases also (CCME 2002b). To, summarize, the application of the model, it utilizes a pre-defined set of 33 parameters based on the toxic equivalent factors (TEQs) defined under CCME (2002a) and CCME (2001c), as specified by the World Health Organization (WHO). The calculations are done based on the Ontario Severe Effect Level (SEL) with total organic carbon being one of the important parameters. In principle, the SeQI is determined on the basis of the parameters comprising of pesticide residues and concentrations of heavy metals. Further, parameters which are not determined by the user are either set to (− 1) or left blank; the parameters which are not detectable are set to 0 (CCME 2001a; b). In general, SeQI results obtained from application of this model varies between 0 and 100 which are categorized as excellent (95–100), good (80–94), fair (65–79), marginal (45–64) and poor (0–44) (CCME 2001a, b).

## Results and discussions

The results obtained have been discussed in detail in each of the sections described below.

### Physico-chemical and pesticide analysis

The results for the physical and chemical analysis for the soil and sediment samples for both the lakes have been summarized in Table 1. The results summarize the various physico-chemical tests performed: the methods used for conducting the tests along with their prescribed limits of the parameters tested.

The texture of the soil was determined to be of clay and the sediments were a mix of sand and clay composing it into fine sand from both the lakes. The variation in the texture might be observant due to seasonal variations (Gupte and Shaikh 2014). The colour of the soil also plays an important role depending on soil moisture, organic components and mineral composition. The soil colour is therefore an important factor for plant protection against frost since the darker soils with high organic content usually tend to absorb more heat (Jackson 2008). The Munsell system was used for determination of colour of both soil and sediments on the basis of hue, value and chroma (Stiglitz et al. 2016). The colour of the soils was lighter as compared to sediments thereby confirming the presence of humus into sediments from the erosion of the top layer of soil containing humus as a major component which is generally obtained as end product of degradation of leaves, twigs and other small insects and usually adds a darker colour to the soil (Spargo 2013).

Further, the soil and sediments from both the lakes were determined to be mildly alkaline in nature with values of pH corresponding to 7.72 and 7.82 for soil and sediments of lake 1 respectively and 7.70 and 8.30 for soil and sediments of lake 2 respectively. The pH is an important factor in controlling many reactions which affect the environmental conditions for flora and fauna (Das 2000; Kumari et al. 2019). The results are summarized in Table 1.

The humus has high proportion of organic matter (OM) which increases the productivity in lakes with respect to the fish production (Kumari et al. 2019). The organic matter in the soil varies from trace concentrations in desert areas to almost 90% in wetlands. The organic matter was observed to be higher in sediments than in the soils due to continuous erosions. The percentage of organic matter was determined to be 0.68 and 0.34% for sediments and soil for lake 1 and 0.24 and 0.16% for sediments and soil from lake 2 respectively (as summarized in Table 1) which indicates better yield from lake 1 which is observant from the fact that pisciculture is prevalent in the lake. This might be attributed to the fact that the samples were collected in monsoon season which generally leads to heavy rains washing away the top soil rich in organic matter into the lakes.

Similarly, values of organic carbon (OC) were also observed in soil and sediments from both lakes as shown in Table 1. The OC for soil and sediment for lake 1 was determined to be 0.19% and 0.39%. For Lake 2, the OC value was found to be 0.09% and 0.14% for soil and sediment respectively. This indicates a slightly higher value of organic carbon for both soils and sediments for lake 1; however, the overall productivity for both soil and sediments for both lakes is relatively low as per the classification of the standards. The organic carbon (OC) is found to be in higher proportions in fine soils such as sediments due to larger particle bonding to particles than the courser soils as smaller pores protect carbon (Trannum 2006). Further, the presence of organic carbon also gives an idea about the productivity with higher values indicating higher fertility (Banerjea 1967; Sachidanandamurthy and Yajurvedi 2006).

The cation exchange capacity (CEC) in the soil varies from 5 meq/100 g in sandy soils to 15 meq/100 g in soils with high organic content as per standards summarized in Table 1 (Spargo 2013). It was determined for our study conditions that the CEC values for soil and sediment were 17.2 meq/100 g and 11.7 meq/100 g respectively for lake 1. Similarly, the CEC values were determined to be 8.6 meq/100 g and 2.3 meq/100 g respectively for sediment and soil for lake 2 respectively as summarized in Table 1. This signifies that both soil and sediments for both the lakes have relatively high CEC values and therefore can retain and supply nutrients specially cations such as Ca, Mg, K, Al and H (Spargo 2013).

The phosphorous is an essential element in soil for plant growth but the excess concentrations often outflow into lakes with the erosion process causing deterioration in water quality by promoting eutrophication and algal bloom (Bhateria and Jain 2016) whereas a lesser amount may lead to reduced plant growth (Spargo 2013). For our study, the phosphorous concentrations were found to be higher in soils with a value of 15.7 and 14.6 mg/kg respectively for both the lakes. Similarly, the concentrations of phosphorous in the sediments were determined to be 8.6 and 7.6 mg/kg for lakes 1 and 2 respectively. Further, the high alkalinity in the soil allows an easy plant uptake of phosphorous in the soil (Spargo 2013). The level of phosphorous in the soil is high and low for sediments which is good for lakes but it is high in soil confirming a good yield for plants. The nitrogen levels were classified as low as per the standards for sediments with a value of 86 and 82 mg/kg for lakes 1 and 2 respectively but were classified as medium in the case of soils with a value corresponding to 162 and 165 mg/kg respectively for lakes 1 and 2. The range of values for sulphur classifies the soil into a medium category and the sediments into a low classification range as per standards shown in Table 1 for both the lakes. Sulphur plays an important role in nitrogen fixation and is stored in soil's organic matter with moderate levels of sulphur which is supposed to have a good result for plant growth (Spargo 2013) thereby confirming a good status of soils for plant growth.

In principle, the Ca ion concentrations can be considered to be less in the context of its correlation with low pH levels. Cations like calcium are important for fruits and roots for the growing of plants with deficiency leading to problems in cell membranes and walls of plants (Spargo 2013). The deficiency is only found in soils with low pH levels and can be removed by lime treatment (Horneck et al. 2011). The value of pH above confirms the adequate amount of calcium in the soils since the pH is in suitable alkaline range. Similarly, magnesium is an important element which boosts up plant metabolism and is a part of chlorophyll; the deficient soils can easily be recovered by either dolomitic lime or Epsom salts (Spargo 2013). The value of magnesium shown in Table 1 lies in low range for soils with values of 56 and 18 mg/kg for lakes 1 and 2 respectively but were in medium classification for sediments for both lakes with values of 95 and 115 mg/kg for lakes 1 and 2 respectively. The results also confirm a deficiency of magnesium in the soils near the lake which may interfere with photosynthetic activities in plants leading to low plant metabolism (Spargo 2013).

The major source of chloride concentrations is attributed to irrigation water or manures applied in the fields (Horneck et al. 2011). The values of chloride concentrations for both soil and sediments of both the lakes are summarized in Table 1 and were classified as medium category for both soil and sediments of the lakes. Higher concentrations of aluminium can induce toxicity in plants and may interfere with the solubility and uptake of phosphorous. As aluminium is not a plant nutrient, the effects of aluminium are prevalent in soils with pH less than 5.5 (Spargo 2013). The concentration of aluminium lies in trace quantities for both soil and sediment samples for both the lakes. In essence, such low concentrations have no effect since the pH of the soil is in alkaline range.

The percentage of silica is higher in sediments of both the lakes with the values of 63.5 and 66.9% in lakes 1 and 2 respectively. In comparison, the percentage of silica was determined to be 31.5 and 28% respectively in soils of lakes 1 and 2 respectively. In principle, sediments have a higher proportion of silica content and is a characteristic property of them due to terrestrial inflows from drainage basins and stability of silica in the sediments (Tallberg et al. 2014).

Pesticides are the substances used for removal of any unwanted organism of plant other than crop from the fields. There are a huge number of formulations of pesticides commercially available which is used in agriculture (Azevedo 1998; Özkara et al. 2016). It is thought that less than 0.1% of pesticide kills pests with the rest accumulating in the surrounding environment (Pimentel and Levitan 1986; Arias-Estévez et al. 2008). The bioaccumulation of these pesticides often magnifies in the environment with certain category of pesticides lasting in excess of two decades (Larson et al. 1997). Since the degradation of pesticides involves complex procedures (Ghadiri and Rose 2001), its determination in the soil should be considered imperative and essential. In this context, Table 1 summarizes the determination of different pesticides which lies in the vicinity of the soil and sediments of both the lakes. It was observed that *pesticides were not detected* in the soils due to the use of cow dung and other natural fertilizers which is locally available and applied in small quantities.

The following parameters were determined using Trannum equation (Trannum 2006)

### Determination of grain size

Using the above equation (Eq. 1) in the methodology section, the grain size of the sediments was determined to be 221.69

and 224.11 μm respectively for lakes 1 and 2. The value of *phi* (φ) here lies between 3 and 2; hence, the sediments can be classified as fine sand as per Krumbein *phi* (φ) scale table (Krumbein and Sloss 1963; Wentworth 1922; Udden 1914; Dreiseitl et al. 2013; Lemenkova 2018) where *phi* (φ) value is used which is expressed as negative logarithm of base 2 of the particle size expressed in millimetres and is more convenient to be used for expression of size.

### Determination of percentage of pelite

In actual conditions, the proportion of pelite or fine-grained sedimentary rock particles is supposed to increase with depth. In other words, it signifies that the fineness of the particles increases with depth (Trannum 2006). Using Eq. 2 mentioned in the methodology section, the percentage of pelite in the sediment was determined to be 1.28% and 1.24% for sediments of lake 1 and lake 2 respectively and is associated with fineness of particles confirming it to be in the range of fines as obtained in grain-size analysis above.

### Determination of total organic matter (%)

The percentage of TOM indicates the solubility of contaminants in water with the larger value indicates the greater number of particulates in water (Trannum 2006). The TOM% can be calculated through Eq. 3 of the methodology section above so using Eq. 3, the percentage of TOM% in the sediment was determined to be 0.52% and 0.53% for sediments of lake 1 and lake 2 respectively which indicates the lesser number contaminants in the form of particulates and more in dissolved forms.

## Spectral characterization

Field emission scanning electron microscope (FESEM), X-ray diffraction (XRD) and energy-dispersive (EDS) techniques were used for spectral characterization of soil and sediment samples and the results of the same are discussed below.

### Soils of lake 1 and lake 2

Figure 3 a and b illustrate the FESEM image of the soils near lakes 1 and 2 respectively which are used for cultivation of different variety of crops throughout the year. It is observed from Fig. 3 a that the soil of lake 1 can be considered to be in the form of snowflakes which are agglomerated structure having round smooth edges, whereas Fig. 3 b representing the soil of lake 2 consists of soil bounded tightly together forming thin sheets rolling over each other. The edges of the sheets are sharp and the smaller sized broken particles in the form of hail with sharp edges cover the surface of these sheets; both the images have less amount of dark spaces between flakes which shows less voids and signifies low porosity (Liu et al. 2005). The agglomerated structure may be attributed to the presence of clay particles in the soils which is also confirmed by the low porosity which is a characteristic property of clay.

The sharp peaks obtained in both the XRD figures of Fig. 4 a and b respectively were made by plotting the difference in angle of incidence and angle of reflection known as 2 theta on

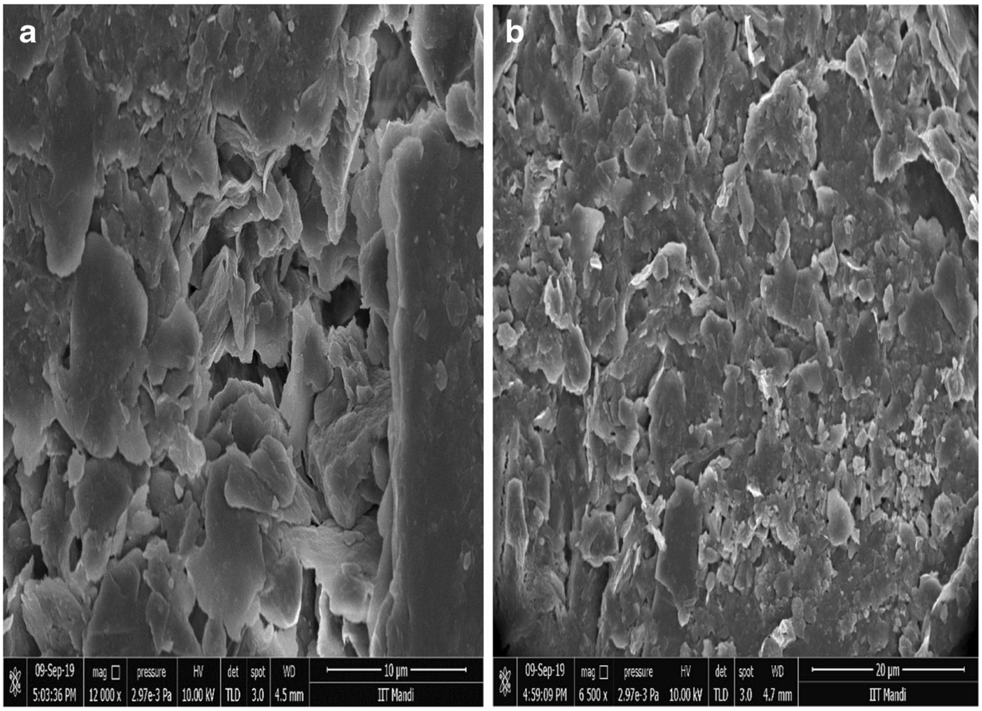


**Fig. 3** **a** SEM micrograph for soil of lake 1. **b** SEM micrograph for soil of lake 2

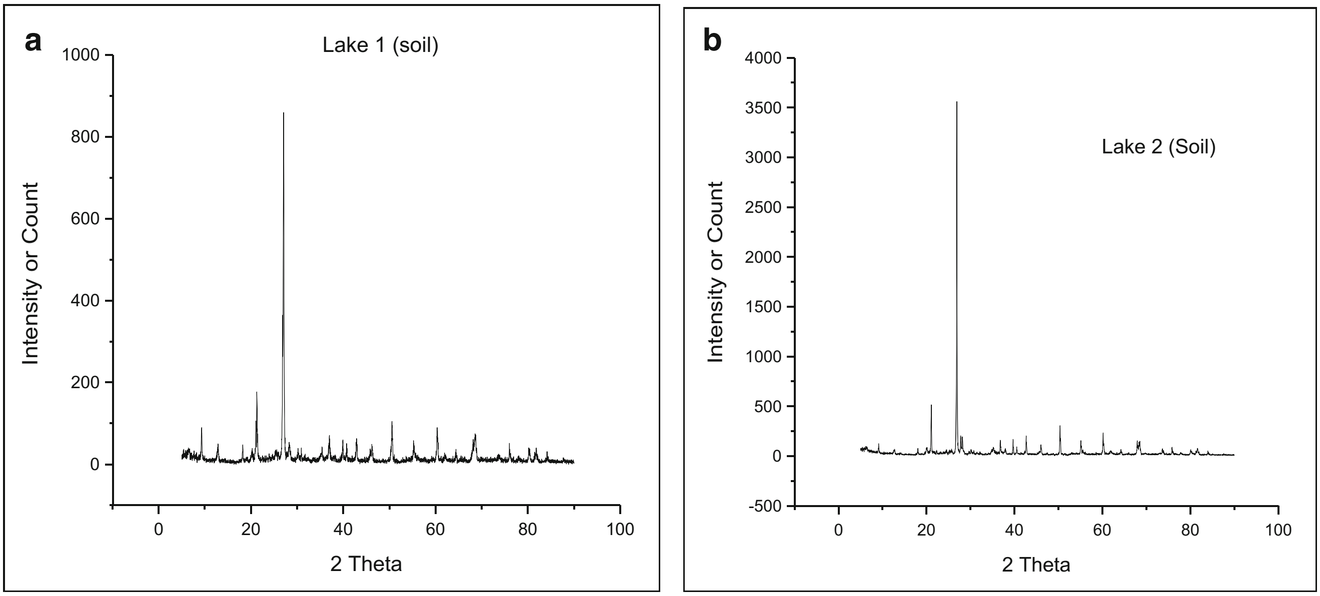


**Fig. 4** **a** XRD graph lot for soil of lake 1. **b** XRD graph lot for soil of lake 2

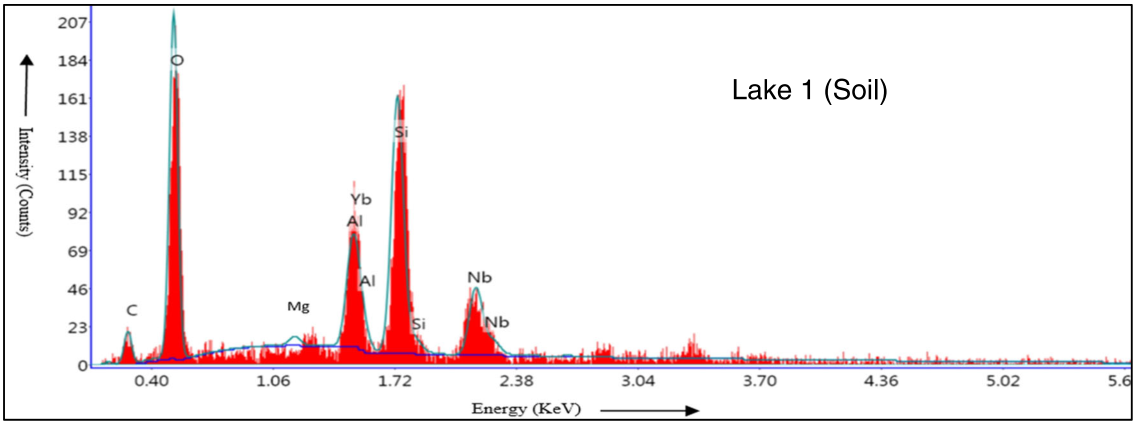
the *x*-axis, and intensity of the X-ray light being focussed on the sample or counts on the *y*-axis is indicative of the presence of crystalline material in the samples which is well confirmed by the EDS pattern obtained and illustrated in Fig. 5 a and b which shows the presence of various elements that are crystalline in nature for both the soils of lake 1 and lake 2.

The EDS is plotted between Kev on the *x*-axis and counts per second (Cps) on the *y*-axis. Figure 5 a shows the image of EDS for the soil of lake 1. The elements detected from the EDS analysis were carbon (C), oxygen (O), aluminium (Al), ytterbium (Yb), silicon (Si) and niobium (Nb). Similarly, Fig. 5 b shows the image of EDS for the soil of lake 2. The elements detected from the EDS were carbon (C), oxygen (O), magnesium (Mg), aluminium (Al) and silicon (Si). In this context, Tables 2(a) and (b) describe the quantitative analysis of the soil samples of lake 1 and lake 2 respectively along with EDS micrograph. The total weight percentage of the sample was considered to be 100% and the weight% of each of the different elements were considered in comparison with total weight% of the sample. Considering this, the weight percentages of oxygen, silicon and niobium were found to be highest amongst all the other elements discovered in the soil sample of lake 1 and the weight% of oxygen (O), carbon (C) and aluminium (Al) was found to be highest amongst all the other elements discovered for soil sample of lake 2.

The oxygen is an important element for survival of humans. The air comprises of 21% of oxygen; therefore, the abundance of this element in the environment leads to high levels of oxygen in the sample. The studies from the past show that aeration is an important factor for plant growth (Gilbert and Shinve 1942; Khondaker et al. 2005). The availability of this element is largely dependent on the soil's water content and diffusion through the soil (Stolzy et al. 1961; Schjønning et al. 2002). The soil having less moisture content shows abundance of the element oxygen in the soil (Geisler 1965).

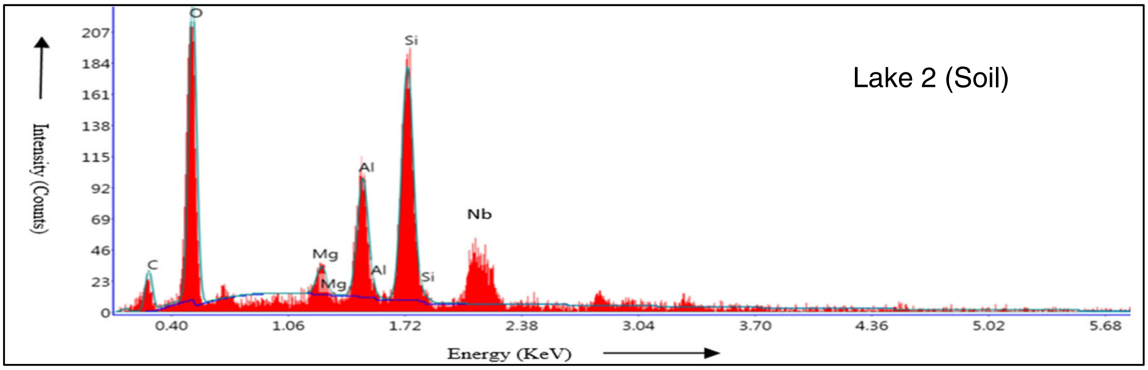
The sources of silica comprise soil, sand, dust and weathering of rocks. The soil comprises of 28% of silica in earth's crust and is the 2nd most abundant element after oxygen. It is essential for strengthening plant walls and their growth by absorption of nutrients. The niobium is a transition metal associated with silicates and has been found to exist as alloys with oxygen (British Geological Survey 2011). The abundance of oxygen in the soil might have caused the formation of oxides of the metal and therefore the element niobium to exist in large concentrations. The niobium is associated with igneous and carbonaceous rocks (British Geological Survey 2011). The element does not have any specific biological effects like human poisoning or death but the dust may cause irritation in the eyes, nose and skin (Emsley 2001).

Similarly, carbon (C) is an essential component of soil organic matter (Ontl and Schulte 2012). The increased carbon content indicates the presence of high level of organic matter leading to improvement in water retention, greater plant productivity, reduced soil erosion and better ground and surface water quality (Ontl and Schulte 2012). The sources of organic carbon in soil are the decay of fresh plants which are rich in organic matter (Ontl and Schulte 2012). However, the presence of cations in acidic ranges in soil can severely affect the uptake of organic carbon in soil (Mossor-Pietraszewska 2001). However, it was observed for our study that the soil lies in basic range thereby reducing the effects of cations on uptake of organic carbon. Plants are also found to be affected by the toxicity of Al kV: 10 Mag: 3500 Takeoff: 9.9 Live Time(s): 30 Amp Time(µs): 7.68 Resolution:(eV) 128



**a**

kV: 10 Mag: 3500 Takeoff: 9.9 Live Time(s): 30 Amp Time(µs): 7.68 Resolution:(eV) 128



**b**

**Fig. 5** **a** EDS micrograph for soil of lake 1. **b** EDS micrograph for soil of lake 2

**Table 2** (a) Quantitative analysis results of soil of lake 1 using EDS micrograph. (b) Quantitative analysis results of soil of lake 2 using EDS micrograph

| Element | Atomic number | Weight % | Atomic % | Series | Error % |
|---|---|---|---|---|---|
| a | | | | | |
| C | 6 | 9.94 | 18.75 | K | 21.46 |
| O | 8 | 38.98 | 55.17 | K | 10.70 |
| Al | 13 | 5.52 | 4.63 | K | 11.88 |
| Yb | 70 | 9.35 | 1.22 | K | 21.31 |
| Si | 14 | 20.27 | 16.35 | K | 7.39 |
| Nb | 41 | 15.94 | 3.89 | K | 13.85 |
| b | | | | | |
| C | 6 | 17.65 | 26.41 | K | 0.04 |
| O | 8 | 42.06 | 47.25 | K | 0.20 |
| Mg | 12 | 2.61 | 1.93 | K | 0.02 |
| Al | 13 | 11.48 | 7.65 | K | 0.09 |
| Si | 14 | 0.01 | 16.76 | K | 0.21 |

(Kollmeier et al. 2001; Marienfeld et al. 2000). Al diminishes the growth of new roots and seedlings affecting the plant growth (Mossor-Pietraszewska 2001).

## Sediments of lake 1 and lake 2

Figure 6 a and b show the SEM images of sediments of lake 1 and lake 2 respectively.

It may be observed from the images the presence of sharp-edged flakes which have a large number of smaller sized particles in both figures respectively in comparison to the SEM image of soils of lake 1 and lake 2 respectively. This is because the sediments are formed after erosion of soil into the lake, and the repeated action of water waves over the surface breaks down the soil into much finer particles which is confirmed by the presence of smaller sharp-edged flaky particles fitted into each other like fine gradient soils such as silt. The

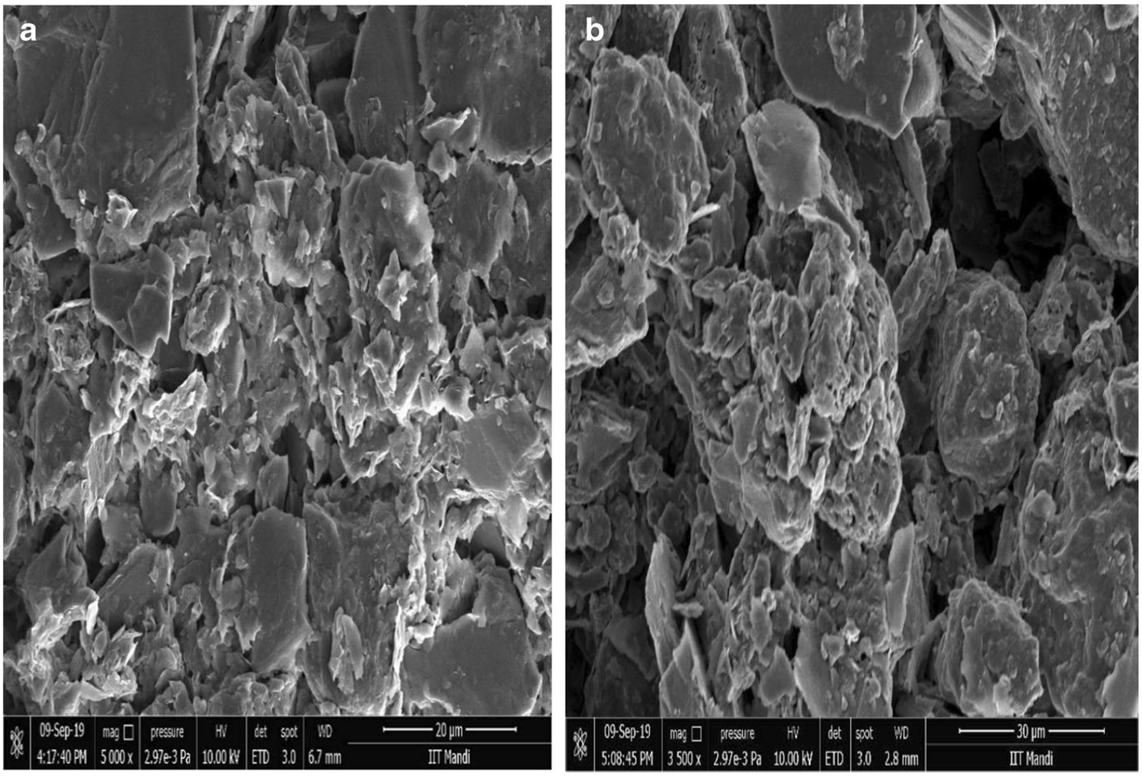


**Fig. 6** **a** SEM micrograph for sediment of lake 1. **b** SEM micrograph for sediment of lake 2

presence of a greater number of dark spaces is visible between the finer small-sized sharp-edged flaky particles which confirms a loosely held structure and greater porosity, similar to observations of earlier study conducted by Liu et al. (2005).

The sharp peaks obtained in both the XRD Fig. 7 a and b are indicative of the presence of crystalline material in the samples as confirmed by the EDS pattern obtained in Fig. 8 a and b for lakes 1 and 2 respectively. The common elements detected from the EDS analysis of the sediments from both the lakes were oxygen (O), aluminium (Al) and tantalum (Ta) as observed from Tables 3(a) and (b) respectively. Interestingly, additional components like magnesium (Mg), thulium (Tm) and silicon (Si) were observed from lakes in sediment 1 while additionally carbon was observed in sediments from lake 2. However, it was observed from Table 3 that for both the lakes the proportion of oxygen and tantalum (Ta) was highest amongst all the elements detected.

To further explain the EDS results of the sediments, it may be mentioned that tantalum is available in the soil and freshwater as well as sea water in the form of particulates (Filella 2017). The source, transportation and the chemistry of this element are still unknown due to its insufficient information and limited use (Filella 2017). Further, no significant effects of environmental pollution due to tantalum have been reported (Filella 2017; TOXNET 2017).

It may be further deduced that many properties of soil and sediments from both the lakes are almost similar with slight changes observed in the morphological structure of soil and sediments.

This can be further elaborated from the knowledge that the ores of tantalum and niobium are the same and both the elements appear identical to each other. The tantalum is found to be present in the form of oxides with niobium known as columbite [(Fe, Mn) (Nb, Ta)$_2$O$_6$] (Scheib et al. 2012). The

**Table 3** (a) Quantitative analysis results of sediment of lake 1 using EDS micrograph. (b) Quantitative analysis results of sediment of lake 2 using EDS micrograph

| Element | Atomic number | Weight % | Atomic % | Series | Error % |
|---|---|---|---|---|---|
| a | | | | | |
| O | 8 | 42.39 | 79.89 | K | 9.29 |
| Mg | 12 | 3.19 | 3.96 | K | 22.62 |
| Al | 13 | 7.36 | 23.56 | K | 12.43 |
| Tm | 69 | 6.21 | 6.63 | M | 31.87 |
| Si | 14 | 0.01 | 0.03 | K | 99.99 |
| Ta | 73 | 40.84 | 55.68 | M | 8.29 |
| b | | | | | |
| C | 6 | 6.69 | 16.35 | K | 20.22 |
| O | 8 | 36.77 | 67.46 | K | 9.99 |
| Al | 13 | 7.58 | 8.25 | K | 10.49 |
| Ta | 73 | 48.96 | 7.94 | M | 7.00 |

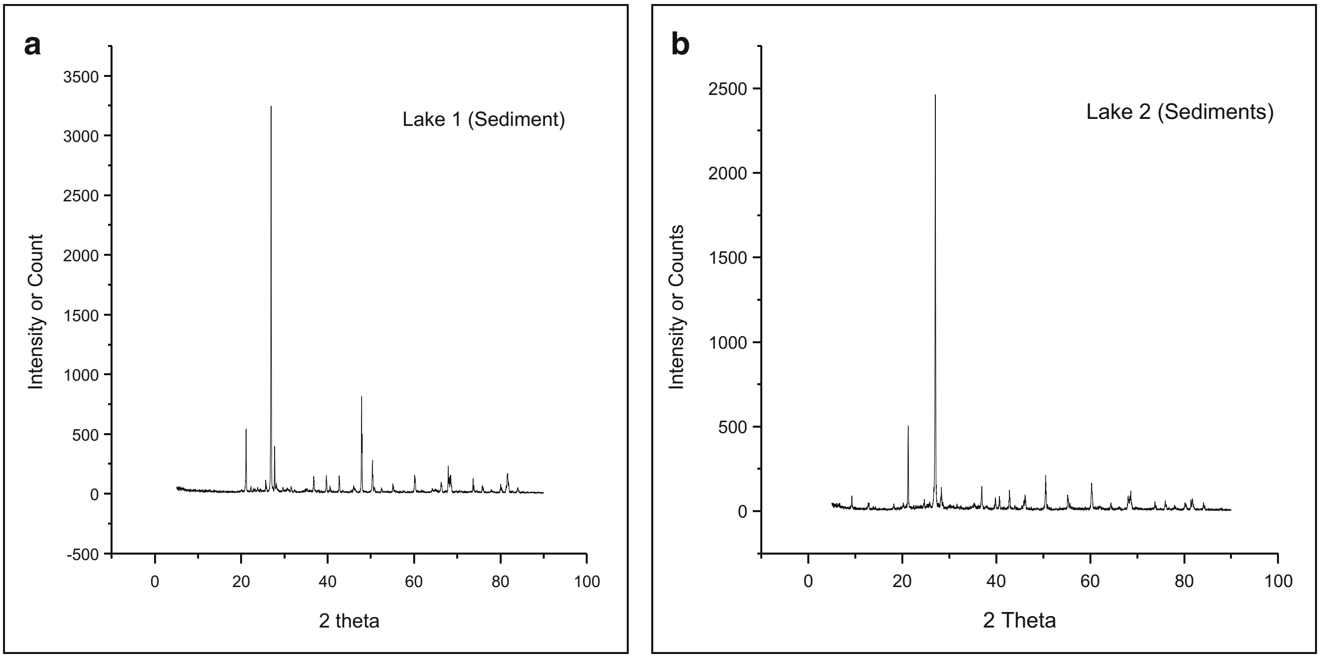


**Fig. 7** **a** XRD graph lot for sediments of lake 1. **b** XRD graph lot for sediments of lake 2

concept of (Nb/Ta) ratio can be used to study earth composition as well as composition of other planetary bodies (Green 1995; Jochum et al. 2000). The presence of Ta in the sediment might be in relation to the presence of Nb in the soil as they are derived from a common ore and significantly a result of excessive erosion of soil from the banks and watershed area into the lakes forming a part of sediments. This can be easily correlated comparing the soil and sediments of both the lakes which show the presence of these elements in either form.

The absence of carbon in sediment of lake 1 might be due to low percentage of organic carbon detected in sediments of lake 1. The presence of silica in the sediment of lake 1 and absence in the sediment of lake 2 might be due to heavy soil erosion from the nearby watershed area of lake 1 which carries the soil from around the vicinity of lake 1 into the lake to form the part of the sediment, since the soil has huge weight% of silica in comparison to the weight% of silica in the soil of lake 2, which is critically low; therefore, an absence of silica might have been detected in lake 2. Therefore, the absence or presence of certain elements in the soils and sediments of lake 1 and lake 2 respectively is dependent on the geological factors as well as geographical and topographical features of the sites and vicinity surrounding it.

### Sediment Quality Index

The Sediment Quality Index (SeQI) was determined on the basis of the parameters as summarized in Tables S1(a) and S1(b) of the supplementary material to check its quality in comparison to different freshwater standards of ISQG and PEL respectively. In operation of the model of the 33 parameters required for the computation of SeQI, (0) shows the parameters that were not detected and majorly representing the 26 pesticide compounds considered for the analysis along with 7 heavy metals. This also signifies that the pesticide as well as heavy metal concentrations were well below the specified limits wherein applicable. Using this modelling conditions, the sediment quality of the lakes was observed to be of the highest category (excellent). In general, the excessive sedimentation on the lake beds can be prevented by dredging the lake sediments at adequate times and the sediments can be either disposed at appropriated sites or alternatively can be mixed with surrounding soil of the lake watershed to enhance its geological properties, so that the mixed content could be used as an earth fill or agricultural soil or for other landfill works.

## Conclusions

The following major conclusions may be drawn from the study:

1. The physico-chemical parameters determined for the soil in vicinity and sediments of both the lakes were found within the prescribed limits and hence may be concluded that the soil and sediments do not pose any threat to the lake water ecosystem and the surrounding environment.
2. No pesticide residuals were determined from the soil and sediment analysis of both the lakes as generally organic manure and fertilizers are used in the soil wherever any agricultural activities are carried out. Hence, it may be

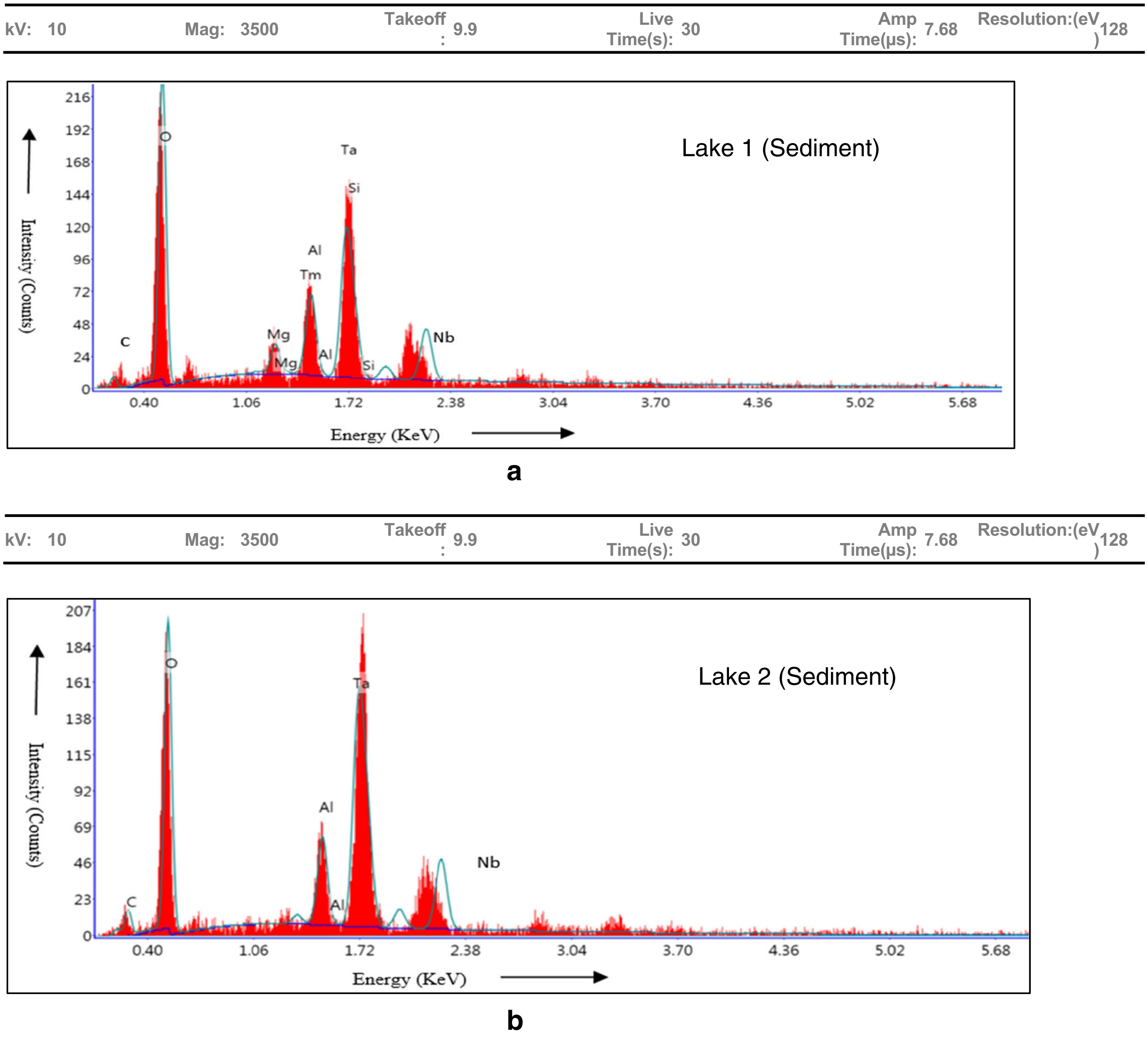


**Fig. 8** **a** EDS micrograph for sediments of lake 1. **b** EDS micrograph for sediments of lake 2

concluded that there are no pesticidal contamination of the soils and sediments.

3. The heavy metal concentrations determined for both the soil and sediments of lake 1 and lake 2 were found to be within the permissible limits and do not impose any serious threats to the lake ecosystem as well as the surrounding catchment area.
4. The organic matter and the organic carbon content in the soil of lake 1 and lake 2 is 0.19% and 0.09% respectively which is < 0.5% and therefore falls in the category of low according to Table 1; the reason for low organic content may be excessive soil erosion which leads to reduction in the fertility from the top soil; therefore, additional measures like adding fresh manure to the fields, and tillage of soil, can be helpful in elevating the organic content of soil; also according to the present status, the soil can be suitable for growth of crops such as paddy, maize, sugarcane, groundnut and vegetables such as potatoes, cauliflower, cabbage and beans which can also help in improvement of soil organic content in the long duration of time.
5. It may be concluded from the FESEM analysis conducted that the morphological structure of the soils represented were flaky, agglomerated and round edged confirming the characteristics of clay for soil samples collected from vicinity of both the lakes.

Similarly, the FESEM analysis revealed that the morphological structure obtained from the sediments of both the lakes showed a sharp edged, flaky and porous structure being classified as sand.

6. The experimental results of FESEM analysis for sediments were also corroborated numerically through the grain size determined from the Eq. 1 of Section 4.1 which clearly categorized the grain size in fine sand with the presence of fine percentage of pelite in it.
7. The EDS graph showed the presence of a large number of similar elements in the surrounding soil and sediments of both the lakes which were further confirmed by the XRD graphs showing sharp peaks indicative of the presence of natural crystalline materials in both soils and sediments. Hence, it may be concluded that the source of the sediment in the lakes is primarily due to the surrounding soil.
8. The surrounding soil and the sediments of both the lakes reported highest proportions of oxygen (O), carbon (C), tantalum (Ta), silica (Si) and niobium (Nb) in a descending scale and the presence of the other elements and transition metals. These are natural elements occurring in soil, and certain elements like tantalum and niobium (metals from same ore) have been less studied with no report of any harmful environmental impacts. Further, it may be concluded that since the ore of both these elements are the same and had been identified in both soils and sediments of both the lakes in either form, the formation of sediments in the lake is highly correlated with the erosion of the soil in the banks and surrounding areas of the lakes.
9. It was concluded from the determined values of Sediment Quality Index (SeQI) that they were in the topmost category and hence were deemed to be free from any harmful contaminants and do not pose any environmental threat to the lake ecosystem and surrounding areas nearby.

## Importance and future aspects of study work

The study gives an insight of the relationship between soil erosion and its association with the severe problem such as pollution of lake water bodies. The study can be a useful tool for the readers and researchers to determine the effects and influences of the various components such as earth metals, pesticides and heavy metals present in the surrounding soil on the lake water as well as its sediments. The study also depicts the possible consequences if the quantity of these components exceeds the permissible limits as well as uses appropriate indexing method such as SeQI to quantify the severity of the problem. The study can be an important tool in determining the impacts of urbanization, deforestation and excessive land use in the form of soil erosion of the nearby banks of watershed areas on the water bodies such as lake and rivers. Similar studies have already been carried in other countries such as Wuhan, China, and hence a similar attempt has been made to carry out such kind of research work in an Indian context to ascertain the implications.

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