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Sequestration of carbon by biochar produced from Calotropis gigantea leaf

Anupama Sahu*, Sudipta Sen, Subash Chandra Mishra

Metallurgical and Materials Engineering Department, National Institute of Technology, Rourkela, 769008, Odisha, India

Abstract

A huge number of fast-growing plants and weeds are abundantly available which can be used for sequestration of carbon to make a high valued product out of it. In this work, the Calotropis gigantea (leaves) were carbonised in the temperature range between 200 oC–900 oCtemperatures to produce biochar. The biomass (raw leaf) and biochars obtained at different carbonisation temperatures were characterised through proximate analysis, digital bomb calorimetry, X-Ray Diffraction (XRD), RAMAN spectroscopy, Field Emission Scanning Electron Microscopy (FESEM) analysis. Ash content was found to increase with increase in carbonisation temperature. Gross Calorific value of the biochar measured by digital bomb calorimeter was highest (of 19.1 MJ/kg) for the sample carbonised at 300 oC, which is comparable for/to be used as a solid fuel. With increasing carbonisation temperature, disordered band and graphitic band pattern of carbon became distinguishable as observed from RAMAN spectroscopy analysis. Further, with increase in carbonisation temperature, cellulose crystalline peak of raw leaf was lost and formations of turbostratic crystallites were, confirmed from XRD analysis. Presence of lots of different dimension pores were found from FESEM analysis, and thus this biochar can be used for adsorption purposes. Also, application/use of such biochars to soil can be projected as a source to sequester carbon in soil, mitigate climate change and reduce greenhouse gas emissions.

Keywords: Biomass; Biochar; Calorific value; Calotropis gigantea; RAMAN; XRD

Introduction

Biochar is being used for different important applications starting from environment protection to soil protection by sequestering carbon in soil. Even ash content in biochar plays an important role in improving soil properties[1,2]. The calorific value of biochars are comparable to coal and can therefore be used as solid fuel [3]. The raman analysis has been proved to be an effective tool for examining disordered and ordered carbon structure in bio

char [4]. There is formation of ordered aromatic structure in biochar after carbonisation [5]. In addition, porous characteristics of the biochar is also increased with increase in carbonisation temperature [6-8].

Several waste precursors from leaves were considered by many researchers to produce biochar and studied their characterisations and properties for different applications [9-11]. Sahota et al.

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studied biochar from leaf waste for removal of Hydrogen Sulphide from biogas cost effectively [12]. Calotropis gigantea is a wasteland weed whose stem was used to produce biochar and activated carbon in earlier work [13,14]. However in this work, leaf of this plant (Fig.1) was successfully attempted to produce biochar and was characterised to find its suitability to be used as a solid fuel or for applications related to adsorption for soil protection andmoderating environmental problem by sequestering carbon in soil.

Fig.1. Calotropis gigantea leaf.

Experimental details

Calotropis gigantea plants were collected from place Pallahara, Odisha, India and then cleaned, dried and grinded. The dried leaf powder samples were considered as raw material of biomass. Carbonisations were done in muffle furnace at 200 ºC, 250 ºC, 300 ºC, 400 ºC, 500 ºC, 600 ºC and 900 ºC of carbonisation temperatures for 1 hour as referred in earlier work [13, 14]. Raw leaf and biochars produced at all these temperatures were further characterised as follows:

Proximate analysis

Moisture, volatile, ash and fixed carbon content of raw leaf samples were found out by proximate analysis.

Bomb calorimetry analysis

Gross calorific value of raw leaf and biochars were found out using Bomb calorimeter (model PARR600 Calorimeter).

XRD analysis

X-Ray diffraction analysis of raw sample and biochars were done using BRUKER D8 ADVANCE X-RAY Diffractometer using Co-Kα (λ=1.79 Ǻ) in the range of 20 – 80° with a scan rate of 10 °/min and step size of 0.02° to find out the crystalline and amorphous phases present in the samples.

Raman analysis

Raman spectroscopy analysis of raw and biochar samples were found out by PL micro Raman Spectrometer (model-XMB3000-3000) using 532nm Argon ion laser.

FESEM analysis

Raw leaf and biochars were subjected to Field emission scanning electron microscope (FEI NOVANANO

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SEM 450) for the study of microstructural analysis.

Results and Discussion

Proximate analysis

Proximate analysis of raw materials of calotropis gigantea leaf were mentioned below: moisture content 7%, Volatile matter 68%, ash content 14% and fixed carbon 11% were observed.

Bomb calorimetry analysis

Table 1: Gross calorific value raw leaf and it's biochar obtained at different temperatures.

Samples	**Gross calorific value (Cal/g)**	**Gross calorific value (MJ/Kg)**
Raw leaf	3717.85	15.53
Leaf biochar-200	4185.62	17.52
Leaf biochar -250	4306.56	18.03
Leaf biochar -300	4550.63	19.05
Leaf biochar -400	4237.13	17.74
Leaf biochar -500	3835.08	16.06
Leaf biochar -600	3618.32	15.15
Leaf biochar -900	1656.31	6.93

Gross Calorific Value (GCV) of raw leaf and biochar obtained at different carbonisation temperatures were given in Table 1. Gross calorific value was increased with increase in carbonisation temperature, up to certain range due to decrease in volatile matter and increase in ash content [15]. Maximum GCV of biochar was 19.05MJ/kg (equivalent to 19.1MJ/kg) obtained at 300^{o}Cof carbonisation temperature. Thus this biochar can also be used as a suitable solid fuel [16].

XRD analysis

X-ray diffraction pattern of raw leaf and it's biochar obtained at different carbonisation temperatures of 200^{o}C, 250^{o}C, 300^{o}C, 400^{o}C, 500^{o}C, 600^{o}C and 900^{o}Cwere illustrated in Fig. 2. The broad peaks at 2theta value of around 25° obtained in raw leaf sample was attributed to cellulose crystalline structure in (110) plane, butthe amorphous natureof raw leaf X-ray diffraction patternwas due to presence of hemicellulose and lignin as was observed in earlier studies[17]. Other crystalline peaks at 2theta value of 33° and 47° which were found both in raw material of leaf and biochars, can beattributed to mineralcrystal peaks[18]. These peaks had become more prominent with increase in carbonization temperature from 200 ^{o}C to 900 ^{o}C.

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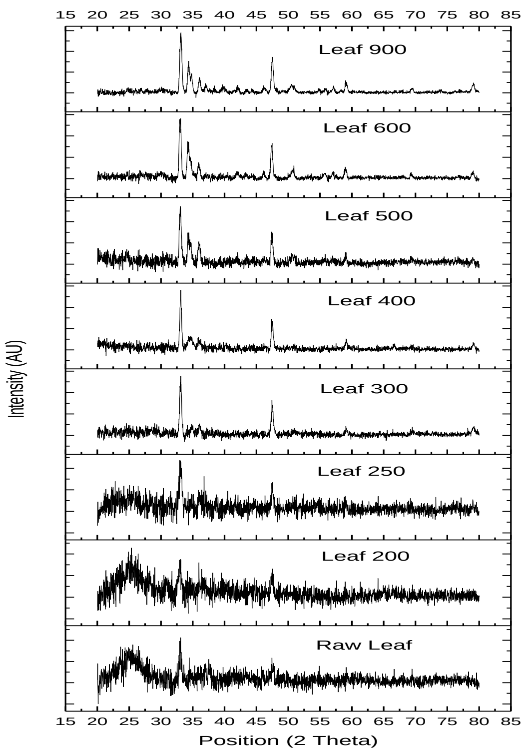

Fig. 2. X-ray diffraction pattern of raw leaf and biochars at different carbonisation temperatures 200 ºC, 250 ºC, 300 ºC, 400 ºC, 500 ºC, 600 ºC and 900 ºC.

Cellulose found in leaf raw is the important structural and chemical components of green plants[19,20]. However, the cellulose crystalline peak was lowered and destroyed in pyrolysis (in between 250 ºC and 300ºC)as was observed by M. Keiluweit et al.[21]. With carbonisation, turbostratic disorder crystallite of carbon-structure was observed in the biochar (for 2theta value equal to 35° and 51°).

Raman analysis

The Raman analysis of raw leaf and biochars obtained at different carbonisation temperatures was illustrated in Fig. 3. The intensity of dis-ordered carbon band found at 1349 $cm^{-1}$was represented as (I_D) and the intensity of ordered/graphitic carbon found at 1596 cm^{-1} was represented as (I_G). The intensity ratio (R) = (I_D/I_G) was indicated as the degree of graphitisation in biochars and activated carbon[4,14].

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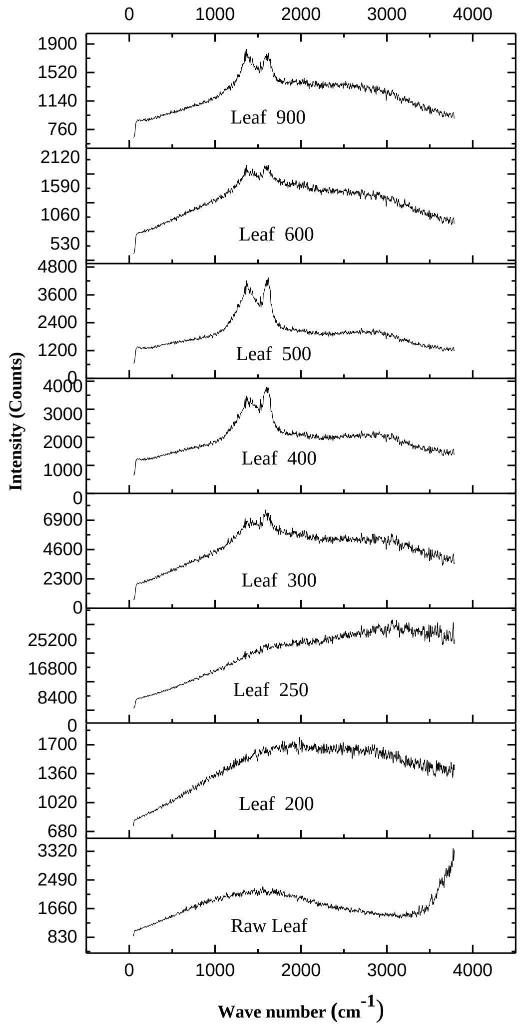

Fig. 3. Raman spectroscopy analysis of raw leaf and biochars at different carbonisation temperatures 200 ºC, 250 ºC, 300 ºC, 400 ºC, 500 ºC, 600 ºC and 900 ºC.

In raw leaf, there were no separate I_D andI_G bands but with increase in carbonisation temperature at around 300ºC, the development of I_D andI_G bands were started. At 400ºC, graphitic carbon band intensity (I_G) was found higher than that of disordered carbon band intensity(I_D). But with further increase in carbonisation temperature, disordered band intensity was increasedtherefore

R value wasalso increased which was evidence of breaking of parallel sheet structure in carbon domain [22]. From Raman spectra it was found that carbon from its organic form was convertedto inorganic form, that'swhy ordered and disordered intensity bands of carbon became visible in biochars by increasing carbonisation temperatures.

FESEM analysis

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FESEM figures of raw leaf and biochars obtained at different carbonisation temperatures 200 ºC, 250 ºC, 300 ºC, 400 ºC, 500 ºC, 600 ºC and 900 ºC,were shown in Fig. 4. In Fig. 4(a) the raw leaf FESEM was shown where continuous structure was found but with increase of carbonisation temperature, microstructure was changed to a great extent. At 200 ºC, 250 ºC, 300 ºC, there was creation of pores but those were closed pores. Whereas at 400 ºC, creation of open pores was started and at 500 ºC, numerous open pores were generated as was found in earlier studies [18]. At 600 ºC of carbonisation, maximum number of open pores were found but the pore sizeswere reduced. The biochars obtained in this work at around 400 ºC onwards, were highly porous without using any activating agent. These pores can be responsible for adsorption related applications. Such kind of porous structure were generally obtained after use of activating agent like KOH as studied by B. Armynah et al. [22].

M. *Giorcelli* et al. had found that highly porous structure of biochar were further improved by high temperature annealing and those thermally annealed biochars were used for energy conversion applications [23]. Similar results were observed in this work i.e. with increase of carbonisation temperature, large number of small sizepores were created which can make the biochar suitable for multifunctional applications.

Conclusion

From this work it can be concluded that, leaf of Calotropis gigantea plant can be used to produce biochar bearing enormous properties viz. it can be used as a solid fueland for adsorption related applications. Turbostractic crystallite structures were found from XRD analyses, which also have great importance for practical applications. Ordered and disordered structures of carbon formed in biocharsafter carbonisation of raw leaf were confirmed from RAMAN spectroscopic analysis. Carbon from organic form of cellulose, hemicellulose and lignin was converted to inorganic form of carbon. Therefore, the biochars can be used for carbon sequestration and can ease environmental climate change problem. Porous biochar made out of this natural resource of biomass waste has a great potential to be used as a valuable product.

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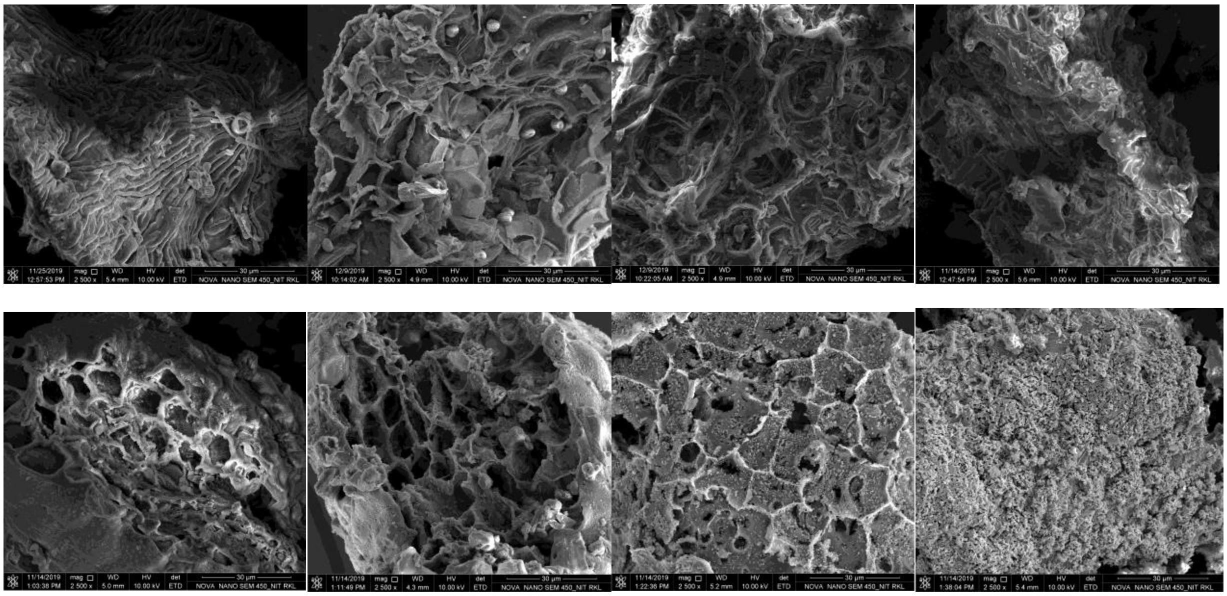

Fig. 4. FESEM figures of raw leaf and biochars obtained at different carbonisation temperatures 200 ºC, 250 ºC, 300 ºC, 400 ºC, 500 ºC, 600 ºC and 900 ºC.

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Eco-dynamics of East Kolkata Wetlands with special reference to biodiversity: Efficacy of the application of GIS and Remote sensing in delineation ecological status

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Abstract:

The sensitive, fragile but productive wetland ecosystems along with their biodiversity wealth have been under major natural and human mediated threats during last few decades for many reasons which have resulted drastic disappearance of wetlands' biodiversity components at alarming rates in so many countries of the world including India. Late appreciation of the values of wetlands have prompted many countries to undertake proper conservation measures focusing on the protection of wetlands and sustainable management of their bio-resources.East Kolkata Wetland (EKW), located at the eastern fringe of the city of Kolkata, West Bengal, India and being a Ramsar site is famous internationally because of its potential as natural sewage recycling system, supporting the lives of galaxy of flora and fauna, acting as the nature's kidney by absorbing and converting waste materials, serving as the lungs of the urban environment by profusely producing oxygen and also catering to the needs of local peoples by supplying ecological goods and services including opening up avenues for employment generation. The present paper has attempted to highlight the biodiversity potential of East Kolkata Wetlands by undertaking ground truth analytical survey for both biodiversity and different physio-chemical parameters as ecological variables influencing the biodiversity of this environmentalong with simultaneous eco-assessment by the application of GIS and Remote sensing tools to record the ecological changes in the water bodies. Based on the generated research information though undertaking ground truth analytical survey along with simultaneous eco-assessment by the application of GIS and Remote sensing tools in order to generate research information not only to highlight the ecological uniqueness of the wetlands of internationally repute but also to discuss on the ongoing threats andprospective eco-management strategies of East Kolkata Wetlands.

Key Words: East Kolkata Wetlands, Ramsar Site,Biodiversity, GIS and Remote Sensing, Physico-chemical parameters, Eco-Management.

Introduction

Wetlands being the ecologically sensitive and fragile ecosystems are considered amongst the most productive ecosystems on the Earth (1) and provide many important services to human society (2). Wetlands are defined as a variety of shallow water bodies and high ground water environments that are characterized by permanent or water saturated conditions (3). Wetlands occur extensively throughout the World from cold Arctic and Alpine region to the moist and warm tropical rainforest and hot and dry sub – tropical deserts (4). The diverse eco – climatic regimes of Indiahave resulted in the formation of a variety of wetland ecosystems ranging from high altitude cold desert wetlands to hot and humid wetlands in coastal zones with its diverse flora and fauna(5). The freshwater wetlands alone support 20% of the known range of biodiversity in India (6). According to Directory of Indian Wetlands, wetlands in India occupy 58.2 million hectares of area, including areas under wet paddy cultivation(5).

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The importance of world's wetlands has been increasing considerably with regard to their contribution of numerous products and services to humanitywhich in turn lead to develop healthy environment in many ways (5). Wetlands provide many services and commodities to humanity. Wetlands exhibit enormous diversity according to their genesis, geographical location, water regime and chemistry,dominant species and sediment characteristics (7). Ecosystem goods provided by the wetlands mainly include: water for irrigation; fisheries; non – timber forest products; water supply and recreation. Wetlands perform numerous valuable functions such as to recycle nutrients, purify water, attenuate floods, maintain stream flow, recharge ground water and also serve to provide drinking water, fish, fodder, fuel, wildlife habitat, control rate of runoff in urban areas, buffer shore lines against erosion and offer recreation to the society(3). The interaction of man with wetlands during the last few decades has been of concern largely due to the rapid population growth accompanied by intensified industrial, commercial and residential development that further leads to pollution of wetlands by domestic, industrial sewage and agricultural wastes such as fertilizers, and pesticides. Economic values of wetlands comprise the direct use of wetland's goods, such as the consumption of fish for food, trees for fuel and wood as building material, water for drinking, cooking and washing (8).

The state of West Bengal, India is gifted in having a diversified forms of wetlands covering 12.48% of total geographic area which includes different forms riverine flood plains, Ox – bow lakes, bheries etc. along with highest number (around 150,000) of small fresh water wetlands (area <2.25 ha), locally named as dighi and ponds (9).

East Kolkata Wetlands (EKW) —AUnique Model for Sewage recycling

The East Kolkata Wetlands (EKW) situated on Latitude 22° 27' N and Longitude 88° 27' E, 5 km from the eastern edge of Kolkata, (Figure 1) in the West Bengal. The vast area under the networks of so many water bodies within the EKW with an expanse of about 12,500-hectare area is a part of the lower deltaic plain of the Bhagirathi-Ganga River system (10). The entire area is a mosaic of different habitats, namely purely terrestrial landscapes (agricultural farm, dumping ground of garbage, locally named as dhapas, uplands around salt lakes etc.) to fullfledgedaquatic ecosystems (bheries, pisciculture ponds or impoundments) which has been intermingling with transitional or intermediate marshy areas. The total area is highly valuable in terms of ecology and economy. Firstly, it receives the rain water or polluted water from the city which are subjected to purification. Secondly, it produces several species of edible fishes in shallow water bodies.Thirdly, it produces a good number of agriculture cropsand vegetables. Besides these, the entire landscape for being a marshy area is nutrients enriched water-based area, and supports the lives of a galaxy of flora and fauna including a host of bird species of different varieties (migratory and local).The most important functions of wetlands include purification of water in an ecological manner, promotion of fisheries and agricultural crops, releasing of huge amount of natural O_2, acting as the kidney of nature by accumulatingand recycling of wastes, both solids and liquids, opening up avenues for the self -employment etc.

East Kolkata Wetlands (EKW) comprising of both water bodies and uplands for dumping and utilizing solid waste (garbage) especially in the area locally named as Dhapa produces 150 tones vegetables daily (11). Around 60,000 working population directly depend on the East Kolkata Wetlands for their livelihood (12).Based on its immense ecological and socio-cultural importance, the Government of India had declared East Kolkata Wetland as a Wetland of International Importance in the year 2003 paying respect to the guidelines of Ramsar Convention, held in the year of 1971 in the city of Ramsar of the country, Iran. Kundu (2010) highlighted the role the wetland system in securing ecological and economic upgradation of the Kolkata city as well as the entire Gangetic Delta in India (1 & 11). East Kolkata Wetlands serve as back – bone of food security of Kolkata city, India as the areas under the Dhaparegion produces 150 tons of vegetables daily (11). Based on its immense ecological and socio-cultural importance, the Government of India had declared East Kolkata Wetland as a Wetland of International Importance.

The EKW receives about 3,500 tons of municipal waste and 680 million liters of sewage daily (13). The partially treated sewage from the EKW is used for fish rearing and irrigation of agricultural lands within the wetland area. Currently, some 300 large fish farms and ponds connected by several canals coming out from dying riverine systems produce 13,000 tons of fish annually. The small-scale upland plots around the EKW produce an average of 150 tons of vegetables per day (36). Institute of Environmental Studies Wetland Management (2004) had reported that 24

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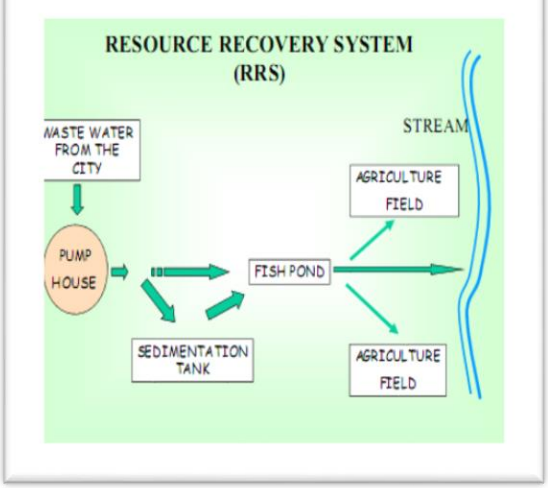
species of vegetables and crops, 5 species of fruit plants and 10 species of ornamental plants were cultivated in the garbage farm of EKW during the decades of 1990s and early 2010s.

1



2

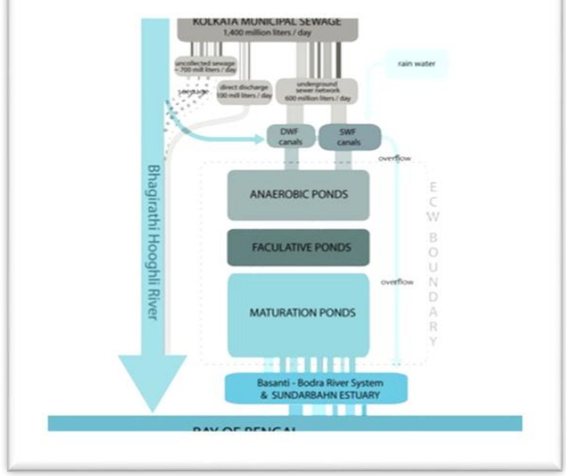


Figure 1: East Kolkata Wetlands: A Resource Recovery System through Productive Activities (14)

Figure 2: Majorhydrological and environmental flows through different phases of bio – geo – chemical transformations of the sewage from Kolkata Municipal Corporation to the networks of East Kolkata Wetlands and there from to the estuarine networks of Gangetic Delta (15).

East Kolkata Wetlands are the greatest natural resource recycling ecosystems with multiple nature services and bridges the gap between of terrestrial and aquatic habitatsin order to support the lives of rich biodiversity components along with their genetic constituents and also help many animal species to find out suitable habitats for the shelter and breeding ground.

Materials and Methods

Physiography of Wetlands in and around East Kolkata: Kolkata is sustained by a unique and eco-friendly water regime, mostly developed by a network of wetlands having an array of ecological and economical beneficial roles which in totality is named as East Kolkata Wetlands (EKW) (Latitude 22°33'– 22°40'N; Longitude 88°25'– 88°35'E) (16). The city of Kolkata has been growing up along the levee of the river Hooghly which flows along the west of the city. The rivers, Kulti and Bidyadhari flow about 30 Kms eastward of this wetland carrying most of the industrials wastes and draining the same to the Bay of Bengal though several large estuarine networks of Sundarbans Mangrove ecosystem like Raimangal, Matla etc. Underneath the city of Kolkata lies a copious reserve of groundwater.The eastern bank of the river Hooghly flanked by a system of low lands and wetlands.The river side on the West of the city of Kolkata belongs to the highest part of the city which slops gradually away from the river towards the East, the natural backyard of the city endowed with the networks of water bodies. The eastern edge of the city of Kolkata possessing the vast wetland area under EKW is instrumental to transform wastewater released from the anthropogenic activities of the city of kolkata in the form of sewage and sludge into fisheries, vegetable gardens and paddy fields in successive tracts of land (17 and 18). The entire drainage and sewage networks of entire Kolkata depends heavily on those natural networks of low-lying water-logged areas, ponds, bheries, ditches, nullahs and tidal creeks connecting with estuarine networks of Hooghly Matla estuarine complex of Mangrove Ecosystems (17 and 18).

The uniqueness of East Kolkata – wetland networks rests on the natural model of waste water recycling system and with the development of sewage fed fisheries on 2500 hactres of low-lying land supplying around 20 tons of fishes daily and employing about thousands of peoples (14). It's resource recovery system,developed by local peoples or cooperative societies, provided employment for a large number of peoples by way of producing significant amount of edible biological components as valuable resources for human consumption (19 and 20).

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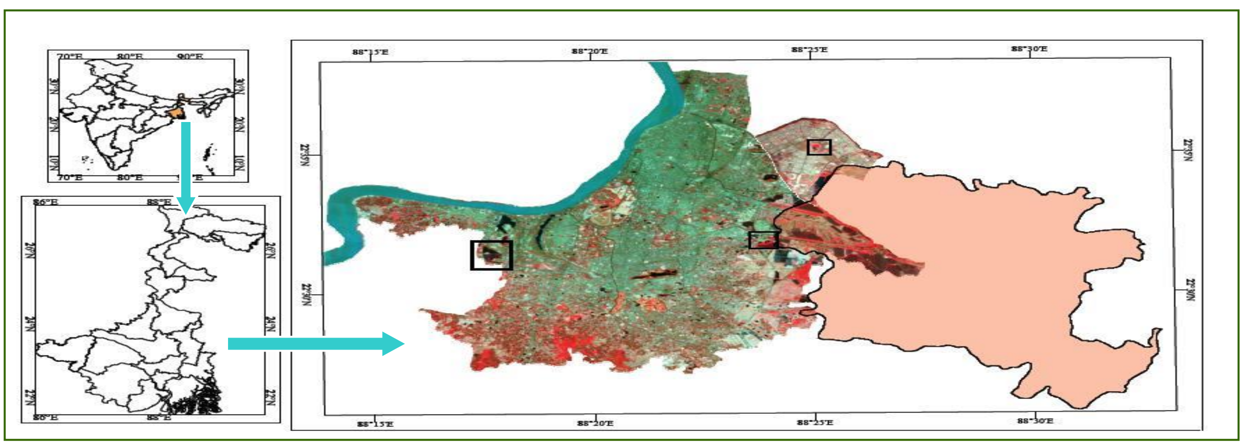
Seasons and Climate: Three distinct seasons prevail in and around the EKW, each with its own climatic characteristics. The pre – monsoon season includes four months (March – June) which is characterized by highest atmospheric temperature and least precipitation; the monsoon season (July – October) experiences highest rainfall, modest air temperature coupled with humidity and the post–monsoon season (November – February) when air temperature comes down to lowest level and receives occasional precipitation.

Selection of Study Sites for detailed ecological study : Initially, through pilot survey, consulting experts and based on literature reviews, different wetlands were identified. Then, (from both – primary and secondary sources) preparation of wetland maps and various information were collected. GIS technique was used for mapping of status of wetlands, especially their sizes, extent and trend of shrinkage. To collect information from primary sources, a number questionnaires were prepared focusing on various aspects of wetlands and subsequently administered among the stack holders associated with the wetlands.

For detailed research investigations, four (4) study sites (water bodies) have been selected along a considerable stretch of the Kolkata Metropolitan city based on contrasting ecological characteristics. Study site – I is a managed water body located in the Central Park, Banabitan, Salt Lake (a site developed for ecotourism). Study site – II (unmanaged wetland, located at ChhappanTalao, Uttar Panchanna Gram, behind Land mark Hotel, by the side of Eastern Metropolitan Bypass (a major roadways of Kolkata) which is an ecologically stressed water body receiving lot of effluents as municipal sewage, detergent wastes out of the activities of washermen and wastes from automobile cleaning activities of nearby regions. Study site – III (within Nature Park) includes one of those water bodies which are in the process of eco-reclamationon receiving waste water from the nearby industries and municipalities. Study site – IV (also in the Nature Park) is an ecorestored aquatic system receiving water after phytoremediation with macrophytes (Figure – 3).



[Figure3 : Location Map of the Study Sites] **1-> S – I** [Managed wetland] – located Central Park, Banabitan, Salt Lake, **2-> S – II** [Sewage fed but Unmanaged wetland] – located located at ChhappanTalao, Uttar PanchannaGram behind Landmark Hotel (EM – Bypass),**3-> S – III** [Sewage fed but Unmanaged wetland] – located at Nature Park, Taratala, Brace Bridge Wetland and **4-> S – IV** [Fish Cultured and ecorestored wetland] – located at Nature Park, Taratala, Brace Bridge Wetland.

Sampling methods

Sampling was made on monthly intervals for three (3) consecutive years (July, 2008 – June, 2011) from four (4) selected study sites.

Collection and Analysis of water samples: Water samples were collected once in a month during early morning at a depth of 0.5m from the surface from four (4) different study sites during three years long studies (July, 2008 – June, 2011) and were kept in 2 liters plastic containers and were placed in ice-box immediately after samplings for qualitative and quantitative analysis of different biodiversity components including zooplankton in the laboratories.

Different Water Quality parameters (viz. temperature, pH, turbidity, TDS, alkalinity, calcium, magnesium, chloride, total hardness, conductivity, DO, BOD, COD, Pb, Cr, Cd and Hg) were estimated by standard methods as outlined by APHA (21). Water quality assessment was done on the basis of average values of physico-chemical components during the study period (2008 – 2011).

Biodiversity Documentation: Extensive pilot survey was conducted in order to unearth research information pertaining to the extent and ecology of four studied wetlands. Different biodiversity components of these ecosystems have been studied based on the collection, preservation and identification (22 & 23). Identification of different biodiversity components was made following standard literatures (24 - 28) and in consultation with the scientists of Zoological Survey of India (ZSI), Botanical Survey of India (BSI) and researchers of different Universities.

Remote sensing Technique

Image Pre-Processing: Atmospheric Correction: The parameters used in different environmental conditions were meant for the detection of algorithms which require physical units, such as at sensor radiance or top-of-atmosphere (TOA) reflectance instead of the raw quantized calibrated pixel values (DN). There exist three advantages in using TOA reflectance rather than at-sensor spectral radiance when comparing images from different sensors (29). Firstly, TOA reflectance removes the cosine effect at different solar zenith angles due to the time difference between data acquisitions. Secondly, TOA reflectance compensates different values of the exo – atmospheric solar irradiance arising from spectral band differences. Thirdly, TOA reflectance corrects the variation in the earth-sun distance between different data acquisition dates. Therefore, the application of TOA reflectance of the ALI, TM, and ETM+ in this study were appeared to be appropriate.

TOA reflectance can be obtained from the quantized calibrated pixel value, as proposed by (30) by the following equation:

$\rho_\lambda = (\pi . L_\lambda . d^2) / ESUN_\lambda . \cos\theta$(Equation1)

Where $\rho_\lambda$is the TOA reflectance of wavelength λ(unit less), d is the earth-sun distance (astronomical units), $ESUN_\lambda$is mean exo – atmospheric solar irradiance (W/ (m2·µm)), $\theta$is the solar zenith angle (degrees), and $L_\lambda$is the spectral radiance at wavelength λat the sensor's aperture [W/ (m2·sr·µm)]. $L_\lambda$can be obtained from the quantized calibrated pixel value also as postulated by (30) with following equation:

$L_\lambda = (L_{MAX} – L_{MIN} / QCAL_{MAX} – QCAL_{MIN}) * (DN - QCAL_{MIN}) + L_{MIN}$ (Equation 2)

where L_{MAX} is the spectral at-sensor radiance that is scaled to $QCAL_{MAX}$[W/ (m2 srµm)], $L_{MIN}$is spectral at-sensor radiance that is scaled to$QCAL_{MIN}$[W/ (m2·sr·µm)], $QCAL_{MAX}$is the maximum quantized calibratedpixel value corresponding to L_{MAX}(DN), $QCAL_{MIN}$is the minimumquantized calibrated pixel value corresponding to L_{MIN} (DN), and QCAListhe quantized calibrated pixel value (DN). The parameters in Equations (1)and (2) can be read from the header files of the ALI, TM, and ETM+ datasets or be retrieved from the USGS website.

Characterizing the wetlands: The entire study of wetland characterization has been done using Landsat TM (P/R 148/44) - for thr year 1989, Landsat TM (P/R 148/44) - for the year 2001 and Landsat 8 (P/R 148/44) - for the year 2014 in TNT maps platform. In this study, the wetlands have been characterized on the basis of turbidity status, chlorophyll concentration, salinity status and the concentration of suspended solids. Those parameters have calculated using different kinds of band algebra and image statistical analysis.

Turbidity Mapping: The wetland water quality has to be maintained in order to sustain the wetland ecosystem. Often, the turbidity level in any wetland is indicative of the quality of the water in it. The NDTI (Normalized Difference Turbidity Index) (Equation 3)is useful for these kinds of mapping.

NDTI = (TM3 – TM2) / (TM3 + TM2) (Equation 3)

Chlorophyll a concentration mapping: Quantifying chlorophyll concentrations in wetland through GIS and Remote Sensing method posed difficulty as variable results were obtained. The inconsistency was partly due to two factors. First, chlorophyll a and inorganic sediment were not separable and, secondly, suspended sediments, which

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tended to dominate the total reflectance in this environment, behaved as a broad band back scatter. Thirty-six 3x3 samples were taken from TM1, TM2 and TM3, and averaged values were converted to find out chlorophyll a concentration (Equation 4) by employing the equation:

Chlorophyll a = -770+4768 x (TM3/TM1)-24·6 x (TM2+TM3)/2 (Equation 4)

Phytoplankton, in whichchlorophyll a is found, have other pigments with varying predominance which combine with the factors in producing the water's spectral reflectance (31 and 32).

Salinity status (Chloride Concentration) mapping: Salinity is defined as the total amount of dissolved materials in a unit volume of seawater when all carbonates are converted to oxide and all bromine and iodine are replaced by chlorine, alongside oxidation of all organic matter. Salinity is measured in parts per thousand (33). Salinity has no effect on water spectral characteristics, as has been proved by laboratory studies (34). Nevertheless, salinity has been successfully predicted from the spectral data (42 &43). It is clear that a correlated parameter highly associated with salinity affects the optical properties of the water. Here 453 x 3 averaged samples were extracted in TM3 and converted to salinity(Equation5) and resultant salinity values are mapped.

Salinity = -102+9·8 * TM3 (Equation 5)

Suspended solid concentration mapping: In East Kolkata wetland complex, 57 samples were taken from the TM image, each 3 x 3 in extent on using the band TM1, which were averaged and converted to suspended – solids concentration (Equation 6)and the resultant values were mapped.

Suspended solids = -427+7·01*TM1(Equation 6)

Apart from aforesaid techniques, digital remote sensing techniques like supervised classification, different kinds of band algebra, image transformations etc. were used to support the experimental and field observations as well.

Images which were used for the shrinkage of East Kolkata Wetlands are as follows: 1975 – Landsat MSS (P/R 148/45); 1990 – Landsat TM (P/R 138/44); 2010 – Landsat TM (P/R 138/44).

Results and Discussion

Biodiversity potential and resource utilization of East Kolkata Wetlands : The continuous interactions of plants (algae, phytoplankton, vascular angiosperms etc.), animals (diversified form of non-chordates, fishes and higher vertebrates) and microbes within the wetlands accelerate the process of decomposition, facilitate the nutrient cycling, alter the properties of water quality, enhance the biological productivity etc. and all these together ecological processes render valuable ecological services.

Number of species representing different flora and fauna in EKW : The wetlands plants possess unique morphological (water roots and adventitious roots) and anatomical characteristics (development of intercellular air spaces) and physiological adaptability to overcome the problems of the oxygen-deficient state of saturated soils by respiring anaerobically as most of them have to survive in the transitional zones in between land and water. Out of so many species of macrophytes that occur in the tropical wetlands**,** floating macrophytes dominate other types in the open water whereas emergent macrophytes remain as predominant floral components in the edge of the wetlands in the EKW. Floristic diversity of the wetland is mediocre particularly in the core area while the diversity of plants is rather high in the surrounding wetlands. Vegetation cover of the wetland areas is significantly low. *Eichhorniacrassipes*and rarely, *Alternanthera philoxeroides*are the only acceptable flora of these wetlands. In addition to significantly rich population of planktonic algae. *Sagittariasagittifolia*, *Rumex dentatus*, *Panicum*sp., *Brachiariamutica*and *Colocasiaesculenta*have appeared to be the major floral components at the waste water canals. *Cryptocoryneciliata*and several species of sedges are found to enjoy prolific growth in waste water canals receiving tidal flush. (Table 1). In EKW, among the phytoplankton more than half of that number are found to be diatoms which are followed by seven other groups such as cyanobacteria, chlorophyceae, dinophyceae, cryptophyceae, euglenophyceae, chrysophyceae, and xanthophyceae.

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Aquatic plants spreading on different zones of wetlands through ecological succession result habitat heterogeneity which help diversified forms of fauna to settle and flourish in diversified habitats mostly associated with aquatic vegetation. Invertebrates utilize aquatic plants as a direct food source, shelter, hiding from predators, spawning and attachment sites as well as feeding on the periphyton growing. The fauna of the EKW is a unique assemblage of animals that include multiple species of birds, mammals, fish, insects, and amphibians in addition to that of galaxy of invertebrates, such as zooplanktons,insects, crustaceans, molluscsetc., all of which sustain the complex food webs of EKW by providing an important dietary niche of the ecosystem.Zooplankton mostly as the microscopic aquatic faunal components are found in all aquatic ecosystems, particularly in the pelagic and littoral zones both inland and marine environment. They can be classified based on their size(ultraplankton, nanoplankton, mesoplankton, macroplankton) as well as in accordance with their lifecycle patterns (holoplankton and meroplankton). Four zooplankton assemblages (cladocera, copepoda, rotifera and protozoa) (35) are usually found to occur in most of the fresh water wetlands and demonstrate succession in response to hydrological periods having distinct ecological conditions which can satisfactorily detect the environmental differences caused by the different hydro-ecological events such as floods and draughts which in turn determine the physico-chemical variables on which most of the zooplankton depend. In the long-term studies, 21 species of zooplankton have been recorded of which rotifers displayed the maximum species diversity followed by – copepods and cladocera (Sanyal et al 2015) (Table 6.2). The rich biodiversity of the East Kolkata Wetland (EKW) is represented by biodiversity (36) by about 104 plant species, about 20 important mammalian species [amongst the rare mammals Marsh mongoose (*Herpestes palustris*), small Indian mongoose (*Herpestesauropunctatus*), Palm civet (*Paradoxurushermaphroditus*) and Small Indian civet (*Viverricula indica*)] (Table 13), more than 65 bird species [including both local and migratory types among these grebe, coot, darter, shag, cormorant, teals, egrets, jacanas, snipes tern, eagle, sand piper, gulls, rails kingfishers, etc.] (Table 12), various threatened reptiles [like, Indian mud turtle *Lissemyspunctuta*(locally threatened) and *Xenochorphis*sp.and *Cerberus rynchops*] (Table 11), 52 endemic varieties of fishes of which 34 are threatened, some amphibians [like, *Rana hexadactyla*, *Rana cyanophlyctis*, *Rana tigrina*and *Rana limnocharis*] (Table 10) and a huge number of diverse microbial populations including those, playing active roles in the wastewater treatment (Table 6). Binary distributions of different flora and Fauna at four different study sites in the EKW are presented below (Tables 1 to 13):

Table 1: List of different macrophytes and their binary distributional pattern in different study sites(S-I, II,III and IV)

Sl. N.	Family	Scientific Name	Study sites			
			S - I	S - II	S - III	S - IV
1	Cyperaceae	*Aeschynomene aspera* L	+	-	+	-
2	Amaranthaceae	*Alternanthera paronychioides*A. St. Hillaire	-	+	-	-
3	Azollaceae	*Azolla pinnata*	+	+	-	+
4	Cannaceae	*Canna indica* L.	-	-	-	+
5	Apiaceae	*Centella asiatica* (L.) Urban.	+	-	-	+
6	Ceratophyllaceae	*Ceratophyllumdemersum*L.	+	-	-	+
7	Araceae	*Colocasia esculenta* (L.) Scott.	+	+	-	+
8	Commelinaceae	*Commelinabenghalensis*L.	+	-	-	+
9	Commelinaceae	*Commelina suffruticosa* Bl.	+	-	-	+
10	Cyperaceae	*Cyperus alopecuroides*	-	+	+	-
11	Rubiaceae	*Dentella repens* (L.) J.R. *et.* J.G.A.Forster	-	-	+	+
12	Asteraceae	*Ecliptaprostrata*(L.) L.	+	-	-	+
13	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.-Laubach.	+	+	+	+
14	Poaceae	*Eragrostisunioloides*(Retz.)Nees ex Steudel	-	+	-	-
15	Hydrocharitaceae	*Hydrilla verticillate* (L. fil.) Royle	+	-	+	+
16	Convolvulaceae	*Ipomoea aquatica* Forssk.	+	+	-	+
17	Poaceae	*Leersiahexandra*Swartz.	+	-	-	+
18	Lemnaceae	*Lemnaperpusilla*Torr.	+	-	-	-
19	Onagraceae	*Ludwigiaadscendens*(L.) Hara	-	-	+	-
20	Marsileaceae	*Marsilea minuta*L.	-	+	-	+

21	Poaceae	*Oplismenuscompositus*Beauv.	-	-	+	-
22	Araceae	*Pistia stratiotes* L.	+	-	-	+
23	Poaceae	*Phragmites karka*(Retz.) Trin.exSteud.	-	-	+	-
24	Alismaceae	*Sagittariamontevidensis*	-	-	-	+
25	Euphorbiaceae	*Sauropusbacciformis*(L.) Airyshaw	-	+	-	-
26	Cyperaceae	*Schoenoplectus sp.*	+	-	-	-
27	Hydrocharitaceae	*Vallisneria spiralis* L.	+	+	-	+

Table 2: List of plants as food for fish in different study sites(S-I, II,III and IV)

Sl. No.	Family	Scientific Name	Study sites			
			S - I	S - II	S - III	S - IV
1	Amaranthaceae	*Alternanthera paronychioides*A. St. Hillaire	-	+	-	-
2	Commelinaceae	*Commelina suffruticosa* Bl.	+	-	-	+
3	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.-Laubach.	+	+	+	+
4	Poaceae	*Eragrostisunioloides*(Retz.) Nees ex Steudel	-	+	-	-
5	Convolvulaceae	*Ipomoea aquatica* Forssk.	+	+	-	+
6	Poaceae	*Leersiahexandra*Swartz.	+	-	-	+
7	Poaceae	*Oplismenuscompositus*Beauv.	-	-	+	-
8	Poaceae	*Phragmites karka*(Retz.) Trin.exSteud.	-	-	+	-
9	Hydrocharitaceae	*Vallisneria spiralis* L.	+	+	-	+

Table 3: List of plants as fodder in different study sites (S-I, II,III and IV)

Sl. No.	Family	Scientific Name	Study sites			
			S - I	S - II	S - III	S - IV
1	Amaranthaceae	*Alternanthera paronychioides*A. St. Hillaire	-	+	-	-
2	Commelinaceae	*Commelina suffruticosa* Bl.	+	-	-	+
3	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.-Laubach.	+	+	+	+
4	Poaceae	*Eragrostisunioloides*(Retz.) Nees ex Steudel	-	+	-	-
5	Convolvulaceae	*Ipomoea aquatica* Forssk.	+	+	-	+
6	Poaceae	*Leersiahexandra*Swartz.	+	-	-	+
7	Poaceae	*Oplismenuscompositus*Beauv.	-	-	+	-
8	Poaceae	*Phragmites karka*(Retz.) Trin.exSteud.	-	-	+	-
9	Hydrocharitaceae	*Vallisneria spiralis* L.	+	+	-	+

Table 4: List of aquatic plants used as green manure in different study sites(S-I, II,III and IV)

Sl. No.	Family	Scientific Name	Study sites			
			S - I	S - II	S - III	S - IV
1	Ceratophyllaceae	*Ceratophyllumdemersum*L.	+	-	-	+
2	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.-Laubach.	+	+	+	+
3	Hydrocharitaceae	*Hydrilla verticillate* (L. fil.) Royle	+	-	+	+
4	Lemnaceae	*Lemnaperpusilla*Torr.	+	-	-	-
5	Araceae	*Pistia stratiotes* L.	+	-	-	+
6	Hydrocharitaceae	*Vallisneria spiralis* L.	+	+	-	+

Table 5: List of Bio-filters for phytoremediation in different study sites(S-I, II, III and IV)

Sl. No.	Family	Scientific Name	Study sites			
			S - I	S - II	S - III	S - IV
1	Amaranthaceae	*Alternanthera paronychioides*A. St. Hillaire	-	+	-	-
2	Ceratophyllaceae	*Ceratophyllumdemersum*L.	+	-	-	+

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3	Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.-Laubach.	+	+	+	+
4	Hydrocharitaceae	*Hydrilla verticillate* (L. fil.) Royle	+	-	+	+
5	Lemnaceae	*Lemnaperpusilla*Torr.	+	-	-	-
6	Poaceae	*Phragmites karka*(Retz.) Trin.exSteud.	-	-	+	-
7	Cyperaceae	*Schoenoplectus sp.*	+	-	-	-

Table 6.1: List of Aquatic Insect species associated with macrophytes in different study sites (S-I, II, III and IV)

Sl. No.	Order	Family	Species Name	Study sites			
				S - I	S - II	S - III	S - IV
1	Hemiptera	Belostomatidae	*Sphaerodermarusticum*	+	+	+	-
2		Belostomatidae	*Sphaerodermaannulatum*	+	-	-	+
3		Nepidae	*Ranatraelongata*	+	+	+	-
4		Nepidae	*Ranatrafiliformis*	+	+	-	+
5		Nepidae	*Laccotrephesruber*	-	+	+	+
6		Notonectidae	*Anisopsbreddini*	+	+	+	-
7		Corixidae	*Micronectascultellaris*	+	-	+	+
8		Notonectidae	*Micronectamerope*	+	-	+	+
9		Hydrometridae	*Hydrometra greeni*	+	+	+	+
10		Corixidae	*Corixaheiroglyphica*	+	-	+	-
11	Coleoptera	Dytiscidae	*Canthydruslaetabilis*	-	+	+	+
12		Dytiscidae	*Cybisterlimbatus*	+	+	-	-

Table 6.2: List of species of zooplankton in different study sites (S-I, II, III and IV)

Family	Name	Site - I	Site - II	Site - III	Site - IV
Rotifera	*Brachionus angularis*	-	+	+	-
	Brachionusfoficula	-	-	+	-
	Brachionusdiversicornis	-	-	+	+
	Brachionusfalcatus	+	-	+	+
	Brachionusrubens	+	-	-	+
	Brachionusquadridentatus	+	-	-	+
	Brachionuspatulus	-	+	-	-
	Lecanepapuana	+	-	+	-
	Polyartha vulgaris	+	+	+	-
	Filinialongiseta	-	+	+	+
	Keratellatropica	-	+	-	-
Cladocera	*Chydorus sp.*	-	-	+	-
	Alona sp.	-	+	+	-
	Ceriodaphnia sp.	-	+	+	-
	Moinadaphnia sp.	+	+	+	+
	Bosmina sp.	+	-	-	-
	Kurzia sp.	+	-	-	-
Copepoda	*Mesocyclops sp.*	+	-	+	+
	Megacyclops sp.	+	-	+	-
	Heliodiaptomus sp.	-	+	+	-

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	Eucyclops sp.	-	+	-	-

Table 7. List of Crustaceans species in different study sites (S-I, II, III and IV)

Sl. No.	Species Name	Study sites			
		S - I	S - II	S - III	S - IV
1	*Macrobrachiumlamarcaei*	+	+	-	+
2	*Macrobrachium rude*	+	-	-	+
3	*Macrobrachiummalcomonii*	+	-	+	+
4	*Sartorianaspinigera*	+	+	-	+

Table 8: List of Molluscs in different study sites (S-I, II, III and IV)

Sl. No.	Order	Species Name	Study sites			
			S - I	S - II	S - III	S - IV
1	Gastropoda	*Bellamya bengalensis*	+	+	+	+
2		*Pila globasa*	+	-	+	+
3		*Digniostomapulchella*	-	+	+	-
4		*Thiaratuberculata*	-	+	+	-
5		*Lymnaealuteola f. ovalis*	-	+	-	+
6		*Lymnaealuteola f. australis*	+	+	-	-
7		*Lymnaeaauminata f. rufescens*	+	-	-	+
8		*Indoplanorbisexustus*	+	-	+	+
9	Bivalvia	*Lamellidensmarginalis*	+	+	-	+
10		*Pelecyora trigona*	+	-	-	-

Table 9: List of Fish fauna in different study sites(S-I, II,III and IV)

Sl. No.	Type of Fish fauna	Scientific Name	Study sites			
			S - I	S - II	S - III	S - IV
1	Cultured fish	*Catlacatla*	+	-	-	+
2		*Labeorohita*	+	-	-	+
3		*Cirrhinusmrigala*	+	-	-	+
4		*Labeobata*	+	-	-	+
5		*Labeocalbasu*	+	-	-	+
6		*Hypothalmicthyesmolithrix*	-	-	-	-
7		*Ctenopharyngodonidella*	-	-	-	-
8		*Aristichthysnobillis nobilis*	-	-	-	+
9		*Oreochromis mossambica*	+	+	+	-
10		*Oreochromis nilotica*	+	+	+	-
11		*Lates calcarifer*	-	-	-	+
12		*Liza parsia*	-	-	-	+
13	Wild fish	*Puntius chola*	+	+	-	+
14		*Amblypharyngodon mola*	+	+	+	+
15		*Glossogobiusgiuris*	+	-	-	+
16		*Mystusvittatus*	+	-	-	+
17		*Channa striatius*	+	-	-	-
18		*Channa gachua*	+	+	-	-
19		*Notopterusnotopterus*	-	-	-	+
20		*Anabas testudineus*	-	-	-	+

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Table 10: List of Amphibian fauna in different study sites(S-I, II,III and IV)

Sl. No.	Species Name	Study sites			
		S - I	S - II	S - III	S - IV
1	*Rana tigrina*	+	+	+	+
2	*Rana hexadactyla*	+	-	-	+
3	*Rana limnocharis*	-	+	+	-
4	*Bufo melanostictus*	+	+	+	+

Table 11: List of Reptilian species in different study sites(S-I, II,III and IV)

Sl. No.	Species Name	Study sites			
		S - I	S - II	S - III	S - IV
1	*Najanaja*	+	-	-	-
2	*Viperarusselli*	+	-	-	-
3	*Lycodonaulicus*	-	+	-	-
4	*Ptyasmucosus*	-		+	+
5	*Xenochropes piscator*	+	+	+	+
6	*Amphiesmastolata*	+	+	+	+
7	*Dendrelaphis tristis*	-	-	+	+
8	*Ahaetullanasuta*	-	-	+	+
9	*Enhydrisentrydris*	+	-	+	-
10	*Eutropiscarinata*	+	-	+	+
11	*Calotes versicolor*	+	+	+	+
12	*Varanus bengalensis*	+	-	+	-
13	*Hemidactylus flaviviridis*	+	+	+	+

Table 12: List of Avian species in different study sites (S-I, II,III and IV)

Sl. No.	Bird species	S - I	S - II	S - III	S - IV
1	*Megalaimazeylanica* (Large green barbet or brownheaded barbet)	+	-	+	+
2	*Megalaimahaemacephala* (Coppersmith Barbet)	+	+	+	+
3	*Upupa epops* (Common Hoopoe)	+	+	+	+
4	*Halcyon smyrnensis* (Whitethroated or White breasted Kingfisher)	+	+	+	+
5	*Meropsorientalis* (Green bee-eater or Small Green Bee-eater)	+	-	+	+
6	*Hierococcyxvarius* (Common hawk cuckoo or Brain-fever bird)	+	-	-	-
7	*Eudynamysscolopacea* (Asian Koel)	+	+	+	+
8	*Centropus sinensis* (Greater coucal or Crow pheasant)	+	+	+	+
9	*Psittaculakrameri* (Rose ringed Parakeet)	+	+	+	+
10	*Cypsiurusbalasiensis* (Asian palm Swift)	+	+	-	-
11	*Columba livia* (Rock pigeon)	+	-	-	+
12	*Streptopelia chinensis* (Spotted dove)	+	+	+	+
13	*Amaurornisphoenicurus* (White breasted water hen)	-	+	-	-
14	*Gallinagogallinago* (Common snipe)	+	+	-	-
15	*Tringaglareola* (Wood sandpiper or Spotted sandpiper)	+	+	+	+
16	*Calidris minuta* (Little stint)	-	-	+	+
17	*Himantopus himantopus* (Black-winged stilt)	+	-	-	-
18	*Charadrius dubius* (Little ringed plover)	+	-	+	+
19	*Gelochelidonnilotica* (Gull billed tern)	+	+	+	+
20	*Sterna aurantia* (River tern)	-	-	+	+

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21	*Milvus migrans* (Pariah kite or Black Kite)	+	-		+
22	*Tachybaptus ruficollis* (Little grebe or Dabchick)	+	+	+	+
23	*Phalacrocorax niger* (Little cormorant)	+	-	+	+
24	*Phalacrocorax carbo* (Large or Great cormorant)	+	+	+	+
25	*Casmerodius albus* (Large or Great Egret)	+	-	-	+
26	*Ardeolagrayii* (Indian pond heron)	+	-	-	+
27	*Anastomusoscitans* (Asian openbill or Openbill stork)	+	+	+	+
28	*Laniusvittatus* (Bay-backed shrike)	+	-	+	+
29	*Dendrocittavagabunda* (Rufous treepie or Treepie)	+	-	-	-
30	*Corvus splendens*(House crow)	+	+	+	+
31	*Dicrurusmacrocercus* (Black Drongo)	+	-	-	+
32	*Copsychussaularis* (Oriental magpie robin)	-	-	-	-
33	*Acridotheres tristis* (Common myna)	+	+	+	+
34	*Hirundosmithii* (Wire-tailed swallow)	+	+	+	+
35	*Pycnonotuscafer* (Red-vented bulbul)	+	-	+	+
36	*Acrocephalusstentoreus* (Clamorous reed warbler or Great reed warbler)	+	-	-	-
37	*Orthotomussutorius* (Common tailor bird)	+	-	+	+
38	*Passer domesticus* (House sparrow)	+	+	+	+
39	*Motacilla flava* (Yellow wagtail)	+	-	-	+
40	*Ploceusphilippinus* (Baya weaver)	+	-	-	+

Table 13: List of Mammalian species in different study sites (S-I, II,III and IV)

Sl. No.	Species Name	Study sites			
		S - I	S - II	S - III	S - IV
1	*Herpestesauropunctuatus*	+	+	+	+
2	*Paradoxurus hermaphroditus*	+	+	+	+
3	*Pteropus giganteus*	+	+	+	+
4	*Pipistrellus coromandra*	+	+	+	+
5	*Mus booduga*	+	+	+	+
6	*Bandicota bengalensis*	+	+	+	+
7	*Mus platythrix*	+	+	+	+
8	*Suncus murinus*	+	+	+	+
11	*Herpestes palustris*	+	-	-	-
12	*Funambuluspennanti*	+	+	+	+

Seasonal dynamics of physicochemical parameters of water

It is very important but challenging too to determine the extent of the influence of the selected environmental variables (pH, Dissoved Oxygen, alkanity, Biochemical Oxygen Demand etc.), to decide upon the differences in species composition from one site of the wetland to another site. Several physicochemical parameters (pH, DO, alkalinity, hardness, turbidity, etc.) of water of different study sites (S-I, S-II, S-III and S-IV) through different months, seasons and years (July, 2008 – June,2011) have revealed distinct seasonal oscillation of all such ecological variables.Temperatureshowed clear seasonal trend with maximum temperature during pre – monsoon followed by monsoon at all study sites.Turbidity was recorded maximum during monsoon both at study site – I and study site – IV, while it exhibited highest value (29.1 NTU) during monsoon'09 and lowest value (11.2 NTU) during pre – monsoon'09 at study site – III. It displayed highest and lowest values during monsoon'09 (26.1 NTU) and pre – monsoon'11(12.7 NTU) at study site – II whereas, the study site – IV showed highest value (9.6 NTU) during monsoon'09 and lowest value during pre – monsoon'09 (5.3 NTU). Highest and lowest values of pH tended to remain more or less same in all four study sites. TDS showed distinct seasonal trend with the maximum value during monsoon at study site – III followed by study site – II, study site – IV and study site – I. The highest value of alkalinity was estimated during pre – monsoon'10 (489.1 mg/l) at study site – III followed by study site – II (329.7

mg/l at monsoon'09), study site – IV (235.8 mg/l at pre – monsoon'10) and study site – I (135.9 mg/l at pre – monsoon'09). Total hardness exhibited highest result also during pre – monsoon'10 (607.2 mg/l) at study site – III followed by study site – IV (482.2 mg/l during post – monsoon'08 – 09), study site – II (387.2 mg/l during pre – monsoon'09) and study site – I (332.8 mg/l during monsoon'10). The chloride content was found to be higher at study site – III (793.4 mg/l during monsoon'09) than other three sites. After reviewing the valuesof both chloride and conductivity of four study sites, chloride was found to be directly corelated with conductivity. Lowest values of both BOD (3.9 mg/l) and COD (26.6 mg/l) were recorded at study site – I during post – monsoon'08 – 09 followed by study site – IV, study site – II and study site – III (Figure 4-10).

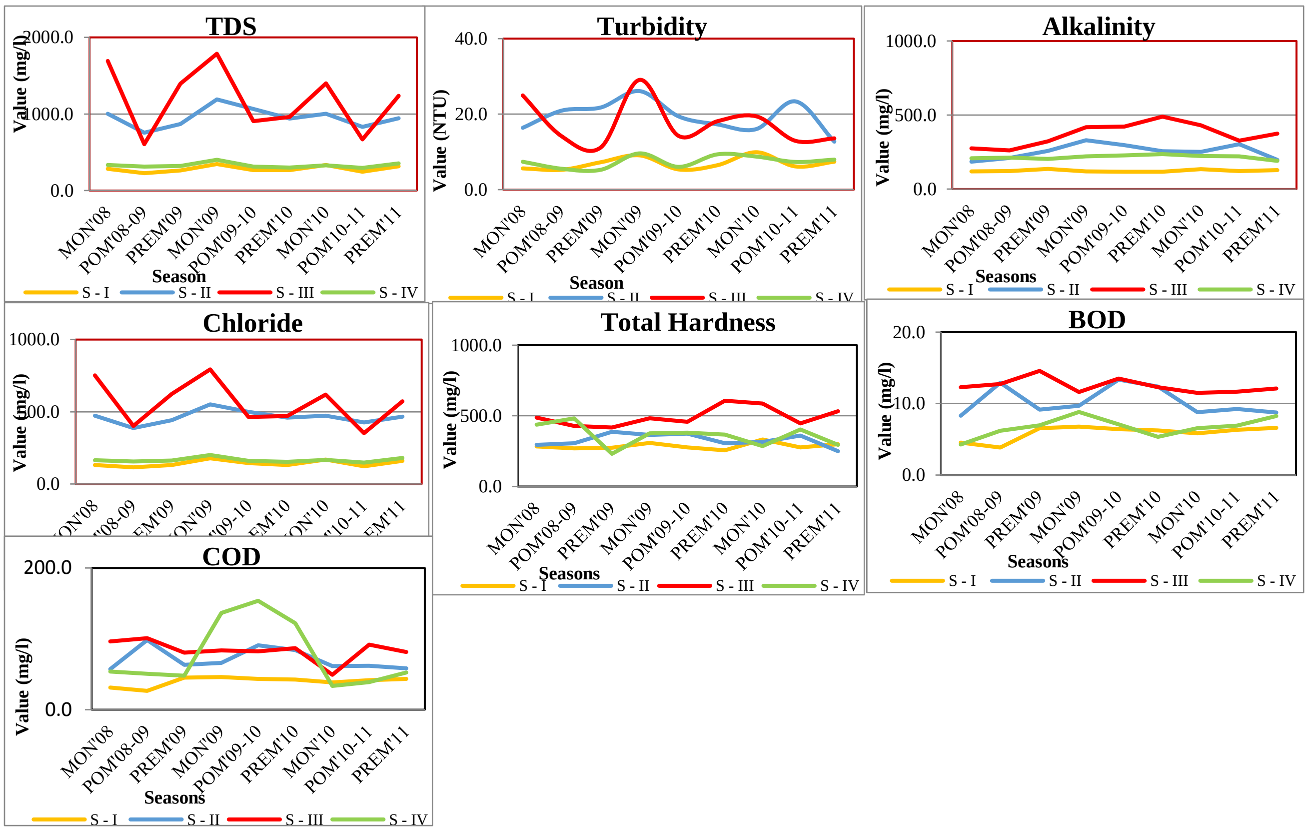

Figure 4-10: Seasonal variation in different physicochemical parameters of water observed during 2008-2011 of four study sites

Seasonal dynamics of zooplankton

Maximum density of rotifers was recorded in post – monsoonwhich reached to minimum density in monsoon. Their minimum density of cladocera was recorded during post – monsoon which reached to maximum during monsoon.Minimum density of copepoda was recorded in post – monsoon which reached to maximum peak in monsoon (35).

Wetland Characterization by GIS and Remote Sensing methods

Remote sensing for the assessment of environmental status involves the techniques for the measurement, of any spectral object of the Earth's surface and atmosphere with distinct features by some special instruments carried by satellites or aircraft. All the generated data and information are used to infer the environmental status with proper quantified interpretations.The successful application of remote sensing techniques to understand several ecological states of wetlands has become emerged as a popular means to study environment and ecology. The eco-dynamics of wetlands are determined by the seasonal fluctuation of physicochemical parameters of the water bodies along with the areal dynamicity. Multispectral satellite data and various band algebra could provide valuable synoptic data on

the dynamics of wetlands. Prior to the applying of remote sensing as an investigating method to unearth the properties of various structural components of the water bodies, it is imperative to understand the physical characteristics of the water with regard to its purity as cleanliness and transparency of water depict how far it can absorb or scatter the incident or down welling sunlight in the water column. Afterwards, it requires proper explanation that to what extent the incident light is affected due to the occurrence of organic and inorganic materials within the water column. The different spectra of wavelengths of the incoming rays are absorbed by water differently. The presence of more suspended sediment particles mostly in the surface layers of the water body, permit higher reflectivity and depict brighter appearance of the water. The apparent colour of the water reveals mild shift to longer wavelengths.

The physicochemical parameters of water like, turbidity status, suspended solid concentration, salinity (chloride content), chlorophyll concentration, etc. were calculated from the digital satellite data on temporal basis using some band algebra following the principle of supervised enhance technique (39) as raster (Figure 11 to Figure13) from which quantification of the amount of all those parameters and all theseoutputrasters after being segregated in five zones were possible. In this study, the wetlands were characterized in terms of their turbidity level as it plays important roles in limiting biological production of wetlands. The red band and green band of Landsat TM data was found to be useful for turbidity classification (39), as spectral reflectance characteristics of pure and turbid water could be separated in these wavelength ranges.

Chlorophyll pigments present in green phytoplanktons tend to absorb more of the blue wavelengths resulting a reflection of greencolour, projecting the water with green appearance due to the abundance of algae. The levels of water surface (smooth, rough, loaded with floating particles, etc.) may invite difficulty in the interpretation because ofspecular reflection mediated development of colours, either light or bright.Chlorophyll has two absorption peaks, one in the blue region (440 nm), and the other in the red (665 nm) region of the electromagnetic spectrum. In a wetland environment, other substances such as iron oxide, dissolved organic pigments and some algal pigments e.g.carotenoidsalso can absorb blue and green light, which result in masking the response in this wavelength significant to chlorophyll *a*. If the calculated environmental variables are compared on temporal basis, the turbidity (Figure 11) and salinity levels (Figure 12) are observed to be decreased in the year of 2014. However, the increment in the percentage of suspended solid was noticed in the year of 2014 whereas percentage of chlorophyll concentration (Figure 13) was seen to follow same trend in the year of 1989.

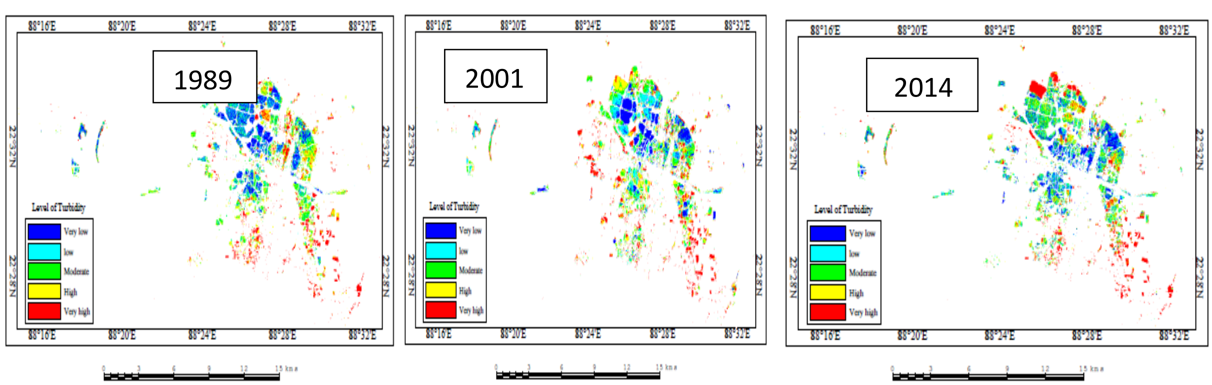

Figure 11: Changing patterns of turbidity (1989, 2001 and 2014)

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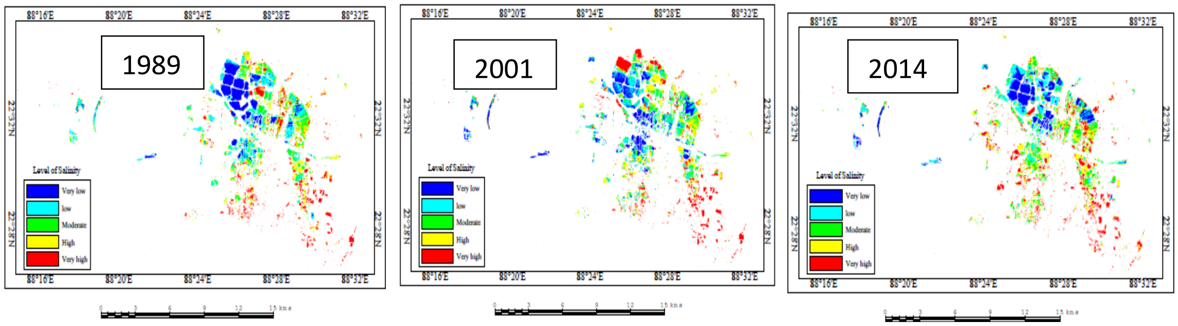


Figure 12: Changing patterns of salinity (Chloride content) (1989, 2001 and 2014)

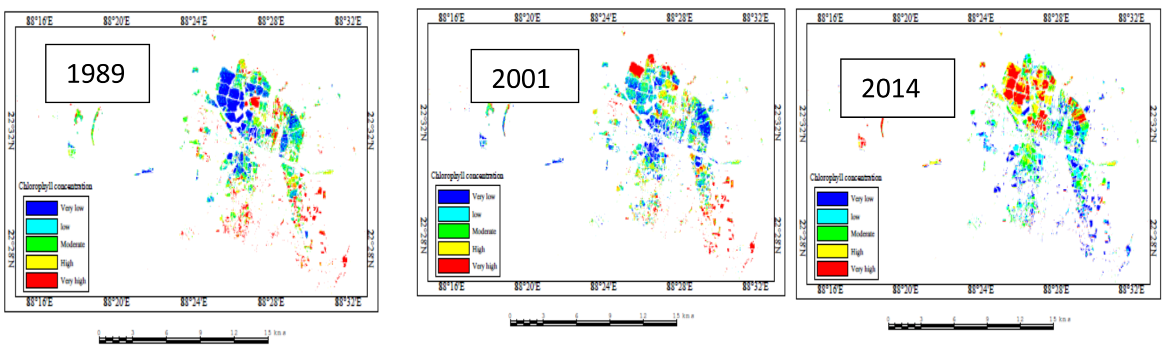


Figure 13: Changing patterns of chlorophyll concentration (1989, 2001 and 2014)

Application of GIS and Remote sensing: Classification on delimitation of the territory of Wetland

The Remote Sensing analysis had revealed the extent of the networks of East Kolkata Wetlands (EKW) mainly based on areal dimensions and have been categorized into four major types, viz. Large (>50acres), Moderate (25 – 50acres) and Small (1 – 25acres).This categorization is done on the global scale, i.e., considering entire wetland areas under Kolkata Municipal Corporation jurisdiction and East Kolkata Wetland boundary. Further analysis of this digital satellite Remote Sensing information had revealed that prevalence of large categorized wetlands was around 21% whereas the wetlands having moderate sizes accounted for 30% and the small wetlands represented the maximum share of the total extent of EKW enjoying 49% (Figure 14).

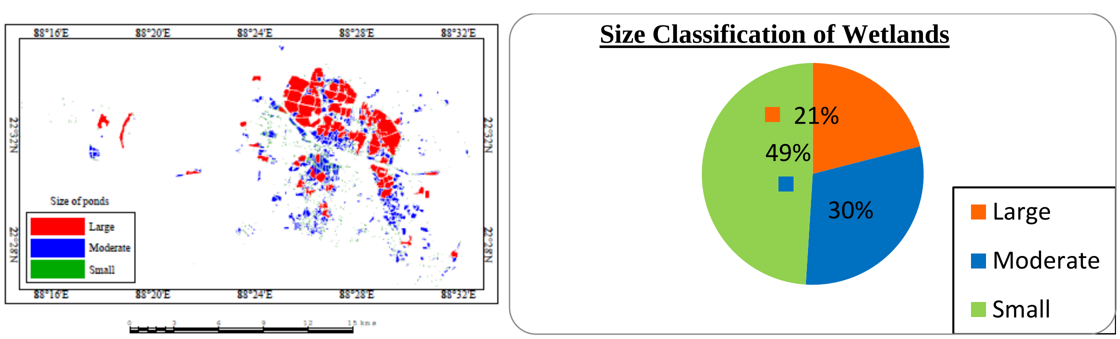


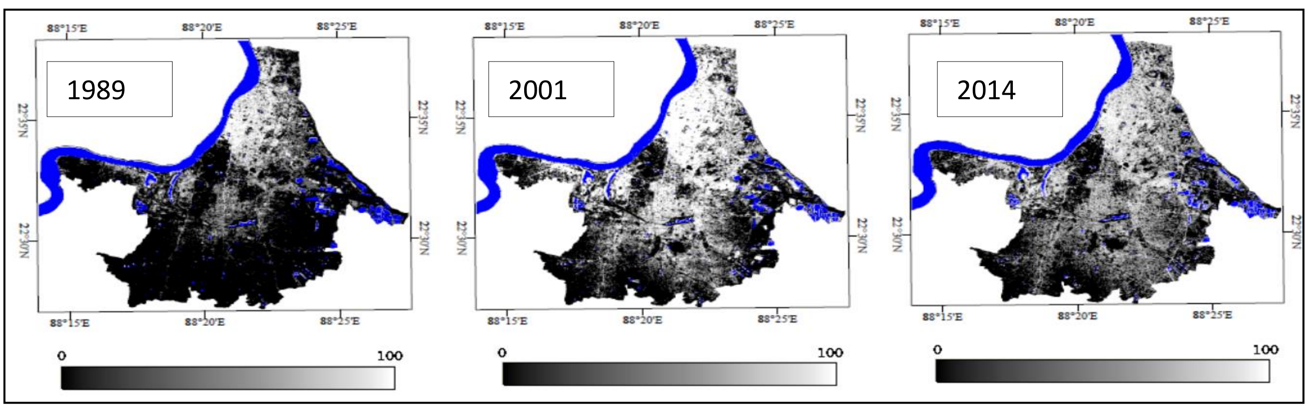
Figure 14: Size Classification of wetlands in KMC and EKW area

Moreover, based on some major ecological parameters viz., salinity (chloride content), turbidity, suspended solids and chlorophyll concentration, entire network of water bodies in the EKW possessing distinct ecological parameters, were categorized as follows: 1) Wetlands with high salinity (chloride content) with least turbidity coupled with low suspended solids; 2) Wetlands with low salinity (chloride content) with least turbidity coupled with high chlorophyll concentration; 3) Wetlands with low salinity (chloride content) with high turbidity with least chlorophyll concentration; The first category mainly included **Large Wetlands (>50acres)**. The second category was represented by **Moderate Wetlands** having an area ranging from **25 – 50acres**. The third category mostly included **Small** sized Wetlands **(<1acres)**. The conventional system of East Kolkata Wetland is endowed with lot of local terminologies such as bheries, estuarine creeks, canals, etc. which mostly belong to first category. Several large but shallow brackish water impoundments which are named locally as Jheels or Lakes while the small water bodies are further categorized into Large (Dighi), Medium (Large Ponds) and Small Ponds (Doba). Based on the above-mentioned classificatory approach of wetlands, the four (4) wetlands which were selected for detailed ecological study belong into two (2) primary categories: large and medium

Ecological Status and Threats

Wetlands represent one of the most threatened habitats of the world. Wetlands in India, as elsewhere are increasingly facing several anthropogenic pressures. Thus, the rapidly expanding human population, large – scale changes in land use along with land covers, burgeoning developmental projects and improper use of watersheds have all caused a substantial decline of wetland resources of the country. Significant losses have been occurred because of destruction threats out of conversion of wetlands for the industrial, agricultural and various urban developmental purposes. All these have led to cause hydrological perturbations, pollution and biodiversity loss. Unsustainable levels of grazing and fishing activities have also resulted in eco – degradation of wetlands (40). East Kolkata Wetlands (EKW) is not an exception of this general trend which through centuries has been struggling to survive sustaining all the ongoing environmental perturbations mainly because of anthropogenic activities.

Increment of Surface Imperviousness: Urban Sprawling Urban sprawling as the uncontrolled and undesirable growth and development in urban areas with large expansion of the geographic extent coupled with rapid increase ofhuman population and thereby stands against the eco-friendly urban planning.



[Figure 15: Nature of surface imperviousness from 1989 to 2014]

The EKW located at the eastern fringe of the city of Kolkata has had to withstand the ecological stress and pressure generated by the unplanned and uncontrolled urban expansion. In this study urban impervious surface has been extracted using linear spectral mixture model as per Otsu statistics which used to show the highest accuracy status from 1989 to till 2014 (Figure 15). In the process of quantitative assessment.it was found that for 1989 impervious area was 74.57sq.km which exhibited a steady increase as reveled by 97.11sq.km and 154.76 sq km. in 2001 and 2014, respectively. Therefore, it can be said that the surface imperviousness has been distinctly changing in an increasing rate (Figure 16 & Table 14) (41).

Table 14. Directional dynamics of surface imperviousness (during 1989 – 2014)

Year	N	NE	E	SE	S	SW	W	NW
1989	2.36	24.7	12.66	7.88	6.17	4.21	6.98	0.24
2001	2.28	25.06	14.15	14.79	10.83	5.32	7.23	0.25
2014	1.52	21.73	17.92	27.39	20.94	12.48	9.05	0.32

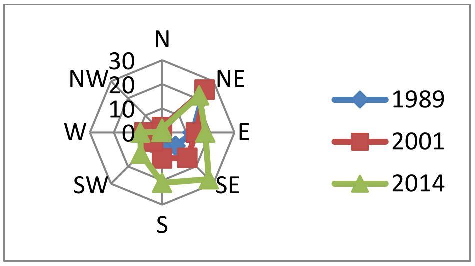


Figure 16: Rate of change of surface imperviousness within KMC and EKW area

The total impervious surface of each year is being segmented in 8 directional zones (Figure 16) and the directional areal dynamics has been accounted (Table 14), it is seen that from the year of 1989 to 2014 the surface imperviousness is tending to be extended towards south – east and south encroaching existing land cover.

Urbanization in Kolkata: Impact on East Kolkata Wetlands:

After the construction of Eastern Metropoliton Bypass (EM bypass), a long metallic road by the side of EKW during mid-70s, the population within the urban agglomeration was started increasing at an alarming rate in the eastward part of the city of Kolkata after grabbing considerable amount of low lands, conversion of agricultural lands with wetland characteristics and also destroying lot of water bodies by forcefully filling up for the construction of built structures, and all of these developments imposed real threats on the normal functioning of the wetlands of international fame. Since1997, information relating to such conversion of water bodies to agricultural land and also for human settlements were started to be kept in records. Thetrend of shrinkage of East Kolkata Wetland in and around north eastern and south western portion from the period of 1975 to the year, 2010 have been assessed with remote sensing method which depicted a loss andshrinkage of the area of EKW at an alarming rateof 1% per annum

(Table 15 &Figures 17, 18 and 19) (41).

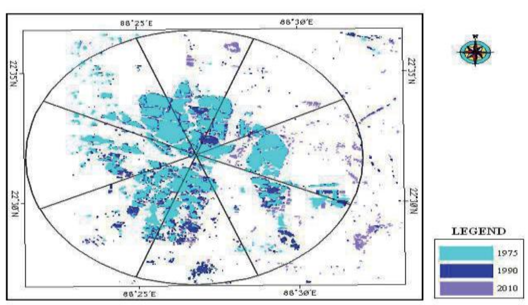
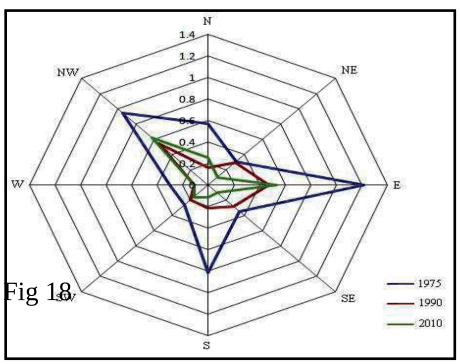


Figure 17: Directional analysis of wetland dynamics of East Kolkata Wetlands

Table 15: Directional dynamics of wetland area (EKW)

Year	N	NE	E	SE	S	SW	W	NW
1975	0.5708	0.3077	1.22	0.3456	0.8102	0.2588	0.3005	0.9475
1990	0.1652	0.2976	0.4711	0.2743	0.213	0.1949	0.1119	0.5442
2010	0.2536	0.1026	0.5343	0.102	0.1155	0.1597	0.1083	0.6229

The circular area (as depicted in the Figure 17) have eight equal pie sections orienting into eight directions and such configurations are used to extract the wetland area in sq. km. of each segment. The data and related information after being extracted are to be stored in tabular format on a temporal basis (eachsegment equals to that of 108 sq. kilometer). The reasons behind such findings can be explained with the trend of conversion of the area of EKW into other forms of land uses. In the natural state, areas under the East Kolkata Wetlands in the fringe areas of the bustling metropolis of Kolkata were represented by depressed and shallow low lands filled up with water which were appeared to be easily used by the contractors and developers in tune with the need of construction of roads, buildings etc.Ironically, several developmental schemeswere initiated for the expansion of Kolkata city much before the current realization and understanding on the importance of the wetlands in respect of their potential for providing ecological goods and services and such mindset towards urban development ultimately led to cause gradualbut steady shrinkage in the total area of the wetlands (Figure 16) (39 & 41)



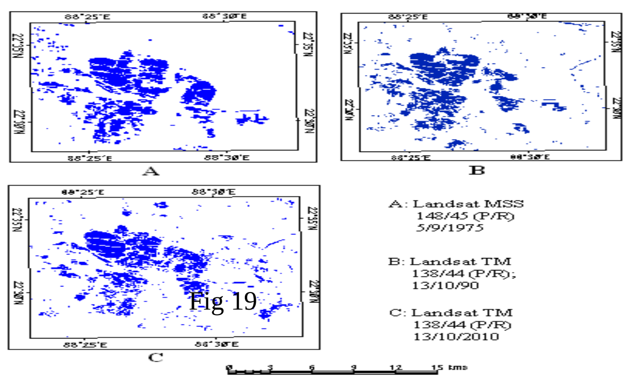


Figure 18: Graph showing the directional dynamics of the shrinkage of wetlands area.

Figure 19: Extracted water body from the information pertaining to East Kolkata wetlands using band algebra

Conclusion

The present study has been taken up with the major objectives of eco-assessment of the environmental status of East Kolkata Wetlands using different methodologies, biological, chemical, and GIS and remote sensing with special emphasis to evaluate the trend of ecological changes in four selected water bodies (S-I, S-II, S-III and S-IV) having contrasting ecological characteristics. From the binary distribution of biodiversity components, study site – I enjoyed first rank with regard to the occurrence of maximum number of species followed by study site – IV, study site – III and study site – II. Research information with regard to different biodiversity components distributed in the study areas (about 104 species of plants) and fauna (21 species of zooplankton, 52 species of fishes; 6 species of amphibians; 22 species of reptilia; more than 65 avian species and about 20 mammalian species) representing only a part of total EKW, have reflected the bio – potentiality of East Kolkata Wetlands. Moreover, state of biodiversity as documented from the present study sites forming a base line information can be compared with the previous as well as future ones, so that a comparative analysis can be made based on which one can understand the trend of changes of biodiversity wealth of the East Kolkata Wetlands and appropriate conservation measures can be undertaken to combat the depletion pattern of biodiversity along with identifying the causative factors for such decline. All such information will help chalking out proper conservation strategies.

The hydro-ecological and geo-morphological uniqueness of wetlands experiencing distinct fluctuation of the water level changes result to develop habitat heterogeneity and niche differentiation and such niche diversification trigger the growth and propagation of more dynamic and diverse taxonomic groups of both flora and fauna including unicellular (algae, and protozoa), meiobenthic (algae, fungi, crustacea, nematoda, etc.), and multi-cellular organisms starting from bryophytes, pteridophytes to woody angiosperms. A large number of microbes (fungi and bacteria) play their roles in the decomposition and other nutrients cyclings. However, clear dominance of a couple species throughout the year such as *Eichornia, Phragmites, Cyperus,Typha, Ipomya*etc. supress the growth and propagation other species of plants and their dependent animals. Remote sensing – satellite imageries have been used successfully to delineate the different environmental characteristics of the wetlands in respect of their extent,

geomorphology and ecological features. Quantification of major water quality parameters (turbidity, suspended solids, salinity – chloride content and chlorophyll concentrations) in different time scales not only substantiated the ground truth information but opened up new vistas in classifying different water bodies constituting the EKW into different categories (small, medium, large etc). Such scope of applicability of the remote sensing analysis have distinctly pointed out the trend and extent of shrinkages of wetlands in one hand, and mode of urban sprawling on the other. In such context, it can be concluded that simultaneous recording of biodiversity and physico – chemical parameters through ground truth study along with application of GIS and remote sensing to record the ecological changing patterns will justify the need of undertaking basic of holistic approach towards integrated eco-management of the sensitive, vulnerable and fragile wetland ecosystems.

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Environmental Management in India

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Abstract

Environment is the basis of our survival and is the ultimate source of our sustenance. In a developing country like India, environment and its management remains crucial as one of the primary factors contributing towards good health, decent standard of living, economic progress and indeed survival. A number of studies have detailed on the factors that contribute towards environmental damage in India like rapid population growth, unplanned urbanisation, economic backwardness of the country to name a few. The purpose of this paper is to understand the scope of environmental management in India by focusing some of the achievements and failures of the country in this regard. The paper also reviews some existing literature and tries to articulate their views on the same. The paper essentially relies on secondary data for developing an idea of environmental management in India..

Key words: Environment, management, urbanisation, pollution, efficiency, awareness

Introduction

Environment management is a recent yet most important management function which the government of a country is expected to perform. With rising incidences of environmental catastrophes and disasters there is an alarming threat to the very survival of mankind. A number of factors come into play when we talk of environmental management ranging from *lack* of development of the country, preparedness and efficiency of the government, awareness and dedication of the citizens towards environment and level of international cooperation. In India, environmental management is given due importance and effective strategies and government policies are prepared to safeguard the environment and deal with any damage.

The paper seeks to review the existing literature on theories of environmental management in India which almost collectively enumerates common causes of concern for India. The paper tries to articulate the views of the researchers and attempts to present a clear picture of the same. Further, with help of secondary data, I have tried to analyse the areas and scope of environmental management by focusing on the commitments both national and international the country has towards its citizens in particular and the world in general with regard to environmental protection. The study therefore helps to examine the expectations from the government. Having understand the same the paper explores the status of achievement and failure of the same by the country. The paper thus analyses

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the position of environmental management in India and attempts to make recommendations for improvement.

Theories on Environmental Management in India

Environmental Management theories in India have significantly focused on the primary issues of environment damage, while most have them have blamed unplanned urbanisation, industrialisation and population growth and even colonial legacy as prime culprits causing environmental degradation in India, some have tried to highlight the limitations of the concerned Ministry in the discharge of their functions.

World Bank, in its report dated 22nd September 2011, appreciated India's economic growth prospect over the past few years and even raised the prospect that such massive spurt might contribute towards complete alleviation of poverty within a generation. However, they also warned that this growth has been accompanied by a continuously degrading physical environment in the country and is coupled with scarcity of natural resources which are essential for sustaining and supporting further growth prospects and eliminating poverty. At the same time, rapid growth has generated another effect, it has created increased public consciousness concerning environment and nature and a demand for efficient management of natural resources including air, water, forests, and biodiversity. The report further highlights the challenges concerning management and clearly lists pollution, natural resources, ecosystem, biodiversity, coastal zone management, climate change and environmental governance as key areas of concern [2].

Similar ideas were echoed by Nagdeve, who too blamed the countries' rapid population growth, industrialisation and urbanisation as responsible for rampant degradation of the environment. Focusing on rapid population growth he points out that it contributes towards many environmental problems like deforestation, land degradation, air, water pollution, spread of disease to name a few [1]. In the same line, Ray and Ray further collaborated that excessive population growth in a country like India is damaging the environment through measures like expansion and intensification of agriculture, unmonitored and unplanned growth of urbanization and industrialization resulting in destruction of natural habitats. The rising level of population and consequent demand for basic amenities like food, energy, and housing have considerably disrupted land-use practices and thus damaged India's forest and environment also. High population growth rates contributes towards increasing population density, rising number of people below poverty line and thus putting undue pressure on natural resources which ultimately results in environmental degradation because of over exploitation of natural resources [3].

Cheeseman, further links population growth and related development of megacities with the problems of waste management and believes that it is making Solid Waste Management (SWM) in India a major problem. He shows that India faces major environmental challenges associated with waste generation and inadequate waste collection, transport, treatment and disposal. Current systems in India are not able to cope with the excessive volumes of waste generated by an increasing urban population, and this impacts on the environment and public health. Despite significant development in social, economic and environmental areas, SWM systems in India have remained

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relatively unchanged and this inefficient. He suggests that there is an urgent need to move to more sustainable SWM, which will in turn require new management systems and waste management facilities. Present SWM systems are incapable with waste management, with waste having a negative impact on public health, the environment and the economy [4].

Unplanned urbanisation too has contributed significantly to environmental damage. Nagdeve, highlights that such rapid and unplanned expansion of cities has resulted in degradation of urban environment. This has also widened the gap between demand and supply of infrastructure services like energy, housing, transport, communication, education, water supply, sewerage and recreational activities, thus causing serious depletion of the already scarce environmental resource base of the cities. The obvious consequence is the rising trend of damage in air and water quality, generation of wastes without proper management options, and the proliferation of slums and undesirable land use changes, which all ultimately contribute to urban poverty [1].Poverty, thus is said to be both cause and effect of environment degradation [3]. The poor people,whose reliance on natural resources are much more than those of the rich, deplete natural resources faster as they have no genuine prospects of gaining access to other types of resources. Nagdeve, states that poorer people, who are unable to meet their subsistence needs through purchase, are forced to rely on common property resources such as forests for food and fuel, pastures for fodder, and ponds and rivers for water [1].

Jacques Pouchepadass, believes that environmental damage in India has a colonial legacy with the colonial masters contributing greatly towards India's present state of affairs, however unfortunately even today the destruction continues and is left unmanaged in the name of modernisation [5].

Commitment

Treaties and Agreements

The following is an enumeration of India's participation in Multilateral Environment Agreements [6]:

The Antarctic Treaty (Washington, 1959)

India signed into the Antarctic Treaty system in 1983 as a Consultative Party Member (CEL, undated). The treaty was framed with the sole purpose that the area south of 60-degree latitude known as the Antarctic Treaty Area (ATA) should not be an area of international discord, instead shall be used for peaceful purposes only. The treaty prohibits all military actions in the region and suspends all sorts of territorial claims. It promotes the use of the region for the purpose of scientific inquiry and international cooperation in scientific activities.

Convention on International Trade in Endangered Species of wild fauna and flora (CITES), 1973

CITES, signed in March 1973 seeks regulation of international trade in endangered species of wild flora and fauna. India had signed the agreement in July 1976 and the

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Director, Wild Life Preservation is India designated CITES Management Authority (MoEF, 2018).

Montreal Protocol on Substances that Deplete the Ozone Layer (to the Vienna Convention for the Protection of the Ozone Layer), 1987

Also known as Montreal Protocol, coming into effect in 1989, it set targets aimed at a reduction in the production and consumption of ozone depleting substances (ODS). The protocol further recognizes the obligations of different nations in reducing emissions of ODS with respect to their financial and technological abilities and identifies countries that are larger contributors than others. The Montreal protocol was adopted by India in September 1992.

Basel Convention on Transboundary Movement of Hazardous Wastes, 1989

Also known as the Basel Convention, it aims for a reduction in the transboundary movement of hazardous wastes. The Convention monitors that the creation of hazardous wastes is minimized and prohibits shipment of hazardous waste to countries unable to dispose of the hazardous waste in an environment-friendly manner. India ratified to the treaty in 1992 and included some provisions of the Basel Convention in The Indian Hazardous Waste Management Rules Act, 1989 (World Bank, undated).

UN Framework Convention on Climate Change (UNFCCC), 1992

The UNFCCC targets regulation of greenhouse gas emissions through international co-operation and agreement to bring emissions to a level that can offset the effects of global warming and climate change. India became a member of the convention in 1992 and went on to ratify it in 1993.

Agenda 21

Agenda 21 was signed in the Earth Summit organized by the United Nations (UN), in Rio de Janerio, Brazil in 1992 to include stakeholders in a non-binding action plan for achieving sustainable development. The stakeholders included both local and national governments, business, international organizations, citizen groups and non-governmental organizations. The concerned stakeholders met again ten years later at the World Summit on Sustainable Development and reviewed developments to forge global partnerships for the implementation of Agenda 21 (World Bank, undated). India is signatory to Agenda 21.

Convention on Biological Diversity, 1992

The Convention on Biological Diversity (CBD) provides for a legally binding framework for the conservation of biodiversity, sustainability in use of biological resources and the equitable sharing of benefits and knowledge that arise in the case of the usage of biological resources. The convention was enforced in 1993 and a complex set of requirements was introduced for nations to ensure the preservation of biodiversity and natural habitats along with their sustainable us.

UN Convention on Desertification, 1994

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The UN Convention on desertification formulated in 1994, seeks a bottom-up approach to pool international co-operation in combating desertification or addressing policy in regions prone to droughts. The convention seeks the participation of local users of land and non-governmental organization within policy activities concerned with the regulations for and alleviation of desertification in terms of its related effects.

Rotterdam Convention, 1998

Also known as the Rotterdam Convention, the treaty looks to promote shared responsibility in the trade of hazardous chemicals. It came into force in February 2004. The convention additionally tries to promote the environmentally safe use of the hazardous chemicals by supporting a national decision making process on their export and import by facilitating information exchange. India ratified the treaty in 2005 (MoEF, undated)

Cartagena Protocol on Biosafety (2003)

The Cartagena Protocol on Biosafety is a supplement to the Convention on Biological Diversity and provides an international regulatory framework for the safe use, transfer and handling of Living Modified Organisms (LMOs) i.e. genetically modified organisms resulting from biotechnology. The protocol came into force in January 2000 and was the first such protocol of its kind (MoEF, 2018). The protocol was negotiated under the Convention for Biological Diversity and aims to provide protection against the exploits of modern biotechnology.

Nagoya Protocol, 2010

The Nagoya Protocol, adopted in 2010 aims to propagate the continued development of the access and benefit sharing framework in the Convention. It also integrates them into national developmental plans and policies (MoEF, 2018).

Other Agreements

Other such agreements include the International Tropical Timber Agreement and The International Tropical Timber Organisation (ITTO), 1983, 1994 which came into force in 1985 with the formation of the ITTO. India ratified the ITTA in 1996. Convention concerning the Protection of the World Cultural and Natural Heritage (Paris, 1972); Convention on Wetlands of International Importance, especially as Waterfowl Habitat (Ramsar, 1971); Convention Relative to the Preservation of Fauna and Flora in their Natural State (1933); International Plant Protection Convention (1951); International Convention for the Prevention of Pollution of the Sea by Oil (1954); Convention on the Conservation of Migratory Species of Wild Animals (Bonn, 1979); Convention on Early Notification of a Nuclear Accident (1986); United Nations Convention on the Law of the Sea (Montego Bay, 1982) Protocol on Environmental Protection to the Antarctica Treaty (Madrid, 1991) (CEL, Undated).

Constitutional Obligations

The Constitution of India clearly states that it is the duty of the Government to protect and improve the environment and to protect the forests and wildlife of the country. It also imposes a duty on every citizen to protect and improve the natural environment including

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forests, lakes, rivers, and wildlife. The 42nd amendment in this regard is worth mentioning.

Article 47 provides that is the duty of the state, to uplift the level of nutrition and the standard of living of its people and to improve public health, the state shall endeavour tobring about prohibition of the consumption except for medicinal purposes intoxicating drinks and of drugs which are injurious to health. Art. 48A provides that the state shall endeavour to protect and improve the environment and to safeguard the forests and wildlife of the country.

Art. 51A, included in the Constitution by the 42nd amendment Act, 1976 has the provisions as fundamental duties, says that it shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wild life, and to have compassion for living creatures and to develop the scientific temper, humanism and the other spirit of inquiry and reform, and to safeguard public property and to abjure violence.

Reality Check

Implementation of International Treaties [6 & 7]:

UN Framework Convention on Climate Change (UNFCCC), 1992

In order to give effect to the convention, India has shown leadership in moving ahead with policy frameworks that includes the National Environment Policy (NEP) and the National Action Plan on Climate Change (NAPCC). Working groups are being constituted by the Ministry of Environment and Forests (MoEF), NATCOM (National Communication) is prepared by the Government, with GHG inventory being properly communicated. Other measures include Establishment of the Technology Information, Forecasting and Assessment Council under the Department of Science and Technology, and formulation of the Participatory Forest Management Strategy of the Government of India

Montreal Protocol on Substances that Deplete the Ozone Layer (to the Vienna Convention for the Protection of the Ozone Layer), 1987

To put the protocol in place, the Ministry of Environment & Forests (MoEF), GoI has formed an Ozone Cell as well as a steering committee on the Montral Protocol in order to implement the India Country Program (World Bank, undated) as well as Ozone Depleting Substances (Regulation and Control) Rules, 2000 (drafted by the MoEF)

Convention on International Trade in Endangered Species of wild fauna and flora (CITES), 1973

Trade in India is jointly regulated through the Wildlife (Protection) Act, 1972, the Import/Export policy of Government of India, and the Customs Act 1962.

Basel Convention on Transboundary Movement of Hazardous Wastes, 1989

The Indian Hazardous Wastes Management Rules Act 1989 provides a statutory framework to give force to this MEA.

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Agenda 21

India has been an active abider of the program and has sought to align various parts of its development infrastructure such as energy, transport, industry, water facilities, climate change policy, forests, biodiversity, ecosystems, marine and coastal management, land policy, agriculture, urban governance and human resource development with the plan.

Nagoya Protocol, 2010

India as some mega-diverse country rich in biodiversity with a rapidly advancing biotechnology industry, has much interest in ensuring effective implementation of the Protocol. In India, the Protocol is being implemented through the three-tiered institutional mechanism of the Biological Diversity Act 2002.

UN Convention on Desertification, 1994

South Asia has a Regional Action Program with seven countries signatory to the convention including India.

Cartagena Protocol on Biosafety

As a part of the Convention on Biological Diversity, India is party to what is also called the Cartagena Protocol on Biosafety as well. India held the sixth meeting of the parties (MOP) in 2012.

Rotterdam Convention, 1998

Statutory backing for the convention has been laid down in Hazardous Wastes (Management and Handling) Rules, 1989.

Laws enumerated by the government for environmental safety:

1. The Wildlife Protection Act, 1972
2. The Forest Conservation Act, 1980
3. The Prevention of Air and Water Pollution, 1974, 1981 (The Central Pollution Control Board) (CPCB) was constituted under this act.
4. The Air Prevention and Control of Pollution, 1981.
5. The Atomic Energy Act. 1982.
6. Environment Protection Act, 1985
7. The Environmental Protection Act, 1986. (It came into force soon after the Bhopal Gas Tragedy)
8. Motor Vehicles Act, 1988
9. Handling and Management of Hazardous Waste Rule in 1989.
10. The Environmental Conservation Act. 1989.
11. The Public Liability Insurance Act (Rules and Amendment), 1992.
12. The National Environmental Tribunal, 1995.
13. National Environmental Appellate Authority Act, 1997.
14. National Environment Management Act (NEMA), 1998
15. The Biomedical Waste Management and Handling Rules, 1998.
16. The Environment (Siting for Industrial Projects) Rules, 1999.

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17. The Municipal Solid Waste (Management and Handling) Rules, 2000.
18. The Ozone Depleting Substance (Regulation and Control) Rules, 2000.
19. Energy Conservation Act, 2001
20. The Biological Diversity Act 2002.
21. The National Green Tribunal, 2010

Progress

The following details are based on the Annual Report (2020-2021) of the Ministry of Environment, Forestry and Climate Change, Government of India [7]

Listing Threatened Species: As of 2020, 18 States and 2 Union Territories namely, Assam, Bihar, Goa, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Manipur, Meghalaya, Mizoram, Orissa, Punjab, Tamil Nadu, Tripura, Uttar Pradesh, Uttarakhand, West Bengal, Andaman and Nicobar Islands and Diu and Dam islands have notified threatened species enumerating a total of 159 plants and 175 animal species.

Training workshop on IT ABS: A Training cum Workshop on IT Access and Benefit Sharing (ABS) Monitoring Tool was organized by the National Biodiversity Authority(NBA), from 19th – 24th January 2020 at Chennai under the NBA-GIZ Partnership Project on ABS to highlight its functions and utility towards monitoring of bio-resources and implementation of ABS mechanism.

Updating of data to World Database on Protected Areas: Division has well initiated aprocess and achieved success in submitting thedata related to protected areas to the World Database on Protected Areas in line with AichiTarget 11 for 10 States and 3 UTs. Process of submitting the data for rest of the states and UTs is in process.

Control of Pollution

Constitution of State Environment Impact Assessment Authorities (SEIAA)

As of 2020, the Ministry has constituted thirty-one State/UT level Environment Impact Assessment Authorities. Nine SEIAA/SEAC and one EACs have been constituted in 2019-20.

Implementation of Single-Window Integrated Environmental Management System: In line with the spirit of 'Digital India' initiation and capturingthe essence of Minimum Government andMaximum Governance, a Single-Window IntegratedEnvironmental Management System namedPARIVESH (Pro-Active and Responsive facilitationby Interactive, Virtuous and Environmental Singlewindow Hub) has been developed by the Ministryof Environment, Forest and Climate Change throughNIC. The PARIVESH was launched on 10th August2018.

Battery (Management & Handling Rules, 2001)

Draft Battery Waste Management Rules, 2020 were notified on the Ministry's website on February 25, 2020 for seeking comments and inputs within a period of 90 days.

A Central Crisis Group Alert System i.e. Red Book has been introduced for coordination during disaster situations. Red book facilitates the quick information exchange during

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chemical emergencies. The Red Book is updated annually and the last updated wasdone in November, 2019. It is hosted on the website of MoEF&CC.

The Cabinet approved Ministry of Environment Forest and Climate Change (MoEF&CC's) proposal to ratify seven persistent Organic Pollutants listed under the Stockholm Convention namely, (i) Chlordecone, (ii) Hexabromobiphenyl, (iii) Hexabromodiphenyl ether and Heptabromodiphenylether (Commercial octa-BDE),(iv) Tetrabromodiphenyl ether and Pentabromodiphenyl ether (Commercial penta-BDE), (v) Pentachlorobenzene, (vi) Hexabromocyclododecane and (vii) Hexachlorobutadiene.

MoEF&CC coordinated with CPCB in development of Guidelines for Biomedical Waste Management arising out of COVID-19 patients/health care workers.

The National Mission for a Green India (GIM) is one of the eight Missions outlined under the National Action Plan on Climate Change and aims towards protecting, restoring and enhancing India's forest cover and responding to Climate Change. It envisages a holistic view of greening and focuses on multiple ecosystem services along with carbon sequestration and emission reduction as co-benefit.

National Natural Resources Management System (NNRMS)

The prime objective of NNRMS scheme isutilization of Remote Sensing Technology for Inventorization, Assessment and Monitoring of country's natural resources.

Environmental Awareness, Education and Training National Green Corps (NGC) 'Ecoclub' Programme: MoEF&CC embarked upon a major initiative for creating environmental awareness among children by formulating National Green Corps (NGC) in 2001- 02. There are around 1,60,000Eco-clubs across the country. A financial assistance of Rs 5,000/- per Eco-club is provided under this programme.

Celebration of important environmental days in schools such as World Environment Day, World Wetland Day, Earth Day, etc. by organising debates, quiz, slogan competition, drawing/poster competition etc, on the related theme.

Plantation drives in and around the school campus, during the months of July and August/monsoon season.

Every school make efforts to become Single use – plastic free school/college; all 'single use' plastic items to be banned in schools such as plastic cups, plastic plates, straws etc.

Significant domestic and international events in climate change:

(i) Climate Ambition Summit: It was a virtual eventhosted by the United Nations, UK and France in partnership with Chile and Italy, on December 12, 2020. The focus of the Summit was to bring world leaders together to make new commitments to tackle climate change and deliver on the Paris Agreement. Hon'ble Prime Minister, Shri Narendra Modi, in the meeting highlighted that India is on track not only to achieve but also to exceed its targets under the Paris Agreement. The emissions intensity of GDP has reduced by 21% over 2005 levels and India's solar energy capacity has grown from 2.63 GW in 2014 to 36 GW in 2020. India's Renewable energy capacity is the 4th largest in the world and further an ambitious target of 450 GW by 2030 has been set. Hon'ble PM

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also mentioned the increase in forest cover in India, and about India's pioneering global initiatives of International Solar Alliance (ISA) and the Coalition for Disaster Resilient Infrastructure (CDRI).

(ii) Launch of India Climate ChangeKnowledge Portal: India's Climate Change Knowledge Portal (https://www.cckpindia.nic.in/) was launched on 27th November, 2020 by Shri Prakash Javadekar. The portal is an important single point Information resource which captures sector-wise adaptation and mitigation actions that are being taken by the various line Ministries in one place including updated information on their implementation.

(iii) CEO Forum on Climate Change: Recognising the role of private sector in creating lowcarbon sustainable economies, in the second India CEO Forum on Climate Change held virtually on 5th November 2020 under the Chairmanship of Shri Prakash Javadekar Hon'ble Minister Environment, Forest and Climate Change, Government of India, around 24 leading Indian companies representing different sectors reaffirmed their commitment to take voluntary actions towards achieving India's NDC goals. A 'Declaration of the Private Sectoron Climate Change' was released in the CEO forum.

(iv) G20 Environment Ministers' meeting: The meeting was held virtually underthe Presidency of the Kingdom of Saudi Arabia, on 16th September 2020. India participated in the Environment andClimate Stewardship Working Group(CSWG) events.

(v) Leadership Group for Industry Transition (LeadIT): Two major virtual events wereheld to build the momentum for industrytransition in hard to abate sectors. A virtualIndustry Transition Day was held on 7th July 2020, where Ministers of eight countriesin a joint ministerial statement called forcontinued momentum and ambitiousaction to ensure an industry transition thattackles the climate change crisis, creates decent jobs and delivers prosperity for all.

(vi) XIth Petersberg Climate Dialogue: Shri Prakash Javadekar Hon'ble Minister Environment, Forest and Climate Change, Government of India participated in the dialogue on April, 2020 in virtual mode. India along with 30 other countries deliberated over ways and means to tackle the challenge of reinvigorating economies and societies sustainably from COVID-19 pandemic.

(vii) UNFCCC June Momentum: The UNFCCC organized a series of informal meetings from 1-10th June 2020 with the objective facilitating active exchanges among governments, experts and relevant stakeholders to build momentum on climate action and to expand the understanding of the way forward into climate action and the negotiation process. About 20 virtual events were held during this period.

(viii) UNFCCC Climate Dialogues were organized from 23rd November to 4th December 2020 to advance work in the subsidiary bodies and COP agenda items. The objective of the Climate Dialogues was to provide a platform for Parties and other stakeholders to showcase progress made in 2020 and exchange views and ideas across the subsidiary bodies and COP agenda items mandated for 2020.

Clean Development Mechanism (CDM): The Clean Development Mechanism (CDM)has been a flagship programme addressingclimate change mitigation and

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simultaneouslygiving an opportunity to developing countriesin meeting their sustainable developmentobjectives.

Government of India has constituted the National CDM Authority (NCDMA) with Secretary, Environment, Forest and Climate Change as the Chairman. NCDMA examines CDM projects as per standard procedures and sustainable development criteria for granting Host Country Approval (HCA).

Some of India's key achievements in CDM

As on 15 December, 2020, 1681 out of total 7846 projects registered by the CDM Executive Board are from India, which so far is the second highest in the world.

Certified Emission Reductions (CERs) issued to Indian projects is 255 million (12.36%) of the total 2062 million CERs issued.

NCDMA has accorded Host Country Approval to 3060 projects covering different sectors of energy efficiency, fuel switching, industrial processes, municipal solid waste, renewable energy and forestry, spread across the country.

CDM supported the deployment of renewable energy especially in solar, wind, hydro and biomass in the country.

Green Climate Fund: Green Climate Fund (GCF) is the operating entity of the financial mechanism of the UNFCCC. It aims to deliver a 50:50 balance between mitigation and adaptation allocations in its portfolio. So far, three (03) projects have been approved to India with USD 177.8 Million of GCF funding.

The establishment of National Project Management Unit (NPMU) for the GCF funded UNDP Project "Enhancing Climate Resilience of India's Coastal Communities" is under progress.

2020 Environmental Performance Index [8 & 9]

The Environmental Performance Index ranks 180 countries on 32 performance indicators across 11 categories covering environmental health and ecosystem vitality [8]. It is a method of quantifying and numerically marking the environmental performance of government policies.This index was developed from the Pilot Environmental Performance Index, first published in 2002, and designed to supplement the environmental targets set forth in the United Nations Millennium Development Goals.

According to latest 12th edition of the biennial Environment Performance Index (EPI Index 2020). India secured 168th rank. The country scored 27.6 out of 100 in the 2020 index. India's rank was 177 (with a score of 27.6 out of 100) in 2018.

India scored dismal below the regional average score on all five key parameters---environmental health, including air quality, sanitation and drinking water, heavy metals and waste management.

It scored below the regional average on parameters related to biodiversity and ecosystem services as well.

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Among South Asian countries, India was at second position (rank 106) after Pakistan on 'climate change'.

The only 11 countries lagging behind India were — Burundi, Haiti, Chad, Soloman Islands, Madagascar, Guinea, Côte d'Ivoir, Sierra Leone, Afghanistan, Myanmar and Liberia.

All South Asian countries, except for Afghanistan, were ahead of India in the ranking.

Denmark stood in the first place, followed by Luxembourg and Switzerland. The United Kingdom ranked fourth, USA is 24th.

According to researchers at Yale and Columbia universities, India needs to accelerate its de-carbonization agenda, and the country faces a number of serious environmental health risks, including poor air quality.

They state that,high-scoring countries usually showcase long-standing commitments and carefully constructed programs to protect public health, conserve natural resources, and reduce greenhouse gas (GHG) emissions.

Leading the South Asian region is Bhutan (107th), with relatively high scores, Sri Lanka (109th) and Maldives (127th) round out the top three countries in Southern Asia, followed by Pakistan (142nd), Nepal (145th), and Bangladesh (162nd).

India, being one of the world's most significant emitters of greenhouse gases, should be appreciated for recent gains in renewable energy investments. However, the data highlights that is not in track to decarbonize fast enough to avoid the worst impacts of climate change. Low EPI scores for India demand a need for national sustainability efforts on a number of areas, including air and water pollution, biodiversity protection, and the transition to a clean energy future. The EPI finds essentially no overall improvement in India's environmental performance over the past decade, though there are gains and losses on individual issues.

Analysis of the Achievement/Failure:

In light of the above account, it can be safely concluded that India is making good progress in terms of environmental protection, however the low EPI score is a dark spot in the ever dedicated efforts of the Indian government. The implementation of International Treaties in India are definitely given due importance and the government over time works on modifying their policies and laws to give effect to the same. The comprehensive nature of National Laws of the country dedicated to Environmental protection also demands an appreciation. An observation of Annual Report as presented by Ministry of Environment, Forestry and Climate Change of the year 2020-2021 creates a feel-good feeling as we see India progressing in multiple directions be that systematic and digitalised data integration on environment, sensitising students at school level, participating in different climate summits worldwide or setting Green Tribunals. Thus, overall the achievements of the concerned ministry and the Government as a whole is commendable and shows no dearth of dedication. World Bank report too highlights that

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India's Ranking on different Indicators	
Overall EPI 2020	168
Health	172
Air Quality	179
Sanitary and Drinking Water	139
Heavy Metals	174
Waste Management	103
Ecosystem Vitality	150
Biodiversity	148
Ecosystem Services	93
Fisheries	35
Climate Change	106
Pollution Emissions	145
Agriculture	108
Water resources	94
Source: EPI 2020	

Table 1: [9]

India has made a substantial effort in attempting to address environmental challenges. It has enacted strict environmental legislation and has developed institutions to monitor and enforce legislation. The National Environmental Policy (NEP) recognizes the value of harnessing market forces andincentives as part of the regulatory toolkit, and India is one of only three countries worldwide which has established a Green Tribunal to exclusively handle environmental litigation [1].

However, one cannot ignore the dismal performance of India as per the Environmental Performance Index 2020, this could be attributed to several factors, for example the rise of population and the consequent destruction of it over nature still remains an irritant, further unplanned urbanisation, poverty, deforestation, unmonitored rise of mega-cities, improper waste management still go unchecked. The need of the hour is a crucial and complete monitoring of such issues by not only the ministry, government but also the citizens of the country in particular. The analysis hints towards the fact that the apparatuses and institutions for environmental management in India are quite appropriate and efficient, yet the issue lies at the level of the implementation of the concerned policies and laws. It is at the level of application and administration of the policies that the concerned stakeholders need to be cautious, alert and diligent.

Recommendations

1.The country needs immediate control of population. Government needs to make special efforts for sensitising the people on the harms of large population through specially designed IEC (Information, Education, Communication) [1].

2. The crisis situation in India demands re-doubling sustainability efforts by the nation on all areas with a particular high-priority focus on critical issues such as air, water quality, biodiversity and climate change.

3. Measures to control pollution, deforestation and soil degradation is to be more effectively reinforced. In contrast, positive steps like afforestation, land restoration, proper waste management, sanitation facilities are to be employed.

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4. Nagdeve suggests that compulsory environment education in schools is imperative [1].

5. The country needs a third-party institution that will remain independent and autonomous in its sphere of activity to inspect, monitor and survey cases of environmental damage, addressing grievances of citizens, ensuring a check on the industries and auditing large-scale industries on a continuous routine basis.

6. Even the most comprehensive National Environmental laws have failed to produce the desired results owing to lack of effective implementation, so an exclusive body to monitor the same is the need of the hour. Apolitical nature and autonomy of the body will remain crucial to its efficacy.

7. Advanced waste segregation techniques and specialised waste processing facilities is to play a key role [5].

8. World Bank report highlights the crucial role of advanced research and capacity building for the country that may open new vistas of environment management [2].

9. Sensitising and educating Indians on the hazards of environmental destruction is equally called for. As most of the damages are caused due to lack of awareness or will on part of the citizens. People are to be made aware of the various Environment laws and policies of the country.

10. Corruption, red-tapism and related administrative fallacies are to checked while dealing with industrial environmental management.

11. Inadequate funds and improper infrastructural facilities are also a hindrance to their competencies. Adequate and routine funds are to be allocated for the efficient disposal of their functions.

12. Effective articulation, tabulation, presentation and analysis of the data is required to systematically prepare, plan and manage environmental concerns.

13. Laws and policies are to be continuously monitored and updated as per the requirements of changing times.

14. Competent and well qualified engineers and experts in field of environment are needed to bring in state of craft modifications in the existing state of environmental management in India.

15. Above all, a dedicated political will and citizen’s support are imperative for the successful implementation and achievement of all environment concerned ideas.

Conclusion

The paper intended to explore the condition of environmental management in India by focusing on the areas of commitment the country has towards environment and the extent to which it has been successful in fulfilling the same. It also made reference to existing literature on the subject, most of which unanimously count on certain factors like massive population, unplanned rise of mega-cities, lack of effective monitoring of urbanisation, improper waste management in the country, and most importantly economic

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backwardness and ever-increasing scenario of unequal distribution of resources and income in the country as the major sources of environmental catastrophe in India. On having studied the varied commitments of the Indian government towards nature, our expectations are aroused. To a great extent the country's efforts in this direction does not disappoint either as evident from series of achievement highlighted by the Ministry of Environment, Forestry and Climate Change. The all-inclusive nature of environmental jurisprudence and Constitutional promises further adds hope.

However, the reality as viewed in everyday lives of the people who particularly poor, live in sub human conditions devoid of effective sanitation, clean water & waste management facilities in dirty roads and shanty homes, present a different India altogether. The piteous condition of slum dwellers in several metropolitan cities in India is a case in point. Not only poor, even the richest of the richest in the country are not served with fresh air and uncontaminated water. The pollution of water, air, land is no hidden fact in India. The ever rising incidences of deforestation, land degradation, smuggling and poaching of innocent animals have not failed to make headlines even for a single day.

Thus, an analysis of the situation demands urgent overhauling of the whole set up of environmental management in India. The onus of responsibility should rather not be completely placed on any one group of stakeholders, rather each and every one associated with Mother Earth has equal and important responsibility of contributing towards its welfare---the government, its ministry, NGOs, environment dedicated clubs or councils, and most importantly citizens have an effective role to play. The policies, laws of the government are only successful if the people abide by it. The paper recommends certain ideas for ensuring sustainability of the environment. It is high time, we come out of the petty materialistic mentality of taking away from the environment without concerning for 'giving back' and individually make efforts to heal the nature and in turn contribute to a healthy, happy, prosperous, safe and secured future not only for us but for our future generations as well.

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Water Quality of Ganga River at Bagbazar Ghat of Kolkata During Pre-Lockdown Months of 2020: A Brief Study

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Abstract

This physio-chemical study was conducted from January 2020 to March 2020 on Ganga River at Bagbazar ghat. In this pre-COVID-19 lockdown phase, water samples were physically collected weekly at a particular time of day. In the laboratory, several nutrient parameters along with dissolved oxygen and chlorophyll were estimated and represented graphically. This point of river was found to exhibit very low salinity (mean 0.32) and comparatively higher BOD content (mean 7.53 mg L^{-1}). The dissolved oxygen concentration was also found to be moderate (mean 8.85 mg L^{-1}). This human inundated point of the river had also exhibited moderate concentrations of PO_4^{-3} – P, NO_2^- – N, SiO_4^{-4} – Si, and NH_3 – N. A comparison of Ganga River water quality was also conducted between the pre-lock down and post lockdown period along with drinking water standards, Finally, the findings of our study was concluded against similar types of the study conducted at Kanpur and Haridwar.

Keywords: water quality, degree of pollution, tidal effect, Ganga river

Introduction

The Ganga River system is the largest in India has several perennial and non-perennial rivers. The Ganga is the most important and iconic river in India and is a lifeline to millions who live along its course. In Hinduism, the Ganga River is familiar as sacred and is personified as the goddess Ganga. This river is also important historically, many former provincial or imperial capitals (such as Patliputra, Kannauj, Kara,Kashi,Allahabad, Varanasi, Murshidabad, Munger, Baharampur, Kampilya, and Kolkata) have been located on its banks. The Ganges, or Ganga, is a transboundary river of Asia that flows through India and Bangladesh. The 2,510 km river originates in the Gangotri Glacier of Western Himalayas in the Indian state of Uttarakhand, at an elevation of 4,356 m (14,291 ft) and flows south and east through the Gangetic Plain of India and Bangladesh, eventually discharges into the Bay of Bengal(Indra B Singh, 2007). The Ganga basin lies substantially in India and Bangladesh and was accumulating the flow of three big rivers, the Ganges, the Brahmaputra, and the Meghna (GBM) (Salehin et al, 2011). The GBM river basin covers an area of about 1.75 million km^2 stretching across Bangladesh (7.4%), India (62.9%), Nepal (8.0%), Bhutan (2.6%), and China (19.1%) (Kuehl et al., 2005).

Along the way between Allahabad and Malda, West Bengal, the Ganges river passes through the towns of Chunar, Mirzapur,Varanasi, Ghazipur, Patna, Hajipur, Chapra, Bhagalpur, Ballia, Buxar, Simaria, Sultanganj, and Saidpur. At Bhagalpur, the river begins to flow south-southeast and at Pakur, it begins its attrition with the branching away of its first distributary, the Bhagirathi-Hooghly, which goes on to become

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the Hooghly River. Just before the border with Bangladesh, the Farakka Barrage controls the flow of Ganges, diverting some of the water into a feeder canal linked to the Hooghly to keep it relatively silt-free. The Hooghly River is formed by the confluence of the Bhagirathi River and Jalangi River at Nabadwip, and Hooghly has several tributaries of its own. The largest is the Damodar River, which is 541 km long, with a drainage basin of 25,820 km^2 (9,970 sq. mi). The Hooghly River empties into the Bay of Bengal near Sagar Island. Between Malda and the Bay of Bengal, the Hooghly river passes the towns and cities of Murshidabad, Nabadwip, Kolkata, and Howrah(P. Srivastava & Shukla, 2009).

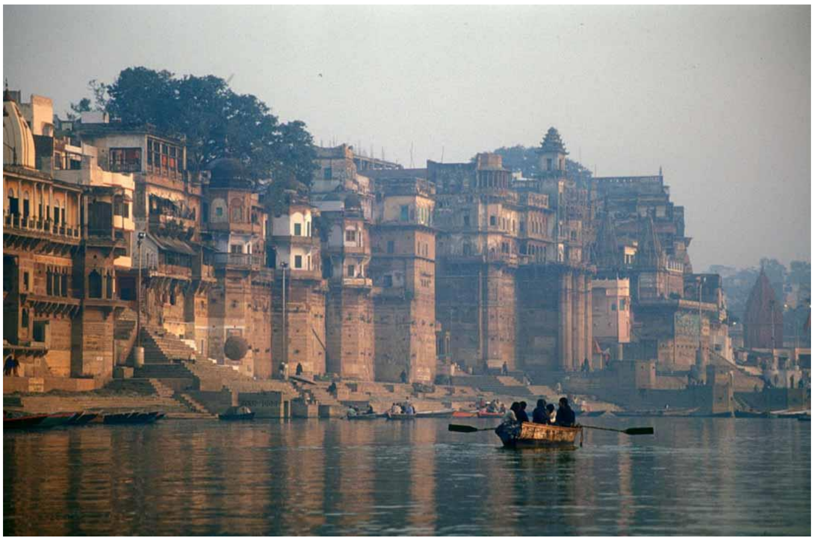

Figure 1 The River Ganga of Varanasi

The Ganges suffers from extreme pollution levels, caused by the 400 million people who live close to the river. Sewage from many cities along the course of the river, industrial waste, and religious offering wrapped in non-biodegradable plastic, and a large number of pollutions to the river as it flows through densely populated areas.The problem is exacerbated by the fact that many poorer people rely on the river daily for bathing, washing, and cooking.The World Bank estimates the health cost of the water population in India to equal three percent of the GDP of India.It has also been suggested that 80% of all illnesses in India and one-third of deaths can be attributed to waterborne disease (Rai, 2013). Varanasi, a city of one million people that many pilgrims visit to take a ‘holy dip’ in the Ganges, releases around 200 million liters of untreated sewage into the river each day, leading to large concentrations of fecal coliform bacteria. According to official standards, water safe for bathing should not contain more than 500 fecal coliforms per 100 ml, yet upstream of Varanasi ghat river water already contains 120 times as much, 60,000 fecal coliform bacteria per 100 ml (Dwivedi et al., 2018).

Between 1985 and 2000, around 10 billion US dollars was spent on the Ganga Action Plan, an environmental initiative that was the largest single attempt to clean up a polluted river anywhere in the world. The Ganga Action Plan has been described variously as a failure, a ‘major failure’(V. K. Srivastava, 2010). In November 2008, the Ganges alone among the river of India was declared a ‘National River’, facilizing the formation of a National Ganga River Basin Authority that would have greater powers to

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implement and monitor measures aimed at protecting the river(Dwivedi et al., 2018). In July 2014, The Government of India announced an integrated Ganges development project titled ‘NamamiGange’ and allocated 2037 crore for this purpose(Mathur, 2020). Recently,studies by the Indian Council of Medical Research (ICMR) say that the river is full of killer pollutants that those living along its banks in Uttar Pradesh, Bihar, and Bengal are more prone to cancer than anywhere else in the country.Conducted by the National Cancer Registry Programmer under the ICMR, the study throws up shocking findings indicating that the river is thick with heavy metal and lethal chemicals that cause cancer (Goswami & Mazumdar, 2016).

Figure 2 The River Ganga of Kolkata

Hooghly River, also spelled Hugly, river in West Bengal state, north-eastern India. An arm of the Ganga River, it provides access to Kolkata (Calcutta) from the Bay of Bengal. It is formed by the junction of the Bhagirathi and Jalangi rivers at Nabadwip. From there the Hugli flows generally south for about 160 miles (about 260 km) to the Bay of Bengal, through a heavily industrialized area with more than half of West Bengal’s population. The tidal effect stretches to over 175 miles length up to Nabadwip where two nonperennial rivers Bhagirathi and Jalangi, both taking off at different sites from the Ganges meet and discharge their rainwater (freshets) into the Hooghly all through the summer months. Other rivers join it also downstream. Annual tide tables are published for three places on the river viz Sagar, Diamond Harbour, and Garden Reach. The major river that drains into the Bhagirathi-Hooghly includes Mayurakshi, Jalangi, Ajay, Damodar, Rupnarayan, and Haldi rivers other than the Ganges(Indra Bir Singh, 1996). The following are some of the important ghats located around Kolkata.

Baboo Ghat (Babu Ghat): Baboo ghat is one of the oldest rivers ghats in Kolkata. It is named after Babu Raj Chandra Das, a zamindar and a rich man during colonial times. This ghat was built in the memory of Babu Raj Chandra Das by his wife Rani Rasmoni.

Princep Ghat: Princep Ghat was built in the memory of James Princep, a British Scholar. The Princep Ghat has a monument that has Greek and Gothic architecture.

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Armenian Ghat: It is said that the Armenians were one of the first foreign settlers in Kolkata. This ghat was also built by an Armenian.

Outram Ghat: Outram Ghat is one of the most preferred, silent, and sober riverside entertainment spots in Calcutta. With its strategic location, near the colossal Howrah Bridge and Babu Ghat, Outram Ghat makes a perfect destination for an early morning and evening walk.

Annapurna Ghat: This ghat was previously known as Raghu Mitra's Ghat whose father Govinda Ram Mitra was ranked as 'black depute' by the British during the British Rule.

Chatulal Ghat: This ghat has a colonial history to be linked with. It has been built and dedicated to Sir James Outram who was a foot soldier in the army of the British East India Company and later rose to the rank of a general because of his bravery and commitment.

Jagannath Ghat: Jagannath Ghat is located on the eastern bank of River Ganga, just to the north of Howrah Bridge. It was beautifully constructed in classical European style by ShobharamBasak, the famous trader, and merchant, who became a millionaire by supplying textiles to the East India Company.

Bagbazar Ghat: Bagbazar Ghat, on the Ganga River is an old one. It was once called RogoMeeter's Ghat after Raghu Mitra, son of Gobindram Mitra, the black zemindar, and once one of the wealthiest and most influential natives of Kolkata, in the early days of the British East India Company.

Mayer Ghat: It is the bathing ghat at Bagbazar where Ma Sarada used to take a bath during her staying near the ghat.This bathing ghat is known to all as 'Mayer Ghat'.

The Bagbazar Ghat, on the Ganga River, is an old one. The old ghat is used by bathers, people collecting Ganges water for religious ceremonies, for the performance of religious ceremonies, and such mundane tasks as unloading country boats carrying various goods.

Ganga River Pollution

The idol immersion in the festive seasons had an adverse impact on water quality and the plankton community in the Ganga River. During 2011, the water salinity was 0.20 pre idol immersion,0.20 during idol immersion, and 0.19 post idol immersion. Whereas, during 2012 salinity was 0.14 preidol immersion,0.18 during idol immersion, and 0.19 after idol immersion. In 2011 dissolved oxygen content of Ganga River water was 5.2mgL^{-1} during pre-idol immersion, 4.8 mgL^{-1} during idol immersion, and 5.2 mgL^{-1}during the post idol immersion period (Rakshit & Sarkar, 2018). This might be due to the substantial mixing of flowers and leaves,during the immersion phase,increase of organic matter could have a direct negative impact on the low D.O concentration comparing to pre and post immersion phases(Bhattacharya et al., 2014).The phenomenon was reasonably significant for two consecutive years.There was a 2 to 3 percent decrease in the level of dissolved oxygen compared to pre and post immersion. Values of biochemical oxygen demandalso exhibited a similar trend of distribution,

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higher during immersion than pre and post immersion phases. It is revealed that the decomposition of weeds plays a significant role inthe assimilation of organic load inviting microorganisms, resulting in high B.O.Dconcentration as referred. High B.O.D observed during January 2010 was due to utilization of oxygen for the oxidation biodegradation of the organic matter (from idol paints, straws, and flowers). When the immersion of the idol was over, the water gets saturated with oxygen maintaining an overall average concentration of 1.26± 0.21mg/L during the study period(Vass et al., 2010).

The Nitrate – N concentration had exhibited a wide range of radiations with maximum and minimum values of 28.64 µ M during immersion and 14.25 µ M during pre-immersion respectively. The increased nitrate – N level was due to entry of nitrate – N through oxidation of ammonia to nitrite – N. The organic compound, as well as idol paints, also favor the input of subsequent nitrogenous compounds to the water(D. Mukherjee et al., 1993). The low values recorded pre immersion phase were mainly due to the utilization of phytoplankton as evidenced by high photosynthetic activity. During immersion of idols is mainly due to admixing of large amounts of oils, soaps, and synthetic detergents which contain mineral, phosphorous and nitrogenous compounds that act as binding agents that suspend dirt into water. The average concentration of inorganic silicate was recorded 89.02± 28.72 µ M with maximum concentration during post immersion phase mainly due to non-shifting of immersed idol and dissolution of non-degradable substances occurred which might be the main source of this reactive silicate. Higher nutrient loading can also lead to pollutant dispersal and fecal contamination create short- and long-term impacts on water quality in estuaries and coastal environments(Das, 2011).

Objectives

The prime objectives of this study were to analyze the physicochemical and biological parameters in this Bagbazar ghat on a weekly and monthly bases like dissolved oxygen, temperature, salinity, chlorophyll and their variation with time and tide, nutrients content of the water during high tide, and low tide and quantitative and qualitative analysis of plankton's composition to ascertain the water quality.

Study Area

For the convenience of sample collection and to cope up with our objectives properly we had selected Bagbazar ghat for our sample collection purpose. This place has immense importance from time unknown. The old Chitpur Road (renamed Rabindra Sarani) was for many years the lifeline of Bagbazar. It followed the same track as the old pilgrim path built by Sabarna Roy Choudhury from Halisahar to Barisha. Tram tracks along Rabindra Sarani came to Bagbazar in 1904 and are being renewed in 2007. While Rabindra Sarani cuts across Bagbazar from north to south, Bagbazar Street cuts across from Bagbazar Ghat in the west to Bidhan Sarani in the east. Girish Avenue is an extension of Chittaranjan Avenue. When it was built in the 1930s, a portion of the house of Girish Chandra Ghosh was spared and stands in the middle with the two flanges of the road on both sides of the house. There are numerous lanes and by-lanes in Bagbazar. Bagbazar is also on the Kolkata Circular Railway. Shyambazar station

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of Kolkata Metro is within walking distance of most parts of Bagbazar. Hence this point is easy to access.

Figure 3: Map of the Study Area

Figure 4: The Bagbazar Ghat of Kolkata

Though this place is most famously for its Durga Puja festival, one of the best in North

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Kolkata, still the Ganga River morphology also provides an important factor of interest among the river researchers. The mighty Ganga Rives takes a sharp westward turn and flows towards Sankrail. Hence this region acts as a hindrance in the path of the free-flowing Ganga River.

Sample Collection and Filtration

Water samples were collected weekly every Wednesday from January to March 2020. As the samples were collected around 12.00 hours every Wednesday, a variable tidal condition had been observed. Some of the samples were of low tide whereas some others represented high tidal conditions. Surface samples were collected using a clean plastic bucket from the Kolkata Port Trust jetty at Bagbazar. Air and water temperature were measured instantly and dissolved oxygen was fixed accordingly.

Table 1: Description of sample collection

Serial No.	Date of Sampling	Time of Sample Collection	Tidal Condition
1	14th January	12.10 pm	Low Tide
2	20th January	12.20 pm	Low Tide
3	28th January	11.56 am	High Tide
4	5th February	12.17 pm	High Tide
5	12th February	12.26 pm	Low Tide
6	19th February	12.09 pm	High Tide
7	26th February	12.38 pm	Low Tide
8	4th March	12.08 pm	High Tide
9	12th March	11.54 am	Low Tide

Sample collected were carried to university laboratory as soon as possible and filtered through Riviera Cellulose Nitrate filter paper of 0.45 µm pore size. Dried filter papers were weighed initially and after filtration of 1 L water sample, the difference between the two weights gave the amount of Suspended Particulate Matters in g L^{-1} unit. Instantly after weighing each filter paper was dissolved in 90% acetone solution for Chlorophyll-a concentration estimation purpose.

Materials and Methods

Analysis of Dissolved Oxygen, B.O.D$_5$ and Salinity

Dissolved Oxygen (DO) was estimated through the Iodometric method with proper azide modification (APHA, 2005). Triplicate water samples were taken in 300 ml glass-stoppered BOD bottles, 1 ml of each $MnSO_4$ reagent (364 g $MnSO_4$, H_2O in distilled water diluted to 1 L) and alkali-iodide-azide reagent (500 g NaOH, 135 g NaI, in distilled water and diluted to 1 L, mixed with 10 g NaN_3 dissolved in 40 ml distilled water) were added carefully, stopper to exclude air bubbles and mixed by inverting bottles. After settling of the precipitate 1 ml concentrated H_2SO_4 was added, restopper, and mixed by inverting several times until dissolution was completed. The final-colored solution was titrated using standard sodium thiosulfate solution (6.205 g $Na_2S_2O_3$, $5H_2O$ dissolved in distilled water, 0.4 g solid NaOH added to it and diluted to 1 L), standardized against standard potassium bi-iodate solution (0.0021 M, 812.4 mg

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$KH(IO_3)_2$ in distilled water and diluted to 1 L), using the starch solution (1-2%) as an indicator. The DO values were calculated using equation 1 ml 0.025 M $Na_2S_2O_3$ = 1 mg DO/L. This process had a precision of ±50 µg/L with visual endpoint detection.

Biochemical Oxygen Demand (BOD) of the water samples was estimated by a 5-day BOD test (APHA, 2015). Oxygenated tap water was taken as dilution water. Phosphate buffer solution (8.5 g KH_2PO_4, 21.75 g K_2HPO_4, 33.4 g $Na_2HPO_4.7H_2O$ and 1.7 g NH_4Cl diluted to 1 L solution), magnesium sulfate solution (22.5 g $MgSO_4.7H_2O$ diluted to 1 L), calcium chloride solution (27.5 g $CaCl_2$ diluted to 1 L) and ferric chloride solution (0.25 g $FeCl_3.6H_2O$ diluted to 1 L) each at the rate of 1 ml l^{-1} were added to it. The process was standardized against the glucose-glutamic acid check solution (each 3 mg/L). The mean BOD for GGA solution after dilution and seed correction was found 188 ± 14.2 mg/L. Salinity was estimated through argentometric titration (Strickland & Parsons, 1972). Samples of wastewater (15 ml) were titrated against standard $AgNO_3$ solution, using K_2CrO_4 solution (3.5 g l^{-1}) as an indicator. Silver nitrate solution was previously standardized against standard seawater solution (3.5 g NaCl in 96.5 ml distilled water), having chlorinity 19.375 ppt and salinity 35‰. The salinity and chlorinity were related by Knudsen's equation; S‰ = 0.03 + 1.805 Cl‰. This method is accurate up to 0.05 to 0.1 ‰ of salinity.

Analysis of Nutrient parameters

Dissolved Inorganic Phosphate-P, Nitrite-N, Ammonia-N, Silicate-Si, Chlorophyll were analyzed(Hansen & Grasshoff, 1983) using Systronics, UV-VIS Spectrophotometer necessary modification for wastewater analysis were done according to APHA, 1992. Relative accuracy error of ± 3% for Nitrite and Nitrate, ± 5% for Ammonia, ± 2% for Phosphate was achieved (Ray et al., 2017).

Results and Discussions

Variation of Salinity

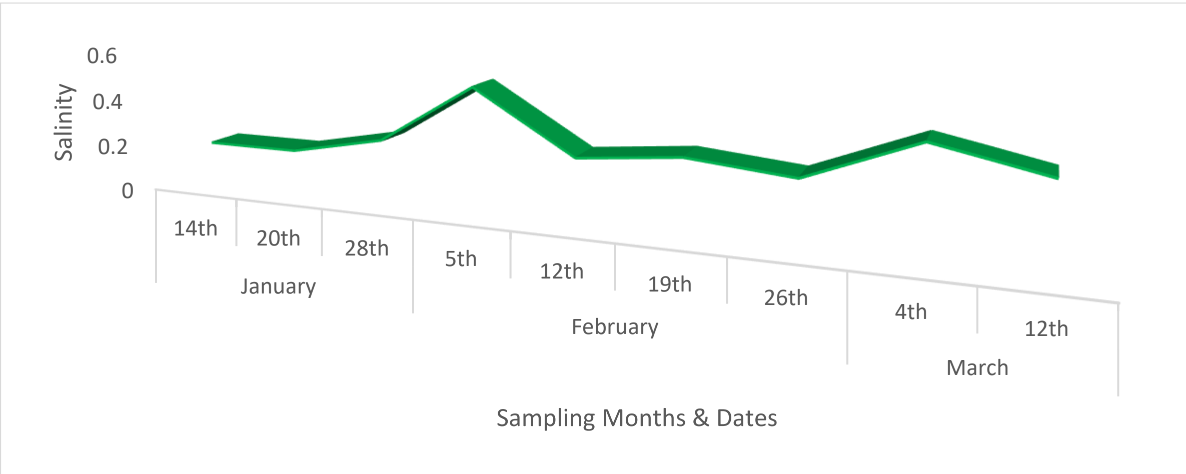

Figure 5: Variation of Salinity at Bagbazar

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The highest salinity of about 0.53 was recorded on 5th February while the lowest salinity of about 0.2 was measured on 14th and 20th January consecutively. During low tidal sampling, the salinity was lower and during high tidal sampling, the salinity was higher. The mean salinity of the Ganga estuary at this Bagbazar point during January, February, and March 2020, was about 0.23, 0.35, and 0.41 respectively. The overall mean salinity of the Ganga River estuary at this human inundated point of Kolkata during this pre-monsoon season of 2020 was about 0.32.

Variation of Dissolved Oxygen

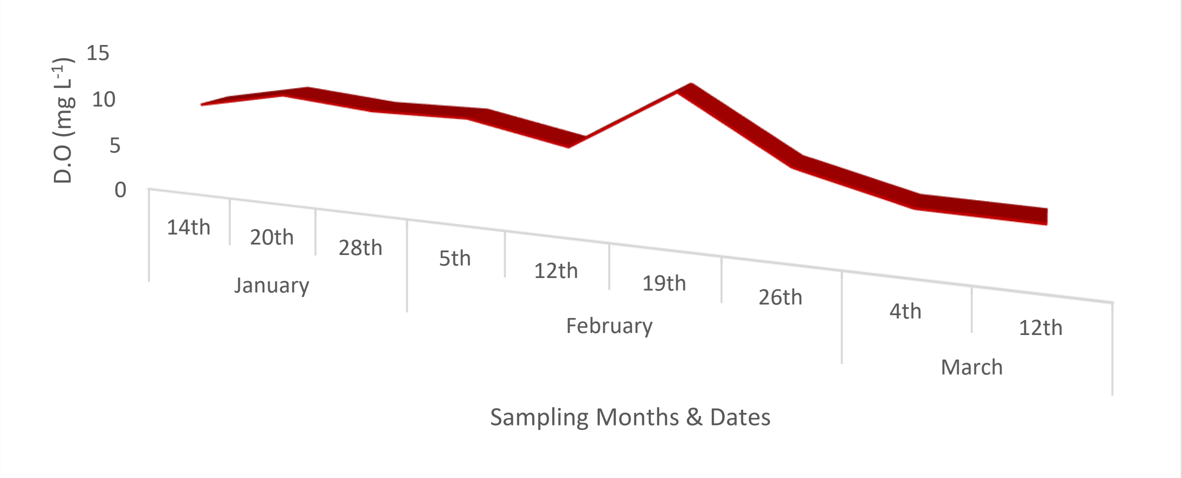

Figure 6: Variation of Dissolved Oxygen at Bagbazar

In January 2020, the highest dissolved oxygen concentration was recorded about 10.8 mg L^{-1} and the lowest was recorded about 9.04 mg L^{-1}. This resulted in a mean D.Oconcentration of 9.91 mg L^{-1} during this month at this Bagbazar sampling point of the Ganga River estuary. In February 2020, the highest D.O concentration was recorded about 13.95 mg L^{-1} and the lowest concentration of the same was about 7.88 mg L^{-1}. This gave rise to a mean D.O concentration of about 9.93 mg L^{-1}. During March 2020, the mean D.O concentration was comparatively lower than the previous two months and of about 5.10 mg L^{-1}. This human inundated sampling point of the Ganga estuary had repeatedly exhibited lower levels of D.O concentrations in our study period. The overall mean D.O concentration at this point was about 8.85 mg L^{-1}.

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Variation of Biochemical Oxygen Demand

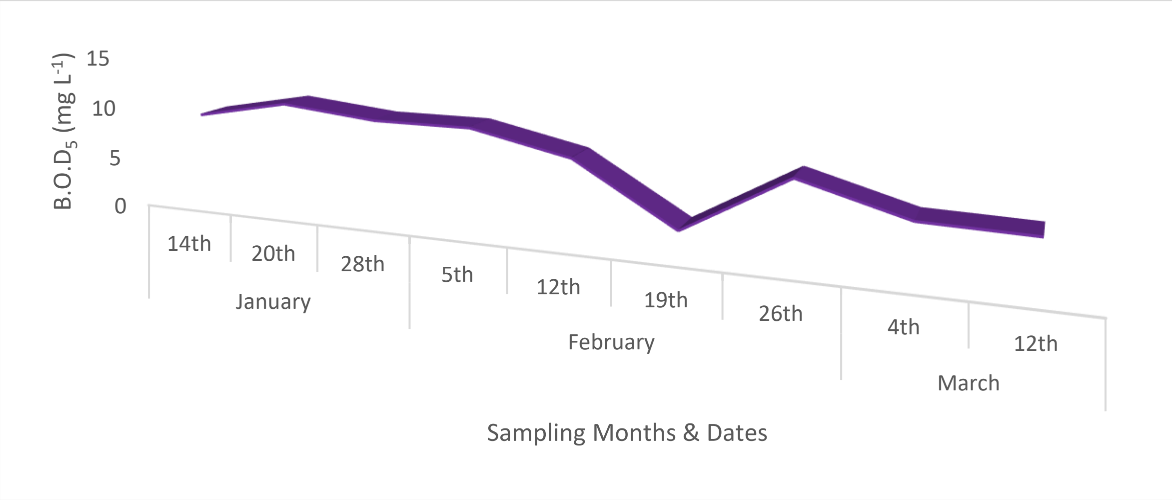

Figure 7: Variation of Biochemical Oxygen Demand at Bagbazar

The five days Biochemical Oxygen Demand is a clear indicator of the organic load present in an aquatic system. In January 2020, the mean B.O.D concentration was recorded about 9.88 mg L^{-1}. In this month the highest B.O.D concentration was recorded about 10.77 mg L^{-1} on the $20^{th}$and the lowest B.O.D concentration was recorded about 9 mg L^{-1} on the 14^{th}. In February 2020, the highest B.O.D concentration was recorded at about 9.91 mg L^{-1} on the 5^{th} and the lowest B.O.D concentration was recorded at about 2.26 mg L^{-1} on the 19^{th}. The mean B.O.D concentration during this February 2020, was recorded about 7 mg L^{-1}. And during March 2020, the concentration of the same parameter was recorded at about 5.08 mg L^{-1}. This human inundated portion of the holy Ganges River had exhibited higher levels of B.O.D concentration than the permissible limit of water to be used as outdoor bathing during our study period. The mean B.O.D concentration at Bagbazar point of Ganga River estuary during the pre-monsoon season of 2020, was about 7.53 mg L^{-1}.

Variation of Phosphate – Phosphorus

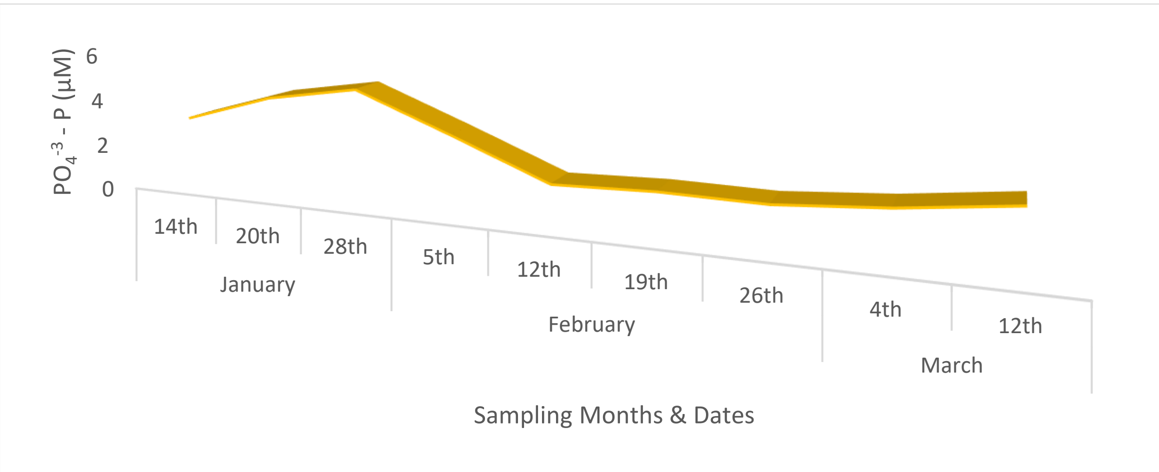

Figure 8: Variation of Phosphate – P at Bagbazar

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The highest concentration of phosphate – P was recorded on 28th January and of about 4.93µM.While the lowest concentration of phosphate– Pwas obtained on 12th February and of about 1.71µM. The mean concentration of phosphate – P recorded during pre-monsoon, 2020, was about 2.86µM.In January 2020, the highest concentration of phosphate – P was recordedabout 4.93µM, and the lowest concentration of phosphate – P was obtained about 3.09 µM. The mean concentration of phosphate – P for this month was about 4.10 µM.In February 2020, the highest concentration of phosphate – P was recorded about 3.35µM, and the lowest concentration of phosphate – P wasrecorded about 1. 71µM. The mean concentration of phosphate – P for this month was about 2.17µM.In March 2020, the mean concentration of phosphate – P was obtained about 2.37 µM

Variation of Nitrite – Nitrogen

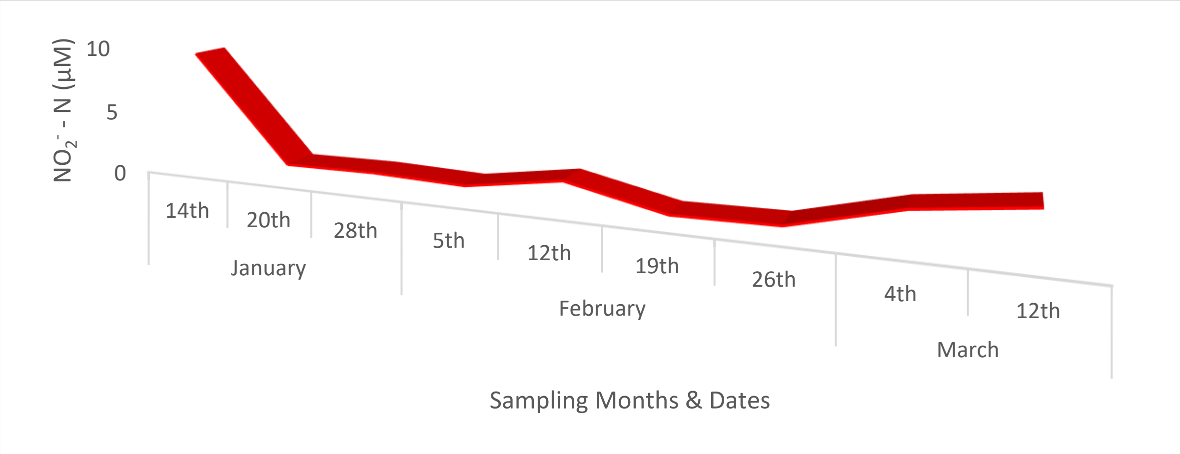

Figure 9: Variation of Nitrite – N at Bagbazar

The highest concentration of nitrite – N was obtained on 14th January and of about 9.34µM. While the lowest concentration of nitrite – N was recorded on 19th February and of about 0.45µM. The mean concentration of nitrite – N during pre-monsoon 2020 was about 2.41 µM.In January 2020, the highest concentration of nitrite – N hadobtained about 9.34µM and the lowest concentration of nitrite – N was recorded about 1.09µM. The mean concentration of nitrite – N for this month was about3.87 µM.In February 2020, the highest concentration of nitrite – N had recorded about 2.08µM and the lowest concentration of nitrite – N wasrecorded about 0.45µM. The mean concentration of nitrite – N for this month was estimated at 1.01µM.The mean concentration of nitrite – N for March 2020was about 3.03µM.

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Variation of Ammonia – Nitrogen

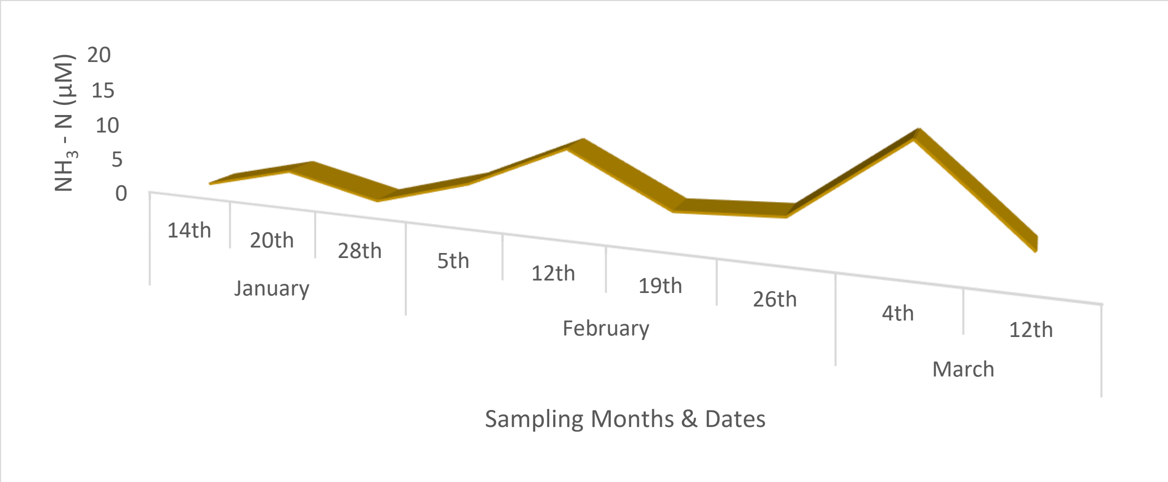

Figure 10: Variation of Ammonia – N at Bagbazar

The highest concentration of ammonia – N was recorded on 4th March and of about 15.26µM. While the lowest concentration of ammonia – N was obtained on 14th January and of about 0.75µM. The mean concentration of ammonia – N during pre-monsoon 2020 was estimated at 5.38µM.In January 2020, the highest concentration of ammonia – N hadobtained about 3.88µM and the lowest concentration of ammonia – N was recorded about 0.75µM. The mean concentration of ammonia – N for this month was about 1.88 µM.In February, the highest concentration of ammonia – N hadrecordedabout 10.64µM and the lowest concentration of ammonia – N was obtained about 3.88µM. The mean concentration of ammonia – N for this month was about 5.98 µM.In March 2020, the mean concentration of ammonia – N was recorded about 9.44µM.

Variation of Silicate – Silicon

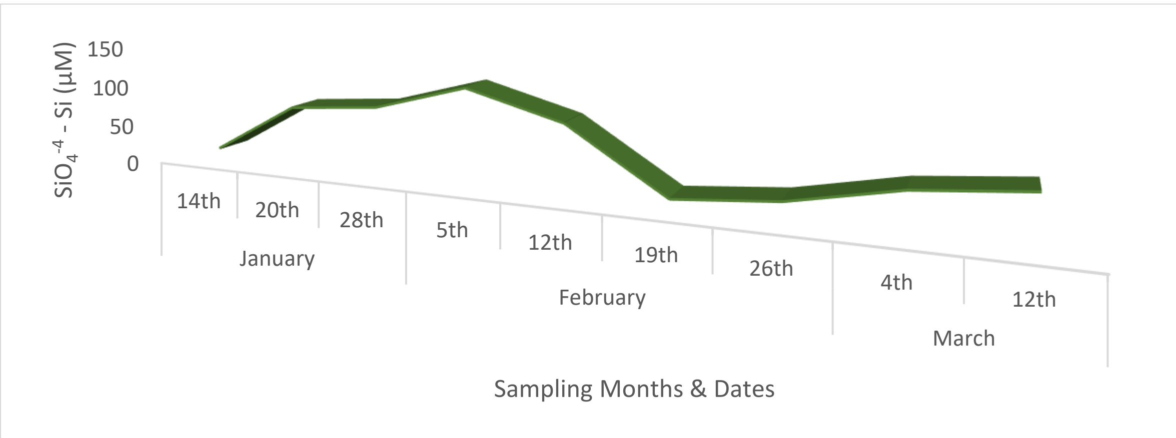

Figure 11: Variation of Silicate – Silicon at Bagbazar

The highest concentration of silicate – Si was recorded on 5th February and of about 120.33µM. While the lowest concentration of silicate – Si was recorded on 19th February and of about 13.26µM. The mean concentration of silicate – Si during pre-monsoon 2020 was estimated at60.14 µM.In January 2020, the highest concentration of

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silicate – Si had recorded about 88.54µM and the lowest concentration of silicate – Si was obtained about 16.31µM. The mean concentration of silicate – Si for this month was about 61.37 µM.In February 2020, the highest concentration of silicate – Si had recorded about 120.33µM and the lowest concentration of silicate – Si was obtained about 13.26µM. The mean concentration of silicate – Si for this month was calculated at about 61.56µM.In March, the mean concentration of silicate – Si was estimated at 55.45 µM.

Suspended Particulate Matter (SPM) in water are some organic and inorganic materials, which include minerals and ions that are dissolved in a particular quantity in water.SPM in water can come from different sources such as minerals in chemicals used for treating water, runoff from the road salts, and chemicals or fertilizers from the farms. We measured the SPM by filtration method by using cellulose nitrate filter papers of 0.45 µm pore size. We had measured the initial weight of the wet filter paper and the final weight of sediment containing wet filter paper, the difference gave the weight of the wet total dissolved solids in the samples collected.

In January 2020, the highest dissolved solid concentration was recorded about 0.32 g L^{-1} and the lowest concentration was recorded about 0.07 g L^{-1}. This resulted in a mean T.D.S concentration of 0.20 g L^{-1} during this month at this Bagbazar sampling point of the Ganga River estuary. In February 2020, the highest T.D.S concentration was recorded about 0.23 g L^{-1} and the lowest concentration of the same was about 0.09 g L^{-1}. This gave rise to a mean T.D.S concentration of about 0.15 g L^{-1}. During March 2020, the mean T.D.S concentration was comparatively higher than the previous two months and of about 0.39 g L^{-1}. This human inundated sampling point of the Ganga estuary had repeatedly exhibited moderate levels of T.D.S concentrations in our study period. The overall mean T.D.S concentration at this point was about 0.22 g L^{-1}.

Variation of Weight of Suspended Particulate Matter

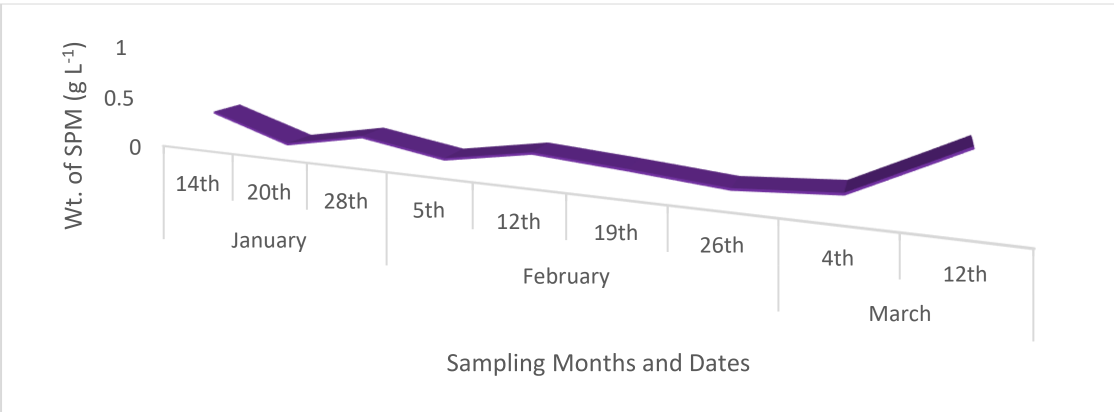

Figure 12: Variation of Weight of SPM at Bagbazar

The chlorophyll-a concentration is a clear indicator of the phytoplanktonic productivity of an aquatic system. As there are three distinct formulas available for estimating the concentration of chlorophyll a, the mean of these three procedures was taken as a representative of that particular field sampling. In January 2020, the mean chlorophyll-a concentration was recorded at about 4.88 mg m^{-3}. In this month the highest chlorophyll-a concentration was recorded about 6.48 mg m^{-3} on 14th and the lowest chlorophyll-a concentration was recorded about 3.17 mg m^{-3} on the 20th. In February 2020, the highest chlorophyll-a concentration was recorded at about 4.05 mg m^{-3} on the 19th and the lowest chlorophyll-a concentration was recorded at about 1.96 mg m^{-3} on the 12th

Variation of Chlorophyll-a Pigment

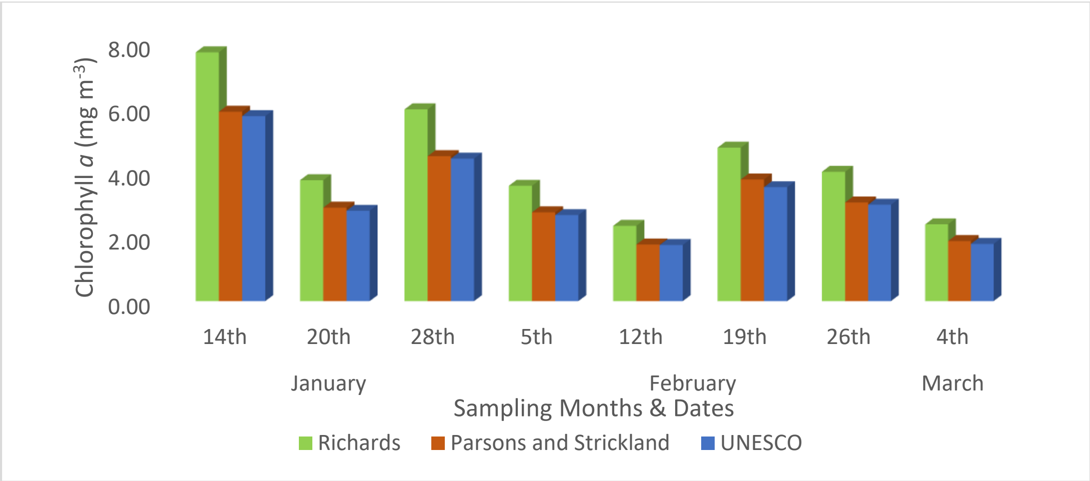

Figure 13: Variation of Chlorophyll-a at Bagbazar

The mean chlorophyll-a concentration during this February 2020, was recorded at about 3.10 mg m^{-3}. And during March 2020, the concentration of the same parameter was recorded at about 2.02 mg m^{-3}. This human inundated portion of the holy Ganges River had exhibited lower levels of chlorophyll-a concentration than other productive portions of this region. The mean chlorophyll-a concentration at Bagbazar point of Ganga River estuary during the pre-monsoon season of 2020, was about 3.63 mg m^{-3}.

Pictorial Representation of Zooplankton Specimens Isolated

The identification of planktons was done by qualitative analysis of unfiltered water samples. The sample of water collected through the net during the high and low tide. The collected sample of water in the small bottle attached to the zooplankton net was poured into the container with 5 ml of formalin for preservation. After few hours of settlement, the sediments were settled down at the bottom, and a sample from the top was collected through a pipette for observation under a microscope, 1 drop of the sample was placed under the clean slide and placed a coverslip. Under the microscope, the phytoplankton and the zooplankton were observed(Rao, 2001).

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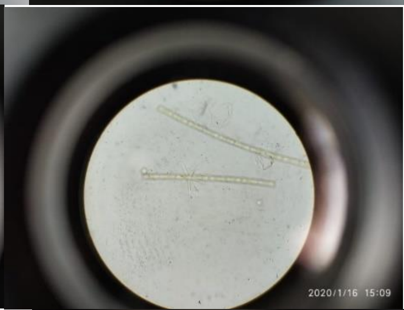

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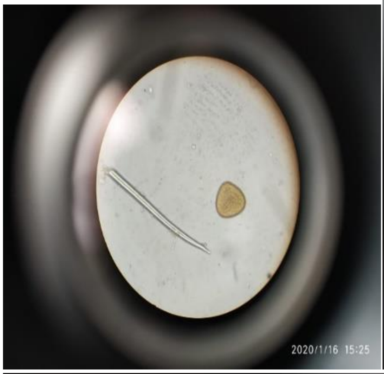

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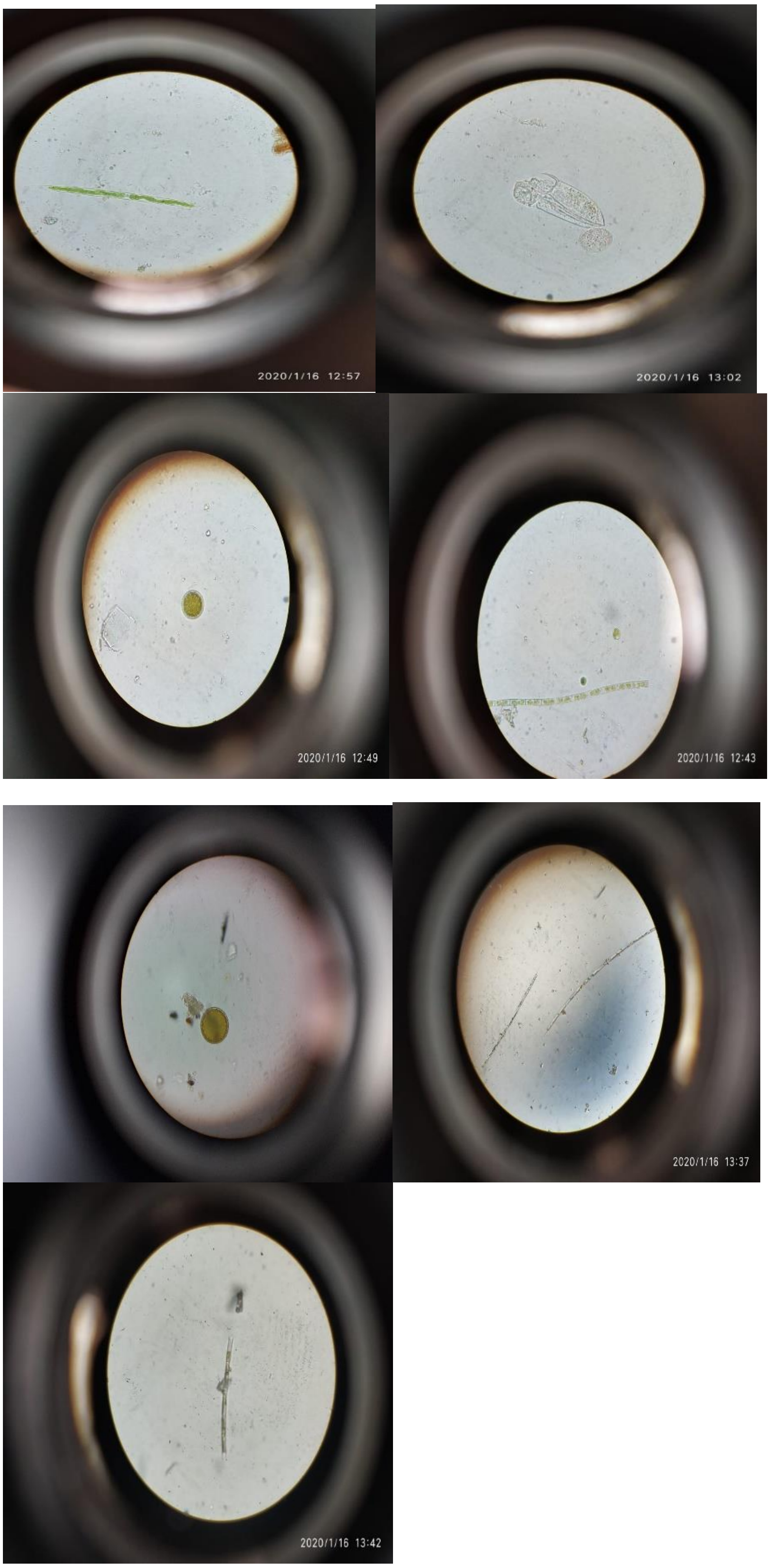

Figure 14. Above represents the types and picture of few zooplanktons found during our study.

Table 1. Comparison Between Drinking Water & Ganga Water During Lock Down

Parameters	Ganga Water Before Lock Down	Ganga Water During Lock Down	Drinking-Water
pH		7.9	6.5 – 8.5
Particulate Matter (mg L^{-1})	~ 1100	~ 400	
Cl^- (10^{-3})		0.18	0.25
D.O (mg L^{-1})	2.5 – 3.2	9.5	
Turbidity (NTU)		~ 1	Up to 5

As per Edition, 2011,the pH of drinking water should be around 6.5 - 8.5. But in our study, the pH of the Ganga estuary at this Bagbazar point was about 7.9. In the nationwide COVID-19 lockdown phase, the amount of suspended particulate matter present in Ganges water was around 400 ppm (J. Dutta et al., 2020), which was around 1100 before lockdown, in our study phase. The permissible amount of chloride (Cl^-) in drinking water is 0.25 ppt, whereas in Ganga it was around 0.18 ppt. During the nationwide lockdown phase that the dissolved oxygen content of the Ganga estuary had also increased remarkedly (Arora et al., 2020). The amount of dissolved oxygen concentration found in our study was around 2.5 - 3.2 mg L^{-1} which was increased up to 9.5 mg L^{-1}during the lockdown phase. According to Mukherjee et al., 1993,the Ganga water should have at least 5 mg L^{-1} dissolved oxygen content, which in this case haddecreased to 2 - 2.5 mg L^{-1}during our study.The turbidity of the Ganga water was also found to be increased in our study period. For water to be drinkable thepermissible turbidity value is up to 5 NTU, wherein in the lockdown phase it was decreased to 1 NTU (Garg et al., 2020). According to V. Dutta et al., 2020, during the nationwide lockdown phase,the industries and other commercial establishments were closed and had resulted in the lowering of water pollution by chemicals,sewage, and flowers. Though this had recovered the water quality of Ganga remarkedly but did not mean that the Ganga River water could be useful for drinking purposes. Again a variety of bacterial species were found in Ganga River water in its course of flow (Biswas et al., 2015). These are remarkedly harmful to human health and make the water of Ganga inconvenient for drinking purposes. But the nationwide lockdown had also removed that threat to greater extents (P. Mukherjee et al., 2020). For this reason, if the Ganga water becomes clean then its environmental health will recover automatically.

Conclusion

During 2008, the water quality parameters of the Ganga River around the Kanpur city during pre-monsoon, monsoon, and post-monsoon seasons were correlated using statistical tools. An appreciable significant positive correlation was found for total alkalinity with total hardness, Ca^{+2}, Mg^{+2}, Cl^-, TDS, organic carbon, and F^-. and Cl^- with Mg^{2+}, TDS, organic carbon, and total hardness. It was concluded that the Ganga water of Kanpur was though fit for drinking purposes yet it needed treatment to minimize the contamination especially turbidity and iron contents (Trivedi et al., 2009). The variation of Ganga River water quality around Haridwar was also monitored over eleven years (2000 to 2010) using the water quality indices namely, River Ganga index of Ved Prakash(Abbasi & Abbasi, 2012), weighted arithmetic index, and WQI by the National Sanitation Foundation (NSF) (Bhutiani et al., 2016). It was concludedthat the water quality of the River Ganga over the 11-yearstudy period ranges from poor to good, which also conformed to various studies on the WQI of the river.

The biomonitoring of Ganga River water at Bagbazar ghat during pre-monsoon, 2020 had also revealed some surprising facts. Lower levels of salinity had identified the sampling point as a freshwater-dominated one. Whereas the lower dissolved oxygen contents and higher B.O.D concentrations had exhibited the increasing pollution threat to aquatic organisms. The higher concentrations of ammonia – N and lower nitrite – N concentration had exhibited the presence of sewage in this part of the river. While the moderate phosphate – P concentration had indicated continuous bathing of local people while sampling. The dynamic effect of the river flow, continuous process of upwelling and downwelling, continuous inflow of sewage and industrial wastewater, and consecutiveinfluence of high tide and low tide twice a day had provided us with variable changes occurring inside the Ganga River system around Kolkata. The physio-chemical conditions of various water quality parameters at other human inundated points (ghats) of the holy Ganga around Kolkata city could be an important aspect of future research

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Combustion synthesis and optical properties of nanocrystalline $Pr_4Al_2O_9$

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Abstract

Lanthanide aluminate with $2Ln_2O_3.Al_2O_3$ ($Ln_4Al_2O_9$) composition is attaining considerable attention in recent times due to their possible application as high temperature protective coating and optical materials. Among these, $Pr_4Al_2O_9$ is a metastable compound that is difficult to obtain in phase pure form with high temperature synthesis methods. Here we report a cost effective single step solution combustion synthesis of $Pr_4Al_2O_9$ nanoceramic. The compound crystallized in monoclinic structure with $P2_1/c$ space group and crystallite size evaluated using Scherrer's equation revealed the nanocrystalline nature of the powder. TEM analysis is used to study the morphology and size distribution of the nanoparticles. Optical behaviour of the compound towards UV and visible light is studied using UV-Visible diffuse reflectance spectroscopy. The compound has an optical band gap of 4.0 eV with indirect-allowed transition. Ceramic pellets of density greater than 90% are obtained at 1260 ^oC by pressure less sintering and observed to undergo phase transitions to $PrAlO_3$ and Pr_6O_{11}.

Keywords: Lanthanide aluminates, solution combustion synthesis, nanoceramics,

Introduction

$Pr_4Al_2O_9$ is a metastable compound in the class of lanthanide aluminates ($2Ln_2O_3.Al_2O_3$or $Ln_4Al_2O_9$) and its existence is first predictedin the $Pr_2O_3.Al_2O_9$ phase-diagram by Wu and Pelton [1]. $PrAlO_3$ ($Ln_2O_3.Al_2O_3$) with perovskite structure and $Pr_3Al_5O_{12}$ ($3Ln_2O_3.5Al_2O_3$) with garnate structure are the other stable compositions in praseodymium aluminate. It is observed that high temperature synthesis of $Pr_4Al_2O_9$ends up in other stable composition and/or their combinations[2]. However, successful synthesis of $Pr_4Al_2O_9$in phase pure form is reported by J. Dohrup et al. through a co-precipitation method; but it requires a prolonged calcination at 900 ^oC.

$Ln_4Al_2O_9$ aluminates are recently attracting research interestdue to their high temperature and optical applications.Suitability of $Ln_4Al_2O_9$ in other applications are also under study. Theoretical and experimental investigationson $Yb_4Al_2O_9$ as prospective thermal and environmental coating is reported by H. Xiang et al. [4]. Y. Liet. al. reported the optical, electronic, and magnetic behaviour of $Tb_4Al_2O_9$[5]. Electrical conductivity of $Gd_4Al_2O_9$ and its effect on divalent cation substitution is presented by O. Hassan et al. [6]. D. Singh et al. suggested the application of Eu^{3+} doped $La_4Al_2O_9$ and $Gd_4Al_2O_9$ in plasma display panels, solid-state lighting panels and other flat panel devices[7]. However, no report about $Pr_4Al_2O_9$, its properties or application, is available.

Here we report a single stepprocess for the synthesis ofnanocrystalline $Pr_4Al_2O_9$through citric acid combustion method. Its optical properties are studied and band gap energy is determined along with mechanism of optical transition. An attempt is also made to preparehigh-densityceramic pellets though conventional sintering technique with combustion synthesized $Pr_4Al_2O_9$ powder.

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Materials and methods

Sample preparations

Combustion synthesis is based on the concepts of sol-gel and propellant chemistry. Stoichiometric amount of metal precursors, oxidizing agent and fuel are the basic components needed forcombustion synthesis.Here Pr_6O_{11} and $Al(NO_3)_3$. $9H_2O$ are used as metal precursors, nitric acid (~ 25 ml) as oxidizing agent, and citric as fuel. To obtain high purity product, energy release during combustion is maximized by keeping oxidant to fuel ratio as unity by calculating the amount of citric acid base on the total valency of oxidizing and reducing agents. Citric acid also acts as a complexing agent during combustion that ensures the homogeneous mixing of metal cations. To maximize the interaction of metal cations with fuel, pH of the solution is adjusted to 7 by adding NH_4OH which also acts as secondary fuel[8]. The final solution is kept on a hot plate maintained at 250 ^{o}C in ventilated fumehood. Heating resulted in dehydration followed by gel formation, which on persistent heating resulted in auto-ignited combustion giving fluffy combustion powder.

In order to make pellet sample, the combustion powder is mixed with 5 wt.% poly vinyl alcohol (PVA), dried and subsequently grinded in an agate motor for half an hour to obtain fine powder. The powder is molded using a die of 10 mm diameter by applying a pressure of 20 MPa using uniaxial hydraulic press. Obtained green pellet is sintered in a conversional heating furnace with resistive heating tungsten filament as heating source at different temperatures.

Characterizations

Phase purity and crystallinity of prepared samples are analyzed using X-ray diffraction (XRD) technique. XRD data are collected using D8 Bruker X-ray powder diffractometer (Germany) with Cu $K\alpha_1$ radiation source, operating at 40 kV, and 40mA, at a step size of 0.02°.Particulate properties ofcombustion powder are examined by transmission electron microscopy (TEM) using Joel/JEM 2100 (USA) electron microscope operating at 200 kV. For imaging, the sample is dispersed in acetone for half an hour and kept on a copper grid coated with carbon.

Optical characterization of the compound is carried out using UV-Visible Diffuse Reflectance Spectroscopy (UV-Vis DRS). PerkinElmer Lambda 35 UV/vis spectrometer (Singapore) having Labsphere RSA-PE-20 integrated sphere accessory (USA) is used for the purpose. Diffuse reflectance standard material, Spectralon, is used for calibration.

To image surface morphology of pellet sample, Field Emission Scanning Electron Microscope (FESEM), FEI Nova NanoSEM 450 (USA) is used. The sample is prepared by polishing in sandpaper with grit number P600, P800, P1000, P1500, and P2000 for10 min, 20 min, 40 min, 1 hour 20 min, and 2 hour 40 min respectively and etching at a temperature 100 ^{o}C less than sintering temperature for 30 min.

Resulta and Discussion

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FIg. 1 shows the X-ray diffraction pattern of the combustion synthesised $Pr_4Al_2O_9$ powder. The pattern is well matching with the reference data of $Pr_4Ga_2O_9$ (ICDD 01-089-1749) and the peaks are indexed using the same. $Ln_4Al_2O_9$ and $Ln_4Ga_2O_9$ are reported to be isostructural compounds that crystallise in monoclinic structure with $P2_1/c$ space group[9]. Crystalline nature of the prepared sample is revealed

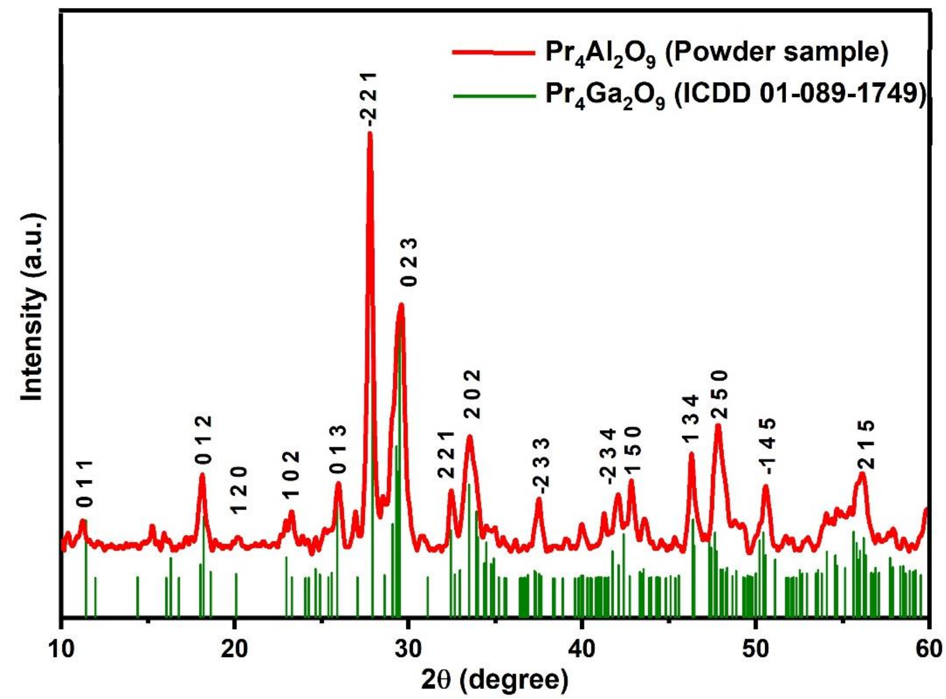

Fig1. Powder XRD pattern of combustion synthesized $Pr_4Al_2O_9$compared with referencepattern

fromthe well-defined XRD peaks and phase purity is confirmed by the absence of any additional peaks.Interplanar spacing d and unit cell parameters a, b, c, and β are determined using Bragg's law with first order approximation given by

$$\frac{1}{d^2} = \frac{h^2}{a^2 \sin^2 \beta} + \frac{k^2}{b^2} + \frac{l^2}{c^2 \sin^2 \beta} - \frac{2hl \cos \beta}{ac \sin^2 \beta}$$

where h, k, l are Miller indices corresponding to different plains. The obtained values are a = 7.80 Å, b = 10.96 Å, c = 11.47 Å, and β = 109.11°and are comparable with the parameters reported by J. Dohrup et al.[2] for $Pr_4Al_2O_9$.Broad peaks in XRD are related to factors such as microstrain, instrumental broadening and small crystallite size. The relation of peak broadening with crystallite size, D is given by Scherrer's equation,

$$D = \frac{k\lambda}{\beta \cos \theta}$$

where k is shape factor related to the shape of the particle (here taken as 0.89), λ is the wave length of XRD source (here 1.5406 Å), β is the FWHM of peak at 2θ diffraction angle. The average crystallite size calculated is about 42.18 nm, which reveals the nanocrystalline nature of the combustion synthesised $Pr_4Al_2O_9$.

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Morphological image processing of combustion powder by TEM analysis is shown in Fig. 2. The particles are found to be agglomerated with almost spherical morphology. Average particle size

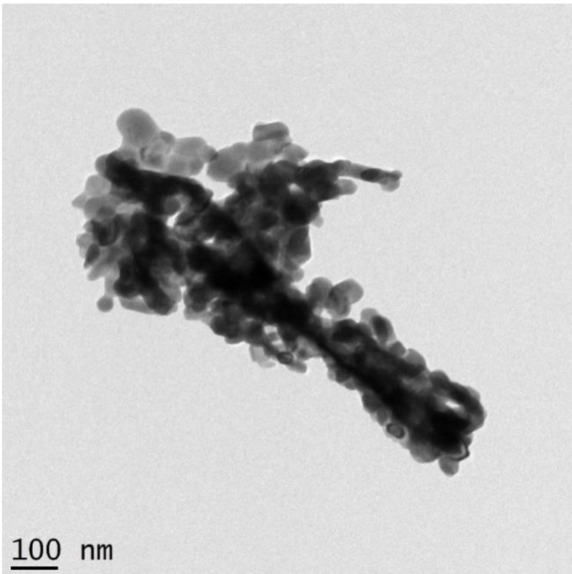

Fig 2. TEM image showing overall morphology

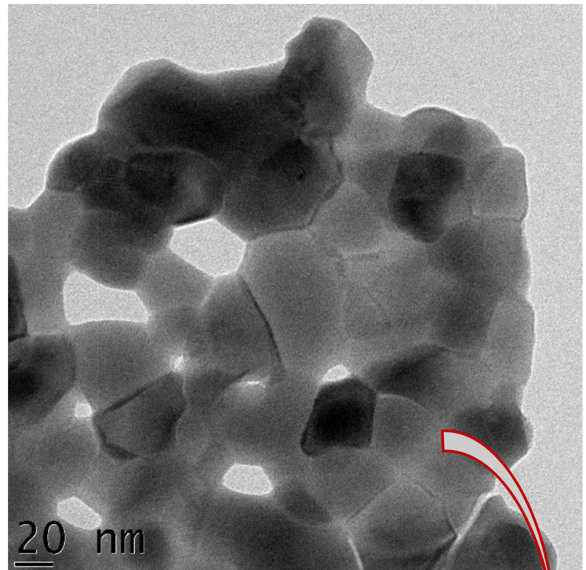

Fig 3. TEM image showing particle distribution of combustion powder

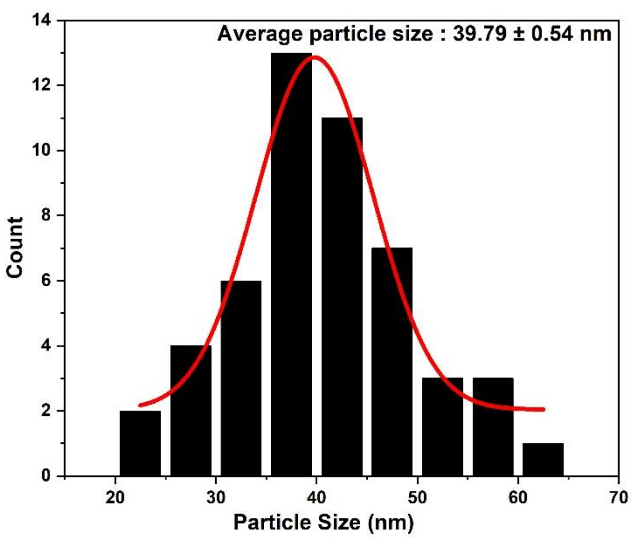

Fig 4. Graph showing particle size distribution

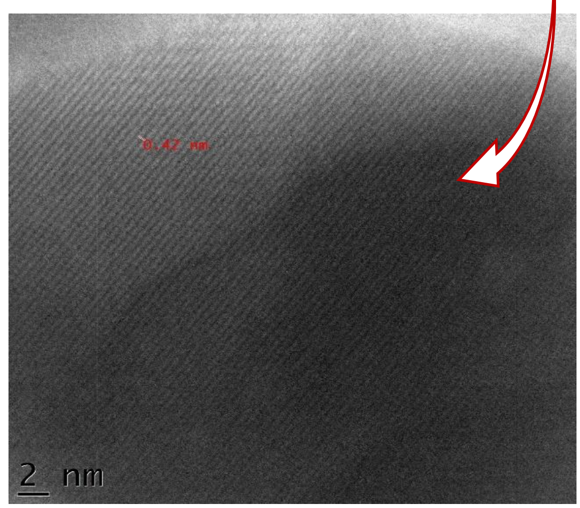

Fig5. HRTEM image showing different diffraction plains

evaluated from the image (Fig. 3) is shown in Fig.4. The particle size varied between 24.4 nm and 60.2 nm with an average particle size of 39.8 nm, which is comparable with the average crystallite size evaluated from XRD. High Resolution TEM image (HRTEM) shown in Fig. 5 visualisesa diffractionplain with interplanar spacing 0.42 nm, corresponding to the (1 2 0) plain present inthe $Pr_4Al_2O_9$ crystal system.

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UV-Visible Diffuse reflectance spectroscopy is apromising technique to examine optical properties of powder sample[10]. In this study, absorbance and reflectance characteristics of compound towards ultraviolet and visible radiationsare traced by exploiting enhanced scattering property of powder samples. Fig. 6and Fig. 7show the absorbance and reflectance characteristics of the $Pr_4Al_2O_9$. The compound shows an absorption peak in the UV region; and a reduced absorbancein the visible region.Absorption band edge (discontinuity in absorption curve) is observed at 320.6 nm corresponding to an energy value

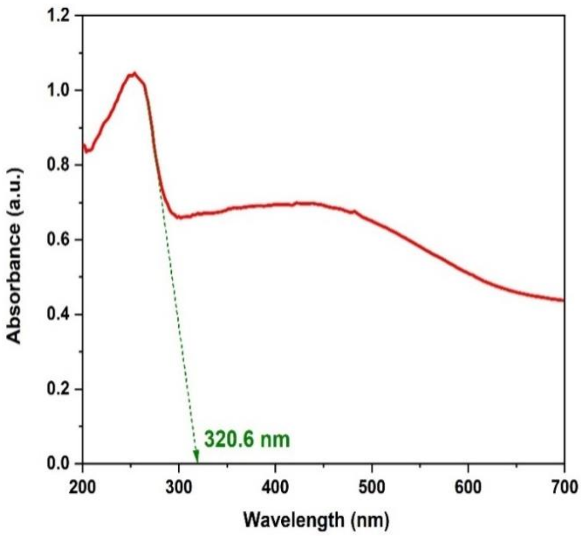

Fig 6. Absorbance spectrum of $Pr_4Al_2O_9$

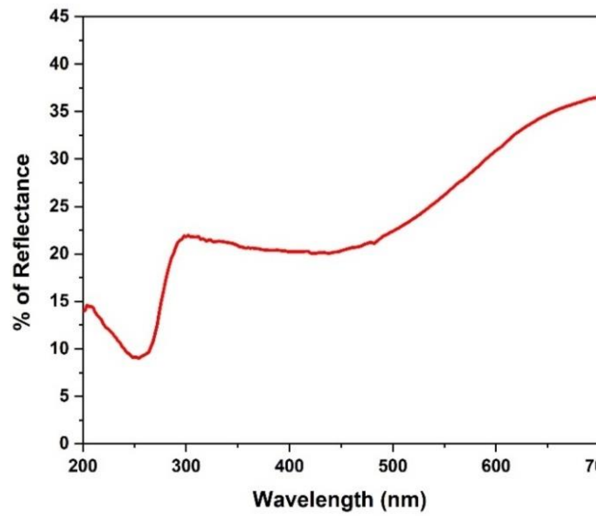

Fig 7. Reflectance spectra of $Pr_4Al_2O_9$

of 3.87 eV. Thishas a direct relation with optical band gap of the material[11]. To evaluate the optical band gap and mechanism of transition prevailing in band gap region, Tauc's relation [12]

$$F(R)h\upsilon = A(h\upsilon - E_g)^n$$

is used; where *h* is planks constant, ν is the frequency of radiation, *A* is a proportionality constant, E_g is

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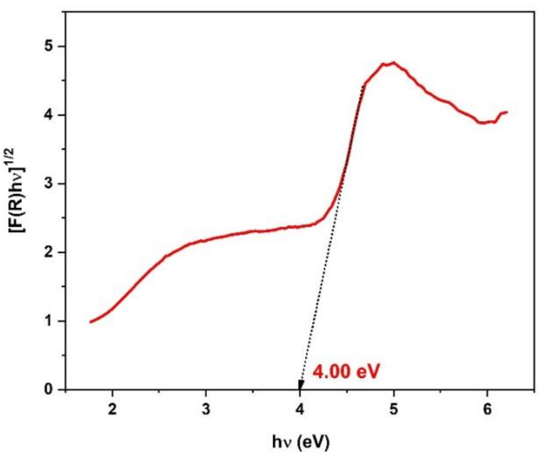

Fig 8.Tauc’s plot with n = 2

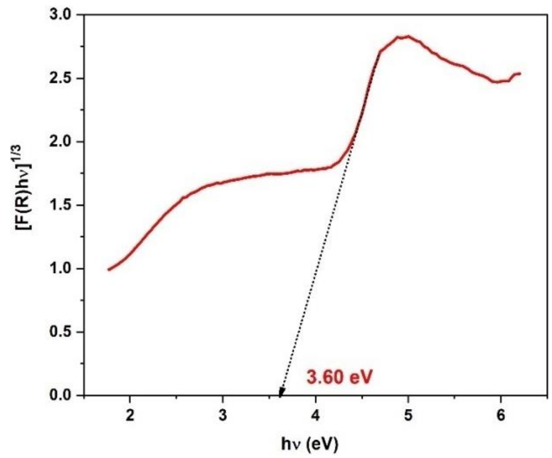

Fig 9.Tauc’s plot with n = 3

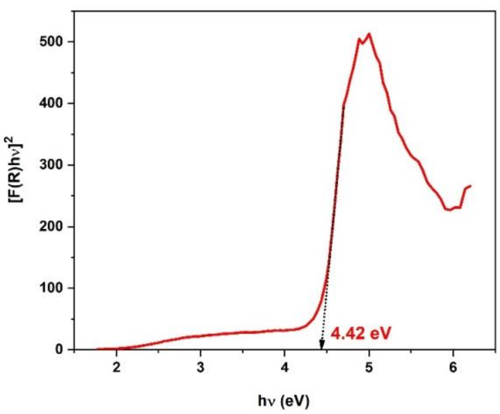

Fig 10.Tauc’s plot with n = 1/2

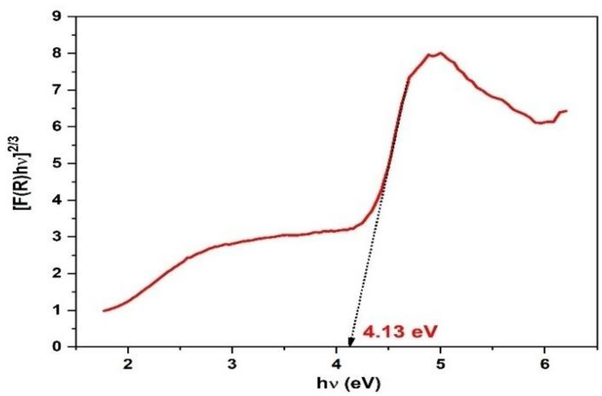

Fig 11.Tauc’s plot with n = 3/2

the band gap energy, n takes values 1/2, 3/2, 2, and 3 corresponding to direct allowed, direct forbidden,indirect allowed, and indirect forbidden electronic transitions, and F(R) is called Kubalka-Munkfunction that can be evaluated from reflectance data using the relation

$$F(R) = \frac{(1-R)^2}{2R}$$

A plot of$[F(R)h\nu]^{1/n}$ against $h\nu$is called Tauc’s plot andextrapolating linear part of the curve to x-axis gives the bang gap energyE_g. Fig. 8, Fig. 9, Fig. 10, and Fig. 11 show the Tauc’s plot for different $n$values.The obtained band gap values are tabulated and compared with the energy obtained from

Table 1. Band gap energy obtained from absorbance and Tauc’s plots

Compound	**Band Gap (eV)**				
	Absorbance plot	Tauc's Plot			
		n = 1/2	**n = 3/2**	**n = 2**	**n = 3**
$Pr_4Al_2O_9$	3.87	4.42	4.13	4.00	3.60

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absorbance band edge (Table 1).The band gap corresponding to n = 2 is the closest value to absorption edge. Therefore, the preferred electronic transition in the band gap region of $Pr_4Al_2O_9$ is the indirect allowed transition.

An attempt is also made to synthesis high density pellet sample from $Pr_4Al_2O_9$ combustion powder. For the synthesis, green pellets are heated in a conventional furnace at different temperatures. Ceramic pellets of density above 90% are obtained at a sintering temperature of 1260 °C, for a heating rate of 6°C/min and soaking time of 2 hours. The density is calculated by measuring weight and geometrical dimensions of the pellet. Fig. 12 shows the surface morphology of the densified pellet sample, imaged using Field Emission Scanning Electron Microscope (FESEM). Grain size is distributed in the range of 62 nm and

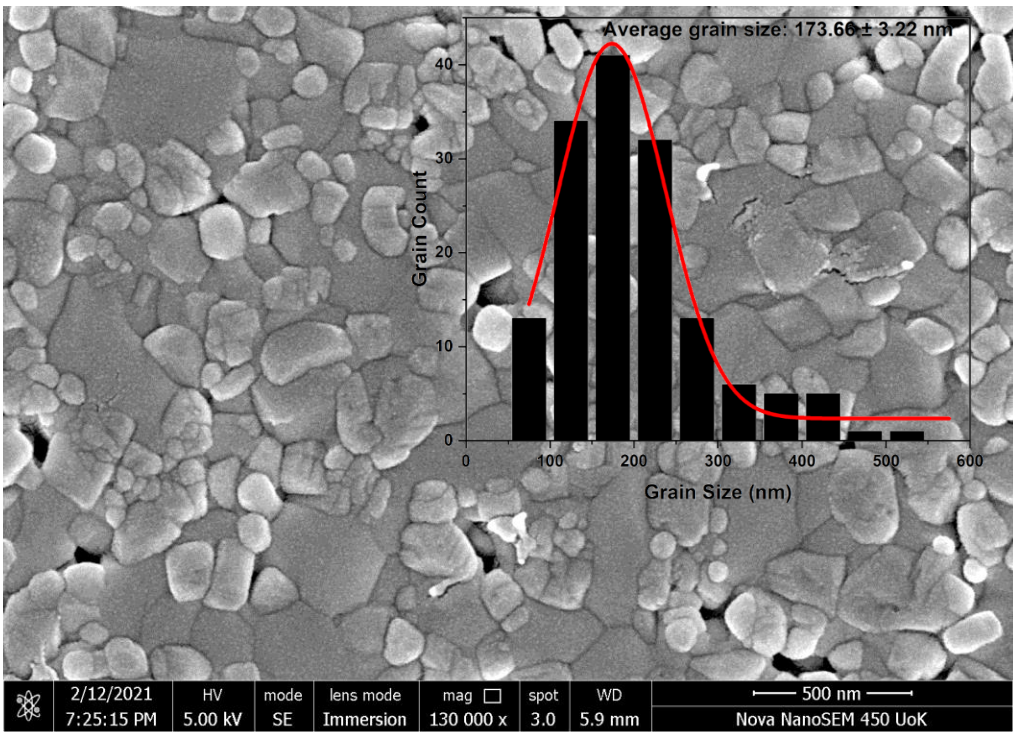

Fig 12. . SEM image of pellet sintered at 1260 ° C for 2 hours

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564 nm. This is due to the grain grown mechanism during sintering; i.e., during sintering adjacent grain boundaries merge to form large grains, reducing pores and vacant spaces in the sample, thereby increasing the density. The average grain size is about 173.7 nm indicating most of the grains are in a state of its growth. Phase purity of the pellet sample is examined using XRD analysis. The XRD pattern of pellet sample is shown in Fig. 13. Though the combustion synthesised powder was in phase pure form, a complete phase transition from $Pr_4Al_2O_9$ to $PrAl_3O_9$, and $Pr_6O_{11}$is observed in the pellet. This may be due the heat treatment above 1200 ^oC during sintering [2]. Therefore, to obtain phase pure $Pr_4Al_2O_9$ pellets, low temperature sintering is essential. This can be achieved by the addition of sintering aids or with non-conventional sintering techniques like microwave sintering, hybrid sintering, etc**.**

Conclusion

Nanocrystalline $Pr_4Al_2O_9$ is successfully synthesized using solution combustion method with citric acid as fuel. The particles are agglomerated and average particle size is about 39.79 nm. $Pr_4Al_2O_9$ is an indirect

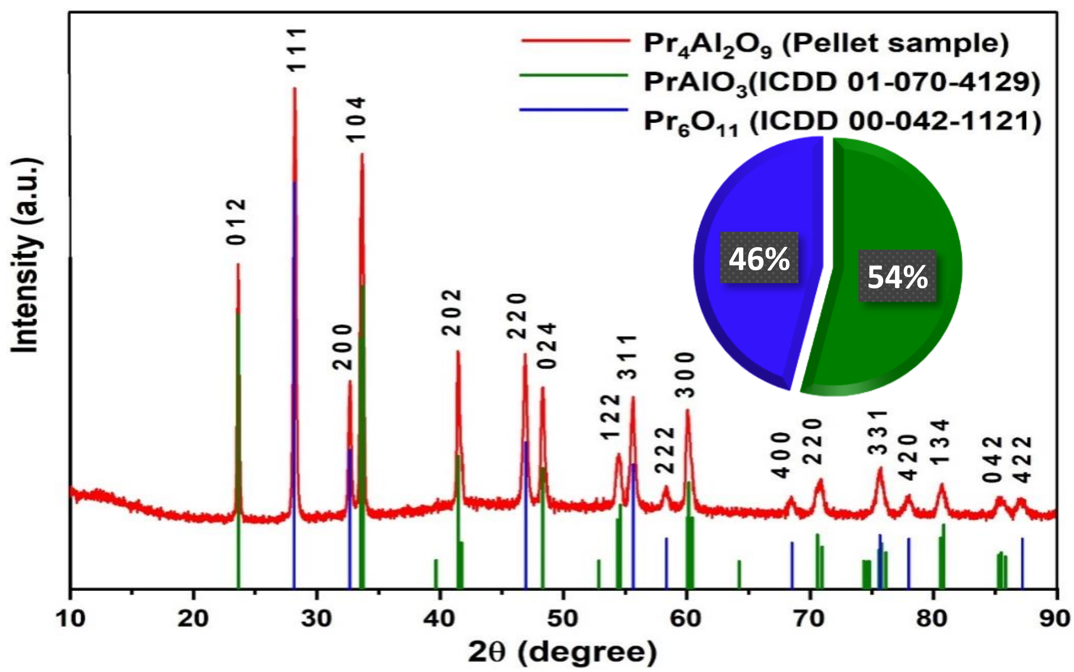

Fig 13**.** XRD pattern of pellet sintered at 1260 ^oC for 2 hours.

wide band gap material with band gap value of 4.0 eV. Conventional sintering of $Pr_4Al_2O_9$ pellet at 1260 ^oC resulted in phase transitions to $PrAlO_3$ and $Pr_6O_{11,}$ suggesting low temperature sintering methods or sintering aids for making phase pure $Pr_4Al_2O_9$ ceramic pellets with density greater than 90 %.

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