Study on littoral zone sediment quality and aquatic Macrophyte diversity of opencast coal pit-lakes in Raniganj coal field, West Bengal, India

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ABSTRACT

Littoral zone sediment quality and species diversity of aquatic macrophytes were studied in four opencast coal pit-lakes at Raniganj Coalfield areas. Quantitative estimation of different soil parameters revealed that pH was neutral to low alkaline (7.00 to 8.90), conductivity, 130 to 670 $\mu$S/cm, available nitrogen, 22.0 to 194 kg/ha, available phosphorus, 2.04 to 27.1 kg/ha, available potassium, 85.5 to 424 kg/ha and organic carbon content was varied from 0.096 to 2.83 %. Distribution and concentration of heavy metals in the sediments were recorded as, Pb (0.033 to 1.57 mg/kg), Cd (0.018 to 0.108 mg/kg), Cr (non-detectable to 0.022 mg/kg) and As (non-detectable level). Aquatic macrophyte community was enriched by the most predominant nine species, viz., Potamogeton malainus, Ipomoea fistulosa, Typha angustifolia, Alternanthera philoxeroides, Vallisneria spiralis, Hydrilla verticillata, Marsilea minuta, Nymphoides indica and Nymphaea nouchali. The main objective of this work is to create a concrete baseline data of the water quality and soil parameters of the pit-lakes in the RCF areas. This work has been able to establish a relationship between the sediment properties, nutrient availability and growth of the macrophytes with different species composition.

Keywords: Littoral zone, Sediment quality, Opencast coal pit-lakes, Ecological restoration.

1. Introduction

Deterioration of ecological condition of the coal pit-lakes, locally called Khadans, created after the surface mining operations, is due to unavoidable evacuation of top soil, destruction and loss of natural soil profile, land degradation, leaching from huge overburden (Kundu and Ghose, 1994) and reduction of fertility of top soil. In mine pit-lake the morphometry of void and the nature of the bottom sediments from where the macrophytic community may develop can be changed by the overburden and waste rocks (Schultze et al., 2013). So, the chemical properties including organic carbon, available nitrogen, available phosphorus and available potassium of the pit-lake sediment are mainly dependent on the nutrients present in the overburden top soil, which is mostly containing less nutrients for the growth of the plants (Ghose, 2001; Dutta and Agrawal, 2002; Ghose, 2004; Mercuri et al., 2005; Maiti, 2007; Sheoran et al., 2010). Toxic chemicals present in the overburden soil and the presence of different heavy metals in the rocky bottom sediments are the major contaminants of the OCP water bodies. (Stoertz et al., 2002; Johnson, 2003; Pagnanelli et al., 2004; Razo et al., 2004; Marín-Guirao et al., 2005; Sun and Zhao, 2006; Maiti, 2007; Bhuiyan et al., 2010; Das and Chakrapani, 2011). A series of chemical and biochemical reactions has been taken place.
when pyrite and other sulfide minerals became associated with soil or rock of the mining areas that are exposed to water and oxygen. Actually, the mine-water discharge containing high concentration of metals *viz.*, Fe, Cu, Zn, Co, Cr, Mn, Pb, Cd, etc., leads to metal pollution in the coal pit-lakes ecosystem, as similar in water and soil in the Raniganj Coalfield (RCF) areas (De and Mitra, 2002; Singh et al., 2009; Singh et al., 2010; Das and Chakrapani, 2011).

Sediment of a water body is considered as the ‘biological engineer’ as well as reservoir of nutrients which directly supports the growth and development of autotroph community like macrophytes (Barko and Smart, 1986; Barko et al., 1991) and phytoplankter which are the baseline food sources for the other aquatic organisms at subsequent consumer levels. So, the physicochemical composition and nature of the bottom sediments including its nutrient availability may play a major role in the process of natural ecorestoration in the pit-lake aquatic system. But there is no detailed report on the inter-relationship between the nature and composition of sediment and species diversity of macrophytes in abandoned coal mine pit-lakes in India particularly in RCF areas. So, the objective of this work is to establish the relationship between the littoral zone sediment’s chemical properties and the macrophyte diversity of these pit-lakes required for the gradual process of natural ecological restoration in this newly developed aquatic reservoir.

2. Material and methods

![Figure 1: Location map of experimental OCP lakes (Source: Google earth)](image-url)
2.1 Study area

Raniganj Coalfield areas (RCF) are the birthplace of Indian coal mine covering an area of about 1,530 km² containing about 1,306 km² of direct coal bearing land. It is extended over Burdwan, Birbhum, Bankura and Purulia districts in West Bengal and Dhanbad district in Jharkhand, however, most of the RCF areas are in Burdwan district. It is bounded by Ajoy River in North and Damodar River in South. About 78 old opencast coal pits (OCPs) embedded in RCF areas are now recognized and declared as abandoned pit-lakes.

This study was carried out in four old OCPs viz., Millenium OCP [M OCP] and Kumardih A OCP [K OCP] under Bankola area and Pursatampur East OCP [P OCP (E)] and Pursatampur West OCP [P OCP (W)] under Jhanjra area. Total area of M OCP, K OCP, P OCP(E) and P OCP(W) are 2.76, 0.5, 0.08, 0.4 km² respectively. Maximum depth of these OCPs are 35 – 36 m. Year of declaration of abandonment of M OCP, K OCP, P OCP(E) and P OCP(W) were 1999, 1981, 1986 and 1981 respectively. Longitude and latitude of M OCP, K OCP, P OCP(E) and P OCP(W) are 23º40'11.93" N and 87º14'04.55" E, 23º40'11.09" N and 87º15'29.10" E, 23º41'39.56" N and 87º17'02.92" E and 23º41'43.00" N and 87º16'57.76" E respectively (Figure 1).

2.2 Geology of the study area

Raniganj Coalfield is mostly endowed by the Archean rocks. Soil-cover in this area is alluvial type, and coal bearing Gndwana strata lies beneath this soil. The rocks of this area are consisted of fine to medium grained buff coloured sandstone, grayish to greenish micaceous shale, coal seams and silt stones (Sengupta, 1966; Singh et al., 2010).

2.3 Sampling processes and analytical processes

Littoral zone sediment samples were collected seasonally (winter, summer and rainy) for three consecutive years 2005 - '06, '06 - '07 and '07 - '08 from different sites of each OCPs, and was mixed well before analysis. From each OCP one sediment sample was taken in every season. All the samples were brought to the laboratory, air dried, and analysed as earliest possible time. pH and conductivity of sediments were measured following the methods described by Saxena (1998). Other parameters like available nitrogen, available phosphate, available potassium, organic carbon and metals were analysed following the methods described by Black (1965), Olsen et al. (1954), Subbiah and Asija (1956), Walkley and Black (1934a) and Ming and Ma (2001) respectively. For the analysis of pH and conductivity, the air dried sediment samples were dissolved in distilled water in 1:10 (w/v) ratio. Available nitrogen, available phosphate and available potassium as well as metals viz., Pb, Cd, Cr and As were analysed from the air dried sieved sediment samples.

The macrophyte diversity in the littoral zone of each OCPs were recorded seasonally for these three consecutive years, and all the aquatic macrophyte species available in these areas were collected and brought to the laboratory, preserved and identified as per Bengal Plant (Prain, 2004).

3. Results

3.1 Sediment quality
pH of littoral zone sediment of these OCPs was observed to vary from neutral to low alkaline (7.00 to 8.90) with an average value of 8.10 (±0.458) (mean ±SD). In most of the cases, maximum pH was recorded during rainy seasons (Figure 2).

Figure 2: Seasonal analysis of pH in littoral zone subsoil

Conductivity was found in the Range of 130 to 670 µS/cm with an average of 352 (±147) µS/cm. Low conductivity was observed in the rainy season in all the OCPs (Figure 3). Available nitrogen was recorded in the Range of 22.0 to 194 kg/ha with an average value of 121 (±41.7) kg/ha.

Figure 3: Seasonal analysis of conductivity in littoral zone subsoil

Although the concentrations were changed seasonally, but the trend of change was not so distinct (Figure 4). Available phosphorus was in the range of 2.04 to 27.1 kg/ha with an average of 9.10 (±8.09) kg/ha. Low available phosphorus was observed mostly in the rainy season (Figure 5). Available potassium was recorded in the range of 85.5 to 424 kg/ha with an average value of 199 (±92.3) kg/ha.
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Figure 4: Seasonal analysis of available potassium in littoral zone subsoil

Figure 5: Seasonal analysis of available phosphate in littoral zone subsoil

Figure 6: Seasonal analysis of available nitrogen in littoral zone subsoil

In all the OCPs, the maximum values were recorded during rainy seasons (Figure 6). In this study, organic carbon content in the littoral zone sediment of these OCPs was valued in the range of 0.096 to 2.83 % with an average of 1.27 (±0.813) %. Maximum concentration of organic carbon was found during summer and minimum in rainy season (Figure 7).
3.2 Metal

Concentrations of different metals in different OCPs are recorded in Table 1. Concentration of lead (Pb), cadmium (Cd) and chromium (Cr) in the littoral zone sediments of these OCPs varied in the ranges of 0.033 to 1.57 mg/kg, 0.018 to 0.108 mg/kg, non-detectable to 0.022 mg/kg respectively; arsenic (As) was not detected in the sediment samples.

Table 1: Analysis of metal concentration (in mg/kg) in littoral zone sediment of OCPs

<table>
<thead>
<tr>
<th></th>
<th>M OCP</th>
<th>K OCP</th>
<th>P OCP (E)</th>
<th>P OCP (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean ±SD</td>
<td>Range</td>
<td>Mean ±SD</td>
</tr>
<tr>
<td>Pb</td>
<td>0.033-1.078</td>
<td>0.611 ±0.531</td>
<td>0.188-0.960</td>
<td>0.651 ±0.408</td>
</tr>
<tr>
<td>Cd</td>
<td>0.032-0.100</td>
<td>0.065 ±0.034</td>
<td>0.025-0.094</td>
<td>0.057 ±0.035</td>
</tr>
<tr>
<td>Cr</td>
<td>0.008-0.022</td>
<td>0.013 ±0.008</td>
<td>NL-0.008</td>
<td>0.003 ±0.004</td>
</tr>
<tr>
<td>As</td>
<td>NL</td>
<td>NL</td>
<td>NL</td>
<td>NL</td>
</tr>
</tbody>
</table>

NL = non-detectable limit

3.3 Aquatic macrophyte diversity

Aquatic macrophyte species as observed in these OCPs were Potamogeton malainus, Ipomoea fistulosca, Typha angustifolia, Alternanthera philoxeroides, Vallisneria spiralis, Hydrilla verticillata, Marsilea minuta, Nymphaoides indica and Nymphaea nouchali (Table 2). Maximum species diversity in the macrophyte community was observed in M OCP.

4. Discussion

Ecological condition of a water body is highly influenced by the sediment properties of the concerned water body. Macrophytes, the ‘biological engineers’ are functioning to establish a linkage between the nature of bottom sediment and properties of water column (Canfield et al., 1983; Sand-Jensen, 1997; Demars and Harper, 1998; Sand-Jensen, 1998). They explained the reason that the senescent and decaying stems and leaves are the sources of nutrients

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released into waterbody or through the anoxic reaction in the sediments containing dense dead plant bodies (Carignan and Kalff, 1980). Nitrogen (N), phosphorous (P) and potassium (K) are the primary macronutrients which are required for the growth of plant as well as aquatic weeds. Organic carbon of the soil is the fraction of the soil profile composed of mostly dead organic materials of the living organisms.

In this study, pH of littoral zone sediment in these OCPs was observed in the range from neutral to slightly alkaline (7.00 to 8.90) with an average of 8.10 (±0.458) which was supported earlier by Kumar et al. (2011) when they reported the pH of the overburden soil in the range of 6.30 to 8.80 in RCF areas. Soil pH influences the richness and diversity of plant species by enhancing the solubility of nutrients as well as availability of nutrient to plant (Gough et al., 2000). It also affects the presence of microorganisms which are responsible for breaking down of the organic materials and other chemicals. Maximum pH was observed during rainy season may be due to wash off the overburden soil and erosion.

Table 2: Diversity of aquatic macrophytes in OCP lakes

<table>
<thead>
<tr>
<th>Name of the Macrophyte</th>
<th>M OCP</th>
<th>K OCP</th>
<th>P OCP (E)</th>
<th>P OCP (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Potamogeton malainus</em></td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Ipomoea fistulosa</em></td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Typha angustifolia</em></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Alternanthera philoxeroides</em></td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>Vallisneria spiralis</em></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Hydrilla verticillata</em></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Marsilea minuta</em></td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Nymphoides indica</em></td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Nymphaea nouchali</em></td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

+ indicates presence, - indicates absence

was supported earlier by Kumar et al. (2011) when they reported the pH of the overburden soil in the range of 6.30 to 8.80 in RCF areas. Soil pH influences the richness and diversity of plant species by enhancing the solubility of nutrients as well as availability of nutrient to plant (Gough et al., 2000). It also affects the presence of microorganisms which are responsible for breaking down of the organic materials and other chemicals. Maximum pH was observed during rainy season may be due to wash off the overburden soil and erosion.

Soil conductivity endorsed the concentration of soluble salts in soil. Littoral zone sediment conductivity of these OCPs was found in the range of 130.00 to 670.00 µS/cm with an average value of 352 (±147) µS/cm. Kumar et al. (2011) reported conductivity of the overburden soil in the range of 30.0 to 210 µS/cm in RCF areas. Rai et al. (2009) recorded a quite high conductivity in top soil of south-eastern part of JCF (610 to 890 µS/cm). Richards (1954) and Rhoades and Loveday (1990) classified the soil according to soil conductivity into four classes, and tabulated the suitability of crop production in those classes of soil. According to Richards (1954) and Rhoades and Loveday (1990) classification of the soil based on soil conductivity, littoral zone sediment in these OCPs is suitable for sensitive plant
also. Values of conductivity did not show any seasonal trend that might be due to fluctuation of different ions in the sediment.

Nitrogen is an essential component of many important structural, metabolic and genetic compounds like chlorophyll, ATP and nucleic acid in plant cells. It is a major constituent of amino acids, the building blocks of proteins which act as structural units of plant cells or enzymes. Available nitrogen in littoral zone sediment of these OCPs was recorded in the range of 22.0 to 194 kg/ha of an average value of 121 (±41.7) kg/ha. Kundu and Ghose (1997) reported quite similar quantity of available nitrogen (174 to 266 kg/ha) in unmined soil collected adjacent to an OCP area in eastern part of Eastern Coalfield Limited (ECL) located in Bihar state. But Maiti (2007) showed lower values of available nitrogen (non-detectable to 48.5 kg/ha) in overburden, reclaimed and unmined soil collected from Central Coalfield Limited (CCL) area. According to Subbiah and Asija (1956) classification of the soil based on the concentration of the soil available nitrogen, littoral zone sediment in these OCPs contains low quantity of available nitrogen.

Phosphorus is not only a vital component of DNA, RNA and ATP, but also essential for photosynthesis, normal development, growth and production of plant. In this study available phosphorus in littoral zone sediment of these OCPs was observed in the range of 2.04 to 27.1 kg/ha with an average of 9.10 (±8.09) kg/ha. Rai et al. (2009) observed that the available phosphorus in the top soil of south-eastern part of Jharia Coalfield (JCF) was in the range of 3.42 to 5.51 kg/ha. Kundu and Ghose (1997) reported the available nitrogen in unmined soil collected adjacent to an OCP area in eastern part of ECL located in Bihar state was in the range of 6.70 to 10.6 kg/ha. According to Olsen et al. (1954) classification of the soil based on the concentration of the soil available phosphorus, littoral zone sediment in these OCPs contains low to medium quantity of available phosphorus. Low available phosphorus was observed mostly in the rainy season may be due to plant uptake for growth.

Potassium is an essential macronutrient for plant growth (Pfeffer, 1900; Sparks and Huang, 1985). It is associated with osmoregulation, and enzyme catalytic activity in plant tissue. In this study, presence of available potassium in littoral zone sediment of OCPs was recorded in the range of 85.5 to 424 kg/ha of an average value of 199 (±92.3) kg/ha. Kundu and Ghose (1997) reported available potassium in the range of 199 to 254 kg/ha in unmined soil collected from adjacent OCP area in eastern part of ECL area of Bihar state. According to Scholenberger and Simon (1945) classification of the soil based on the concentration of the soil available potassium, littoral zone sediment in these OCPs contains low to high quantity of available potassium. Maximum values were recorded during rainy seasons may be due to runoff in this seasons.

Soil organic carbon includes the decomposing part of plants, animals and microbes in soil. It plays an important role in controlling the soil fertility and agricultural production (Hilgard, 1906; Jenny, 1941; Tiessen et al., 1994). In this study, organic carbon content in the littoral zone sediment of these OCPs was recorded in the range of 0.096 to 2.83 %. Although most of the other workers showed the low percentage of organic carbon in soil collected from mining area. Rai et al. (2009) found organic carbon in the top soil of south-eastern part of JCF in the range of 0.210 to 0.410 % of an average value of 1.28 (±0.810) %. Kundu and Ghose (1997) found the low values of it (0.570 to 0.880 %) in unmined soil collected adjacent to an OCP area in eastern part of ECL located in Bihar state. Dutta and Agrawal (2002) reported that average organic carbon percentage was 0.460 (±0.020) of freshly mine spoiled soil of NCL area. Maiti (2007) reported that the soil of overburden, reclaimed and unmined area of CCL contained 0.560 to 1.82 % of organic carbon. This is in consonance with the present analysis.
According to Walkley and Black (1934b) classification of the soil based on the soil organic carbon percentage, littoral zone sediment in these OCPs contains low to high quantity of organic carbon. Maximum concentration of organic carbon was found during summer because of depletion of water label, and death of most of the aquatic macrophytes resulting into the deposition of dead plants in the sediment. Whereas, minimum organic carbon percentage was observed during rainy season might be due to wash off the sediment by shower.

Concentrations of lead (Pb), cadmium (Cd) and chromium (Cr) in the subsoil of OCPs were observed in the ranges of 0.033 to 1.57 mg/kg, 0.018 to 0.108 mg/kg, and non-detectable to 0.022 mg/l respectively. Gupta et al. (2008) reported a comparatively higher concentration of Cd (27.0 mg/kg) and Cr (118 mg/kg) in the soil adjacent to this study area. Das and Chakrapani (2011) assessed Cr concentration (143 to 642 mg/kg) in the soil of RCF areas. Singh and Hasnain (1999) found Cr concentration in the range of 10.0 to 33.0 mg/kg in the sediment collected from Damodar river which were affected by RCF mine water and industrial discharge. De and Mitra (2002) reported Pb, Cd, Cr and As concentrations in soils collected from reclamation site of mining-generated wastelands at Akusha-Gopalpur abandoned opencast project; in RCF areas it was in the range of 21.6 to 27.9 mg/kg, 0.080 to 0.150 mg/kg, 13.3 to 18.1 mg/kg and 3.14 to 6.78 mg/kg respectively. Kabata-Pendias and Pendias (1984) recorded the critical phytotoxic concentration for Pb, Cd, Cr and As were 100 to 400 mg/kg, 3.00 to 8.00 mg/kg, 75.0 to 100.0 mg/kg and 15.0 to 50.0 mg/kg respectively in soil. Present study showed that the metal concentrations in littoral zone sediment of all these OCPs were below the critical phytotoxic level may be due to sediment density and diffusion phenomena.

Aquatic macrophytes are considered as the important plant communities in the world for their role in nutrient cycling and high productivity (Penfound, 1956; Westlake, 1963; Sculthorpe, 1976; Reddy, 1984). Aquatic macrophytes are being in the baseline of ecological food pyramid provide the food source, ensure the habitat to other aquatic organisms, remove carbon dioxide as well as produce the oxygen flux in the aquatic ecosystem. Nine different types of macrophyte species growing traditionally in these OCP-water bodies were, viz., *Potamogeton malainus*, *Ipomoea fistulosa*, *Typha angustifolia*, *Alternanthera philoxeroides*, *Vallisneria spiralis*, *Hydrilla verticillata*, *Marsilea minuta*, *Nymphoides indica* and *Nymphaea nouchali*. Among these *T. angustifolia* was predominant in all the OCPs. Very little or scanty reports were available on the aquatic macrophyte diversity in pit lakes. Burner and Leist (1953) found *Potamogeton foliosus*, *Typha augustifolia* and some other species in strip mine lakes. In the present study, these plants were found only in the littoral zone due to low depth as also addressed by other workers (Sampson et al., 1996; McCullough, 2008). Maximum macrophyte diversity was observed in M OCP, it may be due to gradual inclined slope (structural stretch), availability of nutrient and depth of littoral zone. In M OCP, there is a stretch littoral zone with low depth. Growth of aquatic macrophytes are dependent on water depth (Casanova and Brock, 2000; Thomaz et al., 2006) due to low light availability (Chambers and Kalff, 1985; Best et al., 2001). Here the available macrophytes are categorized in two types, i.e., rooted submerged and rooted emergent. Submerged macrophytes are considered as pioneering species for lake restoration, and play important role in mineral recycling in the aquatic ecosystem (Qiu et al., 2001; Lauridsen et al., 2003). All the species found in these OCPs are of perennial type. Although rooted submerged species die during the summer season due to lowering of the water level.

5. Conclusion
Present study revealed that the sediment quality in the littoral zone of OCPs as well as concentration of soil nutrients are slightly low. But the result of occurrence and the species diversity of the aquatic macrophytes suggest that the nutrients are sufficient for the development and growth of this biotic community. So, it can be concluded that the process of restoration in this ecosystem is slow and is directly and/or indirectly linked up with the sediment quality of these abandoned opencast pit-lakes. The authority may device some indigenous mechanisms for necessary improvement and enhancement of ecological restoration in the RCF areas.

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