ABSTRACT

High altitude Himalayan lakes are considered as potential hotspots for studying the impact of climate change as well as long-range transport of pollutants. Their remote location, less human interference, shallow depth, and fragile and sensitive nature make these lakes suitable for such scientific research. However, in the high altitude lakes of Nepal, such studies seem scarce. The present study was carried out with the aim of understanding the response of Panchpokhari, a high altitude lakes located in Central Nepal Himalaya, in the present context of changing climate and long-range transport of pollutants, by analyzing water chemistry, lake-bed sediment and distribution of diatom species as the bio-indicators. Panchpokhari (meaning 'five lakes' in Nepali language) is one of the famous, sacred pilgrimage sites for Hindus and Buddhists. These are natural, glacial-fed, shallow lakes situated at an elevation of 4160 masl between $28^0$2.41'- $28^0$2.54'N latitudes and $85^0$42.96'- $85^0$43.25' E longitudes in Sindhupalchowk district of Central Nepal.

With respect to physiochemical characteristics, the Panchpokhari lakes are in oligotrophic state with negligible amount of nutrients (total nitrogen and total phosphorus) and low dissolved ions (electrical conductivity and total dissolved solids). The pH value recorded in pre-monsoon was lower < 4 scale in some sites as compared to post-monsoon season (< 6 Scale). The acidic nature of lake water reflects either atmospheric inputs or geo-lithological sources from the catchment. With respect to cations, Ca^{++} was the dominant in both seasons, which was thought to be due to bed rock weathering, particularly calcium-bearing rocks such as calcite, gneisses, limestone, etc. In terms of anions, Cl^- and HCO_3^- were the dominant in the pre-monsoon and post-monsoon season, respectively. Presence of high silica in inlet and outlet might be derived from weathering of silicates and alumino-silicates from bed rock and soil from the catchment. Likewise, dominance of Ca^{++} and HCO_3^- ions is due to calcium bearing bed rock and carbonate weathering, respectively. The presence of high Cl^- is mainly due to high rate of organic decomposition. Cations like Na^+ and K^+ were significantly correlated with pH. Similarly, EC, TDS and SO_4^{--} were significantly correlated with Cl^-, which was mainly due to low pH and weathering of bed rocks.

The ^{210}Pb dating showed sedimentation rate of Lake-1 of Panchpokhari lake series to be 0.1cm per year. Based on this rate of sedimentation, the core sediment of 26 cm length gives more than 200 years history of the lake.

In terms of trace metals (TMs) in surface water, the lake is receiving the inputs from anthropogenic source through long-range transport of atmospheric pollutants. In both the seasons, the average concentrations of trace metals were found in the increasing order of Bi < Th < Tl < Be < Ga < Cs < U < Cd < As < Sc < Mo < Ag < Co < V < Se < Sn < Cr < Pb < Rb < Cu < Ni < Sr < Ba < Sb < Ti < Zn < Mn < Al < Fe and Bi < Tl < Th < Be < Cd < Cs < Ga < U < Co < V < Sc < Mo < Ag < As < Sn < Pb < Rb < Ni < Ba < Sr < Sb < Cr < Cu < Ti < Mn < Se < Zn < Al < Fe. But, most of the trace metals lie within WHO Guideline Values and European Standards for drinking water quality, except Fe and Mn. Seasonal variation was observed in the concentration of trace metals like Fe, Al, Zn, Mn, Ti, were higher in post-monsoon, while Bi, Th, Tl, Be were lower during pre-monsoon season, possibly due to the dilution effect of monsoon rain. Enrichment Factor (EF) showed very low Al (0.261 ppb) to extremely high Ti (3457 ppb) in both the seasons, which could be due to the inputs of pollution from different sources. The metals like Ni, Cr, Sn, Zn and Pb showed significant enrichment, Cd, Cu Se and Mo very high enrichment and Tl, Ag, As and Sb were extremely high enriched, indicating likely anthropogenic sources.

Moreover, depth-wise distributions of average trace metals were found to vary considerably and occurred in the increasing order of Hg < Lu < Cd < Tm < Ag < Tb < Bi < Ho < Eu < Se < Yb < Er < Mo < Be < Dy < Sn < Pr < As < U < Sc < Co < Th < Cs < Ga < Nd < Cu < La < Pb < Ni < Li < Ce < Cr < Zn < Rb < Mn < Ba < Ti < Fe. The lake-bed sediment showed the concentrations of trace metals in three distinct layers, i.e., uppermost layer (0-10 cm), middle layer (10-18 cm), and lowermost (18-26 cm) in broadly varying concentrations. With the exception of Fe, Mn, As, Zn, Se, Pb, Mo and Hg, almost same concentration of metals was observed in the core sediment from 18-26 cm depth. However, notable fluctuations were seen in the core depth of 10-18 cm, which could be either due to natural geological disturbances or possibly due to the influence of atmospheric pollutants during the period between 180 and 100 year before present. The concentration of trace metals in the uppermost layer, i.e. from 0 to 10 cm depth could likely be due to recent atmospheric transfers and deposition of pollutants at the bottom of lake over the past few decades. Enrichment factor (EF) varies from very low for Bi (0.003 ppm) to extremely high for Ti (12136 ppm) within (0 to 26 cm) depth. Most of the rare earth metals like Nd, Sm, Gd, Er, Ag and V were seen to be significantly enriched. Likewise, Sb showed very high EF and Ti showed extremely high enrichment. This trend suggests that, the lake-bed sediment was enriched over time either due to long-range transport of pollutants or from mineral dissolution in the surrounding catchment of lakes washed during monsoon rains. Similarly, Geo-accumulation value showed uncontaminated to moderately contaminated level, and Pollution Index (PI) value showed non-polluted levels in most of trace metals, strong level of PI was observed for Se and Sb, and very strong level for Ag. Deposition of organic matter was also found increased in the lake-bed sediment; especially on the upper layer of sediment and high carbonate deposition as well.

In connection to diatom species, altogether, 43 taxa were identified in the littoral zone, whereas 34 taxa in the lake-bed sediment. The dominance of *Acnanthes, Aulocasira, Tabellari, Eunotia,* and *Pinnularia* taxa from the different substrate like algae, bryophytes (Marchantia and Moss), submerged stone, sand, sediment and mud, in the littoral zone, and *Eunotia, Aulacosira, Tabellaria, Pinnularia* and *Fragillaria* taxa were dominant in the lake-bed core sediment. However, the presence of some acid sensitive species like *Acnanthedium* and *Psamothidium* and acid tolerant species such as *Eunotia, Acnathes, Navicula,* and *Fragillaria* indicates that the lake has been responding with changing climate, and this could either be due to long-range pollutant deposition or leaching minerals from the surrounding catchment.