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Review Article

Recent Contributions in the Field of Sediment Geochemistry

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Sediment geochemistry is a powerful tool to investigate earth surface processes because sediments record geochemical signatures of their provenance, generation, transport, deposition, and environmental conditions. A significant advancement in the technology of analytical geochemistry has made geochemical analyses of sediments more rapid and precise, which together provided an impetus to the study of sediment system. As a result, high-quality research papers on sediment geochemistry have been published during the last five years from India. A foreseeable growth of research and an increase in the publication are likely in the future because of the new set-ups of state- of the- art analytical instruments for geochemical research at various research and academic institutions in India. Here we are presenting the published important work on sediment geochemistry under three categories, i.e., weathering, erosion, deposition and provenance determination; sediment geochemistry as palaeoclimate proxy; and environmental geochemistry.

Keywords: Sediment; Geochemistry; Weathering; Provenance; Palaeoclimate; Environment

Introduction

Sediments form by weathering and erosional processes operating on the exposed crust of the earth. The source rock structure and composition, environmental factors (atmospheric chemistry, temperature, and rainfall), geomorphic factors (tectonics and topography), biological factors (vegetation and anthropogenic activities), and period elapsed for weathering control the mineralogy and geochemistry of the sediments. Hydraulic sorting and mixing are phenomena which modify the sediment composition during transport and sedimentation. Depositional processes modify sediment geochemistry by precipitating soluble ions around clastics under the influence of depositional conditions, e.g., Eh and pH conditions. Despite a complex sequence of processes modify the sediment geochemistry, in situ weathering, sediment sorting, and mixing processes are the major defining factors of the sediment's geochemistry. Chemical weathering of rocks fractionates weatherable minerals from resistant minerals (see Vyshnavi *et al.*, 2013; Vyshnavi and Islam, 2015; Gaur *et al*. and Patel *et al*., 2014). Hydraulic activity during transport fractionates the coarse-grained particles from the fine-grained weathered products (see Khanna *et al*., 2011; Shynu *et al*., 2011; Rao *et al*., 2015). The sedimentary sorting produces different size grades of the coarse-grained material, such as sand, pebble, cobble, etc. The coarse-grained size grades mainly contain resistant minerals or rock fragments, the original unweathered constituents of the source lithology. However, the fine-grained weathered and resistant mineral fragments behaving hydrodynamically similar manner get homogenised in the suspension during transport (Owens *et al*., 2005). Unlike the coarse-grained sediments, this phenomenon of natural homogenization of the fine-grained sediments produces a better representative sample of the average composition of the provenance (McLennan *et al*., 1993; Fralick and Kronberg, 1997; Weltje and Eynatten, 2004). Therefore, understanding the provenance lithology using the sediment geochemical composition has been a major research objective of many studies in India in the last few years (e.g., Ahmad and Chandra, 2013; Rashid *et al*., 2015; Singh, 2010; Tripathi *et al*., 2013).

Weathering of rocks controls the mineralogy and composition of secondary minerals (essentially clays)

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(Fedo *et al*., 1995). In turn, the clay minerals partitioned into the fine-grained fractions during sorting, control the geochemical composition of the clastic sediments. Thus, the geochemical composition of the sediments has been used to calculate weathering indices (e.g., chemical index of alteration-CIA) to quantify the degree of chemical weathering (Nesbitt and Young, 1982, 1984; Fedo *et al*., 1995). The quantification helps to infer climatic conditions of weathering in the provenance. The CIA index has been extensively used to study weathering conditions of the provenance and also used as an important proxy to understand the palaeoclimate (see Sharma *et al*., 2013; Vuba *et al*., 2014; Chauhan *et al*., 2013b; Sheikh *et al*., 2014).

The carbon and nitrogen composition (elemental and isotopic) of organic matter associated with detritus are also useful to understand productivity and biological processes in the provenance of sediments. Total organic carbon (TOC) and total nitrogen (TN) have been used to understand the source of organic carbon (Choudhary *et al*., 2013; Agrawal *et al*., 2015). Source of carbon can be identified using ^{14}C, ^{12}C, ^{13}C isotopes. Radiocarbon (^{14}C) dating provides the age of the carbon, which is useful in dating sediment deposits (Kotlia *et al*., 2010; Raj *et al*., 2015). $^{13}C/^{12}C$ ratios are required to calculate $\delta^{13}C$ values to identify C3 and C4 photosynthesis pathways and type of vegetation in the provenance (see Agrawal *et al*., 2015; Choudhary *et al*., 2013; Das *et al*., 2010; Kotlia *et al*., 2010). In addition to $\delta^{13}C$, $\delta^{15}N$ values (calculated using $^{15}N/^{14}N$ ratios) is also used as an important proxy to the vegetation in the palaeoclimate studies (Choudhary *et al*., 2013; Agrawal *et al*., 2015). Phosphorus fractions (organic, inorganic and iron bound) extracted from sediments have also been used as an important proxy for the biological productivity and weathering conditions in the provenance (Srivastava *et al*., 2013).

Minerals are not only the source of elements, needed as nutrients for vegetation or as metals for the technological use of civilization, but minerals also release contaminants and pollutants through chemical weathering or anthropogenic activities, such as mining, metallurgy, energy usage, agriculture, transport, and industrial activities. The fine-grained sediments hold important clues on the environment because of the nature of their constituents. Besides carbonates, phosphates, sulphides, sulphates, clays and oxy-hydroxide of Fe, Al and Mn significantly control the contaminant and pollutant dynamics in the sediments (Brown Jr and Calas, 2011). In the last five years, studies on sediments pollution have been undertaken on lakes (Purushothaman, *et al*., 2012; Sheikh *et al*., 2014), rivers (Verma *et al*., 2012; Hejabi and Basavarajappa, 2013; Giri *et al*., 2013), aerosol (Agnihotri *et al*., 2015), and road dust (Mathur *et al*., 2011; Singh, 2011; Pathak *et al*., 2013). To assess the pollution level in the sediments various indices have been calculated using geochemical data of samples and reference materials, for example, enrichment factor (EF), geoaccumulation index (Igeo), pollution load index (PLI) and concentration factor (CF) (see Giri *et al*., 2013; Silva *et al*., 2014). Sequential extraction of various chemical fractions in sediments has also been used to know the association and form of metals in the polluted sediments (Hejabi and Basavarajappa, 2013).

A considerable advancement in the field of geochemistry and its analytical tools has enabled sediment geochemistry to be a powerful tool to comprehend geochemical information on provenance, paleoclimate, and the environmental assessment of sediments. A quite large number of papers have been published in India and elsewhere on sediment geochemistry. Here in this review, we present the important research on sediment geochemistry from India, during 2010 to 2015.

Weathering, Erosion, Deposition and Provenance Determination

Weathering and denudation shape the earth's surface and in the result produce sediments. The sediments from the source area get transferred by geological agents to the depositional basins. During the production of sediments and then its transit to deposit, geochemistry of sediment gets evolved. In this section, we mainly document papers related to the geochemistry of *in situ* rock weathering, provenance studies, lakes and rivers sediments, and offshore sediments received from the Indian rivers.

Papers on rock weathering in the Himalayan region were contributed by Vyshnavi and Islam (2015) and Vyshnavi *et al*. (2013). Vyshnavi and Islam (2015) studied two weathered profiles developed on porphyry granite gneiss and granite gneiss in the Alaknanda valley of the Garhwal Lesser Himalaya. By the use of major, trace and rare earth elements the study found that the climate and tectonic milieu was responsible for the development of such weathered profiles in the Himalayan sector. Vyshnavi *et al*. (2013) studied the elemental behaviour during weathering in a highly eroded and humid region with high annual rainfall of ~2600 mm on granodioritic lithology at Anini village, at an altitude of 1644 meters, in the NE Himalaya of Arunachal Pradesh. The study inferred that the variable geochemical proxies in soil profile are resultant of high precipitation in the tectonically active north-eastern Himalaya. Gour *et al*. (2014) examined the geochemical alteration of rocks and minerals and transport of weathering products in the southern Purulia district, West Bengal. They have shown that the studied part of Purulia district underwent intense chemical weathering and physical disintegration. Patel *et al*. (2014) carried out a geochemical and mineralogical study of bauxite deposits of the Mainpat Plateau, Sarguja, central India. The presence of bohemite and goethite was found to be due to an intense weathering during the formation of the bauxite deposit. The extremely high values of CIA (100) supported an intense weathering origin of the bauxite deposit.

The phosphorus fractionation study has been applied to both in rock weathering (Mishra *et al*. (2013) as well as lake sediments (Purushothaman and Chakrapani, 2015). Mishra *et al*. (2013) have studied phosphorus (P) fractionation pattern on two different rock types, i.e. amphibolites and granitic gneisses, subjected to semi-arid and humid climatic conditions in the catchment of the Kaveri river, southern India. They have suggested that with the increase in weathering inorganic P transformed to organic fraction, which resulted in the net loss of P causing high P availability for the fertile soil in the Kaveri catchment. Purushothaman and Chakrapani (2015) have studied the high altitude lakes of Kumaon Himalaya (Nainital, Bhimtal, Sattal, and Naukuchiatal), India. They have concluded that relationship between total P and major elements in sediment showed that P was sequestered more by calcium than iron and aluminum oxides, as carbonate flourapatite. The study also showed that biogenic silica and sulphate were major competitors of phosphorus for sorption sites of iron oxides, which resulted in the release of phosphorus from sediments.

The source lithology and chemical weathering aspects in the provenance are the most important aspects dealt in many studies on sediments from different parts of India. These studies mainly used major elements, trace elements including REE, and radiogenic isotopes of Sr and Nd on sediments from different environments. Studies from the Kashmir valley of the Himalaya includes loess-paleosol and lake sediments by Ahmad and Chandra (2013) and Rashid *et al*. (2015), respectively. Fluvial sediments from the upper Ganga River and its tributaries of the Garhwal Himalaya was studied by Singh (2010). Khanna *et al*. (2011) studied stream sediments from Pinjaur Dun, whereas Verma *et al*. (2012) have studied sub-sand size fraction of the suspended sediments of the Himalayan Tawi river. Tripathi *et al*. (2013) and Mondal *et al*. (2012) have studied alluvial sediments of the Ganga plains. From the peninsula, sediments from the Mahi and Godavari rivers, and Kachchh dryland fluvial system were studied by Sharma *et al*. (2013), Vuba *et al*. (2014) and Prizomwala *et al*. (2014), respectively. Rao *et al*. (2015), Shynu *et al*. (2011) and Prajith *et al*. (2015) studied sediments from Mandovi-Zuari estuaries. Sappal *et al*. (2014) studied Pichavaram mangroves sediments, and Mazumdar *et al*. (2015) studied Krishna-Godavari (K-G) and Mahanadi offshore basin sediments.

Ahmad and Chandra (2013) in a detailed study on chemical weathering and provenance of loess-paleosol sediments of the Karewa Group of Kashmir Valley found that the sediments were derived from the mixed source rocks, a large provenance with variable geological settings, which apparently have undergone weak to moderate recycling processes. In the geochemical study of Wular Lake sediments from Jammu and Kashmir, northern India, Rashid *et al*. (2015) attempted to understand the relative role of physical and chemical weathering processes. Their investigations have revealed the clay–silt dominant Wular Lake sediments were derived as a result of low to moderate chemical weathering in the source region.

The study of Singh (2010) examined major, trace and REE compositions of sediments from the upper Ganga River and its tributaries in the Himalaya to study the weathering in the Himalayan catchment region and to determine the dominant source rocks to the sediments in the Plains. The study indicated silicate weathering has not been an important process in the Himalayan catchment region of the Ganga River. The geochemical comparison has shown that the Higher Himalayan Crystalline Series were the dominant source. Khanna *et al*. (2011) studied stream sediments from Pinjaur Dun to understand the geochemical characteristics in general and REE fractionation in oxygenated surface environments in particular. They observed that the geochemistry of Pinjaur Dun sediment samples probably reflects both the mechanical dispersion/erosion of catchment's host rocks and the hydromorphic transport and transfer of REE from the aqueous phase to the stream sediments.

The Sr and Nd isotope study of sediments from the Quaternary Indo-Gangetic plains by Tripathi *et al*. (2013) displayed large variation in $^{87}Sr/^{86}Sr$ ratios and only a limited range of the εNd values. The study showed that isotopically the western part of the Indo-Gangetic plains has a significant juvenile component, surface sediments from east and north of theYamuna in the central Indo-Gangetic plains were largely sourced from the High-Himalayan Crystallines. In the southern part, sediment budget was largely attributed to the peninsular lithologies. Mondal *et al*. (2012) in their geochemical study of floodplain sediments of the Hindon river of the Ganga plain suggested that the active tectonics of the Himalaya and effect of monsoon climate enhanced physical erosion of the source rocks of the Siwaliks. They have pointed out that low chemical weathering favoured Hindon in retaining parental and tectonic signature even after recycling. The chemical behaviour of the sub-sand size (<0.062 μm) fraction of the suspended sediments of the Himalayan Tawi river was studied by Verma *et al*. (2012). They have found that the Th/Sc and Zr/Sc ratios reflected a change from the felsic-dominated metamorphic and igneous rocks of the upper reaches to the sedimentary terrain of the lower reaches. The major contribution from the felsic continental crust was shown by the rare earth elements (REEs) patterns showing negative Eu anomalies and light rare earth elements (LREEs) enrichments as compared to the upper continental crust.

Sharma *et al*. (2013) studied the sediments deposited by the Mahi River in a tectonically active, semi-arid region draining the Deccan Traps in western India. The low CIA values and presence of basalt fragments and smectite in the samples suggested incipient weathering in the semi-arid Mahi catchment. The UCC normalized light REE depleted patterns in the Mahi sediments confirmed Deccan basalt contributions from the provenance with about 70–75% basalts and 25–30% Archean biotite-rich granitoid. Vuba *et al*. (2014) studied the riverbed sediments from lower reaches of the Godavari river and suggested that they were derived from weathering of felsic rocks. The REE pattern in the lower Godavari sediments was found to be influenced by the degree of source rock weathering. They found high values of CIA suggesting a moderate chemical weathering environment. Prizomwala *et al*. (2014) evaluated the provenance characteristics of the Kachchh dryland fluvial system. Major sources of sediments within catchment were identified as upland sedimentary rocks of Juran and Bhuj Formation sandstone-shale and middle reaches volcanic Deccan Trap Formation basalt.

A study by Rao *et al*. (2015) found that suspended particulate matter (SPM) and sediments of Mandovi-Zuari estuaries show the intense chemical weathering of laterites in the catchment. The claim of intense chemical weathering was strengthened by high $^{87}Sr/^{86}Sr$ ratios at river end stations of both estuaries. High Nd and near uniform values of εNd along both estuaries depicted the influence of lateritic weathering and anthropogenic contribution of ore material. Shynu *et al*. (2011) studied REE in the SPM of the Mandovi estuary and found that the mean total-REE and light REE to heavy REE ratios were lower than that of the average suspended sediment in the World Rivers and Post-Archean average Australian shale. Strong to moderate correlation of the total REE with Al, Fe and Mn in all seasons indicated adsorption and co-precipitation of REEs with aluminosilicate phases and Fe, Mn-oxyhydroxides. They concluded that Fe-Mn ore dust is the most dominant source of REE. Prajith *et al*. (2015) analysed mineralogy, major elements (Fe, Mn, and Al), REE and yttrium (Y) of bulk sediments in four gravity cores recovered along the main channel of the Mandovi estuary, western India. They concluded that its texture primarily controlled the REE of sediments, and REE of dominantly ore material in the upper/middle estuary, and dominantly silicate material in the lower estuary/bay.

Sappal *et al*. (2014) studied sediment cores from the Pichavaram mangroves to establish the abundance, distribution, and enrichment of REE to track the sediment sources and infer biogeochemical processes occurring in the mangrove wetlands. The Pichavaram sediments showed the origin of REE from the natural weathering of post-Archean charnockitic and gneissic terrane. Principal-component analysis delineated three main processes controlling REE distribution in Pichavaram, namely natural weathering, inherent physicochemical processes, and *in situ* biogeochemical processes occurring in the mangrove environment.

Mazumdar *et al*. (2015) studied sediments of the cores collected from Krishna-Godavari (K-G) and Mahanadi offshore basin. Data on bulk major, trace and REE compositions and clay mineralogy of the fine-grained sediments have shown that the Mahanadi sediments were primarily derived from the felsic rocks belonging to the late Archean-early Proterozoic peninsular gneissic complexes. Whereas, the Krishna-Godavari sediments were derived from the mixing of the late Archean-early Proterozoic peninsular gneissic complexes and Late Cretaceous Deccan basalt sources.

Sediment Geochemistry as Paleoclimate Proxy

Sediments hold important clues on the past geology and climate of depositional basins. It is a challenge to explore for the past climatic signatures in sediment archives to understand the future climate changes. Sediment geochemistry, along with other proxies of climate change, has become very useful in tracing the past climatic excursions. We document here important research work on unconsolidated sediment deposits of the Quaternary period,where the geochemical proxy is an important proxy among others in the paleoclimate study. Studies in this regard include lake deposits of the Himalaya (Choudhary *et al*., 2013; Srivastava *et al*., 2013; Kotlia *et al*., 2010; Agrawal *et al*., 2015; Das *et al*., 2010), the Ganga plain (Saxena *et al*., 2015) and the peninsular region (Chauhan *et al*., 2013a; Chauhan *et al*., 2013b; Prasad *et al*., 2014; Raj *et al*. 2015). Studies on fluvial deposits of the Narmada valley (Sridhar *et al*., 2015) and Cauvery delta (Singh *et al*., 2015) in the peninsular region have also yielded good results. Offshore sediments from the western Bay of Bengal helped in understanding the Himalayan sediment supply during the last glacial maxima (LGM) (Tripathy *et al*. 2014).

Lake deposits have been found to be very productive in the palaeoclimatic study of the Himalayan region. A landslide dammed 4.9-m-thick lake sequence in the semiarid Garhwal Himalaya, was studied by Srivastava *et al*. (2013) to understand past monsoonal variations in the region. Organic phosphorus (OP) and inorganic apatite phosphorus (AIP), along with other proxies, indicated that the Indian summer monsoon ameliorated in the early Holocene after 12 ka cooling, and it appears that all the proxies from the lake have captured this globally recognized early Holocene warming. Four phases of wet conditions (intensified monsoon) were recognized at ~11.5 ka, ~11–10.5 ka, ~10–9 ka and ~8–7 ka with maximum uncertainties of ~1000 years. The wet phases were characterized by high magnetic susceptibility, increased OP, and reduced AIP. Another tectonic lake in the Champawat district of eastern Kumaun Himalaya formed at ca. 21500 BP was studied by Kotlia *et al*. (2010). Multi-proxy data (carbon isotopes, pollen analysis, mineral magnetism and clay minerals) revealed well-established abrupt climatic events globally in the last 20,000 years, such as the LGM, Older Dryas, Younger Dryas, Holocene warming, and 8.2 ka and 4.2 ka events. They have suggested that the inter-tropical convergence zone may have played a key role in controlling the behaviour of the southwest monsoon since the LGM.

The study of Choudhary *et al*. (2013) found an average sedimentation rate of 3.6 mm/year for a sediment core (35 cm) from the Lake Bhimtal, NW India with a provisional 100 years of sedimentation history. The data on total organic carbon (TOC), total nitrogen (TN), total sulfur (TS), stable isotopes ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$), and specific biomarkers (n-alkanes and pigments) indicated an increase in primary productivity as a result of the change in trophic state correlating temporally with the increase in anthropogenic activities. This study suggested that in the absence of instrumental records, multiple geochemical data from lake systems help to reconstruct their paleoenvironmental history. Agrawal *et al*. (2015) reconstructed paleo-vegetation history in the northeast Himalaya during the past 2700 years from a lake section near Anini village, DibangValley, Arunachal Pradesh, India. They have analysed sediments for stable carbon and nitrogen isotopic composition, TOC, TN content as well as magnetic susceptibility. $\delta^{13}C$ values in the section suggested mixed C3-C4 plants and a distinguishable increasing trend in $\delta^{13}C$ during 2700 to 1300 years indicated the change in vegetation pattern from C3 to C4 plants due to change from wetter to drier conditions. After 1300 years $\delta^{13}C$ values decreased rapidly by 1.3‰ due to increasing abundance of C3 plants in wetter climatic condition. They have suggested a stable climatic condition in the region during 1200 yrs to the present. Das *et al*. (2010) studied paleoclimate variability during the Holocene through biogeochemical and amino acids analysis on a 30-m-long core from Mansar Lake. By the C/N ratio and $\delta^{13}C$ values they have suggested a hot and wet climatic regime during the early Holocene (ca. 7580 BP) and a dry and cold in the late Holocene period (ca. 4050 BP).

Saxena *et al*. (2015) studied a 2.1 m thick sediment profile from Chaudhary-Ka-Tal (lake) of Raebareli District using organic/inorganic carbon analyses along with pollen and sediment texture data. They have suggested that around 8470 to 6422 cal year BP grasslands with interspersed forest groves thrived in the region under a warmer and moderately humid climate than today and further similar scenario existed ~3150 to 1110 cal BP. However, they found that forest groves became less varied owing to weakening of the SW monsoon from 1110 cal BP, which was corroborated by the increase in carbonate content.

In the study of Nitaya Lake of Hoshangabad district, Madhya Pradesh, Chauhan *et al*. (2013a) have suggested that loss on ignition (LOI) and carbonate data are crucial as a potential tool in corroborating the findings made by other proxies and even for the sites where biota preservation is absent. The multiproxy study of Chauhan *et al*. (2013b) used geochemistry along with pollen, grain-size and magnetic susceptibility of a sediment core from Padauna Swamp, southeastern Madhya Pradesh. They have suggested that the overall change in the vegetation mosaic reflects that a warm and more humid climate prevailed in the region, probably on account of strengthening of southwest monsoon. This observation was corroborated by organic/inorganic carbon ratio, the increase in clay content with matured mineralogy, significantly higher CIA and magnetic susceptibility values. They found that since 2800 cal yr BP onwards, the modern Sal dominated deciduous forests were established in a warm and more humid climate. The timely arrival of the SW monsoon benefitted the Sal growth.

A multi-proxy study including carbon isotopes and magnetic mineralogy was carried out on Wadhwana Lake sediments from the sub-humid zone of mainland Gujarat to determine the mid-Holocene climatic fluctuations and its possible impact on the Harappan culture by Prasad *et al*. (2014). The study concluded that onset of dry climate after 5500 cal yr BP was a regionally spread synchronous event also documented in several lake records of western India. A sediment core from Pariyaj Lake in the Gujarat Alluvial Plains of western India has been studied by Raj *et al*. (2015) to reconstruct the palaeoclimate, palaeoenvironment, and tectonic history and to understand the role of these factors played in the geomorphological evolution of the area during the Holocene. Based on multiproxy data (palynological and phytolith studies, texture, organic/inorganic carbon, major and trace element geochemistry and clay mineralogy) they characterized five climatic phases during the last 11,000 years BP. They have highlighted wet climate and high lake stand ~ 11,000, 7630 and between 4680 and 3500 cal year BP; winter precipitation ~ 7630 and between 4680 and 3500 cal year BP, as regional phenomena; and, decreased precipitation and dry climate between 5864-4680 and 8000-9000 cal year BP.

Sridhar *et al*. (2015) studied multi-proxy data including chronology and geochemistry of preserved sediments from the lower Narmada valley, western India. Three major environmental perturbations at 809, 1487, and 1187 cal BP have been identified, which was corroborating well with the regional fluctuations in southwest monsoon variability. They have found a phase of dominant marine influence (between 2185 and 1809 cal BP) and then transition from marine marsh environment to a phase of high fluvial influx around 1809 cal BP. They have suggested using geochemical and other supplementary data that the fluvial regime stabilized between 1487 and 1187 cal year BP, as recorded in the overbank sediments, the sedimentation occurred under a highly oxidizing and high energy condition with long distance transport of sediments. Singh *et al*. (2015) studied the famous fertile Cauvery delta in southern India. The delta has been supporting the humanity at least over the last ~2300 years BP. The chronostratigraphy of the six sediment cores from the region indicated Holocene evolution of the present delta in response to the past sea-level changes. They have found that the geochemistry of sediments indicated the presence of plagioclase as well as the dominance of 2 : 1 clay. They have suggested that the source of sediments was a weathering-limited provenance of southern granulite type rocks in the high relief and tectonically more active region of Nilgiri–Kodaikanal–Palani–Biligirirangan hills. They have concluded that the continuous deposition since the beginning of the Holocene resulted in the formation of fertile farmlands in the Cauvery delta.

Tripathy *et al*. (2014) investigated major and trace elements in sediments from the western Bay of Bengal to study the changes in provenances and related controlling factors. Their inverse model calculation of Al-normalized elemental ratios of the sediments estimated an average sediment contribution of 66 ± 13% and 34 ± 13% from the Himalayan and the peninsular Indian rivers, respectively, to the core site. They observed relatively reduced Himalayan contribution (through the Ganga river) of sediments during the LGM, which was due to the weakening of south-west monsoon and reduction in available exposure area for weathering due to the extent of glacier cover in the Himalaya.

Environmental Sediment Geochemistry

Sediments are an open system for contaminants or pollutants from the surrounding environment. Sediment properties and environmental conditions (e.g., temperature, Eh, and pH conditions) regulate the elemental dynamics. Here we document papers on environmental aspects of sediment geochemistry from urban, mining, lake, streams and coastal areas.

Purushothaman *et al*. (2012) studied water, interstitial water and sediments for major oxides, nutrients and metals in the lake. The high concentration of chloride, NH_4, SO_4 and metals at the sediment-water interface and the interstitial water indicated denitrification, sulfidation and sulfide oxidation in the anoxic bottom water. The geoaccumulation index indicated that the metals zinc, cobalt, and nickel are moderately polluted than other metals. Sediment samples and water samples from the Wular Lake, Kashmir Himalaya, was studied by Sheikh *et al*. (2014) to assess the weathering and anthropogenic impact on sediment and water chemistry. CIA values of theWular Lake sediments reflected moderate weathering of the catchment area. By using geoaccumulation index and US Environmental Protection Agency sediment quality standards, they found no pollution effect of heavy metals (Zn, Mn, Pb, Ni, and Co). However, they concluded that the Wular Lake suffered both natural and anthropogenic influences.

Mathur *et al*. (2011) have studied Pt, Pd and Rh levels in road dust samples collected from Hyderabad city. They have reported that although concentrations were lower when compared with several other cities around the world, their concentrations were above upper crust values. Significant correlation of Pt, Pd and Rh indicated a common source of these metals. They have found that traffic flow conditions significantly influenced emission of platinum group elements (PGE) from the automobile catalytic converters. To study elemental chemistry and geochemical partitioning of heavy metals in road dust from Dhanbad and Bokaro regions, Singh (2011) analysed particle size characteristics and elemental composition of road dust samples. He found that in comparison to the bulk composition, a fine fraction (<63 μm) tend to contain 1–3 times higher metals. He reported that except Pb and Mn other measured metals like Fe, Ti, Zn, Cr, Cu, Ni, and Co lie below grade zero indicating no pollution threat on later metals in the roadway dust.

Surface dust samples collected during three different seasons from Faridabad industrial area adjoining Delhi were studied by Pathak *et al*. (2013) for different metals, their spatial and temporal variations, and sources. They have reported that Cd, V, Co, Ba, Ti, Ni, Cu, Cr and Zn show significant spatial and temporal variations, and enrichments compared to UCC indicating their anthropogenic sources. They also found that the sites located in the residential areas near the unorganized industry were more polluted compared to sites near large industries, suggesting that the small scale unorganized industries cause more pollution. Machender *et al*. (2011) studied heavy metal contamination in soils of Balanagar industrial area and found that the soils in the study area are significantly contaminated, showing the high level of toxic elements than the normal distribution. Their assessment was based on the geoaccumulation index, enrichment factor, contamination factor, and degree of contamination. In another study, Machender *et al*. (2014) determined extent and distribution of heavy metals (Cu, Cr, Ni, Pb, Zn, As) in the sediments of Balanagar industrial area. They have suggested that high concentration of heavy metals in sediments was attributed to some pharmaceutical and metal industries in the study area. They have also suggested remedial measures such as phytoremediation and bioremediation for reduction of heavy metals in sediments. Krishna *et al.* (2013) assessed heavy metal contamination in soils around chromite mining areas, Nuggihalli, Karnataka and found that concentrations of Cr, Ni, and Co in soils of the study area exceeded the Soil Quality Guideline Limits. Enrichment of these heavy metals was correlated with the past mining activities.

To create a regional database of background mineral dust from a semi-arid zone of western India, Agnihotri *et al*. (2015) measured the chemical composition of ambient particles, with aerodynamic diameter ≤5 µm (PM5), collected from seven locations in Jaipur city, in the vicinity of Thar Desert at varying altitudes. They observed significant differences in chemical compositions among the seven sites. The bulk chemical compositions of the particles, broadly consistent with those of individual particles, have shown predominance of crustal elements like Si, Al, Ca, Fe, K, and Mg, K. Non-crustal elements (e.g., Cu, S, C, Ag and Pb) were found only in aerosols over the main city at ground level.

Hejabi and Basavarajappa (2013) studied heavy metals like Cu, Cr, Fe, Mn, Ni, Pb, and Zn in the sediments of the Kabini River, Karnataka to determine the association of metal with various geochemical phases by sequential extraction method. This geochemical study indicated that the metals were present mostly in the least mobilizable fraction in the overlying water, and they have concluded that heavy metals in these sediments were to a great extent derived from multisource anthropogenic inputs besides geochemical background contributions. Giri *et al*. (2013) studied the distribution of metals throughout Subernarekha river to know their inputs from different sources. Bed sediments were analysed and assessed for metals using geo-accumulation, enrichment factor value, concentration factor, and pollution load index. Metals in the river sediments were found variable in concentration but at certain locations, they encountered high values. They concluded that the contamination of Pb and Cu was more serious than that of Ni, Zn, Co and Ba,basically due to anthropogenic activity. Whereas, the presence of Fe, Mn, and Cr was suggested to be primarily from natural sources. Distribution and characteristics of metal concentrations and consequently the sediment quality of the Subarnarekha river indicated inputs from anthropogenic activity as well as geogenic sources.

Kessarkar *et al*. (2013) studied the geochemistry of the suspended sediment to identify the sources of SPM and to understand the physicochemical processes in the Mandovi and Zuari river estuaries. They found that canal stations exhibited the highest concentrations of major and trace metals. High metal/Al ratios were found at stations in the upstream of Zuari and the confluence of canals in the Mandovi estuary. Enrichment factors analysis of metals indicated that the samples were significantly polluted with Mn. They have suggested that the compositions of SPM were controlled by the particulates from the ore dust, geology of the drainage basins, and physicochemical processes in the estuaries.

Paleosol control of arsenic pollution in the deltaic sediments of the West Bengal was studied by McArthur *et al*. (2011) and Ghosal *et al*.(2015) involving detailed geochemical analyses of sedimentary cores covering a large terrane in arsenic affected area of 24 Parganas in West Bengal. McArthur *et al*. (2012) studied Mn and other trace elements in the groundwater of parts of deltaic Bengal Basin to unravel the sedimentological control of their distribution.

To evaluate the geochemical behaviour and coastal pollution on surface deposits, Silva *et al.* (2014) analysed multi-element concentrations in 16 surface sediment samples collected from the offshore of the Cauvery delta. Pollution indices like enrichment factor (EF) and geoaccumulation index showed the enrichment of Cu, Cr and Zr. Whereas, contamination factor has shown enrichment of Cu and Cr. A strong positive association between Cu and Zn with $CaCO_3$ showed the role of carbonates in precipitating these metals from the overlying water column possibly related to agricultural pollution. Ranjan *et al*. (2011) evaluated the sources and fate of organic matter (OM) in the Pichavaram mangrove–estuarine ecosystem. C(org), N(total), C/N(atm), and stable isotopes (δ^{13}Corg and δ^{15}N(org)) of five ^{210}Pb dated sediment cores were analyzed. The study has shown variable inputs of marine and terrestrial OM in this area, OM degradation, replacement of native vegetation due to increasing salinity, and early diagenetic changes. Some of these changes were suggested to be due to anthropogenic activities.

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