A Contemplation On Pitlakes of Raniganj Coalfield Area: West Bengal, India

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Abstract

Pitlakes (PLs) form when surface mines close and open pits filled with water, either through groundwater recharge, surface water diversion or active pumping. The primary goal of this study was to prepare an inventory of PL in Raniganj coalfield (RCF), West Bengal, India, along with the status of water quality in these PLs for promoting sustainable utilization of the PL resources for socioeconomic development of the local stakeholders in due course of time. A total of 40 PLs were enumerated and characterized to determine their nature, position, depth, area and comparative account in RCF during the period of 2014–2017. A consecutive 2-year study of physicochemical parameters of water and soil was recorded at 27 selected mine PLs to understand its quality. A total of 30 species belonging to 21 families of frequent hydrophytes/marginal plant species dominating these PLs were observed. successional stages of plant species were noticed and grouped in accordance with their growth pattern. During the study period, the 15 most frequently cultured/naturally occurred fish species under 4 orders, 5 families and 14 genera were collected and identified from the PL. After the analysis of PL water quality and questionnaire survey of the local stakeholders, we have recorded that developmental pisciculture project can be started in 25 PLs. PLs aged over 20–30 years turned naturally into wetland ecosystem harbouring a good amount of aquatic biota, excellent water quality and stabilized embankment. Sixty species of wetland birds (with terrestrial counterparts in the adjoining floral habitat) belonging to 15 orders and 34 families were recorded. The main findings of this work was to explore the ecological health status, study the ecological census of PL in RCF, exploration of ecological health status of the PL on, accessibility of the biological resources of PL.

Keywords

Pitlakes · Water quality · Soil quality · Developmental activity · Floral succession

Abbreviations

AMD	Acid mine drainage
BOD	Biochemical oxygen demand
DA	Discriminant analysis
ECL	Eastern Coalfields Limited
FT	Foot
Ha	Hectare
Km	Kilometre
LULC	Land use and land cover
N	Nitrogen
OCP	Open-cast pit
OC	Organic carbon

PCA	Principal component analysis
PL	Pitlake(s)
RCF	Raniganj Coalfield
SO_4^-	Sulphates
TDS	Total dissolved solid

1 Introduction

All surface mining process creates drastic changes in the landscape. They result in the formation of large overburden dumps, huge voids and pitlake (PL) ecosystems in the mining sites (Kumar et al. 2017; Raj et al. 2018). By definition a PL is a lake that forms by flooding of an excavated mining pit. PL differs physically from natural lakes in having markedly higher relative depths. During active mining, surface water is diverted around open pits, and perimeter and dewatering pumps are used to control groundwater inflow and direct rainfall. PL forms when the pumps are shut off and post-mining drainage of surface/groundwater and precipitation begin to accumulate inside the inactive pit. PL can form in open-cut mining pits, which extend below the groundwater table. Pits from mining of chemically inert materials tend to mirror the geochemistry of their surroundings, and lakes that form in such pits do not produce pits with various physical, geochemical and ecological mine impoundments, such as tailings ponds, are not included in the above definition. PL waters are typically contaminated with metals, metalloids, saline or acidic/alkaline and rarely approach natural waterbody chemistry (Dimitrakopoulos et al. 2016).

Physically, PL has unique bathymetries, is often strongly wind sheltered and has very small catchments. Nevertheless, PL waters often constitute a vast resource but of limited beneficial use (due to water quality issues), with a potential to contaminate regional surface and groundwater resources. Water in PL has the potential to be useful for a range of purposes in characteristically hot, dry climatic regions in India with relatively few natural water bodies. Their value as resources for recreation, fisheries, water supply and wildlife habitat depends mostly on their topography and their safety. PL may have long-term benefits as a water source for industrial activities rather than relying on natural systems (Palit et al. 2017; Ram and Meena 2014).

Ecological restoration and ecosystem management is an essential component of any habitat conservation (Banerjee et al. 2018; Jhariya et al. 2018a, b). Coal mining started in the Raniganj Coalfield (RCF) area in 1774 during the British East India period. The RCF covers an area of 1530 sq. kilometre (Km), containing about 1306 sq. km of coal-bearing land. In West Bengal, especially in RCF region, opencast mining has become increasingly common over the last few decades through changes in excavation technology and ore economics. Moreover, such operations frequently leave a legacy of open mine pits once mining ceases. The lack of knowledge on PL continues to hinder their proper management. Information on PL occurrence, distribution, bio-profile, water quality and usefulness aspects is not nationally collated and requires immediate and perpetual attention from both mining companies and regulating authority (Palit et al. 2014). Lack of a readily available database pertaining to PL occurrence, distribution and water quality fails to promote both mining companies and communities in RCF region in assessing the potential of these water resources.

PL ecosystems are not only ecologically threatened and critical aquatic landscapes but also a source of potential biological resources for the future. They may support a rich biodiversity and high abundance of animal and plant species, many of them threatened on a local or worldwide basis (Maltby and Barker 2009). The lack of knowledge on PL continues to hinder their proper management. Wetland and freshwater systems such as PL are important for the provision of environmental and ecological services (MEA 2005) in developing countries that result from their varied bio-geo-chemical functioning, ranging from fresh water to provision of services economically useful to human populations, for example, food provision from fishing and income generation via ecotourism.

However, recent investigations on aquatic systems have highlighted the fact of continued decline in aquatic species and degradation of wetland and freshwater habitats across the world (Hassall 2014). One of the reasons for human failure to use the natural environment and resources of freshwater ecosystems in a sustainable way is because the long-term benefits to be derived from such sustainable use are not always as obvious as the perceived short-term benefits from economic development which destroys or damages the freshwater habitat.

Freshwater resources of the world are a repository of rich biodiversity (Murphy et al. 2003; Dudgeon et al. 2006; Schmidt-Mumm and Janauer 2014; Clarke 2015). They support many key ecological processes (Cereghino et al. 2014) and provide a number of benefits free of cost to the human society. Studies on freshwater resources in connection with their ecology, biodiversity, multipurpose usages and conservation have investigated in many different parts of the world (Janauer 2012; Gupta and Palit 2014; Turak et al. 2017; Inomata et al. 2018; Dhakal et al. 2016).

Thus quality assessments of selected PL in RCF have been carried out during 2014–2017 in order to assess the overall hydrological conditions, bio-profile and efficacy to evolve strategies for an ecological restoration, conservation and management.

2 Genesis of Pitlakes

2.1 Background

Coal mining started in the RCF area in 1774 during the British East India period. The RCF covers an area of 1530 sq. km, containing about 1306 sq. km of coal-bearing land. All surface mining process creates drastic changes in the landscape. They result in the formation of large overburden dumps, huge voids and PL ecosystems in the mining sites.

2.2 Pitlake Formations

Open-cast mining operations have become a common practice over the last few decades in India, as a method of extracting commercially useful ore found near the surface. Since backfilling is normally unfeasible practically or economically, an open pit after completion of extraction operations is left which is known as mine void. After mine operations are discontinued and dewatering ceases, most of those that extend below the natural groundwater table, fill by inflow of groundwater, direct rainfall, and runoff from adjacent drainage basins and the void catchment. Natural filling may take many years to complete. To reduce oxidation of mining waste and wall rocks, to inhibit the activity of acidophilic sulphur-oxidizing bacteria and to promote anoxic conditions at the lake bottoms which may minimize the formation of acids and dissolved metals, some PLs are rapidly filled with stream or river diversions. The water qualities in such PL depend on the filling water and geological catchments and are highly variable. Although the water level may continue to fluctuate as it equilibrates or as climate and local groundwater levels alter, once containing water, the empty mine void has now become a PL. The number of future open-cut mines is likely to continue with current and predicted demands for minerals and energy, the global financial crisis notwithstanding. Except for those in the most arid areas, deep open-cut mines are likely to develop PL when mining operations end. Given the large number of PL that will form worldwide and the large volume of water they will contain, the quality of the water in these lakes will be of profound importance, especially in areas with scarce water resources (Blanchette and Lund 2016).

2.3 Pitlake Characteristics

PL differs physically from natural lakes in having a markedly higher ratio of depth to surface area. This is described by percent relative depth, which is defined as the percentage of a lake's maximum depth compared to its width calculated from its surface area by assuming the lake is approximately circular. A typical natural lake has a relative depth of less than 2%, although some may exceed 5%. PL commonly has relative depths between 10% and 40% (Doyle and Davies 1999). This causes PL to easily stratify with the consequential changes in chemical characteristics with depth.

Total dissolved solids (TDS) and electrolytic conductivity tend to increase with depth; values near the bottom are often several times those at the surface. The hypolimnion (lower stratum) of a stratified lake has the tendency to contain low dissolved oxygen concentrations, if enough oxygen demand (chemical and/or biological) is high enough. The existence of a sub-oxic or anoxic (no oxygen) layer in a PL can have significant effects on the lake's chemical and biological characteristics and thus on its potential for remediation. Where pit sides are battered for public access or to promote development of riparian (fringing vegetation) zones, deep pits will still have a bathymetry unlike natural lakes with steep sides below the battering.

As PL typically has limited catchments, inflows of surface water tend to be small which may be useful in preventing worsening water quality from exposed geologies.

However, where exposed geologies are not problematic, it may be desirable for PL water quality to capture clean surface waters, and small catchments may limit this. PL water quality can be highly variable, particularly for acidity, salinity, hardness and metal concentrations which are primarily governed by the PL catchment hydrology and geochemistry (Miller et al. 1996). For example, PL water quality may become acidic, through oxidation of reactive iron-bearing geologies as acid mine drainage (AMD) (Klapper and Geller 2002; Hinwood et al. 2011, 2012; Verma et al. 2015). Such acidic mine waters are often toxic to aquatic biota (Spry and Wiener 1991; Doyle and Davies 1999; Storer et al. 2002; Stephens and Ingram 2006).

PL waters affected by salinity and acidity may also adversely influence nearby and regional groundwater resources and receiving environments, e.g., wetlands with contaminated plumes from flow-through PL extending large distances down-gradient. The extent of such an impact may vary from insignificant in low hydraulic conductivity rocks and groundwater systems already saline to considerable in high hydraulic conductivity rocks and naturally low-salinity groundwater environments (Commander et al. 1994; Johnson and Wright 2003).

The majority of PL studies conducted in India have focussed on physical and chemical characteristics of water quality. These studies have demonstrated that PL water quality is influenced by many factors including climate, groundwater quality, depth, pit filling method and local mineralogy. Many PLs contain high levels of acid, sulphate and dissolved metals/metalloids. The chemical characteristics of a lake depend on the alkalinity of the local groundwater, the composition of the wall rocks, the chemistry of the surrounding vadose zone and the quality and quantity of runoff from the surrounding land (Plumlee et al. 1992; Davis et al. 1993). Rock that is exposed to oxidizing conditions during dewatering can be a major source of acid, even though it lies below the water table before mining operations begin and after the lake fills (Miller et al. 1996). The most common set of reactions producing acidity in mine lakes is the oxidation of PL resource sulphide and iron in pyrite (FeS_2) in the following two reactions (Castro and Moore 1997):

1. $FeS^2 + 7/2O^2(aq) + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$
2. $Fe^{2+} + 1/4O^2(aq) + 5/2H^2O \rightarrow Fe(OH)^3 + 2H^+$

In natural systems pH is typically buffered by a carbonate buffer system (at pH of 6–8.5); however PLs of lower pH are often buffered by aluminium complexes (pH 4.5–5.5) or iron complexes (pH 2.0–4.0).

2.4 Land Use Pattern of Adjoining Areas

Several studies on RCF area revealed that it is free from AMD (Ghosh et al. 1984, 2005; Tiwary and Dhar 1994). Different studies on limnological parameters depicted the high conductivity, total suspended solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), sulphates (SO_4^-), etc., in mine water of this area (Ghosh 1990; Tiwary and Dhar 1994; Singh et al. 2009, 2010). Few records are available on assessment of water quality and seasonal variations of the Indian coal PL (Ghosh et al. 2005; Singh et al. 2009, 2010; Mukherjee et al. 2013; Palit et al. 2017; Meena et al. 2018).

Mining operation, undoubtedly, has brought wealth and employment opportunity in the area but simultaneously has led to extensive environmental degradation and erosion of traditional values in the society (Kumar et al. 2016; Jhariya et al. 2013, 2016). The rate and the intensity of land use and land cover change are very high in developing new mining area because of various human activities. Mining of coal, both surface and subsurface, causes enormous damage to the flora, fauna, hydrological relations and soil biological properties of the systems. Destruction of forests during mining operation is invariably accompanied by an extensive damage and loss to the system. A detailed understanding of the environmental impact of coal mining on changes in land use/land cover pattern and fragmentation of time and space is a prerequisite for the district.

2.5 Present Scenario of Pitlakes and Its Adjoining Areas

The current scenario of the PL in this region is generated for the first time. Further extensive research, investigation, seasonal monitoring and pilot-scale study with socioeconomic purview in the next phase of the study will produce valuable research findings. However, recent investigations on aquatic systems have highlighted the fact of continued decline in aquatic species and degradation of wetland and freshwater habitats across the world (Hassall and Anderson 2015).

One of the reasons for human failure to use the natural environment and resources of freshwater ecosystems in a sustainable way is because the long-term benefits to be derived from such sustainable use are not always as obvious as the perceived short-term benefits from economic development which destroys or damages the freshwater habitat. Thus, ecological restoration and ecosystem management is an essential component of any habitat conservation.

PL ecosystems are not only ecologically threatened and critical aquatic landscapes but also a source of potential biological resources for the future. They support rich biodiversity and high abundance of animal and plant species, many of them threatened on a local or worldwide basis (Maltby and Barker 2009). The lack of knowledge on PL continues to hinder their proper management which is also observed under the present investigation. Wetland and freshwater systems such as PL are important for the provision of environmental and ecological services (Millennium Ecosystem Assessment 2005) in developing countries that result from their varied bio-geo-chemical functioning, ranging from fresh water to provision of services economically useful to human populations, for example, food provision from fishing and income generation via ecotourism. The present work would have valuable practical applications since PLs play an important role in the ecosystem functioning and hydrology of the area. They provide habitat for migratory birds, fisheries, water plants, animals and microbes.

In view of this, the present work is of clear importance especially for policy designers. The findings of UPAR1 would contribute to the following outputs for conservation of PL in RCF-WB:

1. This revealed the current condition of the PL of the target region but also provides necessary guidelines for implementation of PL management/livelihood generation programmes for the benefit of stakeholders inhabiting the area.
2. After successful completion of this research study, it is now possible to provide data on the ecology, biodiversity and environmental values of the PL in RCF-WB. The research thus contributed to the development of decision support systems for better conservation, management and sustainable use of wetlands to promote the key message of the Ramsar Convention's (1971) mission to achieve "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world."

2.6 Change Analysis in Different Land Use/Land Cover

Land use and land cover (LULC) are categorized into nine classes; these are crop area, moist fallow, land surface deep waterbody (pond and abandon quarry), river water, river sand, dense forest, open forest, settlement and quarry. The result of the change analysis shows that there are directly or indirectly influences on different land use and land cover due to the impact of mining activity. According to the study, the decrease of the LULC is 298.16 sq. km of the moist fallow, 53 sq. km of the dense forest, 117.37 sq. km of the open forest, 12.71 sq. km of the river water and 1.27 sq. km of the river sand, and the increase of the LULC is 91.52 sq. km of the crop area, 88.13 sq. km of the surface deep waterbody, 103.81 sq. km of the settlement and 199.99 sq. km of the quarry area that has changed due to the mining activity during 1990–2014. More than 90 sq. km area of moist fallow, 2 sq. km area of dense forest and 10 sq. km of open forest have been converted into the open-cast mining during that period.

An elaborative description of 40 PLs of RCF was tabulated in Table 1. Overall PL was classified with its age series. Area and depth of each PL was noticed and documented. According to age range, each PL is grouped into six classes. Class 1 has those PLs that belong to their age of 1–20 years. In such manner classes 03, 06, 07, 18, 19, 20, 22, 25, 28, 35, 39 and 19, 7 and 1 consist of the PLs having their age range of 21–40, 41–60 and 61–80, respectively. Areas of most of the PLs were in ranged from 1 to 150 bighas. Dalmia, Alkusa Gopalpur and Kumardihi Old PLs were ranged from 150 to 200 bighas. The areas of Nimcha Damali Harabanga, Nimcha Harabanga and Gunjan Ecological Park PLs have the largest area such as 250 bighas, 300 bighas and 250–300 bighas, respectively. Ramnagar (400 foot) was the deepest PL found in RCF. Kumardihi Old, Vatas 1 and Vatas 2 were the second deepest PLs. The depthness of Katapahari PL was less in comparison to all other PLs of RCF. All PLs were ranged within 40–400 ft in accordance with their depth.

Table 1 An account of genesis of PL of RCF, West Bengal, India

Serial no.	Name of the PL	Origin of PL (years)	Area (bigha)	Depth (feet)	Area of mining	Block	Nearest village/town
PL01	Chora PL	30	50	80	Bankola	Pandabeswar	Chora
PL02	Joyalbhanga 1 PL	35	>80	70	Bankola	Pandabeswar	Joyalbhanga
PL03	Vatas PL	20	70–80	300	Sripur	Baraboni	Vatas
PL04	Katapahari PL	50	50–60	100	Sripur	Baraboni	Katapahari
PL05	Amdia PL	40	80	250	Salanpur	Salanpur	Amdiha
PL06	Samdi PL	20	>40	250	Salanpur	Salanpur	Samdi
PL07	Dalmia PL	30	162	250	Salanpur	Salanpur	Sikhdaspur
PL08	Bamna PL	50	30	100	Salanpur	Salanpur	Bodra
PL09	Bonbedi PL	60	>50	250	Salanpur	Salanpur	Bonbedi
PL10	Alkusa Gopalpur PL	70	>150	250	Salanpur	Salanpur	Alkusa
PL11	Sikhdaspur PL	20	50	70	Salanpur	Salanpur	Sikhdaspur
PL12	Jambad 5 PL	70	>70	150	Kajora	Andal	Benedi
PL13	Jambad 4 PL	60	50	120	Kajora	Andal	Benedi
PL14	Jambad Bottom-Up PL	50	>50	100	Kajora	Andal	Benedi
PL15	Western Kajora PL	40	125	40	Kajora	Andal	Kajora
PL16	Atewal PL	40	70	60	Kajora	Andal	Jogrambati
PL17	Khadan Kali PL	40	125	40	Kajora	Andal	Polashbon
PL18	Babuisolsib Mandir PL	15	125–126	60	Kajora	Andal	Babuisol
PL19	Ramnagar PL	10	100	400	Sodepur	Pandabeswar	Ramnagar
PL20	Belpahari Kottadihi PL	10	1	40	Pandabeswar	Pandabeswar	Belpahari
PL21	Dalurbandh PL	40	>100	100	Pandabeswar	Pandabeswar	Dalurbandh
PL22	Nagrakonda PL	3	50	100	Pandabeswar	Pandabeswar	Nagrakonda
PL23	Pathaldanga PL	15	70–80	120	Sripur	Jamuria	Tinpatia
PL24	Nimcha Harabanga PL	30	300	80	Satgram	Raniganj	Harabhanga
PL25	Real Kajora PL	20	>80	100	Kajora	Andal	Kajora
PL26	Chakrambati PL	15	80	90	Kajora	Andal	Railgate Majhipara

(continued)

Table 1 (continued)

Serial no.	Name of the PL	Origin of PL (years)	Area (bigha)	Depth (feet)	Area of mining	Block	Nearest village/town
PL27	Dhanderdihi 1 PL	50	<100	120	Kajora	Andal	Dhandadihi
PL28	Dhanderdihi 2 PL	12	50	80	Kajora	Andal	Dhandadihi
PL29	Dhandadihi 3 PL	30	50	100	Kajora	Andal	Dhandadihi
PL30	Porasiakhadan PL	20	>50	150	Kajora	Jamuria	Porasia
PL31	Babuisol Colony PL	30	125	30	Kajora	Andal	Palashban
PL32	Kumardihi PL	30	60	100	Bankola	Pandabeswar	Kumardihi
PL33	Kumardihi Old PL	35	200	300	Bankola	Pandabeswar	Kumardihi
PL34	Joyalbanga 2 PL	40	125–150	100	Bankola	Pandabeswar	Joyalbhanga
PL35	Sankarpur PL	10	< 90	70	Bankola	Andal	Sankarpur
PL36	Gunjan Ecological Park PL	40	250–300	80	Satgram	Jamuria	Sripur
PL37	Nimcha Damali Harabanga PL	29	250	80	Satgram	Raniganj	Damali
PL38	Patmohana Ranisayar PL	60	50	120	Sodepur	Kulti	Pathmohona
PL39	Vatas 2 PL	20	100	300	Sripur	Baraboni	Vatas
PL40	Chapuikhas PL	40	40	150	Satgram	Raniganj	Chanda

3 Characteristics of Pitlakes and Comparative Account of Different Pitlakes

As many as 40 PLs in RCF area were inventorized. Comparative studies of different PLs were done which are as described in Tables 2, 3, 4 and 5.

Table 2 The subdivision, block and Eastern Coalfields Limited (ECL) mining area wise location

Name of the PL	Subdivision	Block	ECL area of mining
Chora PL	Durgapur	Pandabeswar	Bankola
Joyalbhanga 1 PL	Durgapur	Pandabeswar	Bankola
Vatas 1 PL	Asansol	Baraboni	Sripur
Katapahari PL	Asansol	Baraboni	Sripur
Amdia PL	Asansol	Salanpur	Salanpur
Samdi PL	Asansol	Salanpur	Salanpur
Dalmia PL	Asansol	Salanpur	Salanpur
Bamna PL	Asansol	Salanpur	Salanpur
Bonbedi PL	Asansol	Salanpur	Salanpur
Alkusa Gopalpur PL	Asansol	Salanpur	Salanpur
Sikhdaspur PL	Asansol	Salanpur	Salanpur
Jambad 5 PL	Durgapur	Andal	Kajora
Jambad 4 PL	Durgapur	Andal	Kajora
Jambad Bottom-Up PL	Durgapur	Andal	Kajora
Western Kajora PL	Durgapur	Andal	Kajora
Atewal PL	Durgapur	Andal	Kajora
Khadan Kali PL	Durgapur	Andal	Kajora
Babuisol Sibmandir PL	Durgapur	Andal	Kajora
Ramnagar PL	Durgapur	Pandabeswar	Sodepur
Belpahari Kottadihi PL	Durgapur	Pandabeswar	Pandabeswar
Dalurbandh PL	Durgapur	Pandabeswar	Pandabeswar
Nagrakonda PL	Durgapur	Pandabeswar	Pandabeswar
Pathaldanga PL	Durgapur	Jamuria	Sripur
Nimcha Harabanga PL	Asansol	Raniganj	Satgram
Real Kajora PL	Durgapur	Andal	Kajora
Chakrambati PL	Durgapur	Andal	Kajora
Dhanderdihi 1 PL	Durgapur	Andal	Kajora
Dhanderdihi 2 PL	Durgapur	Andal	Kajora
Dhandadihi 3 PL	Durgapur	Andal	Kajora
Porasia Khadan PL	Asansol	Jamuria	Kajora
Babuisol Colony PL	Durgapur	Andal	Kajora
Kumardihi PL	Durgapur	Pandabeswar	Bankola
Kumardihi Old open-cast project (OCP) PL	Durgapur	Pandabeswar	Bankola
Joyalbanga 2 PL	Durgapur	Pandabeswar	Bankola
Sankarpur PL	Durgapur	Andal	Bankola
Gunjan Ecological Park PL	Asansol	Jamuria	Satgram
Nimcha Damali Harabanga PL	Asansol	Raniganj	Satgram
Patmohana Ranisayar PL	Asansol	Kulti	Sodepur
Vatas 2 PL	Asansol	Baraboni	Sripur
Chapuikhas PL	Asansol	Raniganj	Satgram

Table 3 A synoptic accounts of various PLs showing nearest village, age of PL, mean depth of PL and major uses of PL

Name of the PL	Nearest village/town	Age of PL (years)	Mean depth (feet)	Major uses
Chora PL	Chora	30	80	DOM
Joyalbhanga 1 PL	Joyalbhanga	35	70	DOM, LIB, IRR, WSP, RLG, PIS
Vatas 1 PL	Vatas	20	300	DOM, LIB, IRR, IDS, AGC
Katapahari PL	Katapahari	50	100	DOM, FSH, PIS
Amdia PL	Amdiha	40	250	DOM, FSH, WSP, RLG, PIS
Samdi PL	Samdi	20	250	DOM, LIB, WSP
Dalmia PL	Sikhdaspur	30	250	DOM, LIB, WSP
Bamna PL	Bodra	50	100	DOM, FSH, WSP, RLG, PIS
Bonbedi PL	Bonbedi	60	250	DOM, PIS
Alkusa Gopalpur PL	Alkusa	70	250	DOM, WSP, PIS
Sikhdaspur PL	Sikhdaspur	20	70	DOM, RLG, PIS
Jambad 5 PL	Benedi	70	150	DOM, LIB, PIS
Jambad 4 PL	Benedi	60	120	DOM, WSP
Jambad Bottom-Up PL	Benedi	50	100	DOM, LIB, IRR, FSH, PIS
Western Kajora PL	Kajora	40	40	DOM, RLG, PIS
Atewal PL	Jogrambati	40	60	DOM, PIS
Khadan Kali PL	Polashbon	40	40	DOM, RLG
Babuisol Sibmandir PL	Babuisol	15	60	DOM, RLG, PIS
Ramnagar PL	Ramnagar	10	400	WSP
Belpahari Kottadihi PL	Belpahari	10	40	DOM, PIS
Dalurbandh PL	Dalurbandh	40	100	DOM, LIB, RLG, PIS
Nagrakonda PL	Nagrakonda	3	100	DOM, LIB, FSH, PIS
Pathaldanga PL	Tinpatia	15	120	DOM, LIB, FSH, RLG
Nimcha Harabanga PL	Harabhanga	30	80	DOM, RLG, PIS
Real Kajora PL	Kajora	20	100	DOM, PIS
Chakrambati PL	Railgate Majhipara	15	90	DOM, LIB, FSH
Dhanderdihi 1 PL	Dhandadihi	50	120	DOM, FSH, RLG, PIS
Dhanderdihi 2 PL	Dhandadihi	12	80	DOM, IRR, PIS
Dhandadihi 3 PL	Dhandadihi	30	100	DOM, FSH
Porasia Khadan PL	Porasia	20	150	DOM, FSH, RLG, PIS
Babuisol Colony PL	Palashban	30	30	DOM, RLG
Kumardihi PL	Kumardihi	30	100	DOM, RLG, PIS
Kumardihi Old OCP PL	Kumardihi	35	300	DOM, PIS
Joyalbanga 2 PL	Joyalbhanga	40	100	DOM, FSH, PIS
Sankarpur PL	Sankarpur	10	70	DOM, IRR, RLG
Gunjan Ecological Park PL	Sripur	40	80	DOM
Nimcha Damali Harabanga PL	Damali	29	80	DOM, FSH, WSP, RLG, PIS
Patmohana Ranisayar PL	Pathmohona	60	120	DOM, LIB, PIS
Vatas 2 PL	Vatas	20	300	DOM, LIB, IRR, FSH, WSP, PIS
Chapuikhas PL	Chanda	40	150	DOM, LIB, FSH

DOM domestic use, *FSH* fishing purpose use, *WSP* water supply use, *RLG* religious purpose use, *PIS* pisciculture use, *LIB* livestock purpose use, *IRR* irrigation use

Table 4 The major problems of PL, cause of sinking, fishing activity and occurrence of migratory bird in these PLs

Name of the PL	Major problem	Cause of sinking	Fishing activity	Migratory bird
Chora PL	WDS	NIL	NIL	N
Joyalbhanga 1 PL	WTS,FIS	NIL	P	Y
Vatas 1 PL	WTS	ECR, FIL	PA	Y
Katapahari PL	WDS,WTS	ECR	P	Y
Amdia PL	WTS	ECR	P	Y
Samdi PL	NIL	FIL	P	N
Dalmia PL	FIS	NIL	P	Y
Bamna PL	WTS	ECR	P	N
Bonbedi PL	NIL	ECR	P	Y
Alkusa Gopalpur PL	WTS, FIS	NIL	P	Y
Sikhdaspur PL	WDS	NIL	P	Y
Jambad 5 PL	NIL	NIL	P	Y
Jambad 4 PL	WTS, FIS	NIL	P	Y
Jambad Bottom-Up PL	NIL	NIL	P, PA	Y
Western Kajora PL	FIS	NIL	P	Y
Atewal PL	FIS	NIL	P	N
Khadan Kali PL	FIS	NIL	P	Y
Babuisol Sibmandir PL	FIS	NIL	P	N
Ramnagar PL	WTS	ECR	NIL	N
Belpahari Kottadihi PL	NIL	NIL	PA	Y
Dalurbandh PL	WDS, FIS	NIL	P	Y
Nagrakonda PL	FIS	NIL	P	Y
Pathaldanga PL	NIL	ECR	P	N
Nimcha Harabanga PL	FIS	NIL	P	Y
Real Kajora PL	FIS	NIL	P	Y
Chakrambati PL	FIS	FIL	P	Y
Dhanderdihi 1 PL	FIS	NIL	P	Y
Dhanderdihi 2 PL	NIL	NIL	P	Y
Dhandadihi 3 PL	NIL	NIL	PA	N
Porasia Khadan PL	FIS	NIL	PA	N
Babuisol Colony PL	WDS	NIL	P	N
Kumardihi PL	FIS	NIL	P	N
Kumardihi Old OCP PL	NIL	IDS	P	Y
Joyalbanga 2 PL	FIS	NIL	P	N
Sankarpur PL	WTS	ECR, IDS	P	Y
Gunjan Ecological Park PL	NIL	NIL	P	Y
Nimcha Damali Harabanga PL	WTS	NIL	P	Y
Patmohana Ranisayar PL	NIL	NIL	P	N
Vatas 2 PL	NIL	ECR	P	Y
Chapuikhas PL	NIL	ECR	P	Y

WDS weed infestation, *WTS* water supply, *Fis* fishing activity, *ECR* encroachment, *FIL* filling, *IDS* industrial runoff, *P* present, *PA* past, *Y* yes, *N* no

Table 5 Classification of PL according to the subdivision, block, mining area, age, depth, fishing activity and abundance of migratory bird

Criteria of classification	Characteristic types	PL code	No. of PL	Percentage
Subdivision	Durgapur	PL01, PL02, PL12, PL13, PL14, PL15, PL16, PL17, PL18, PL19, PL20, PL21, PL22, PL23, PL25, PL26, PL27, PL28, PL29, PL31, PL32, PL33, PL34, PL35	24	60%
	Asansol	PL03, PL04, PL05, PL06, PL07, PL08, PL09, PL10, PL11, PL24, PL30, PL36, PL37, PL38, PL39, PL40	16	4%
Blocks	Pandabeswar	PL01, PL02, PL19, PL20, PL21, PL22, PL32, PL33, PL34	9	22.5%
	Baraboni	PL03, PL04, PL39	3	3.5%
	Salanpur	PL05, PL06, PL07, PL08, PL09, PL10, PL11	7	17.5%
	Andal	PL12, PL13, PL14, PL15, PL16, PL17, PL18, PL25, PL26, PL27, PL28, PL29, PL31, PL35	14	35%
	Jamuria	PL23, PL30, PL36	3	7.5%
	Raniganj	PL24, PL37, PL40	3	7.5%
	Kulti	PL38	1	2.5%
Area of mining	Bankola	PL01, PL02, PL32, PL33, PL34, PL35	6	15%
	Sripur	PL03, PL04, PL23, PL39	4	10%
	Salanpur	PL05, PL06, PL07, PL08, PL09, PL10, PL11	7	17.5%
	Kajora	PL12, PL13, PL14, PL15, PL16, PL17, PL18, PL25, PL26, PL27, PL28, PL29, PL30, PL31	14	35%
	Sodepur	PL19, PL38	2	5%
	Pandabeswar	PL20, PL21, PL22	3	7.5%
	Satgram	PL24, PL36, PL37, PL40	4	10%
Age	1–20 years	PL03, PL06, PL07, PL18, PL19, PL20, PL22, PL25, PL28, PL35, PL39	11	27.5%
	21–40 years	PL01, PL02, PL04, PL05, PL08, PL15, PL16, PL17, PL21, PL24, PL26, PL29, PL30, PL31, PL33, PL34, PL36, PL37, PL38, PL40	20	50%
	41–60 years	PL09, PL10, PL12, PL13, PL14, PL23, PL27, PL32	8	20%
	61–80 years	PL11	1	2.5%

(continued)

Table 5 (continued)

Criteria of classification	Characteristic types	PL code	No. of PL	Percentage
Depth	<100 ft	PL04, PL11, PL14, PL22, PL26, PL28, PL29, PL35, PL37, PL40	10	25%
	>100–<300 ft	PL01, PL02, PL03, PL05, PL06, PL08, PL09, PL10, PL12, PL13, PL15, PL16, PL17, PL18, PL20, PL21, PL24, PL25, PL27, PL30, PL31, PL32, PL33, PL34, PL36, PL38, PL39	27	67.5%
	>300 ft	PL07, PL19, PL23	3	7.5%
Fishing activity	Present	PL02, PL04, PL05, PL06, PL07, PL08, PL09, PL10, PL11, PL12, PL13, PL15, PL16, PL17, PL18, PL21, PL22, PL23, PL24, PL25, PL26, PL27, PL28, PL31, PL32, PL33, PL34, PL35, PL36, PL37, PL38, PL39, PL40	33	82.5%
	Past	PL03, PL20, PL29, PL30	4	10%
	Present and past	PL14	1	2.5%
	Nil	PL01, PL19	2	5%
Migratory birds	Present	PL02, PL03, PL04, PL05, PL07, PL09, PL10, PL11, PL12, PL13, PL14, PL15, PL17, PL20, PL21, PL22, PL24, PL25, PL26, PL27, PL28, PL33, PL35, PL36, PL37, PL39, PL40	27	67.5%
	Absent	PL01, PL06, PL08, PL16, PL18, PL19, PL23, PL29, PL30, PL31, PL32, PL34, PL38	13	32.5%

4 Physicochemical Characteristics of Pitlake Water

A consecutive 2-year study of physicochemical parameters of water was recorded at 27 selected mine PLs and presented in Table 6. A mean value of pH 7.72 was recorded which ranged between 6.93 and 9.01 during the study period. The mean values 442.87 µS/cm for conductivity and 294.75 mg/Lt for TDS were recorded in the present study. The highest value of alkalinity 41.33 mg/Lt was recorded along with the lowest value 16 mg/Lt along with mean value 26.72 mg/Lt. Total hardness value varied between 75.33 mg/Lt and 96.34 mg/Lt with a mean value of 223.70 mg/Lt. Chloride concentration ranged between 18.32 mg/Lt and 59.80 mg/Lt with a mean value of 32.42 mg/Lt. Among the nutrient parameters, nitrate nitrogen was recorded with a mean value of 17.17 mg/Lt which is much lower than the standard value. Similarly phosphate phosphorus was recorded with a mean value of 1.61 mg/Lt, respectively. The mean value of DO is 4.90 mg/Lt with a maximum value 6.68 mg/Lt and minimum 3.75 mg/Lt. BOD value ranged between 1.45 mg/Lt and 2.85 mg/Lt with a mean value of 2.20 mg/Lt.

Table 6 Variation of water parameters measured in PL with *National Standard (IS 10500)

Parameters	Code	Mean ± standard deviation	IS10500
pH	PH	7.72 ± 0.54	6.5–8.5
Conductivity (μS/cm)	CON	442.87 ± 210.95	–
TDS (mg/Lt)	TDS	294.75 ± 155.98	500
Alkalinity (mg/Lt)	ALK	26.72 ± 6.44	200
Hardness (mg/Lt)	HRD	223.70 ± 162.13	200
Chloride (mg/Lt)	CHL	32.42 ± 10.09	250
Nitrate nitrogen (mg/Lt)	NIN	17.17 ± 22.93	45
Phosphate phosphorus (mg/Lt)	PHO	1.61 ± 0.35	5
Dissolved oxygen	DO	4.90 ± 0.74	–
Biological oxygen demand	BOD	2.20 ± 0.31	3

Table 7 depicts the eigenvalues derived from discriminant analysis (DA) where F1 and F2 explain 73.79% of cumulative variations. A discriminant function analysis (Manly 1994; Legendre and Legendre 1998) was carried out to portray the differences in the water parameters and the PL as well. The data revealed significant variations among the PL in terms of the water physicochemical parameters, reflected through the discriminant function analysis (Fig. 1). Figure 2 revealed the distribution of PL in respect to its environmental condition.

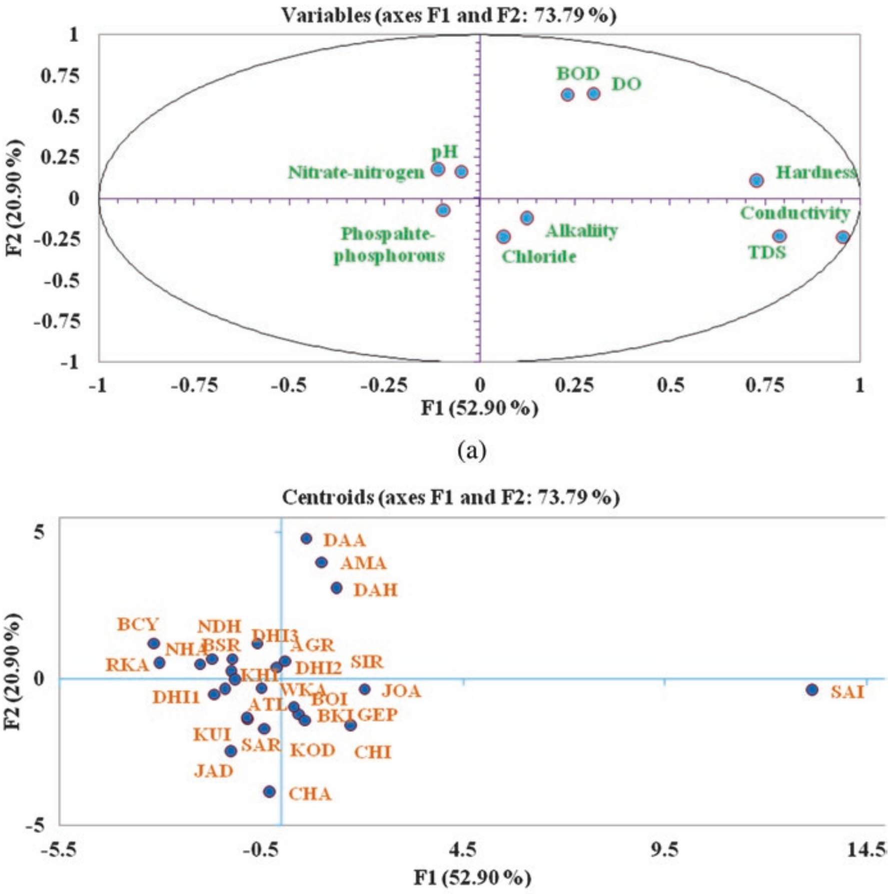
The eigenvalue percentage of total variation explained by cumulative percentage of total variance and rotated loadings for daytime data, were given in Table 8. This table gives the relation of the factors with the water quality parameters. It was observed that the first factor explains the highest percentage of the entire variance. The subsequent factors have diminishing variance to explain the water quality. Although all factors having value >1 can be thought to be significant, this significance diminishes after the first three factors. The first eigenvalue was 2.61 and explains 26.12% of the total variation. The second was 1.76 and explains 17.62% of total variation, and the third was 1.24 and explains 12.44% of total variation. Figure 3 depicts the effect of water parameters on PL. Hardness, TDS and conductivity were three parameters that mostly affected the BOI, KUI, GEP, SIR, KOD, JOA and SAI PL. Phosphate phosphorus, alkalinity and chloride affected HI, JAD, CHA, WKA, DHI1, DO and BOD PL, and nitrate nitrogen were less significant in case of BKI, NHA, AGR, DAH, DAA and AMA PL. pH was significantly low in KHI, ATL, NDH, DHI3, DHI2, SAR, BSR, RKA and BCY PL.

5 Physicochemical Characteristics of Pitlake Soil

The descriptive analysis of physicochemical parameters of soil samples was represented in Table 9. A mean value of pH 7.29 was recorded during the study period. Conductivity was recorded with a mean value of 0.63 μS/cm. With a mean value of 1.69 g/cm^3, bulk density of soil varies from 0.31 to 13.87 g/cm^3. Particle density ranges from 0.61 to 31.49 g/cm^3 with a mean value of 6.01 g/cm^3. Water holding capacity ranges from 0.09 to 30.59 inch/ft. with a mean value of 8.39 inch/ft.

Table 7 Eigenvalues derived through discriminant analysis of water parameters during the study period

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Eigenvalue	9.3105	3.6783	1.4743	1.1272	0.5749	0.4928	0.4102	0.3180	0.1568	0.0581
Discrimination (%)	52.8966	20.8980	8.3763	6.4042	3.2664	2.8001	2.3306	1.8066	0.8909	0.3303
Cumulative (%)	52.8966	73.7946	82.1709	88.5751	91.8415	94.6416	96.9722	98.7788	99.6697	100.0000



(b)

Fig. 1 The results of the discriminant analysis (DA) for the observed variations in the response variables (PL) against the explanatory variables (water parametric features). (**a**) Biplot with the ordination of the explanatory variables and (**b**) biplot with the ordination of the response variables

Organic carbon (OC) value ranges from 0.27 to 12.30 with a mean value of 3.32%. The mean values of available nitrogen (N) and phosphate phosphorus were observed with the mean values of 39.44 and 15.39 g/ha, respectively.

Table 10 depicts the eigenvalues derived from DA analysis where F1 and F2 explain 69.66% of cumulative variations. A discriminant function analysis (Manly 1994; Legendre and Legendre 1998) was carried out to portray the differences in the soil parameters and the PL as well. The data revealed significant variations among the PL in terms of the soil physicochemical parameters, reflected through the discriminant function analysis (Fig. 4). Figure 5 revealed the distribution of PL in respect with to its environmental condition.

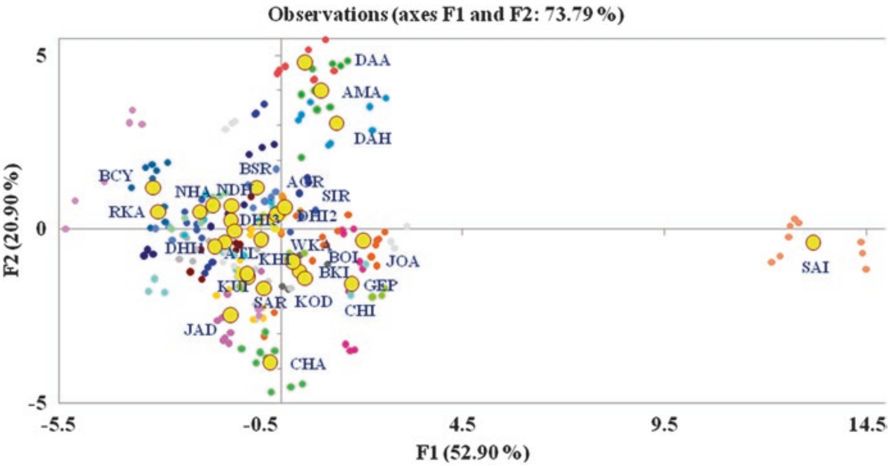


Fig. 2 Prevailing pattern of aquatic environment in RCF PL during the study period derived through DA of water parameters during the study period
CHA Chora, *JOA* Joyalbhanga, *AMA* Amdia, *SAI* Samdi, *DAA* Dalmia, *BOI* Bonbedi, *AGR* Alkusa Gopalpur, *SIR* Sikhdaspur, *JAD* Jambad, *WKA* Western Kajora, *ATL* Atewal, *KHI* Khadan Kali, *BSR* Babuisol Sibmandir, *BKI* Belpahari Kottadihi, *DAH* Dalurbandh, *NHA* Nimcha Harabhanga, *RKA* Real Kajora, *CHI* Chakrambati, *DHI1* Dhanderdihi 1, *DHI2* Dhanderdihi 2, *DHI3* Dhanderdihi 3, *BCY* Babuisol Colony, *KUI* Kumardihi, *KOD* Kumardihi Old, *SAR* Sankarpur, *GEP* Gunjan Ecological Park, *NDH* Nimcha Damali Harabhanga

The eigenvalues, percentage of total variation explained by cumulative percentage of total variance and rotated loadings for daytime data, were given in Table 11. This table gives the relation of the factors with the soil quality parameters. It was observed that the first factor explains the highest percentage of the entire variance. The subsequent factors have diminishing variance to explain the soil quality. Although all factors having value >1 can be thought to be significant, this significance diminishes after the first three factors. The first eigenvalue was 2.39 and explains 29.90% of the total variation, the second was 1.51 and explains 18.83% of total variation and the third was 1.14 and explains 14.22% of total variation.

6 Biological Resources of Pitlakes

6.1 Assessment of Plant Community

(a) *Hydrophyte Study*

Enumeration of Hydrophytes and Embarkment Plants in Pitlakes
PL hydrophytes and marginal floral assemblage observed during the study period is tabulated in Table 12. A total of 30 species belonging to 21 families of frequent hydrophytes and marginal plant species dominating these PLs were observed.

Table 8 Results of principal component analysis (PCA) showing eigenvectors of extracted components (>1), rotated using Varimax method with Kaiser normalization

Variable	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
pH	−0.1805	−0.3617	0.5612	0.1492	0.2286	−0.0607	0.4163	0.4830	−0.1596	0.1069
Conductivity	0.5264	−0.2136	0.0176	−0.0634	0.0576	−0.1373	−0.0480	−0.1027	−0.6850	−0.4107
TDS	0.5665	−0.1330	−0.0515	0.0092	0.0989	0.0404	0.0548	−0.0939	0.0071	0.7971
Alkalinity	0.0290	−0.0405	−0.3853	0.7230	−0.1173	−0.4965	0.2487	0.0089	0.0514	−0.0375
Hardness	0.5099	−0.2440	0.1623	0.0398	0.0809	0.0426	−0.0459	0.1274	0.6865	−0.3932
Chloride	0.1590	0.4501	−0.2820	−0.1983	0.3591	0.1735	0.6825	0.0855	0.0141	−0.1442
Nitrate nitrogen	−0.0606	0.2560	0.1865	0.2381	0.7960	−0.1892	−0.3516	−0.2146	0.0151	0.0047
Phosphate phosphorus	−0.1058	−0.3384	−0.2648	0.4114	0.1833	0.7596	−0.0333	−0.0914	−0.0982	−0.0720
DO	0.2368	0.5086	0.0628	0.2858	−0.1633	0.2120	−0.3209	0.6351	−0.1454	0.0250
BOD	0.1114	0.3214	0.5648	0.3199	−0.3025	0.1990	0.2527	−0.5158	−0.0095	−0.0434
Eigenvalue	2.6122	1.7622	1.2436	1.0784	1.0255	0.7915	0.5853	0.4344	0.2932	0.1736
Variability (%)	26.1219	17.6218	12.4364	10.7842	10.2551	7.9154	5.8534	4.3438	2.9322	1.7359
Cumulative (%)	26.1219	43.7437	56.1801	66.9643	77.2194	85.1347	90.9882	95.3320	98.2641	100.0000

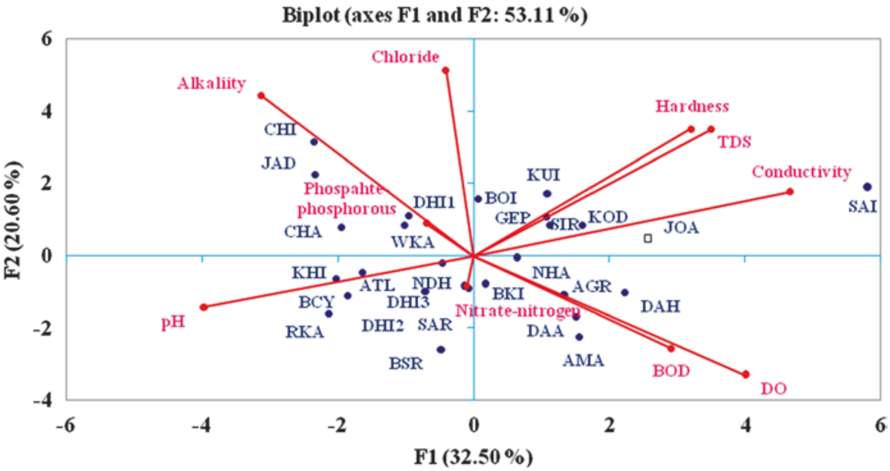


Fig. 3 Loading plots of PCA of water parameters for 27 PLs

Table 9 Descriptive statistics on soil parameters measured in PL during the study period

Soil parameter	Code	Mean
pH	PH	7.2859 ± 1.10
Conductivity (μS/cm)	CON	0.6337 ± 2.88
Bulk density (g/cm^3)	BDN	1.6929 ± 1.64
Particle density (g/cm^3)	PDN	6.0115 ± 5.81
Water holding capacity (inch/ft)	WHC	8.3899 ± 7.58
OC (%)	ORC	3.3243 ± 2.62
Available N (g/ha)	AVN	39.4387 ± 15.06
Available phosphate phosphorus (g/ha)	AVP	15.3944 ± 4.53

Table 10 Eigenvalues derived through DA of soil parameters during the study period

	F1	F2	F3	F4	F5	F6	F7	F8
Eigenvalue	1.6014	1.1422	0.5528	0.2587	0.1818	0.1158	0.0641	0.0220
Discrimination (%)	40.6577	28.9988	14.0353	6.5677	4.6145	2.9391	1.6282	0.5586
Cumulative (%)	40.6577	69.6565	83.6918	90.2595	94.8740	97.8131	99.4414	100.0000

Among these species eight were floating, four submerged and two reed swamp. Notable hydrophytes include *Hydrilla verticillata* (Indian star grass), *Nymphaea* sp. (water lily), *Salvinia* sp. (water moss), *Vallisneria spiralis* (eel grass), *Eichhornia crassipes* (water hyacinth), etc.

Variation in hydrophytes and embarkment plant type in PL of RCF is presented in Fig. 6. At 21 sites, of the total 30 plant species reported, 27% were represented by floating, 13% were represented by submerged, 7% were reed swamp and the rest of the 53% were represented by embankment/marginal plants.

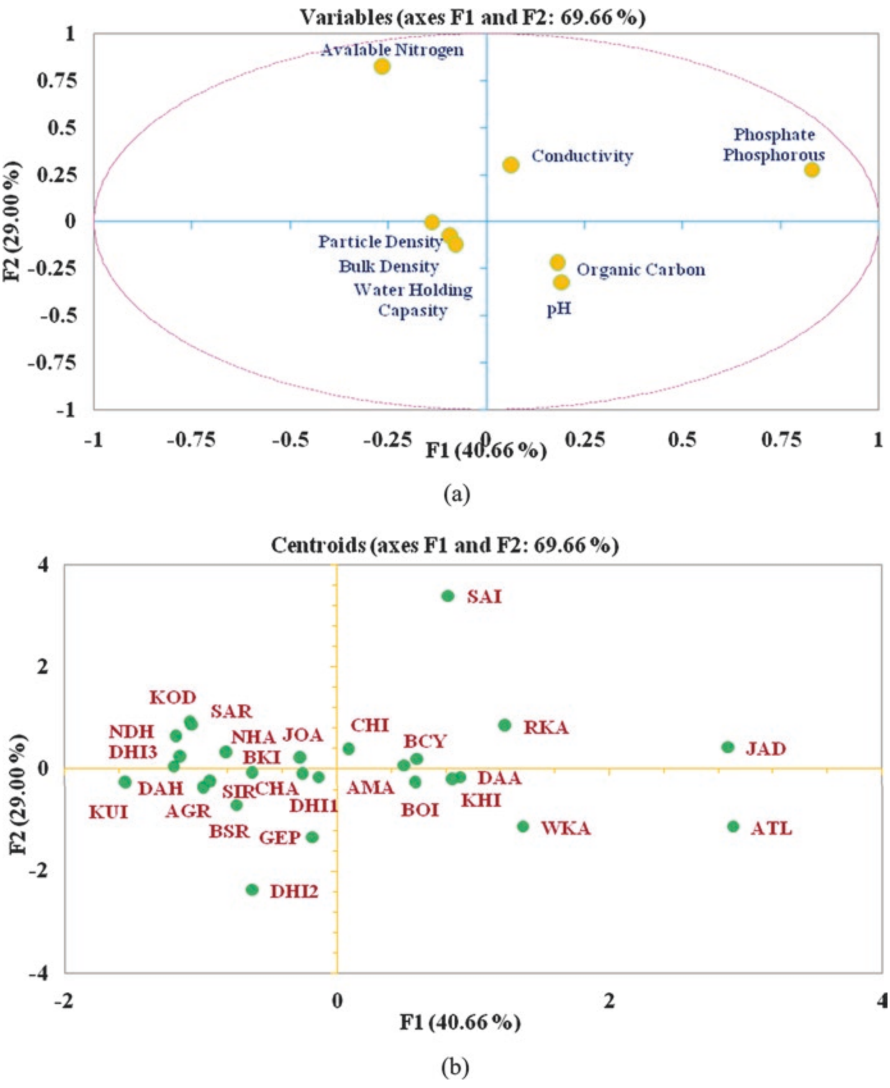


Fig. 4 The results of the discriminant function analysis (DA) for the observed variations in the response variables (PL) against the explanatory variables (soil parametric features). (**a**) Biplot with the ordination of the explanatory variables and (**b**) biplot with the ordination of the response variables

(b) *Terrestrial Plant Study*

PL floral assemblage observed during the study period is tabulated in Tables 13, 14 and 15. A total of 56 species belonging to 29 families of frequent plant species dominating these PLs were observed. Among these species 34 were herbs, 7 shrubs and 15 trees. Fabaceae was the most dominant family comprising nine species each.

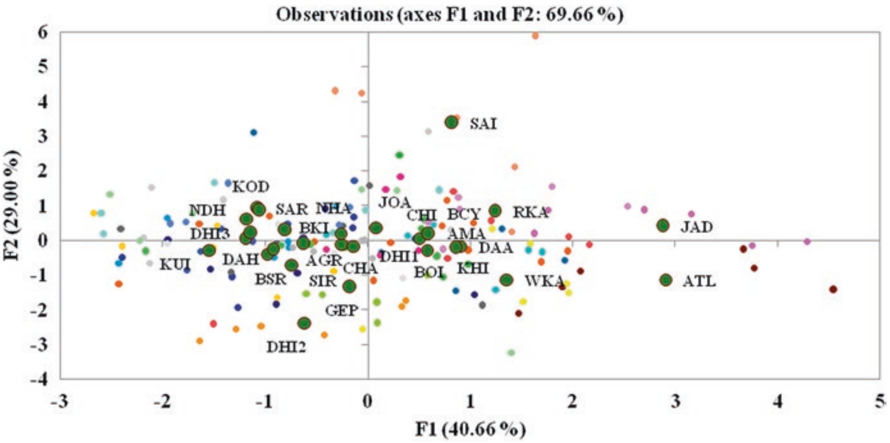


Fig. 5 Prevailing pattern of aquatic environment in RCF PL during the study period derived through DA of soil parameters during the study period

Table 11 Results of principal component analysis showing eigenvectors of extracted components (>1), rotated using Varimax method with Kaiser normalization

Variable	F1	F2	F3	F4	F5	F6	F7	F8
pH	0.1216	−0.5025	−0.0743	−0.6315	0.3968	0.3876	0.0727	−0.1235
Conductivity	−0.1010	0.0976	0.7718	−0.3970	0.1286	−0.4507	−0.0828	0.0194
OC	−0.5286	0.0619	−0.1024	−0.2039	−0.2165	−0.0731	0.7699	−0.1404
Bulk density	−0.1806	0.5777	0.1552	−0.2712	−0.2300	0.6450	−0.2419	−0.0924
Particle density	0.5367	0.2259	0.1012	−0.1058	−0.0369	0.1289	0.4550	0.6438
Water holding capacity	−0.4943	−0.3566	−0.0340	−0.0873	−0.2411	0.0636	−0.2734	0.6948
Available N	0.0183	−0.4131	0.5911	0.4566	−0.1815	0.4203	0.2103	−0.1315
Phosphate phosphorus	−0.3609	0.2267	0.0584	0.3180	0.7961	0.1671	0.1028	0.2039
Eigenvalue	2.3922	1.5062	1.1373	0.8963	0.7619	0.6256	0.3910	0.2896
Variability (%)	29.9029	18.8272	14.2161	11.2032	9.5237	7.8197	4.8877	3.6194
Cumulative (%)	29.9029	48.7301	62.9461	74.1493	83.6731	91.4928	96.3806	100.0000

The next important family is Asteraceae. Eighteen families were observed with only one species.

Variation in plant type around PL of RCF is shown in Fig. 7. At 27 sites, of the total 56 plant species reported, 61% were represented by herbs, 12% were represented by shrubs and 27% were represented by trees. Thus the study reveals that naturally occurring plant species at the site was dominated by herbs. Among all herbaceous species, *Lantana camara* (Raimunia), *Hyptis suaveolens* (American mint) and *Solanum sisymbriifolium* (sticky nightshade) are the most dominant species. It was noticed that *Calotropis gigantea* (crown flower) and *Saccharum*

Table 12 Enumeration of hydrophytes and embarkment plants in PL in RCF

Serial no.	Scientific name	Family	Habitat	PL01	PL02	PL04	PL05	PL06	PL07	PL09	PL11	PL13	PL15	PL16	PL17	PL20	PL21	PL24	PL31	PL32	PL33	PL34	PL36	PL37
1	*Chara* sp.	Characeae	Submerged	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
2	*Eichhornia crassipes*	Pontederiaceae	Floating	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–
3	*Enhydra fluctuans*	Asteraceae	Floating	–	–	–	–	+	+	–	–	+	–	–	+	–	–	–	–	–	–	–	–	–
4	*Hydrilla verticillata*	Hydrocharitaceae	Submerged	+	–	+	–	–	+	–	–	–	+	–	+	–	+	–	–	–	+	+	–	–
5	*Ipomoea aquatica*	Convolvulaceae	Floating	+	+	–	+	–	+	+	–	+	+	–	+	+	+	+	+	+	+	–	–	–
6	*Nymphaea* sp.	Nymphaeaceae	Floating	+	+	+	–	–	+	–	–	–	+	–	+	+	+	+	+	+	+	+	+	+
7	*Nymphaea nouchali*	Nymphaeaceae	Floating	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
8	*Nymphoides* sp.	Menyanthaceae	Floating	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+
9	*Phragmites karka*	Poaceae	Reed swamp	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	+	–	–	–	–	–
10	*Potamogeton* sp.	Potamogetonaceae	Submerged	–	–	–	–	–	+	–	–	–	–	–	–	+	–	–	–	–	–	+	–	–
11	*Salvinia* sp.	Salviniaceae	Floating	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
12	*Typha domingensis*	Typhaceae	Reed swamp	–	+	–	+	+	+	–	+	–	+	+	–	+	+	+	+	+	+	–	+	–
13	*Trapa natans*	Lythraceae	Floating	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–
14	*Vallisneria spiralis*	Hydrocharitaceae	Submerged	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	+	–	–
15	*Achyranthes aspera*	Amaranthaceae	Embankment	–	+	–	+	–	+	–	–	+	+	–	–	+	+	–	–	–	+	+	–	–
16	*Alternanthera sessilis*	Amaranthaceae	Embankment	+	+	–	–	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+
17	*Argemone mexicana*	Papaveraceae	Embankment	+	–	–	–	–	–	+	–	+	–	–	–	–	+	–	–	+	–	–	–	–
18	*Cassia sophera*	Fabaceae	Embankment	–	+	–	+	–	+	+	+	+	+	–	+	+	–	+	–	+	+	+	+	+
19	*Cassia tora*	Fabaceae	Embankment	–	+	–	+	+	+	+	+	+	+	–	+	–	–	+	+	+	+	–	–	+
20	*Centella asiatica*	Apiaceae	Embankment	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–
21	*Cleome viscosa*	Capparidaceae	Embankment	+	+	–	+	–	–	+	–	+	+	–	–	–	+	–	–	+	+	–	+	–
22	*Hygrophila spinosa*	Acanthaceae	Embankment	–	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–
23	*Ipomoea carnea*	Convolvulaceae	Embankment	+	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	–	+	–	+

24	*Lantana camera*	Verbenaceae	Embankment	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	+
25	*Lippia geminata*	Verbenaceae	Embankment	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
26	*Mikania* sp.	Asteraceae	Embankment	+	+	–	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	–
27	*Polygonum* sp.	Polygonaceae	Embankment	–	+	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–
28	*Saccharum spontaneum*	Poaceae	Embankment	+	–	+	–	+	–	–	–	–	–	+	–	+	+	–	–	+	–	+	–	–
29	*Sida cordifolia*	Malvaceae	Embankment	–	–	–	+	+	+	+	+	+	–	+	–	+	–	+	–	–	–	–	–	–
30	*Xanthium strumarium*	Asteraceae	Embankment	+	+	–	+	–	–	+	–	+	–	–	+	–	–	–	+	+	+	–	–	–

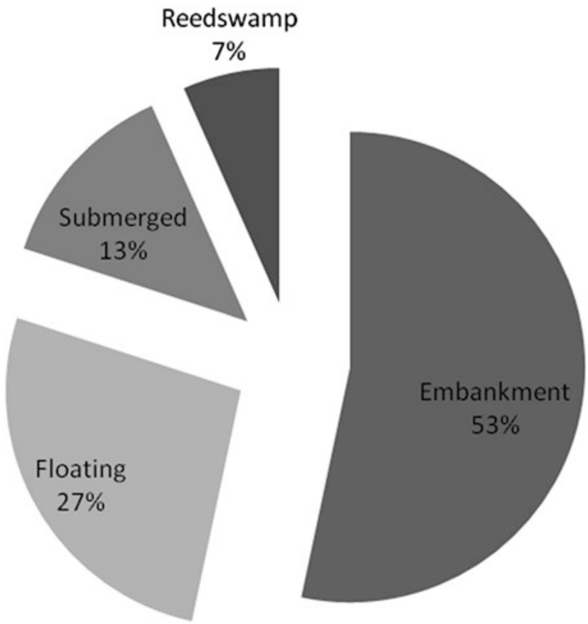


Fig. 6 Variation in hydrophytes and embarkment plant type in PL of RCF

spontaneum (Kans) are the most commonly occurring shrubs. It was also observed that *Acacia auriculiformis* (earleaf acacia) and *Azadirachta indica* (neem) were the most frequent naturally colonizing tree species around PL.

Table 16 depicts the abundance status of different plant species in PL which reveals that the highest percentage of plant frequency is found in Jambad 4 PL (34%) followed by Joyalbhanga 1 PL (29%), Amdia PL (28%), Chora PL (27%), Bonbedi PL (27%) and Alkusa Gopalpur PL (26%).

(c) *Successional Stages of Different Plant Community*

A hydrosere is a plant succession which occurs in an area of fresh water. In time, an area of open fresh water will naturally dry out, ultimately becoming woodland. During this change, a range of different land types such as swamp and marsh will succeed each other.

Phytoplankton Stage Unicellular floating algal plants such as diatoms are pioneer species of a bare waterbody, such as a pond. Their spores are carried by air to the pond. The phytoplankton is followed by zooplankton. They settle down to the bottom of the pond after death and decay into humus that mixes with silt and clay particles brought into the basin by runoff water and wave action and form soil. As soil builds up, the pond becomes shallower and further environmental changes follow.

Table 13 Enumeration of plants observed around PL of Pandabeswar and Jamuria block (RCF)

Serial no.	Plant name	Family	Type	Chora PL (PL01)	Joyalbanga PL01 (PL02)	Belpahari Kottadihi PL (PL20)	Dalurbandh PL (PL21)	Kumardihi PL (PL32)	Kumardihi Old OCP PL (PL33)	Sankarpur PL (PL35)	Gunjan Ecological Park PL (PL36)
1	*Acacia auriculiformis* Benth.	Fabaceae	Tree	–	+	+	+	+	+	+	+
2	*Acacia nilotica* (L.) Delile	Fabaceae	Tree	–	–	–	–	–	–	–	–
3	*Acalypha indica* L.	Euphorbiaceae	Herb	–	+	–	–	–	–	–	+
4	*Achyranthes aspera* L.	Amaranthaceae	Herb	–	+	+	+	+	+	–	–
5	*Aegle marmelos* (L.) Corrêa	Rutaceae	Tree	–	–	–	–	–	–	–	–
6	*Ailanthus excelsa* Roxb.	Simaroubaceae	Tree	–	–	+	–	–	–	–	–
7	*Albizia lebbeck* (L.) Benth.	Leguminosae	Tree	+	+	–	–	–	+	–	+
8	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	Tree	–	–	–	–	–	–	–	–
9	*Amaranthus spinosus* L.	Amaranthaceae	Herb	+	+	–	–	–	–	–	–
10	*Amaranthus viridis* L.	Amaranthaceae	Herb	–	–	–	–	–	–	–	–
11	*Andrographis paniculata* (Burm. f.) Nees	Acanthaceae	Herb	–	–	–	–	–	–	–	–
12	*Argemone Mexicana* L.	Papaveraceae	Herb	+	+	–	+	+	–	–	–

(continued)

Table 13 (continued)

Serial no.	Plant name	Family	Type	Chora PL (PL01)	Joyalbanga PL01 (PL02)	Belpahari Kottadihi PL (PL20)	Dalurbandh PL (PL21)	Kumardihi PL (PL32)	Kumardihi Old OCP PL (PL33)	Sankarpur PL (PL35)	Gunjan Ecological Park PL (PL36)
13	*Azadirachta indica* A. Juss	Meliaceae	Tree	–	–	+	–	–	+	–	–
14	*Boerhavia diffusa* L.	Nyctaginaceae	Herb	–	–	–	–	–	+	–	–
15	*Borassus flabellifer* L.	Arecaceae	Tree	–	–	–	–	–	–	–	+
16	*Butea monosperma* (Lam.) Taub.	Fabaceae	Tree	–	–	–	–	+	–	–	+
17	*Caesalpinia pulcherrima* (L.) Sw.	Fabaceae	Tree	–	–	–	–	–	–	–	–
18	*Calotropis gigantea* (L.) W.T. Aiton	Asclepiadaceae	Shrub	+	+	+	+	+	+	+	+
19	*Cassia sophera* L.	Fabaceae	Herb	–	+	+	–	+	+	+	+
20	*Cassia tora* L.	Fabaceae	Herb	–	+	–	–	+	+	–	–
21	*Centella asiatica* (L.) Urb.	Apiaceae	Herb	–	–	–	–	–	–	–	–
22	*Cleome viscose* L.	Capparidaceae	Herb	+	+	+	+	+	+	+	+
23	*Clerodendrum viscosum* Vent.	Verbenaceae	Herb	+	+	–	+	+	–	+	–
24	*Colocasia esculenta* (L.) Schott	Araceae	Herb	+	–	–	–	–	+	+	+
25	*Commelina benghalensis* L.	Commelinaceae	Herb	+	+	+	+	+	+	+	+
26	*Croton bonplandianus* Baill.	Euphorbiaceae	Herb	+	+	+	+	+	+	+	+
27	*Dalbergia sissoo* Roxb.	Papilionaceae	Tree	+	–	–	–	–	+	–	+

28	*Desmodium gangeticum* (L.) DC.	Fabaceae	Herb	+	+	–	–	–	–	–	–
29	*Datura metel* L.	Solanaceae	Herb	+	–	–	–	+	+	+	+
30	*Eclipta alba* (L.) Hassk.	Asteraceae	Herb	–	+	–	–	–	–	–	–
31	*Eupatorium odoratum* L.	Asteraceae	Shrub	+	+	+	+	+	+	+	–
32	*Euphorbia hirta* L.	Euphorbiaceae	Herb	+	–	+	–	+	+	+	+
33	*Ficus benghalensis* L	Moraceae	Tree	+	+	–	–	–	–	–	–
34	*Ficus religiosa* L.	Moraceae	Tree	+	–	–	–	–	–	–	–
35	*Heliotropium indicum* L.	Boraginaceae	Herb	–	–	–	–	–	–	–	–
36	*Hyptis suaveolens* (L.) Poit.	Lamiaceae	Herb	+	+	+	+	+	+	+	–
37	*Ipomoea carnea* Jacq.	Convolvulaceae	Shrub	+	+	+	+	+	–	+	–
38	*Lantana camara* L.	Verbenaceae	Shrub	+	+	+	+	+	+	+	–
39	*Leonotis nepetifolia* (L.) R.Br.	Lamiaceae	Herb	–	–	–	–	–	–	+	–
40	*Leucas aspera* (Willd.) Link	Lamiaceae	Herb	+	+	+	+	+	+	+	+
41	*Mimosa pudica* L.	Fabaceae	Herb	–	–	–	–	–	–	–	–
42	*Oldenlandia corymbosa* L.	Rubiaceae	Herb	–	–	–	–	–	–	–	–
43	*Parthenium hysterophorus* L.	Compositae	Herb	+	+	+	+	+	+	+	+
44	*Pergularia daemia* (Forssk.) Chiov.	Asclepiadaceae	Herb	–	–	–	+	–	–	+	–

(continued)

Table 13 (continued)

Serial no.	Plant name	Family	Type	Chora PL (PL01)	Joyalbanga PL01 (PL02)	Belpahari Kottadihi PL (PL20)	Dalurbandh PL (PL21)	Kumardihi PL (PL32)	Kumardihi Old OCP PL (PL33)	Sankarpur PL (PL35)	Gunjan Ecological Park PL (PL36)
45	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	Tree	+	–	+	–	–	+	+	–
46	*Phyllanthus amarus* Schumach. & Thonn.	Euphorbiaceae	Herb	–	+	–	–	–	–	–	+
47	*Saccharum spontaneum* L.	Poaceae	Herb	+	+	+	+	+	–	+	+
48	*Sida acuta* Burm.f.	Malvaceae	Herb	+	+	+	–	+	+	+	–
49	*Sida cordifolia* L.	Malvaceae	Herb	–	–	+	–	–	–	–	–
50	*Solanum sisymbriifolium* Lam.	Solanaceae	Herb	–	–	+	+	+	–	+	–
51	*Tephrosia purpurea* (L.) Pers.	Fabaceae	Herb	+	+	+	+	+	–	–	–
52	*Tridax procumbens* L.	Asteraceae	Herb	–	+	+	+	–	+	+	–
53	*Vernonia cinerea* (L.) Less.	Asteraceae	Shrub	+	–	–	–	+	+	–	–
54	*Vitex negundo* L.	Verbenaceae	Shrub	–	–	–	–	–	–	–	–
55	*Xanthium strumarium* L.	Asteraceae	Shrub	+	+	–	–	+	+	–	–
56	*Ziziphus jujuba* Mill.	Rhamnaceae	Tree	–	+	+	–	–	–	–	–

Table 14 Enumeration of plants observed around PL of Andal block (RCF)

Serial no.	Plant name	Family	Type	Jambad PL 4(PL13)	Western Kajora PL (PL15)	Atewal PL (PL16)	Khadan Kali PL (PL17)	Babuisol Shibmandir PL (PL18)	Real Kajora PL (PL25)	Chakrambati PL (PL26)	Dhanderdihi 1 PL (PL27)	Dhanderdihi 2 PL (PL28)	Dhandadihi 3 PL (PL29)	Babuisol Colony PL (PL31)
1	*Acacia auriculiformis* Benth.	Fabaceae	Tree	–	–	–	–	–	–	+	–	–	–	–
2	*Acacia nilotica* (L.) Delile	Fabaceae	Tree	–	–	+	–	–	–	–	–	–	–	+
3	*Acalypha indica* L.	Euphorbiaceae	Herb	–	–	–	–	–	–	–	–	–	–	–
4	*Achyranthes aspera* L.	Amaranthaceae	Herb	+	+	–	–	–	+	+	–	–	+	–
5	*Aegle marmelos* (L.) Corrêa	Rutaceae	Tree	+	+	–	–	–	–	–	–	–	–	–
6	*Ailanthus excelsa* Roxb.	Simaroubaceae	Tree	–	–	–	–	–	–	–	–	–	–	–
7	*Albizia lebbeck (L.)* Benth.	Leguminosae	Tree	–	–	–	–	–	–	–	+	–	–	–
8	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	Tree	+	–	–	–	–	–	–	–	–	–	–
9	*Amaranthus spinous* L.	Amaranthaceae	Herb	+	+	–	+	+	–	–	–	–	–	+
10	*Amaranthus viridis* L.	Amaranthaceae	Herb	+	–	–	–	–	–	–	–	–	–	–
11	*Andrographis paniculata* (Burm.f.) Nees	Acanthaceae	Herb	–	–	–	–	–	–	–	–	–	+	–
12	*Argemone Mexicana* L.	Papaveraceae	Herb	+	+	+	+	–	+	+	–	+	–	–
13	*Azadirachta indica* A. Juss	Meliaceae	Tree	–	+	–	–	–	–	–	–	–	–	–
14	*Boerhavia diffusa* L.	Nyctaginaceae	Herb	+	–	–	+	–	–	+	–	–	–	–
15	*Borassus flabellifer* L.	Arecaceae	Tree	–	–	–	–	–	–	–	+	–	–	–
16	*Butea monosperma* (Lam.) Taub.	Fabaceae	Tree	+	+	–	+	+	–	–	+	+	–	–
17	*Caesalpinia pulcherrima* (L.) Sw.	Fabaceae	Tree	–	+	–	–	–	–	–	–	–	–	–

(continued)

Table 14 (continued)

Serial no.	Plant name	Family	Type	Jambad PL 4(PL13)	Western Kajora PL (PL15)	Atewal PL (PL16)	Khadan Kali PL (PL17)	Babuisol Shibmandir PL (PL18)	Real Kajora PL (PL25)	Chakrambati PL (PL26)	Dhanderdihi 1 PL (PL27)	Dhanderdihi 2 PL (PL28)	Dhandadihi 3 PL (PL29)	Babuisol Colony PL (PL31)
18	*Calotropis gigantean* (L.) W.T. Aiton	Asclepiadaceae	Shrub	+	+	+	+	+	+	+	+	+	+	+
19	*Cassia sopher*a L.	Fabaceae	Herb	+	+	–	+	+	+	+	–	–	–	–
20	*Cassia tora* L.	Fabaceae	Herb	+	+	–	+	+	+	+	–	–	–	+
21	*Centella asiatica* (L.) Urb.	Apiaceae	Herb	+	–	–	–	–	–	–	–	–	–	–
22	*Cleome viscose* L.	Capparidaceae	Herb	+	+	–	–	–	+	+	–	–	–	–
23	*Clerodendrum viscosum* Vent.	Verbenaceae	Herb	+	+	+	+	+	–	+	+	–	+	+
24	*Colocasia esculenta* (L.) Schott	Araceae	Herb	–	–	–	–	–	–	–	–	–	–	–
25	*Commelina benghalensis* L.	Commelinaceae	Herb	+	+	–	–	–	+	–	–	–	–	–
26	*Croton bonplandianus* Baill.	Euphorbiaceae	Herb	+	–	–	+	+	+	–	+	+	–	+
27	*Dalbergia sissoo* Roxb.	Papilionaceae	Tree	–	–	+	+	–	–	–	–	–	+	–
28	*Desmodium gangeticum* (L.) DC.	Fabaceae	Herb	+	–	–	–	–	–	–	–	–	–	–
29	*Datura metel* L.	Solanaceae	Herb	–	–	–	–	–	–	–	+	–	–	–
30	*Eclipta alba* (L.) Hassk.	Asteraceae	Herb	–	–	–	–	–	–	–	–	–	–	–
31	*Eupatorium odoratum* L.	Asteraceae	Shrub	+	+	+	+	+	+	+	+	+	+	+
32	*Euphorbia hirta* L.	Euphorbiaceae	Herb	+	+	–	+	+	–	–	–	–	–	+
33	*Ficus benghalensis* L	Moraceae	Tree	–	–	–	+	–	–	–	–	+	–	–
34	*Ficus religiosa L.*	Moraceae	Tree	–	–	–	–	–	–	–	–	+	–	–
35	*Heliotropium indicum* L.	Boraginaceae	Herb	–	–	–	–	+	–	–	–	–	–	–

36	*Hyptis suaveolens* (L.) Poit.	Lamiaceae	Herb	+	+	+	+	+	+	+	+	+	+	+
37	*Ipomoea carnea* Jacq.	Convolvulaceae	Shrub	+	+	–	+	+	–	+	+	+	–	+
38	*Lantana camara* L.	Verbenaceae	Shrub	+	+	+	+	+	+	+	+	+	+	+
39	*Leonotis nepetifolia* (L.) R.Br.	Lamiaceae	Herb	–	–	–	–	–	+	–	–	–	–	–
40	*Leucas aspera* (Willd.) Link	Lamiaceae	Herb	+	–	–	–	–	+	–	–	–	–	–
41	*Mimosa pudica* L.	Fabaceae	Herb	–	–	–	–	–	–	+	–	–	–	–
42	*Oldenlandia corymbosa* L.	Rubiaceae	Herb	+	–	–	–	–	+	–	–	–	–	–
43	*Parthenium hysterophorus* L.	Compositae	Herb	+	+	+	+	+	+	+	+	+	+	+
44	*Pergularia daemia* (Forssk.) Chiov.	Asclepiadaceae	Herb	–	–	–	+	–	–	–	–	–	–	–
45	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	Tree	–	+	+	+	+	–	+	+	+	+	+
46	*Phyllanthus amarus* Schumach. & Thonn.	Euphorbiaceae	Herb	+	–	–	–	–	+	–	–	–	–	–
47	*Saccharum spontaneum* L.	Poaceae	Herb	+	–	+	–	+	+	+	+	+	–	+
48	*Sida acuta* Burm.f.	Malvaceae	Herb	+	+	+	+	+	+	+	–	–	–	+
49	*Sida cordifolia* L.	Malvaceae	Herb	+	–	+	–	+	+	+	+	–	+	–
50	*Solanum sisymbriifolium* Lam.	Solanaceae	Herb	+	–	–	–	+	–	+	–	–	–	–
51	*Tephrosia purpurea* (L.) Pers.	Fabaceae	Herb	+	+	+	–	+	–	–	+	+	+	–
52	*Tridax procumbens* L.	Asteraceae	Herb	–	–	+	+	+	+	–	–	+	+	–
53	*Vernonia cinerea* (L.) Less.	Asteraceae	Shrub	+	–	–	–	–	+	–	–	–	–	+
54	*Vitex negundo* L.	Verbenaceae	Shrub	–	–	–	–	–	–	+	+	–	–	–
55	*Xanthium strumarium* L.	Asteraceae	Shrub	+	–	+	+	–	+	+	–	–	–	+
56	*Ziziphus jujuba* Mill.	Rhamnaceae	Tree	+	+	+	+	+	+	+	+	–	+	+

Table 15 Enumeration of plants observed around PL of Salanpur and Raniganj block (RCF)

Serial no.	Plant name	Family	Type	Amdia PL (PL05)	Samdi PL (PL06)	Dalmia PL (PL07)	Bonbedi PL (PL09)	Alkusa Gopalpur PL (PL10)	Sikhdaspur PL (PL11)	Nimcha Harabanga PL (PL24)	Nimcha Damali Harabanga PL (PL37)
1	*Acacia auriculiformis* Benth.	Fabaceae	Tree	+	+	+	–	+	–	–	–
2	*Acacia nilotica* (L.) Delile	Fabaceae	Tree	–	–	–	–	–	–	–	–
3	*Acalypha indica* L.	Euphorbiaceae	Herb	–	–	–	–	–	–	–	–
4	*Achyranthes aspera* L.	Amaranthaceae	Herb	+	–	+	+	+	–	–	–
5	*Aegle marmelos* (L.) Corrêa	Rutaceae	Tree	–	–	–	–	–	–	–	–
6	*Ailanthus excelsa* Roxb.	Simaroubaceae	Tree	+	–	–	–	–	+	+	+
7	*Albizia lebbeck* (L.) Benth.	Leguminosae	Tree	–	–	–	–	+	–	+	–
8	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	Tree	–	–	–	–	–	–	–	–
9	*Amaranthus spinous* L.	Amaranthaceae	Herb	–	–	–	+	–	–	–	–
10	*Amaranthus viridis* L.	Amaranthaceae	Herb	–	–	–	–	–	–	–	–
11	*Andrographis paniculata* (Burm.f.) Nees	Acanthaceae	Herb	–	–	–	–	–	–	–	–
12	*Argemone Mexicana* L.	Papaveraceae	Herb	–	–	–	+	+	–	–	–
13	*Azadirachta indica* A. Juss	Meliaceae	Tree	+	+	–	+	+	+	–	–
14	*Boerhavia diffusa* L.	Nyctaginaceae	Herb	–	–	+	–	+	–	–	–
15	*Borassus flabellifer* L.	Arecaceae	Tree	–	–	–	–	–	+	–	–
16	*Butea monosperma* (Lam.) Taub.	Fabaceae	Tree	+	–	+	+	–	+	+	+
17	*Caesalpinia pulcherrima* (L.) Sw.	Fabaceae	Tree	–	–	–	–	–	–	–	–
18	*Calotropis gigantean* (L.) W.T. Aiton	Asclepiadaceae	Shrub	–	+	+	+	+	–	+	+
19	*Cassia sophera* L.	Fabaceae	Herb	+	–	+	+	–	+	+	+
20	*Cassia tora* L.	Fabaceae	Herb	+	+	+	+	+	+	+	+
21	*Centella asiatica* (L.) Urb.	Apiaceae	Herb	–	–	–	–	–	–	–	–
22	*Cleome viscose* L.	Capparidaceae	Herb	+	–	–	+	+	–	–	–

23	*Clerodendrum viscosum* Vent.	Verbenaceae	Herb	–	+	+	+	+	+	+	–
24	*Colocasia esculenta* (L.) Schott	Araceae	Herb	–	–	–	–	–	–	–	–
25	*Commelina benghalensis* L.	Commelinaceae	Herb	+	+	–	–	–	–	–	–
26	*Croton bonplandianus* Baill.	Euphorbiaceae	Herb	+	+	+	+	+	+	+	+
27	*Dalbergia sissoo* Roxb.	Papilionaceae	Tree	–	–	–	–	–	–	–	–
28	*Desmodium gangeticum* (L.) DC.	Fabaceae	Herb	–	–	–	–	–	–	–	–
29	*Datura metel* L.	Solanaceae	Herb	+	–	–	+	–	–	+	–
30	*Eclipta alba* (L.) Hassk.	Asteraceae	Herb	–	+	–	–	–	–	–	–
31	*Eupatorium odoratum* L.	Asteraceae	Shrub	+	+	–	+	+	+	+	+
32	*Euphorbia hirta* L.	Euphorbiaceae	Herb	+	+	–	+	+	+	+	+
33	*Ficus benghalensis* L.	Moraceae	Tree	–	+	–	–	–	–	–	–
34	*Ficus religiosa L.*	Moraceae	Tree	–	–	–	+	–	–	–	–
35	*Heliotropium indicum* L.	Boraginaceae	Herb	–	–	–	–	–	–	–	–
36	*Hyptis suaveolens* (L.) Poit.	Lamiaceae	Herb	+	+	–	+	+	+	+	+
37	*Ipomoea carnea* Jacq.	Convolvulaceae	Shrub	+	+	+	+	+	+	+	+
38	*Lantana camara* L.	Verbenaceae	Shrub	+	+	+	+	+	+	+	+
39	*Leonotis nepetifolia* (L.) R.Br.	Lamiaceae	Herb	+	–	+	+	–	–	–	–
40	*Leucas aspera* (Willd.) Link	Lamiaceae	Herb	–	–	–	–	–	+	+	–
41	*Mimosa pudica* L.	Fabaceae	Herb	–	–	–	–	+	–	+	–
42	*Oldenlandia corymbosa* L.	Rubiaceae	Herb	–	–	–	+	+	–	–	–
43	*Parthenium hysterophorus* L.	Compositae	Herb	+	+	+	+	+	+	+	+
44	*Pergularia daemia* (Forssk.) Chiov.	Asclepiadaceae	Herb	+	–	–	–	–	–	–	+
45	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	Tree	+	–	+	–	+	+	+	+
46	*Phyllanthus amarus* Schumach. & Thonn.	Euphorbiaceae	Herb	–	–	–	–	–	–	–	–
47	*Saccharum spontaneum* L.	Poaceae	Herb	+	+	+	+	+	+	+	+

(continued)

Table 15 (continued)

Serial no.	Plant name	Family	Type	Amdia PL (PL05)	Samdi PL (PL06)	Dalmia PL (PL07)	Bonbedi PL (PL09)	Alkusa Gopalpur PL (PL10)	Sikhdaspur PL (PL11)	Nimcha Harabanga PL (PL24)	Nimcha Damali Harabanga PL (PL37)
48	*Sida acuta* Burm.f.	Malvaceae	Herb	+	–	–	+	+	+	+	+
49	*Sida cordifolia* L.	Malvaceae	Herb	+	+	+	+	+	+	+	–
50	*Solanum sisymbriifolium* Lam.	Solanaceae	Herb	+	+	+	–	+	+	–	–
51	*Tephrosia purpurea* (L.) Pers.	Fabaceae	Herb	+	+	–	–	–	+	–	+
52	*Tridax procumbens* L.	Asteraceae	Herb	+	+	–	+	+	–	–	–
53	*Vernonia cinerea* (L.) Less.	Asteraceae	Shrub	–	–	–	–	–	–	–	–
54	*Vitex negundo* L.	Verbenaceae	Shrub	–	–	–	–	–	–	–	–
55	*Xanthium strumarium* L.	Asteraceae	Shrub	+	–	–	+	–	+	+	–
56	*Ziziphus jujuba* Mill.	Rhamnaceae	Tree	+	+	–	+	+	+	+	+

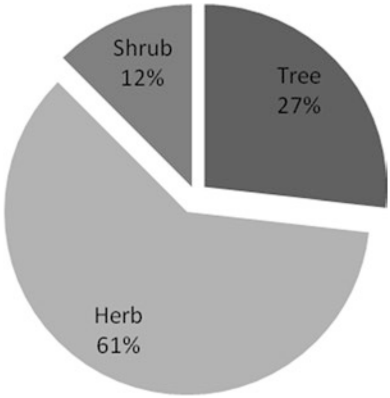


Fig. 7 Variation in plant type around PL of RCF

Submerged Stage As the waterbody becomes shallower, more submerged rooted species are able to become established due to increasing light penetration in the shallower water. This is suitable for growth of rooted submerged species such as *Myriophyllum*, *Vallisneria*, *Elodea*, *Hydrilla* and *Ceratophyllum*. These plants root themselves in mud. Once submerged species colonize, the successional changes are more rapid and are mainly autogenic as organic matter accumulates. Inorganic sediment is still entering the lake and is trapped more quickly by the net of plant roots and rhizomes growing on the pond floor. The pond becomes sufficiently shallow (2–5 ft) for floating species and less suitable for rooted submerged plants.

Floating Stage The floating plants are rooted in the mud, but some or all their leaves float on the surface of the water. These include species like *Nymphaea*, *Nelumbo* and *Potamogeton*. Some free-floating species also become associated with root plants. The large and broad leaves of floating plants shade the water surface, and conditions become unsuitable for growth of submerged species which start disappearing. The plants decay to form organic mud which makes the pond shallower yet (1–3 ft).

Reed Swamp Stage The pond is now invaded by emergent plants such as *Phragmites* (reed grasses), *Typha* (cattail) and *Zizania* (wild rice) to form a reed swamp. These plants have creeping rhizomes which knit the mud together to produce large quantities of leaf litter. This litter is resistant to decay, and reed peat builds up, accelerating the autogenic change. The surface of the pond is converted into water-saturated marshy land.

Sedge Meadow Stage Successive decreases in the water level and changes in substratum help members of Cyperaceae and Gramineae such as *Carex* spp. and *Juncus* to establish them. They form a mat of vegetation extending towards the centre of the pond. Their rhizomes knit the soil further. The above water leaves transpire water to lower the water level further and add additional leaf litter to the soil. Eventually the sedge peat accumulates above the water level, and soil is no longer totally water-

Table 16 Abundance of plant species observed around PL in studied PL of RCF

Sites	Status	Frequency	Relative frequency
Chora PL	0	29	51.79
	1	27	48.21
Joyalbhanga 1 PL	0	27	48.21
	1	29	51.79
Amdia PL	0	28	50.00
	1	28	50.00
Samdi PL	0	35	62.50
	1	21	37.50
Dalmia PL	0	39	69.64
	1	17	30.36
Bonbedi PL	0	29	51.79
	1	27	48.21
Alkusa Gopalpur PL	0	30	53.57
	1	26	46.43
Sikhdaspur PL	0	33	58.93
	1	23	41.07
Jambad 4 PL	0	22	39.29
	1	34	60.71
Western Kajora PL	0	33	58.93
	1	23	41.07
Atewal PL	0	39	69.64
	1	17	30.36
Khadan Kali PL	0	33	58.93
	1	23	41.07
Babuisol Sibmandir PL	0	34	60.71
	1	22	39.29
Belpahari Kottadihi PL	0	32	57.14
	1	24	42.86
Dalurbandh PL	0	37	66.07
	1	19	33.93
Nimcha Harabanga PL	0	33	58.93
	1	23	41.07
Real Kajora PL	0	33	58.93
	1	23	41.07
Chakrambati PL	0	33	58.93
	1	23	41.07
Dhanderdihi 1 PL	0	38	67.86
	1	18	32.14
Dhanderdihi 2 PL	0	41	73.21
	1	15	26.79
Dhandadihi 3 PL	0	42	75.00
	1	14	25.00
Babuisol Colony PL	0	38	67.86
	1	18	32.14

(continued)

Table 16 (continued)

Sites	Status	Frequency	Relative frequency
Kumardihi PL	0	31	55.36
	1	25	44.64
Kumardihi Old OCP PL	0	31	55.36
	1	25	44.64
Sankarpur PL	0	33	58.93
	1	23	41.07
Gunjan Ecological Park PL	0	38	67.86
	1	18	32.14
Nimcha Damali Harabanga PL	0	38	67.86
	1	18	32.14

1 = total number of species present, 0 = total number of species absent

Table 17 Successional stages of PL in RCF areas

Phytoplankton stage	Submerged stage	Floating stage	Reed swamp stage	Sedge meadow stage	Woodland stage	Climax stage
	PL01, PL04, PL07, PL15, PL16, PL17, PL20, PL21, PL33, PL34	PL01, PL02, PL04, PL05, PL06, PL07, PL09, PL11, PL13, PL15, PL17, PL20, PL21, PL24, PL31, PL32, PL33, PL34, PL36, PL37	PL02, PL05, PL06, PL07, PL11, PL15, PL16, PL20, PL21, PL24, PL31, PL32, PL33, PL36			

logged. The habitat becomes suitable for invasion of herbs (secondary species) such as *Mentha*, *Caltha*, *Iris* and *Galium* which grow luxuriantly and bring further changes to the environment. Mesic conditions develop and marshy vegetation begins to disappear.

Woodland Stage The soil now remains drier for most of the year and becomes suitable for development of wet woodland. It is invaded by shrubs and trees such as *Salix* (willow), *Alnus* (alder) and *Populus* (poplar). These plants react upon the habitat by producing shade, lower the water table still further by transpiration, build up the soil and lead to the accumulation of humus with associated microorganisms.

Climax Stage Finally a self-perpetuating climax community develops. It may be a forest if the climate is humid, a grassland in case of subhumid environment or a desert in arid and semiarid conditions. A forest is characterized by the presence of all types of vegetation including herbs, shrubs, mosses, shade-loving plants and trees. Decomposers are frequent in climax vegetation.

Successional stages of all PLs were noticed (Table 17), and it was found that phytoplankton stage was absent in case of all PLs. Submerged stages are predominant in PL, i.e., Chora (PL 01), Katapahari (PL 04), Dalmia (PL 07), Western Kajora

(PL 15), Atewal (PL 16), Khadan Kali (PL 17), Belpahari Kottadihi (PL 20), Dalurbandh (PL 21), Kumardihi Old (PL 33) and Joalbhanga 2 (PL 34). All PL vegetation showed floating stages of successional pattern except Atewal (PL 16). Reed swamp stage of vegetation structure was also noticed in almost all PLs except Chora (PL 01), Katapahari (PL 04), Bonbedi (PL 09), Jambad 4 (PL 13), Khadan Kali (PL 17), Joalbhanga 2 (PL 34) and Nimcha Damali Harabhanga (PL 37). Sedge meadow stage, woodland stage and climax stage were absent in all studied PLs in RCF areas.

Categorization of Pitlakes on the Basis of Successional Characteristics
Successional stages of 21 PLs in RCF areas are given in Table 17. On the basis of successional stages, the PL can be put into three categories; a brief account on each of which is presented in the following:

(i) Waterbodies rich in rooted submerged hydrophytes like Indian star grass, eel grass, etc. which grow at various depths and seen in PL01 (Chora PL), PL04 (Katapahari PL), PL06 (Samdi PL), PL07 (Dalmia PL), PL15 (Western Kajora), PL16 (Atewal PL), PL17 (Kadhan kali), PL20 (Belpahari Kottadihi PL), PL21 (Dalurbandh PL), PL33 (Kumardihi Old OCP PL) and PL34 (Joyalbhanga 2 PL).
(ii) Waterbodies dominated by plant species rooted in the mud with their leaves reaching the water surface to float, e.g., *Nymphaea nouchali* (blue water lily), *Trapa natans* (water chestnut), etc., and by free-floating plants that are not fixed in the mud, e.g., *Lemna* sp. (duckweed), water moss, etc., as seen in PL01 (Chora PL), PL02 (Joyalbanga PL1), PL04 (Katapahari PL), PL05 (Amdia PL), PL07 (Dalmia PL), PL09 (Bonbedi PL), PL11 (Sikhdaspur PL), PL13 (Jambad 4 PL), PL15 (Western Kajora PL), PL17 (Khadan Kali PL), PL20 (Belpahari Kottadihi PL), PL21 (Dalurbandh PL), PL24 (Nimcha Harabanga PL), PL31 (Babuisol Colony PL), PL32 (Kumrdihi PL), PL33 (Kumardihi Old OCP PL), PL34 (Joyalbhanga 2 PL), PL36 (Gunjon Ecological Park PL) and PL37 (Nimcha Harabanga Damali PL).
(iii) Waterbodies in reed swamp stage with plants that are mostly rooted, but most parts of their shoots remain exposed, e.g., amphibious plants like *Typha domingensis* (cattail), etc. These plants react not only to shade the surface water but also to build up the margins by retaining sedimentary material washed into the waterbody and rapidly accumulating plant remains. These plant populations are much denser. PLs that belong to this category are PL02 (Joyalbanga 1 PL), PL05 (Amdia PL), PL06 (Samdi PL), PL07 (Dalmia PL), PL11 (Sikhdaspur PL), PL15 (Western Kajora PL), PL16 (Atewal PL), PL20 (Belpahari Kottadihi PL), PL21 (Dalurbandh PL), PL24 (Nimcha Harabanga PL), PL31 (Babuisol Colony PL), PL32 (Kumrdihi PL), PL33 (Kumardihi old OCP PL) and PL36 (Gunjon Ecological Park PL).

6.2 Enumeration of Avifaunal Composition in and Around Pitlakes of RCF

(a) *Residential Avifaunal Composition in Pitlakes During the Study Period*

Good and effective aquatic life supporting environment have been observed in these PLs which is also supported by the rich avifaunal resources in and around these PLs. Fifty nine species of wetland birds (with terrestrial counterparts in the adjoining floral habitat) belonging to 15 orders and 34 families were recorded (Table 18). The family Passeriformes represented by 22 species dominated the wetland bird community of the study area. Lesser whistling duck (*Dendrocygna javanica*) is the most important resident bird in these PLs.

6.3 Notable Piscifauna Observed in Pitlakes

During the study period, the 15 most frequently cultured/naturally occurred fish species under 4 orders, 5 families and 14 genera were collected and identified from the PL of RCF, West Bengal, India (Table 19). The maximum number of species was found under the order Cypriniformes (11). Cyprinidae was the most species (11)-bearing family. Our study revealed that according to the red list threat category, least concern (LC) category (66.66%) was the maximum fish species-comprising category followed by not evaluated (NE, 11%), near threatened (NT, 20%) and data deficient (6.66%), respectively. The population trend includes 73.33% fish species with unknown status (UN) followed by 20% with decreasing (DE) and only 6.66% fishes with stable (ST) status. We found that there is ample scope of intensive pisciculture practices in most of the PL.

Developmental Project Based on Pitlake Water for Site-Specific Pisciculture Practices

Pitlakes are large deep open ecosystem. We have inventorized 40 PLs, and among them recreational fishing and for feeding purposes fishing activity take place in 34 PLs. Sometimes commercial fishing takes place for some 18 PLs as secondary livelihood purposes. After analysis of PL water quality and questionnaire survey of local stakeholder, we have recorded that developmental pisciculture project can be started in 25 PLs. These PLs are, namely, Joyalbhanga 1 PL, Vatas 1 PL, Amdia PL, Samdi PL, Dalmia PL, Bamna PL, Bonbedi PL, Alkusa Gopalpur PL, Sikhdaspur PL, Jambad 5 PL, Jambad 4 PL, Jambad bottom-up PL, Atewal PL, Khadan Kali PL, Dalurbandh PL, Nagrakonda PL, Pathaldanga PL, Nimcha Harabanga PL, Real Kajora PL, Dhandadihi 2 PL, Babuisol Colony PL, Kumardihi Old OCP PL, Joyalbhanga 2 PL, Nimcha Damali Harabanga PL and Vatas 2 PL. The above-mentioned PLs were selected in accordance with their suitability for aquaculture practice. Due to high adaptability of such PL, the pisciculture techniques will be initiated here.

Table 18 Enumeration of residential birds observed in and around PL of RCF

Species code	Bird name	Scientific name	Order	Family	Population trend	Status
S1	Ashy prinia	*Prinia socialis*	Passeriformes	Cisticolidae	Stable	R
S2	Ashy wood swallow	*Artamus fuscus*	Passeriformes	Artamidae	Stable	R
S3	Asian openbill stork	*Anastomus oscitans*	Ciconiiformes	Ciconiidae	Unknown	R
S4	Asian palm swift	*Cypsiurus balasiensis*	Caprimulgiformes	Apodidae	Stable	R
S5	Asian pied starling	*Sturnus contra*	Passeriformes	Sturnidae	Increasing	R
S7	Bengal bush lark	*Mirafra assamica*	Passeriformes	Alaudidae	Stable	R
S8	Black-crowned night heron	*Nycticorax nycticorax*	Pelecaniformes	Ardeidae	Decreasing	R
S9	Black drongo	*Dicrurus macrocercus*	Passeriformes	Dicruridae	Unknown	R
S10	Black-hooded oriole	*Oriolus xanthornus*	Passeriformes	Oriolidae	Unknown	R
S11	Black kite	*Milvus migrans*	Accipitriformes	Accipitridae	Unknown	R
S12	Black-rumped flameback	*Dinopium benghalense*	Piciformes	Picidae	Stable	R
S14	Brahminy kite	*Haliastur indus*	Accipitriformes	Accipitridae	Decreasing	R
S15	Brahminy sterling	*Sturnus pagodarum*	Passeriformes	Sturnidae	Unknown	R
S16	Bronze-winged jacana	*Metopidius indicus*	Charadriiformes	Jacanidae	Unknown	R
S18	Cattle egret	*Bubulcus ibis*	Pelecaniformes	Ardeidae	Increasing	R
S19	Chestnut-tailed starling	*Sturnus malabaricus*	Passeriformes	Sturnidae	Unknown	R
S21	Common kingfisher	*Alcedo atthis*	Coraciiformes	Alcedinidae	Unknown	R
S22	Common moorhen	*Gallinula chloropus*	Gruiformes	Rallidae	Stable	R
S23	Common myna	*Acridotheres tristis*	Passeriformes	Sturnidae	Increasing	R
S26	Common tailorbird	*Orthotomus sutorius*	Passeriformes	Sylviidae	Stable	R
S27	Coppersmith barbet	*Psilopogon haemacephalus*	Piciformes	Megalaimidae	Increasing	R
S31	Greater coucal	*Centropus sinensis*	Cuculiformes	Cuculidae	Stable	R
S32	Green bee eater	*Merops orientalis*	Coraciiformes	Meropidae	Increasing	R
S34	House crow	*Corvus splendens*	Passeriformes	Corvidae	Stable	R
S35	House sparrow	*Passer domesticus*	Passeriformes	Passeridae	Decreasing	R
S36	Indian cormorant	*Phalacrocorax fuscicollis*	Suliformes	Phalacro coracidae	Unknown	R
S37	Indian pond heron	*Ardeola grayii*	Pelecaniformes	Ardeidae	Unknown	R

S38	Indian robin	*Saxicoloides fulicatus*	Passeriformes	Muscicapidae	Stable	R
S39	Indian silverbill	*Lonchura malabarica*	Passeriformes	Estrildidae	Stable	R
S40	Jungle babbler	*Turdoides striata*	Passeriformes	Timaliidae	Stable	R
S41	Lesser whistling duck	*Dendrocygna javanica*	Anseriformes	Anatidae	Decreasing	R
S42	Little egret	*Egretta garzetta*	Pelecaniformes	Ardeidae	Increasing	R
S43	Oriental magpie robin	*Copsychus saularis*	Passeriformes	Muscicapidae	Stable	R
S45	Purple sunbird	*Nectarinia asiatica*	Passeriformes	Nectariniidae	Stable	R
S46	Red-vented bulbul	*Pycnonotus cafer*	Passeriformes	Pycnonotidae	Increasing	R
S48	Red-whiskered bulbul	*Pycnonotus jocosus*	Passeriformes	Pycnonotidae	Decreasing	R
S49	Rock dove	*Columba livia*	Columbiformes	Columbidae	Decreasing	R
S50	Rose-ringed parakeet	*Psittacula krameri*	Psittaciformes	Psittacidae	Increasing	R
S51	Rufous treepie	*Dendrocitta vagabunda*	Passeriformes	Corvidae	Stable	R
S52	Scaly-breasted munia	*Lonchura punctulata*	Passeriformes	Estrildidae	Stable	R
S54	Spotted dove	*Spilopelia chinensis*	Columbiformes	Columbidae	Increasing	R
S56	Tricolored munia	*Lonchura malacca*	Passeriformes	Estrildidae	Stable	R
S57	Western koel	*Eudynamys scolopaceus*	Cuculiformes	Cuculidae	Stable	R
S59	White-breasted waterhen	*Amaurornis phoenicurus*	Gruiformes	Rallidae	Unknown	R

R resident

Table 19 Notable piscifauna observed in PL

Species code	Order	Family	Scientific name	Common name (English)	Common name (Bengali)	Population trend
SP1	Cypriniformes	Cyprinidae	*Hypophthalmichthys molitrix*	Silver carp	Silver carp	DE
SP2			*Aristichthys nobilis*	Bighead carp	Bighead carp	DE
SP3			*Labeo bata*	Bata	Bata	UN
SP4			*Catla catla*	Catla	Catla	UN
SP5			*Cyprinus carpio*	Common carp	American rui	UN
SP6			*Ctenopharyngodon idella*	White Amur	Grass carp	UN
SP7			*Labeo calbasu*	Orangefin labeo	Kalibaus	UN
SP8			*Cirrhinus mrigala*	White carp	Mrigal	DE
SP9			*Amblypharyngodon mola*	Mola carplet	Murala	ST
SP10			*Puntius puntio*	Puntio barb	Punti	UN
SP11			*Labeo rohita*	Rohu	Rui	UN
SP13	Perciformes	Cichlidae	*Oreochromis niloticus*	Nile tilapia	Nilotica	UN
SP14		Channidae	*Channa punctatus*	Spotted snakehead	Lata	UN
SP15	Siluriformes	Clariidae	*Clarias batrachus*	Philippine catfish	Magur	UN

DE decreasing, *UN* unknown, *ST* stable

7 Developmental Activities Based on Pitlakes

Under careful management programmes ensuring optimum biotic and abiotic characteristics, PL and their resources can directly and indirectly promote developmental activities. Developmental activities that can be based on RCF PL under the existing conditions are suggested in the following flow chart (Fig. 8; Table 20), which may prove worthwhile for consideration. Such implementation can generate employment and improve the economic conditions of the local people most of whom lie below the poverty level. However, care must be taken to formulate the PL-friendly and sustainable developmental programmes since the use of water resources, fisheries, tourism, recreation, etc. is likely to prove detrimental.

Keeping in mind the present need of the hour to conserve natural resources, PL restoration projects need to be implemented more collaterally with sustainable utilization of its resources. Moreover, extensive and intensive field and laboratory studies in correlation with information obtained from application of remote sensing technology on PL of the RCF can not only rationalize resource utilization but also

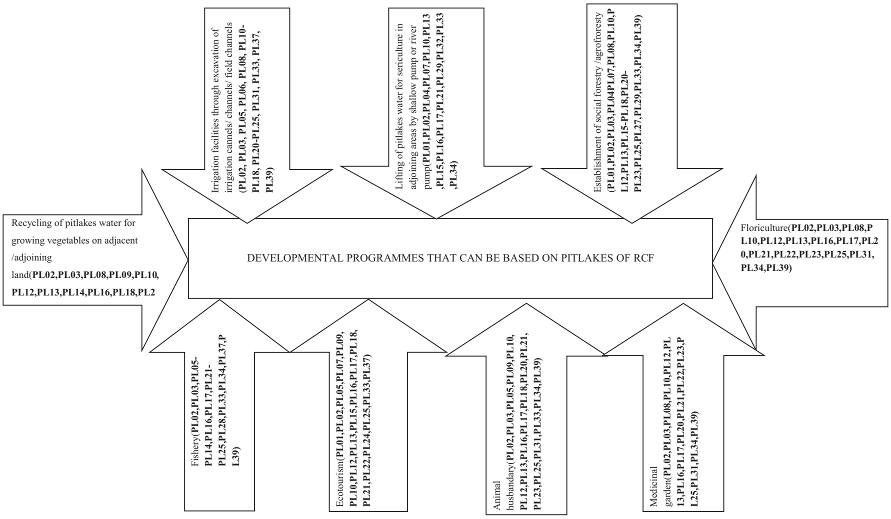


Fig. 8 Developmental programmes that can be based on pitlakes of RCF
Legend of pitlake codes: PL01, Chora pitlake; PL02, Joyalbhanga 1 pitlake; PL03, Vatas 1 pitlake; PL04, Katapahari pitlake; PL05, Amdia pitlake; PL06, Samdi pitlake; PL07, Dalmia pitlake; PL08, Dalmia pitlake; PL09, Bonbedi pitlake; PL10, Alkusa Gopalpur pitlake; PL11, Sikhdaspur pitlake; PL12, Jambad 5 pitlake; PL13, Jambad 4 pitlake; PL14, Jambad bottom-up pitlake; PL15, Western Kajora pitlake; PL16, Atewal pitlake; PL17, Khadan Kali pitlake; PL18, Babuisol Sibmandir pitlake; PL19, Ramnagar pitlake; PL20, Belpahari Kottadihi pitlake; PL21, Dalurbandh pitlake; PL22, Nagrakonda pitlake; PL23, Pathaldanga pitlake; PL24, Nimcha Harabanga pitlake; PL25, Real Kajora pitlake; PL26, Chakrambati pitlake; PL27, Dhanderdihi 1 pitlake; PL28, Dhanderdihi 2 pitlake; PL29, Dhandadihi 3 pitlake; PL30, Porasia Khadan pitlake; PL31, Babuisol Colony pitlake; PL32, Kumardihi pitlake; PL33, Kumardihi Old OCP pitlake; PL34, Joyalbanga 2 pitlake; PL35, Sankarpur pitlake; PL36, Gunjan Ecological Park pitlake; PL37, Nimcha Damali Harabanga pitlake; PL38, Patmohana Ranisayar pitlake; PL39, Vatas 2 pitlake; PL40, Chapuikhash pitlake

help in identifying areas of uncertainty, crisis and problems so that safety, restorative and mitigatory measures can be formulated for practical application. Such an integrated approach can provide scope for protecting the environment from future disaster and strengthen the economy. This work would be considered successful if the findings are used in the future for formulating strategies for both ecological welfare and economic development.

We have inventoried forty 40 PLs and among them irrigation facilities can be started in 24 PLs. After analysis of PL water quality and questionnaire survey of local stakeholder, we have recorded that fishery can be started in 25 PLs. The adjoining areas of 23 PLs are suitable for social forestry or agroforestry, and 16 PLs are suitable for floriculture and medicinal garden. Eighteen PLs can be transformed into an ecotourism centre. The adjoining areas of 18 PLs can be used for animal husbandry, and the adjoining areas of 16 PLs can be used for vegetable garden.

Table 20 Developmental activities based on PL (PL wise)

Serial no.	Name of the PL	Irrigation facilities	Sericulture in adjoining areas	Social forestry/ agroforestry	Fishery	Floriculture	Medicinal garden	Animal husbandry	Ecotourism	Recycling of PL water for growing vegetables on adjacent/adjoining land
PL01	Chora PL		√	√					√	
PL02	Joyalbhanga 1 PL	√	√	√	√	√	√	√	√	√
PL03	Vatas 1 PL	√		√	√	√	√	√		√
PL04	Katapahari PL		√	√						
PL05	Amdia PL	√			√			√	√	
PL06	Samdi PL	√			√					
PL07	Dalmia PL		√	√	√				√	
PL08	Bamna PL	√		√	√	√	√			√
PL09	Bonbedi PL				√			√	√	√
PL10	Alkusa Gopalpur PL	√	√	√	√	√	√	√	√	√
PL11	Sikhdaspur PL	√			√					
PL12	Jambad 5 PL	√		√	√	√	√	√	√	√
PL13	Jambad 4 PL	√	√	√	√	√	√	√	√	√
PL14	Jambad bottom-up PL	√			√					√
PL15	Western Kajora PL	√	√	√	√				√	
PL16	Atewal PL	√	√	√	√	√	√	√	√	√
PL17	Khadan Kali PL	√	√	√	√	√	√	√	√	
PL18	Babuisolsib Mandir PL	√		√				√	√	√
PL20	Belpahari Kottadihi PL	√		√		√	√	√		√
PL21	Dalurbandh PL	√	√	√	√	√	√	√	√	√
PL22	Nagrakonda PL	√		√	√	√	√		√	√
PL23	Pathaldanga PL	√		√	√	√	√	√		

PL24	Nimcha Harabanga PL	√			√				√	
PL25	Real Kajora PL	√		√	√	√	√	√	√	√
PL27	Dhanderdihi 1 PL			√						
PL28	Dhanderdihi 2 PL				√					
PL29	Dhandadihi 3 PL		√	√						
PL31	Babuisol Colony PL	√				√	√	√		
PL32	Kumardihi PL		√							
PL33	Kumardihi Old OCP PL	√	√	√	√			√	√	√
PL34	Joyalbanga 2 PL		√	√	√	√	√	√		
PL37	Nimcha Damali Harabanga PL	√			√				√	
PL39	Vatas 2 PL	√		√	√	√	√	√		√

8 Utilitarian Aspect of Pitlake Resources

Utilization profile of PL measured during the study period is tabulated in Table 21. In most of the PLs, multiple uses were observed. Most of the uses were proportionately related with the age of the PL. PL aged over 20–30 years turned naturally into wetland ecosystem harbouring a good amount of aquatic biota, excellent water quality and stabilized embankment. All of these attributes in recent decades produce some good number of PLs having multifarious prospect.

Our study revealed a total of 13 major uses of PL in RCF, WB region. Around 7 uses/PL (mean 6.47) were observed with a maximum of 11 uses/PL and a minimum of 1 use/PL. Recreational fishing by villagers was the most frequent use which was observed in 34 PLs (89.47%) followed by pisciculture (commercial fishing) in 18 PLs (47.37%).

Thirty-three PLs (86.84%) were used for chiefly domestic purpose. Livestock bathing (12 PLs, 31.58%), religious use (15 PLs, 39.47%) and aesthetic use (27 PLs, 71.05%) were some of the rigorously performed practices in these study sites.

Table 21 Utilization profile of PL measured during the study period

Category	Subcategory	Rel. frequency per category (%)
Piscicultural use	Absent	52.63
	Present	47.37
Recreational fishing use	Absent	10.53
	Present	89.47
Irrigational use	Absent	76.32
	Present	23.68
Domestic use	Absent	13.16
	Present	86.84
Livestock bathing use	Absent	71.05
	Present	31.58
Religious use	Absent	60.53
	Present	39.47
Drinking water use	Absent	76.32
	Present	23.68
Aesthetic use	Absent	28.95
	Present	71.05
Vehicle washing use	Absent	76.32
	Present	23.68
Food source use	Absent	7.89
	Present	92.11
Thatching material use	Absent	65.79
	Present	34.21
Fodder use	Absent	50.00
	Present	50.00
Water supply use	Absent	71.05
	Present	28.95

In nine PLs (23.68%), we observed excellent and efficient irrigation chiefly for water supply and agriculture in the vicinity.

Among the other various practices, different food source collections (e.g., *Trapa* cultivation, edible vegetables, fishes, fruits) comprised the major use (35 PLs, 92.11%) followed by fodder use (19, 50%) and thatching material use (13, 34.21%). One of the vital resources of these PLs is "water", and we observed proper and well-organized water supply system in 11 PLs (28.95%). Drinking water use and vehicle washing were the less frequent practices in these PLs (9, 23.68%) which were performed in selected PL only.

Depths of PL appreciably direct different uses such that there is a trend to use lower depth PL in greater magnitude. Recreational fishing (0.8796), food source use (0.8551), domestic use (0.8510) and aesthetic use (0.7204) are some of the notable usages which were exclusively found in PL with lower mean depth of water column, whereas deeper PLs were used for mostly irrigational use (0.1429), vehicle washing (0.2980) and water supply (0.4061).

During this entire tenure of work, a very brief idea about the current scenario of the PL with special emphasis on limnology, biodiversity, use pattern, etc. in this region is generated. Further extensive research, investigation, seasonal monitoring and pilot-scale study with socioeconomic purview in the next phase of study will produce valuable research findings.

9 Potentiality of Pitlakes for Irrigation/Agriculture

Table 22 depicts the potentiality of PLs for irrigation in Pandaveswar block.

10 Threats/Problems Faced by Pitlakes

Table 23 depicts the different threats which affect the PL in this region. It is observed that soil filling and fly ash filling are the most important drivers for PL stability, sustenance and survival. Presently, ten PLs require proper management and conservation planning for long-term benefits to the human society.

11 Pitlakes and Ecological Sustainability

The impact of large-scale mining on the landscape is a permanent legacy of industrialization and unique to the Anthropocene. Thousands of lakes created from the flooding of abandoned open-cut mines occur across every inhabited continent, and many of these lakes are toxic, posing risks to adjacent communities and ecosystems. sustainable plans to improve water quality and biodiversity in PLs do not exist due to (1) confusion as to the ultimate use of these lakes, (2) involvement of ecologists only after the lake is filled and (3) PL ecology struggling to reach the primary literature. An integrated approach to PL management engages ecologists in PL design,

Table 22 Potentiality of pitlakes for irrigation in Pandaveswar block

Serial no.	Source of water	Location can be irrigated	Approx. no. of beneficiary farmers and area	Distance from source	Details of scheme
1.	Shankarpur OCP at Shankarpur Mouza (PL35)	Shankarpur village	50 nos. (Area = 20 Ha)	1 km from water source	Water should be stored at the pond at that cultivated area
2.	Dalurbandh OCP at Dalurbandh Mouza (PL21)	Bilpahari Mouza	50 nos. (Area = 20Ha)	1.5 km from water source	Lifting of water from the OCP and irrigate at that area
3.	Kumardihi OCP and Kumardihi Old OCP at Kumardihi Mouza abandoned PL (PL32 and PL33)	Kumardihi Mouza	100 nos. (Area = 100Ha.)	1.5–2 km from OCP	From OCP water should be lifted at Sair pukur from where irrigation can be done
1.1.1.4.	Joalbhanga OCP, Purusatyampur OCP and Joyalbanga 2 PL at Joalbhanga Mouza (PL02 and PL34)	Mohal = 100 Ha. Dannya = 80 Ha. Sonabandhi = 80 Ha. Joalbhanga = 100 Ha.	350 nos. (Area = 360 Ha)	1–1.5 km from OCP	From OCP water should be lifted at Bara Sair pukur and Rai pukur, Darkagora ponds from where irrigation can be done

Source: Office of the Assistant Director of Agriculture, Andal, Burdwan

Table 23 Threats/problems faced by PLs

PL code	PL name	Threats/problems
PL01	Chora PL	Plants cover the maximum waterbody
PL06	Samdi PL	Soil filling
PL08	Bamna PL	Excessive use of water for road construction
PL09	Bonbedi PL	Chances of land sliding
PL11	Sikhdaspur PL	Excessive growth of *Salvinia* sp.
PL19	Ramnagar PL	Chances of land sliding
PL20	Belpahari Kottadihi PL	Soil filling
PL26	Chakrambati PL	Fly ash filling
PL35	Sankarpur PL	Soil filling
PL40	Chapuikhas PL	Scarcity of water in premonsoon and post-monsoon season

prioritizing ecological progress and passive treatment in mine closure planning and ultimately empowering communities with post-mining options.

Nevertheless, in an era of increasing recognition of environmental and social damage from an ever-growing scale of mining coupled with increasing corporate social conscience for these activities, the mining industry usually works to reduce operational risk and retain its social licence to mine the community resource through a variety of strategies. Many of these strategies are focused around the concept of sustainability, including creating sustainable livelihoods (employment, community development and infrastructure), optimizing resource use and final closing of mining operations in a manner that minimizes social and environmental harm, and yet retain future options for the lease (BHP Billiton Plc 2005; Rio Tinto Plc 2005; Ashoka et al. 2017). Although understandings do vary (Mudd 2005), sustainable mining commonly incorporates “the evaluation and management of the uncertainties and risks associated with earth resource development” (Meech 1999). This sustainability definition also fits well with the understanding of most government authorities concerned with the regulation of environmental and social impacts of mining (Mudd 2004). As a result of this regulatory focus, sustainability of mining leases is often solely concerned with minimizing the immediate and long-term risks to all stakeholders concerned (e.g., the social and ecological environment surrounding the mine). One potential legacy of open-cut mining is the mining pit(s) left after rehabilitation operations are completed.

12 Conclusion

PLs form when surface mines close and open pits filled with water, either through groundwater recharge, surface water diversion or active pumping. The primary goals of this study was to prepare an inventory of PLs in RCF, West Bengal, India, along with the status of water quality in these PLs for promoting sustainable utilization of the PL resources for socioeconomic development of the local stakeholders in due course of time. A comprehensive water quality and biological monitoring programme is strongly recommended for these PLs in order to be able to predict and manage risks and best utilize the opportunities provided by the PLs for the RCF region economy.

Based on different aspects of PL like subdivision, block, area of mining, major uses, major problem and secondary livelihood like fishing activity and presence or absence of migratory birds, the PL can be classified into small groups. A consecutive 2-year study of physicochemical parameters of water and soil was recorded at 27 selected mine PLs to understand its quality.

Biological resources of all PLs were studied throughout the study period. A total of 30 species belonging to 21 families of frequent hydrophytes/marginal plant species dominating these PLs were observed. successional stages of plant species were noticed and grouped in accordance with their growth pattern. Effective aquatic life supporting environment have been observed in these PLs which is also supported by the rich avifaunal and piscifaunal resources in and around these PLs. In Most of the PLs, multiple uses were observed. Most of the uses were proportionately related with the age of the PL. PLs aged over 20–30 years turned naturally into wetland ecosystem harbouring a good amount of aquatic biota, excellent water quality and stabilized embankment. All of these attributes in recent decades produce some good number of PLs having multifarious prospect.

The benefits of the PL were received by the local residents across different socio-economic backgrounds. The activities of the local residents were focussed across the different age and gender groups, which can pollute and contaminate the pit water and PL areas.

13 Pitlakes: Future Ecological Perspectives

Ecological approaches to develop PL ecosystems may assist in clearly articulating targets for the long-term sustainability of PLs. Such ecological versus physicochemical-driven approaches also recognize mine water-affected landscapes such as PLs as more than a geochemical environment, with consequent further (and often simple) requirements for fundamental limnological and ecological processes also needing to be addressed if restoration to a representative functional ecosystem is to be successful. although it is likely that their broad environmental requirements for food and habitat will be very similar to those in natural systems, PL biota and their ecological requirements remain rarely studied and poorly understood. As such, there remains a pressing need for catchment-scale rehabilitation attempts of PLs to move towards development of aquatic ecosystems as a best practice. These restoration attempts are likely to initially fall short of attaining satisfactory ecosystem values due to a lack of knowledge of general PL formation and ecological processes, as well as intrinsic site-specific considerations. However, monitoring and ad hoc investigation studies of combined physicochemical and ecological characteristics of these early attempts will provide fertile insight for future restoration attempts.

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