



APPLICATION OF GIS AND REMOTE SENSING IN SELECTED LIMNOLOGICAL ASPECTS OF POWAI LAKE, MUMBAI, INDIA

Thesis submitted in partial fulfilment
of the requirements for the degree of

Ph.D. (Aquaculture)

By

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APRIL, 2018

Usman, A., 2018. Application of GIS and remote sensing in selected limnological aspects of Powai lake, Mumbai, India. Ph.D. Thesis, ICAR-Central Institute of Fisheries Education (University Under sec. 3 of UGC Act 1956), Panch Marg, off Yari Road, Versova, Mumbai-400 061.

DEDICATION

Dedicated to my parents Alhaji Usman Bukar and Hajja Fatima Alhaji Bukar; and my beloved wife and daughter Fannah Mustapha Adam and Fatima Abubakar.



भा.कृ.अ.प. - केन्द्रीय मात्स्यिकी शिक्षा संस्थान ICAR-CENTRAL INSTITUTE OF FISHERIES EDUCATION

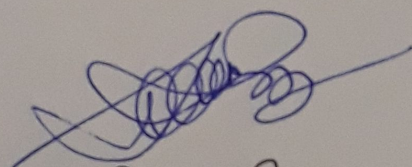
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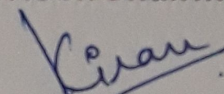
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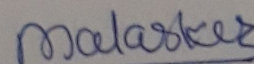
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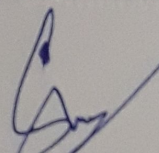

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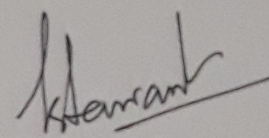
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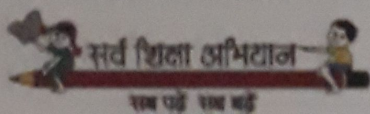

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DECLARATION

I hereby declare that the thesis entitled “**APPLICATION OF GIS AND REMOTE SENSING IN SELECTED LIMNOLOGICAL ASPECTS OF POWAI LAKE, MUMBAI, INDIA**” is an authentic record of the work done by me and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

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ACKNOWLEDGEMENTS

I am grateful to Almighty Allah for making it possible for me to complete this Doctor of philosophy programme. I doubt if I can properly express my gratitude to the people, who helped, encouraged, guided, motivated, accompanied and shaped this thesis to its fruition.

Firstly, I would like to greatly thank my supervisor Dr. Kiran Dube Rawat, Principal Scientist, Aquaculture Division, CIFE, Mumbai, who give me opportunity to complete my doctoral study, for her motherly valuable advises, encouragements, guidance, constructive suggestions, and commitment during studying and patience during writing up the thesis to make it a successful.

I also highly appreciate my advisory committee members Dr. Pramod Salaskar, Founder Secretary, Naushad Ali Sarovar Samvardhini, Powai lake, Dr. Chandra Prakash, Principal Scientist, Aquaculture Division, CIFE, Mumbai, Dr. S. P. Shukla, Principal Scientist, Aquatic Environment and Health Management Division, CIFE, Mumbai, Dr. P. B. Sawant, Senior Scientist, Aquaculture Division, CIFE, Mumbai and Mr. Ram Singh, Division of Fisheries Economics and Statistics for the value contributions to make the thesis more reliable.

Secondly, I would like to appreciate the Indian Council of Agricultural Research International Fellowship Program (ICAR-IF) and Government of India for award and funding supports to make my PhD becomes true.

I wholeheartedly thank Dr. G. Venkateshwarlu, Assistant Director General (EQR), Agricultural Education Division, Indian Council of Agricultural Research, New Delhi and Mr. Bhagwat Singh, Chief Technical Officer, Agricultural Education Division, Indian Council of Agricultural Research, New Delhi for their moral support and encouragement.

I sincerely thank Dr. Gopal Krishna, Director and Vice Chancellor, CIFE, Mumbai, for providing all the facilities during the period of my study.

I express my profound gratitude to Dr. N. K. Chadha, Principal Scientist, the Head, Division of Aquaculture, CIFE, Mumbai, for his moral support and understanding.

I offer my gratitude to faculty members and respected teachers, Dr. V. K. Tiwari, Dr. A. K. Verma, Dr. Babita Rani and many others whose names I may have missed, for their valuable advice and moral support to carry out research.

I take this opportunity to thank Mr. Narendra Aglave, Technical Officer, for his untiring support during the period of my laboratory experimentation, Mrs. Bharati Ghagre, Mrs. Manda, Mr. K. D. Raju, Mr. Nagish, Mr. Rajesh, Mr. Ashish and Mr. Namde of Aquaculture Division for their profound help during my research period.

I will be failing in my duty if I do not thank to Mr. Mantri, boat operator, the entire staff of Maharashtra State Anglers Association and Naushad Ali Sarovar Samvardhini for providing support and security during my field work.

I would like to say thanks to my unforgettable friends in GIS lab: Estifanus Lemma, Department of Civil Engineering, Remote Sensing Division, Indian Institute of technology, Bombay for many discussion and sharing study experiences, and Ajay Nakhawa in the Central Marine Fisheries Research Institute for the valuable input.

My sincere thanks go to my classmates, my association with them before and during my stay at CIFE, Mumbai, will definitely remain a memorable one. I pray that such rewarding association will continue to blossom even after we must have left University. I thank them all for their support and understanding.

My special appreciation goes to my parents, Alhaji Usman Bukar and Hajja Fatima Alhaji Bukar, my wife and daughter, Fannah Mustapha Adam and Fatima Abubakar, and the entire family members; I will like to thank them very much for their support financially, morally and socially and for being there when I needed them most. Their advice and encouragement were my constant source of inspiration, may Allah bless you all and guide you unto the right path.

Finally, I thank my employer, University of Maiduguri for allowing me to undertake this study. My appreciation goes to my Vice Chancellor Prof. Ibrahim A. Njodi. I wish to appreciate the effort of my Head of Department Dr. B. M. Modu, and the entire staff of the Department of Fisheries and Faculty of Agriculture University of Maiduguri, Nigeria.

Lastly, for those of you whose names I do not mentioned here, I offer my apologies but know that those have made this experience so special will never be forgotten.

Abubakar Usman

सारांश

पर्वई झील अक्षांश 19° 17' एन और रेखांश 72° 54' ई के बीच स्थित है और उसका कुल सतह क्षेत्रफल 2.10 किमीस्क्वायर और समुद्र तल से ऊँचाई 35 मीटर है। इस अध्ययन ने प्रदूषित क्षेत्रों की जांच की और पारंपरिक पद्धति के साथ समसामयिक भौगोलिक सूचना प्रणाली (जीआईएस) और दूरस्थ संवेदन उपकरण का उपयोग करके कुछ लक्षित जलीय प्रजातियों के लिए जलीय कृषि स्थलों पर संभावित प्रभाव का मूल्यांकन किया। पानी, प्लैंकटन, मछली और तलछट के नमूने मानसून और मानसून के बाद मासिक आधार पर एकत्र किए गए थे। नतीजे बताते हैं कि झील के भौतिक-रासायनिक वेरीएबल स्टेशनों और महीनों में उनके विशिष्ट गुणों के माध्यम से बदलते थे। विशेष प्लैंकटन प्रजातियों की उपस्थिति, अन्य लिमोनोलॉजिकल विशेषताओं को न समझने से दृढ़ता से पता चलता है कि जल निकाय एक यूट्रोफिक स्थिति में था। उसी झील में पिछले अध्ययन की तुलना में एनपीपी (गीले वजन) और तृतीयक उत्पादकता 100% से अधिक बढ़ी हुई पायी गयी। यह झील की उत्पादन प्रक्रिया चक्र में प्लैंकटन आबादी और द्विपक्षीय समुदायों की मजबूत भूमिका दर्शाता है। वर्तमान जांच में WQImin(69.07), WQIobj (63.80) की तुलना में उच्च स्कोर प्राप्त हुआ। हालांकि, WQImin रिफरेंस स्टेशन और दूसरों को काफी हद तक अलग करने में सक्षम नहीं था, हालांकि पूरे महीनों के लिए कुछ महत्वपूर्ण अंतर पाया गया। निर्धारित सभी मेंटल विश्व स्वास्थ्य संगठन सुरक्षा मानकों, खाद्य एवं औषधि प्रशासन और संयुक्त राज्य पर्यावरण संरक्षण एजेंसी मैक्सिमा के नीचे थीं, तलछट में सिलिकॉन को छोड़कर जो डब्ल्यूएचओ और अन्य नियामक निकायों द्वारा अनुशंसित सीमा से अधिक थी। इस अध्ययन के दौरान दर्ज प्लैंकटन प्रजातियां नौ (9) परिवारों की ग्यारह (11) प्रजातियां थीं। फाइटोप्लैंकटन में छह (6) परिवारों के साथ लगभग 95.09% का अधिक अनुपात शामिल है और जूप्लैंकटन केवल 4.91% के साथ तीन (3) परिवारों के साथ कम प्रभावशाली था। नतीजा में परिवार माइक्रोक्रिस्टेस द्वारा प्रभुत्व दिखाता है जिसमें 84.91% का महत्वपूर्ण अंश शामिल है, और इस परिवार में केवल एक ही प्रजाति (माइक्रोक्रिस्टिस एरुजिनोसा) थी। इसके बाद नेविकुला प्रजाति (8.16%) जो परिवार नेविकुलेसी से एकमात्र प्रजाति थी। प्रतिशत के क्रम में अन्य कम प्रमुख प्रजातियां मोइना ब्रेचिटा (1.66%) परिवार मोइनेडे, कराटेला चोक्लेरिस (1.30%) और ब्रेचियोनस कैलिसीफ्लोरस (0.95%) परिवार ब्राचियोनिडे (2.25%) से थीं। एकार्टियाकिलोसी (0.95%) परिवार एकार्टिडेइ में एकमात्र प्रजाति थी। कम प्रतिशत में यूडोरीना प्रजाति (0.59%) और वोल्बोक्स प्रजाति (0.37%) परिवार वोल्बोसेसे (0.96%) से संबंधित थी। अन्य में पेडियास्ट्रम प्रजाति (0.56%) परिवार हाईडरोडिक्टसी, नितसिया (0.41%) परिवार बेसिलरेसी, और इस्पेरोगायारा (0.09%) परिवार जाइनेमटसी में शामिल थी। इस अध्ययन से पता चलता है कि जीआईएस और रिमोट सेंसिंग में उपयोग की गई जानकारी ने स्कोरिंग मॉडल द्वारा बताए गए जलीय कृषि के लिए मानसून से पहले, मानसून में और मानसून के बाद प्रदूषित क्षेत्रों की पहचान की है। जीआईएस मॉडल पर्वई झील में पिंजरे और पेन कल्चर जैसे जलीय कृषि के लिए सबसे उपयुक्त क्षेत्रों की पहचान के लिए स्थानिक मॉडल स्थापित करने में उपयुक्त प्रभावी हुआ है, जैसे स्टेशन ए, बी और सी। सैटेलाइट छवि ने सरल अनुभवजन्य एल्गोरिदम के लिए एक महत्वपूर्ण भूमिका निभाई है, विशेष रूप से पर्वई झील के लिए जहां डेटा मल्टीस्पेक्ट्रल सेंसर तक सीमित है। भौतिक-रासायनिक मानक स्टेशनों और महीनों से प्रभावित पाये गये हैं, और उनके विशिष्ट गुणों के माध्यम से पता चलता है कि झील में कार्बनिक प्रदूषण है। डब्ल्यूक्यूआई ने पर्वई झील को नवंबर 2016 और अक्टूबर 2017 के बीच 'मार्जिनल' के रूप में वर्गीकृत किया, जहां पानी की गुणवत्ता को लगातार खराब किया जाता है; हालात अक्सर प्राकृतिक / सामान्य या वांछनीय स्तर से निचे पाये गये हैं, जो झील के लगातार खराब होने का कारक हैं। प्लैंकटन प्रजातियों की उपस्थिति, अन्य लिमोनोलॉजिकल विशेषताओं पर विचार किए बिना, यह दृढ़ता से सुझाव देती है कि जल निकाय यूट्रोफिक स्थिति को बनाए हुये है, जहां ईथरोफिकेशन लगातार जारी है जो मछली और अन्य जलीय जीवों के लिए घातक है।

Abstract

The Powai lake is located between latitude 19° 17' N and longitude 72° 54' E with total surface area of 2.10 km² and 35 meters above the mean sea level. This study investigated the effluent areas and evaluated the potential impact on aquaculture sites for some target aquatic species using geographical information system (GIS) and remote sensing tools concurrently with the conventional method. Water, plankton, fish and sediment samples were collected for pre-monsoon, monsoon and post-monsoon on monthly basis at five sampling stations. Results showed that physico-chemical variables of the lake were affected by stations and months. Net primary productivity (wet weight) and tertiary productivity were more than 100% increased compared to previous study in the same lake. This indicated the strong role of plankton population and benthic communities in the production process cycle of the lake. The WQI_{min} in the present investigation yielded high score (69.07) compared to the standard WQI_{obj} (63.80). However, WQI_{min} was not able to separate the reference station and the others to a large extent, though some significant difference for entire months was observed. All the metals determined were below the WHO, FAO and the United States Environment Protection Agency, safety standards. Plankton species recorded during this study were eleven (11) belonging to nine (9) families. Phytoplankton comprise the greater proportion of about 95.09% with six (6) families and zooplankton were less dominant with only 4.91% coupled with three (3) families. The result shows dominance of family *Microcystaceae* comprising a significant fraction (84.91%), and this was the only specie (*Microcystis aeruginosa*) in this family. This was followed by *Navicula* sp. (8.16%) which was the only specie from the family *Naviculaceae*. Other less prominent species in order of percentage were *Moina brachiata* (1.66%) of family *Moinidae*, *Keratella chochlearis* (1.30%) and *Brachionus calyciflorus* (0.95%) of family *Brachionidae* (2.25%). *Acartia clausi* (0.95%) was the only specie of family *Acartiidae*. The lower percentages were 0.59%, *Eudorina* sp. and 0.37% *Volvox* sp belonging to family *Volvocaceae* (0.96%). Others include *Pediastrum* sp. (0.56%) of family *Hydrodictyaceae*, *Nitzschia* sp. (0.41%) of family *Bacillariaceae*, and *Spirogyra* sp. (0.09%) from family *Zygnemataceae*. This study shows that information used in GIS and remote sensing have clearly identified the effluent areas for aquaculture as revealed by the scoring model as station D and E, may be due to discharge from a five star hotel and anthropogenic activities. The application of GIS model shows is suitable effectively in establishing spatial models for identifying the most suitable areas for aquaculture like cage and pen culture in Powai lake, such as station A, B and C. Satellite image played an important role for simple empirical algorithms, particularly for Powai lake where data is limited to multispectral sensors. Overall, the physico-chemical parameters shown to be affected by stations and months through their specific properties revealed that there is organic pollution in the lake. WQI of Powai lake classified it as 'Marginal' between November 2016 and October 2017, where the water quality is frequently threatened and shows continuous deterioration of the lake. The presence of plankton species, notwithstanding other limnological features strongly suggests that the water body is maintaining eutrophic status, where there is continuous eutrophication which is lethal to fish and other aquatic organisms. Finally, the conventional, GIS and remote sensing approach used in the present study revealed relatively similar results for water quality parameters, productivity and plankton concentration of Powai lake.

ABBREVIATIONS

Abbreviation	Description
A/temp	Ambient temperature
ALI	Advanced land image
ANOVA	Analysis of variance
APHA	American Public Health Association
ATSR	Along track scanning radiometer
BOD	Biochemical oxygen demand
BOMBER	Bio-optical model based tool for estimating water quality and bottom properties from remote sensing images
C	Carbon
C2R	Case 2 regional
CCME	Canadian council of ministers of environment
CDOM	Colour dissolved organic matter
Chl-a	Chlorophyll-a
cm	Centimetre
CNES	Centre national d'études spatiales
CO ₂	Carbon dioxide
COD	Chemical oxygen demand
Cond	Conductivity
CZCS	Coastal zone colour scanner
d	Day
<i>d</i>	Margalef's diversity index
D	Simpson's index
DO	Dissolved oxygen
DOC	Dissolved organic matter
DSS	Decision support system
e.g	Example
Ecol.	Ecology
Envisat (A)	Environmental satellite
EO-1	Earth observation 1
ERS	European remote sensing
ESA	European space agency
Et. Al.,	And others
etc	Etcetera, and other similar things
EuMAP	EU map
Fig.	Figure
g	Gram
GBP	Gross biomass productivity
GIS	Geographical information system
GPP	Gross primary productivity
H	Shannon-wiener diversity index
<i>In situ</i>	On the field
Int.	International
IOPs	Inherent optical properties
<i>J</i>	Species equitability or evenness index
k _d	Remote sensing reflectance
L or l	Litre
Landsat	Land satellite

LMI	Linear matrix inversion
MERIS	Medium Resolution Imaging Spectrometer
mg	Milligram
mg l ⁻¹	Milligram per litre
mm	Millimetre
MODIS	Moderate Resolution Imaging Spectroradiometer
MSAA	Maharashtra State Angling Association
MSL	Mean sea level
NASA	Natural aeronautics and space administration
NASS	Naushad Ali Sarovar Samvardhini
NH ⁺ -N	Ammonia nitrogen
NIR	Near-infrared
NO ₂ -N	Nitrite nitrogen
NO ₃ -N	Nitrate nitrogen
NPP	Net primary productivity
OLCI	Ocean and land colour instrument
pH	Hydrogen ion concentration
PO ₄ -P	Phosphate phosphorus
ppm	Parts per million
PRISMA	Preferred reporting items for systematic reviewers and meta-analysis
Publ.	Publication
RapidEye	Rapid eye
Res.	Research
S. E.	Standard error
Sci.	Science
SeaWiFS	Sea-viewing wide field-of-view sensor
SIOps	Mass-specific inherent optical properties
SNAP	Sentinel application platform
SPM	Suspended particulate matter
SPOT	Satellite pour l'observation de la Terre
TDS	Total dissolved solid
Trans	Transparency
TS	Total solid
TSS	Total suspended solid
W/temp	Water temperature
WFD	Water Framework Directives
WQI	Water quality index
WQI _{min}	Water quality minimum
WQI _{obj}	Water quality objective
Wt.	Weight
Zao	Zone from which 90% of water leaving radiance originates

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APPENDICES

APPENDIX I

Variation of sediment at five sampling stations in Powai lake during November, 2016

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	16	32	52	7.5	349	8.37	3.42	5.98
B	15	33	52	7.8	345	8.26	3.43	5.91
C	13	34	53	7.3	260	6.24	2.58	4.48
D	14	31	55	7.8	298	7.15	2.95	5.08
E	15	31	54	7.0	259	621	2.58	4.44

APPENDIX II

Variation of sediment at five sampling stations in Powai lake during December, 2016

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	14	33	53	7.5	336	8.06	3.34	5.75
B	13	33	54	7.6	333	7.99	3.32	5.71
C	14	32	54	7.1	296	7.10	2.95	5.07
D	14	31	55	7.6	293	7.03	2.91	5.00
E	14	33	53	7.4	277	6.64	2.76	4.74

APPENDIX III

Variation of sediment at five sampling stations in Powai lake during January, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	13	36	51	7.4	323	7.75	3.20	5.51
B	12	34	54	7.5	343	8.23	3.42	5.61
C	12	33	55	7.0	332	7.96	3.31	5.70
D	15	32	53	7.5	288	6.91	2.86	4.93
E	12	34	54	7.5	295	7.08	2.93	5.05

APPENDIX IV

Variation of sediment at five sampling stations in Powai lake during February, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	14	35	51	7.3	336	8.06	3.33	5.74
B	14	33	53	7.7	289	6.93	3.27	5.63
C	11	32	57	7.2	298	7.15	2.96	5.09
D	13	33	54	7.5	310	7.44	3.07	5.29
E	14	31	55	7.6	253	6.07	2.51	4.31

APPENDIX V

Variation of sediment at five sampling stations in Powai lake during March, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	15	35	50	7.2	348	8.35	3.46	5.96
B	14	31	55	7.9	314	7.53	3.12	5.37
C	14	30	56	7.5	263	6.31	2.60	4.48
D	16	32	52	7.5	331	7.94	3.28	5.65
E	12	33	55	7.7	211	5.06	2.08	3.70

APPENDIX VI

Variation of sediment at five sampling stations in Powai lake during April, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	14	34	52	7.2	353	8.47	3.51	5.05
B	14	32	54	7.4	335	8.04	3.32	5.72
C	14	33	53	7.6	258	6.19	2.56	4.41
D	15	31	53	7.7	261	6.26	2.59	4.46
E	14	31	55	7.7	257	6.16	2.55	4.39

APPENDIX VII

Variation of sediment at five sampling stations in Powai lake during May, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	14	33	53	7.2	355	8.46	3.53	6.08
B	14	31	55	7.3	352	8.25	3.44	5.93
C	15	32	53	7.6	328	6.57	2.74	4.72
D	15	30	55	7.6	260	6.43	2.68	4.62
E	15	30	55	7.8	258	6.36	2.65	4.56

APPENDIX VIII

Variation of sediment at five sampling stations in Powai lake during June, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	14	32	54	7.3	356	8.47	3.53	6.09
B	15	30	55	7.4	354	8.35	3.48	6.00
C	14	31	55	7.6	329	6.85	2.85	4.92
D	14	32	54	7.6	261	6.71	2.79	4.82
E	14	31	55	7.7	260	6.55	2.73	4.70

APPENDIX IX

Variation of sediment at five sampling stations in Powai lake during July, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	15	31	54	7.4	356	8.61	3.59	6.19
B	15	31	54	7.4	355	8.37	3.48	6.01
C	14	30	56	7.6	330	6.93	2.89	4.98
D	15	31	54	7.7	262	6.90	2.87	4.96
E	14	30	56	7.6	263	6.68	2.78	4.80

APPENDIX X

Variation of sediment at five sampling stations in Powai lake during August, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	15	32	53	7.4	350	8.34	3.48	6.00
B	15	30	55	7.5	348	8.36	3.48	6.01
C	14	31	55	7.4	328	6.71	2.97	4.82
D	14	32	53	7.7	261	6.85	2.85	4.92
E	14	31	55	7.5	264	6.57	2.73	4.72

APPENDIX XI

Variation of sediment at five sampling stations in Powai lake during September, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	15	32	53	7.5	349	8.35	3.48	6.00
B	15	32	53	7.6	331	8.10	3.37	5.82
C	13	32	55	7.5	327	6.55	2.72	4.70
D	14	31	54	7.7	262	6.96	2.90	5.00
E	14	30	56	7.4	263	6.56	2.73	4.71

APPENDIX XII

Variation of sediment at five sampling stations in Powai lake during October, 2017

Station	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ soil)	Available phosphorus (mg 100g ⁻¹ soil)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
A	15	31	54	7.6	347	8.36	3.48	6.00
B	16	32	52	7.8	322	8.30	3.46	5.96
C	12	33	55	7.4	330	6.74	2.81	4.48
D	14	31	55	7.8	254	7.10	2.96	5.10
E	14	31	55	7.2	305	6.82	2.84	4.90

1. INTRODUCTION

Geographical Information Systems (GIS) are geographical computational systems which enable data acquisition, storage, integration, analysis and display of model results (maps or tabular outputs) (Khongpuang, 2011; Carocci *et al.*, 2009; Wadsworth and Treweek, 1999; Burrough, 1986). GIS has been used in many fields related to urban, rural, environmental planning, natural resource management, health and emergency planning, infrastructure organization, marketing, estate, agriculture and forestry, and coastal management (Liao and Tim, 1994). A GIS is usually organized in 5 components including data, hardware, software, procedures and users.

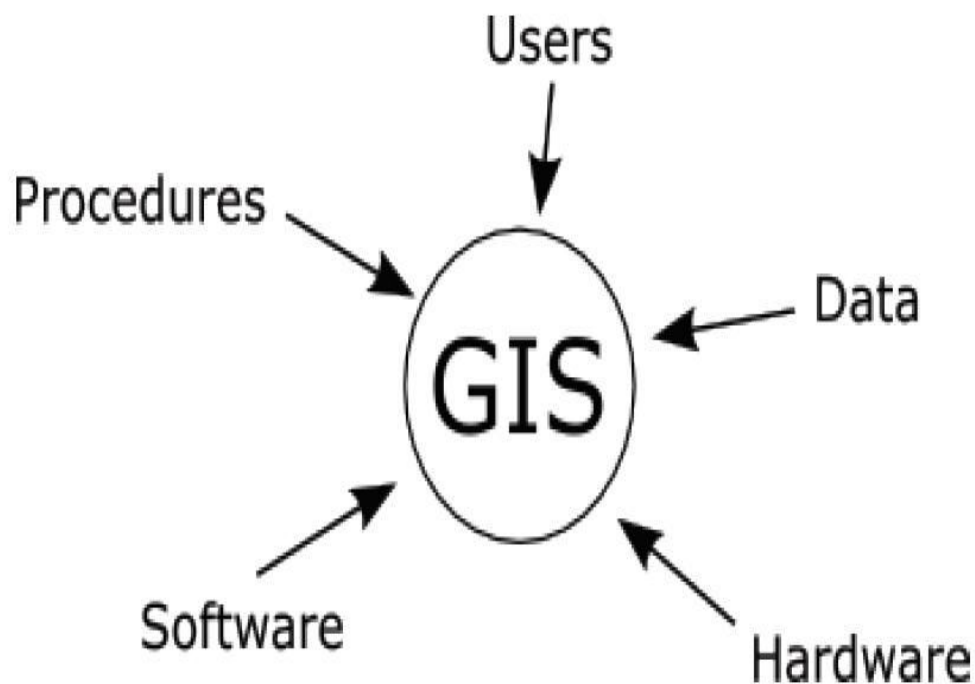


Fig. 1: Components of GIS

The hardware provides the core processing power and input, storage, manipulation and display of results. The GIS software complements this and enables control of all activities in GIS such as capture, storage, database management, manipulation, analysis, modelling and display (Eastman, 1999; Scholten and Lepper, 1994). Data is perhaps the most important component and can be divided into two

types; spatial and attribute data. The spatial data is represented by raster and vector data structures (Nath *et al.*, 2000) which describe the shape and geo-position of an object on the earth, whereas attribute data illustrates the qualities of those objects (Khongpuang, 2011; Eastman, 2006; Luc Anselin, 1992). The effectiveness of how GIS is applied depends upon the knowledge and understanding of the users who define the procedures and methodologies to be applied to any spatial problem (Wadsworth *et al.*, 1999; Liao and Tim, 1994; Burrough, 1986).

Remote sensing, in general, analyses radiation measured by a distant sensor to derive information of a certain object or, in case of lakes, or the water body. To obtain information on lake properties such as water transparency, biota and hydrology, the water leaving radiance in the visible and near-infrared wavelengths, that is the wavelength region where water reflects and scatters most of the incoming solar radiation (400–900 nm) is of major interest (Dekker *et al.*, 2002). Before the incident solar radiation interacts with the water body, it has to pass the atmosphere where it is modified by absorption and scattering. At the water surface, radiation is either reflected or it passes the water surface according to Snell's law and further propagates through the water body. In the water column, optically active constituents, for example suspended particulate matter (SPM), colour dissolved organic matter (CDOM) and chlorophyll-a, alter radiation by absorption and scattering characteristic for each constituent. The sum of these constituents represents the inherent optical properties of a water body (Odermatt *et al.*, 2012). The apparent optical properties such as attenuation (represented by the diffuse attenuation coefficient K_d) or remote sensing reflectance (that is the ratio of water leaving radiance and down welling irradiance) depend on the water itself and additionally on the radiation geometry (example parameters such as solar angles or the angle incoming radiation hits the water surface, that is incidence angle) (Dekker *et al.*, 2002).

In optically deep water, water surface, water body and water constituents are the main sources of radiation from within a lake. In optically shallow water, the water leaving radiance partly includes radiation which has been reflected at the bottom. The water leaving radiance then contains, additionally to water constituents, information on bottom substrate and bathymetry (Mouw *et al.*, 2015). By passing the water surface the water leaving radiation is again refracted and, through its way towards an airborne or satellite sensor, is affected once more by atmospheric

absorption and scattering. Altogether, about 90–98% of the signal obtained by a remote sensor originates from contributions of the water surface and the atmosphere (Gitelson and Kondratyev, 1991). The remaining 2–10% includes the signal that is important for water remote sensing, that is the water leaving radiance. For that reason, an accurate removal of effects due to the atmosphere and water surface is essential (Mouw *et al.*, 2015).

Powai lake (19° 8'N and 72° 54'E), situated 55 meters above mean sea level (msl) and located just outside Sanjay Gandhi National Park, was created by British India in 1891 at an initial cost of Rs 6.5 lakh, as an emergency measure to augment the drinking water supply for the city by recharging the underground water table in the area and by constructing two stone dams of 10 metres height across two hillocks. The water body spread was about 370 acres or 2.10 Sq kilometres (210 hectares) and the depth varied from about 3.05 m (off periphery) to 12.19 m at its deepest which has been reduced to 0.69 m to 6.90 m now due to constant siltation. Powai lake supplied about two million gallons of water to Bombay for domestic use.

Tansa lake became a more viable option, in 1892, Powai was turned over for angling and sport fisheries. Average rainfall at Powai is about 2540 mm per year which makes the lake to overflow for about 60 days each year. The volume of minimum water in summer is 440 lakh liters and in monsoon the maximum water is 528 lakh liters. Total silted area is 420859 sq. meters. It supports a very rich ecosystem with a wide variety of flora and fauna. Over the years, indiscriminate use of the lake as an outlet for storm sewers, water waste drains, domestic sewage, wash water and a wide variety of pollutants have rendered the lake's water highly polluted particularly during pre-monsoon and post-monsoon seasons. Siltation, shallowness, pollution, reclamation, weed infestation, quarrying and blasting, industrial activities within the catchment area, ecosystem degradation, encroachments along the lake, vehicular pollution, loss of aesthetic and recreational value are also some other reasons for degradation of its water quality.

Successful management of aquatic ecosystem such as Powai lake requires fundamental knowledge of dynamic interactions among its various components. Thus, monitoring the physico-chemical and biological parameters of the lake in time and duration is important for short term and long term sustainable exploitation of the

aquatic resource. It will provide an early warning signal for decisions to be made and action taken to minimize impending deleterious effects on the water quality, and any other purpose the water might intended to serve. In long-term, it may provide greater insight why problems can occur and help to discern trends; and assessment of potential remedies of its occurrence (Nwankwo, 1990).

The quality and quantity of animal and plant life on which fish subsist are immensely influenced by the inherent water characteristic of the habitat. Fish can serve as environmental indicator of the toxification and healthy state of water bodies, (APHA 1998). Lakes and reservoirs around the world are critical components in the ecological eco-system. They provide habitat, sanctuary and food for many species of fish and wildlife and are also sources of processed water to a myriad of industries and domestic. These water bodies offer important services to urban and rural populace as bigger lakes but unfortunately are more exposed to pollution than large lakes (Kistemann *et al.*, 2002).

Salaskar *et al.*, 2008 reported that Powai lake is highly degraded water body represents a typical urban wetland polluted directly by entering domestic sewage from the intensively urbanised catchments. The lake exhibits characteristics of a eutrophied ecosystem. Powai lake had a fairly rich fauna of fishes and was originally inhabited by 37 species (Kulkarni, 1947 and Amore, 1955). However, due to the high discharge of wastewaters into the lake in recent years along with the burgeoning silt load from surrounding area, there has been severe loss of diversity of the original fauna whose status requires to be studied for their renewable restoration. Since phytoplankton, zooplankton and benthos play a key role in tertiary production of fish, sustaining biodiversity of these organisms is essential for the health of this water body. These organisms often respond quickly to environmental changes, so the magnitude and dynamics of these organisms can also provide important indication of the quality of the system. Nature has the capacity to rejuvenate itself over the years if water quality is maintained properly.

Water, fish and sediments are commonly used as indicators for the state of pollution of aquatic ecosystem (Aremu *et al.*, 2007). Aquatic animals (including fish) bio-accumulate heavy metals in considerable amount in tissues over a long time and the dependence of the people on water body for domestic water supply and its

aquatic organisms (fish) as source of protein makes it imperative to assess the level of metals in aquatic ecosystem in view of the health implications that cut across the food strata of ecosystem for the benefits of the people and its environments (Opaluwa and Umar, 2010).

Objectives of the study:

1. To identify the effluent areas using GIS and remote sensing in Powai lake.
2. To relate GIS and remote sensing data with some physico-chemical and biological parameters of the lake.
3. To assess the concentration of heavy metals in sediment, water and fish in the lake.

2. REVIEW OF LITERATURE

2.0 Geographical Information System (GIS) and its application for fishery resources and environmental management

2.1 Working principles of GIS

The working principle of GIS is outlined in Fig. 2. Input data is the main material which usually comprises a variety of data types originating from maps, tables, databases, and data logger files, field instruments, satellite images or the Internet. The system employs these data and process under the control of users. The processing steps in GIS is usually known as capturing, encoding, editing, storing, retrieving, manipulating, analyzing and displaying. After processing step, the system provides the outputs which can be displayed in similar form of input data such as reports, maps, images, tables, GIS models, data and database.

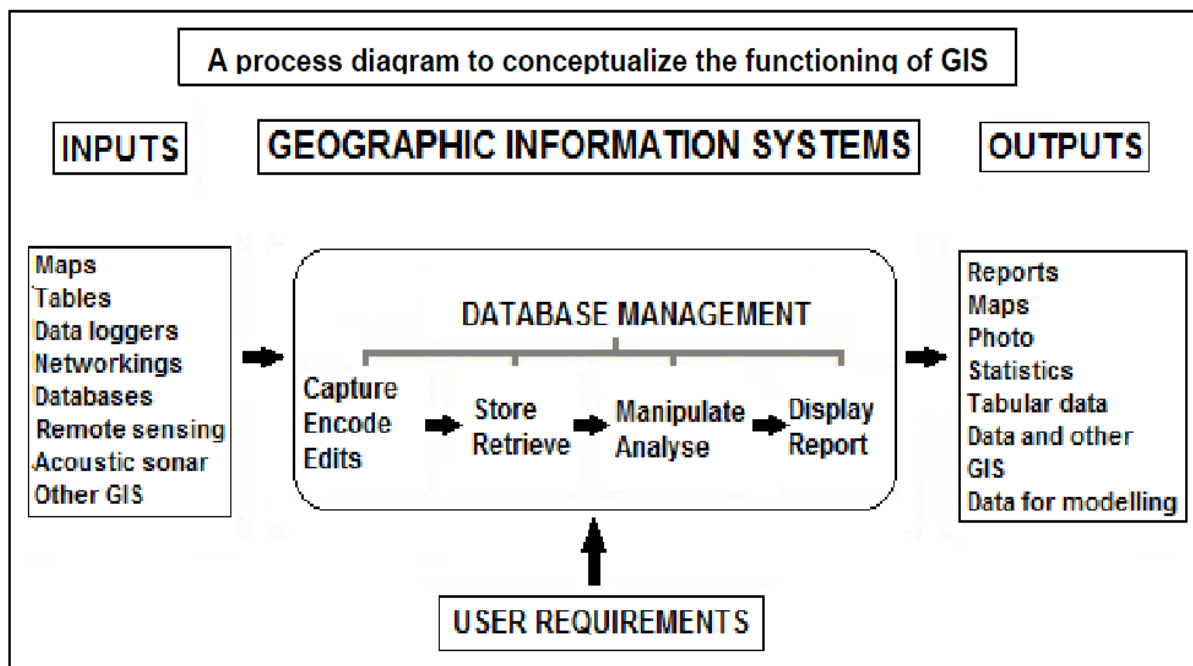


Fig. 2: A conceptual diagram of a GIS.

Source: Nath *et al.*, (2000)

2.2 The use of GIS for decision support in aquaculture development

GIS can be used as a powerful facility for assisting decision-makers in many fields. GIS can provide geo-referenced model outcomes and supporting information to entrepreneurs, developers, policy makers and regulators at a variety of spatial scales. When spatial models are developed by skilled end-users, they are of particular value in identifying optimized sites for aquaculture and zoning. There are many examples of studies applying GIS to aquaculture site selection (Nath *et al.*, 2000; Kapetsky, 1989; Kapetsky *et al.*, 1990), or to contribute to the sustainability of aquaculture (Longdill *et al.*, 2008), and for managing the development of fisheries and aquaculture (De Freitas and Tagliani, 2009; Meaden and Kapetsky, 1991).

GIS models have also been used to identify suitable sites for aquaculture and coastal planning (Latinopoulos *et al.*, 2012; Luis Alvarez and Perez Roa, 2012), for shrimp site selection in coastal areas (Rajitha *et al.*, 2007; Giap *et al.*, 2005; Salam *et al.*, 2003), and for cage aquaculture (Halide *et al.*, 2009; Ross *et al.*, 1993). GIS has also been used for planning and management of inland aquaculture (Kapetsky, 1997) modelling for carps and native species (Peredo-Alvarez, 2011; Salam *et al.*, 2005), giant prawn (Hossain and Das, 2010) and catfish culture (Kapetsky *et al.*, 1988). GIS has also been applied to define suitable sites for valuable shellfish culture in several regions including oyster (Cho *et al.*, 2012; Buitrago *et al.*, 2005), scallops (Radiarta and Saitoh, 2009; Radiarta *et al.*, 2008) or to evaluate the impacts from environmental issues to aquaculture species (Silva *et al.*, 2011) and predicting production for cockle and mussels (Khongpuang, 2011).

2.3 Mathematical models for environmental modeling integrated with the GIS

GIS can greatly enhance the management and visualization of environmental models as it provides a framework and tool for spatial mathematics, enabling encoding, spatial analysis, manipulation, and presentation of model outputs.

Most applicable utility of GIS in aquaculture and natural resources management is as a Decision Support System (DSS), which is a computerized system based on calculating various alternatives scenarios and their calibrated values which aim to support decision makers, planners, managers and stakeholders

in resolving problems. A DSS has the benefit of adaptability, flexibility, economical efficiency, and support for modeling by decision maker. DSS within GIS can be built for carrying a number of functions.

2.4 Background of Inland water remote sensing

Separation of the various contributors from the water leaving radiance allows obtaining quantitative information on water constituents (SPM, CDOM, phytoplankton or cyanobacteria) and, for shallow water, bathymetry and bottom substrate (benthic vegetation, sediment). To this end, various empirical and semi-analytical algorithms exist. Empirical approaches require *in situ* measurements of the variable of interest which serve as a basis for establishing an empirical relationship (linear or non-linear regression) with the water leaving radiance measured in one or multiple sensor bands. The regression equation is then applied to every image element (pixel) providing a spatial depiction of the respective indicator. The setup of empirical models is relatively easy; their application, however, is often limited to a specific study site and/or a particular sensor (Giardino *et al.*, 2010b). Advanced, semi-empirical algorithms such as artificial neural networks rely on large data sets of remote sensing and accompanying *in situ* data (Doerffer and Schiller, 2007; Ceyhun and Yalcin, 2010). Using large parts of this database the artificial neural network is trained to derive a statistical relationship between remote sensing data and one or multiple optical constituent(s). Similar to empirical approaches the remaining data serve as a validation basis to derive performance criteria. Matthews (2011) provides a systematic overview of empirical and semi-empirical algorithms.

Owing to the complex optical behaviour of lakes, various scientists developed semi-analytical algorithms based on radioactive transfer in the water column (Mobley, 1989; Giardino *et al.*, 2012; Gege, 2014). Applying the radioactive transfer equation enables to separate optically active constituents from the water leaving radiance. Semi-analytical models, however, require detailed spectral information of optically active water constituents in a lake. Nevertheless, due to their physical basis these models are broadly applicable (Giardino *et al.*, 2010b). Solving the radiative transfer equation mainly follows two approaches, that is via look-up tables and inversion methods. Look-up tables consist of a large spectral database containing water leaving radiance spectra with known constituent concentrations, inherent optical

properties, bathymetry and bottom properties. Image spectral signatures and data base records are compared until the closest match for all variables is found. Dekker *et al.*, (2011) provide a comparison of different look-up table approaches in coastal waters. Inversion approaches simulate spectral signatures according to the radiative transfer and a set of constant and variable model parameters characterising lake inherent and apparent optical properties. For each pixel, variable parameters are modified iteratively until deviations between simulated and image spectral signatures reach a minimum. The resulting maps provide spatial distributions of water constituents, bathymetry or bottom substrates.

Empirical classification approaches (supervised and unsupervised) are another possibility to derive bottom substrates such as submerged aquatic vegetation and sediment types. Unsupervised classifiers assign image pixels to classes according to statistical similarities in their spectral signatures. Afterwards the user defines thematic attributes for each class (Dogan *et al.*, 2009; Oppelt *et al.*, 2012). In a supervised classification the user defines training pixels with known class properties prior to classification. Using the spectral signatures of the training pixels the classifier then allocates each image pixel to one of the predefined classes (Hunter *et al.*, 2010a; Oppelt *et al.*, 2012).

The aforementioned methods mainly use the visible and to some extent near-infrared wavelengths; to obtain water surface temperatures we need sensors measuring radiation in the thermal infrared (7–13 μm). The earth emits radiation depending on the temperature (Stefan–Boltzmann law) and the emissivity of a surface (Kuenzer and Dech, 2013). To retrieve surface temperatures several approaches exist including semi-empirical and physically based algorithms (Hulley *et al.*, 2011). Several authors developed semi-empirical, mono-window (that is one thermal band located in one atmospheric window) algorithms which are mainly applicable for Landsat imagery (1972–2011). They use approximations of the radiative transfer equation relying on estimates of atmospheric water vapour to specify the atmospheric transmissivity (Jimenez-Munoz *et al.*, 2009). Semi-empirical, split-window (thermal bands in two different atmospheric windows) algorithms have been developed for sensors with more than one thermal band. The differences in two neighbouring bands enable an enhanced estimate of the atmospheric transmissivity which increases retrieval accuracy (Rozenstein *et al.*, 2014).

Assessing accuracies of obtained remote sensing indicators requires *in situ* measurements of related parameters contemporary to image acquisition since lake conditions may change rapidly. Retrieved water constituent concentrations often are compared with water samples from the upper water column which are analysed in laboratory (Odermatt *et al.*, 2012). The validation of bottom substrates is challenging since it requires mappings from boat or by divers (Hunter *et al.*, 2010a). The same applies for shallow water bathymetry which may be validated using, rarely existing, echo sounding data (Gege, 2014a). *In situ* measurements of water temperature near the surface enable a comparison with remote sensing based temperature measurements. Visual observations are the basis to validate remote sensing indicators of ice phenology, (Latifovic and Pouliot, 2007). In most cases, coefficients such as the coefficient of determination or the root mean square error serve as accuracy measures, while only a few approaches include simulated data sets (Odermatt *et al.*, 2012).

Satellite sensors suitable for retrieving remote sensing indicators are mainly multispectral (Landsat, RapidEye), i.e they record reflected or emitted radiation in a few spectral bands that cover a relatively broad range of the electromagnetic spectrum. Hyperspectral sensors measure “contiguously across the electro-magnetic spectrum in numerous narrow bands” (Oppelt *et al.*, 2015). Hyperspectral systems are available for airborne platforms; planned satellites are example EnMAP, HySpIRI and PRISMA. The high spectral resolution of these sensors allows analysis of narrow spectral features such as Chl-a absorption at ~670 nm.

Water transparency is an essential lake property influencing light availability (Peeters *et al.*, 2009). Light availability is important for biological, chemical and physical processes such as primary production and formation of macrophytes and is therefore a physical sentinel of climate change and water quality (Peeters *et al.*, 2009; Williamson *et al.*, 2009). Inherent optical properties influence water transparency and therefore light availability due to absorption and scattering (Kirk, 2011). Secchi disc depth is the depth where a white Secchi disc is no longer visible for human eye (Kirk, 2011), euphotic depth is the depth where the radiation available for photosynthesis is 1% of its value at surface (Kirk, 2011), Z_{90} is the zone from which 90% of water-leaving radiance originates (Doerffer and Schiller, 2007)) and the diffuse attenuation coefficient of down welling irradiance K_d represent widely used

remote sensing indicators for transparency. Using semi-analytical or advanced empirical approaches indicators are often derived together.

Remote sensing has long been recognised as having the potential to complement conventional approaches to lake monitoring (Bukata, 2013). Indeed, research on the remote sensing of inland waters has been undertaken for almost as many years as that in ocean colour science, but whereas satellite observations are used operationally to measure ocean colour, their use for monitoring inland waters has made less progress. Inland water remote sensing has faced, and continues to face, many challenges not only in terms of the science underpinning the retrieval of physical and biogeochemical properties over what are typically high optically complex waters, but it has also suffered from the lack of funding, infrastructure and the mechanisms required to coordinate research efforts across what has been historically a rather fragmented community.

Several recent works have reviewed water constituent retrieval algorithms applied to inland waters using various sensors (Kutser, 2009; Matthews, 2011; Odermatt *et al.*, 2012), an ongoing and major challenge in such optically-complex systems.

In spite of their limited capabilities, satellite sensors have been used extensively in lake remote sensing for several years. Several researchers were done and continue to exploit the relatively high spatial resolution of sensors intended primarily for land applications. Verdin (1985), used Landsat to retrieve chl-a and Secchi depth in US lakes. Dekker and Peters (1993) assessed Landsat TM capabilities in retrieving various Dutch lake water characteristics (seston dry weight, sum of chl-a and phaeopigments and Secchi depth), although accuracy of the results was found to be limited. Dekker *et al.*, (2001, 2002) obtained reliable total suspended matter (TSM; dry seston weight) retrievals from Landsat and from the Satellite Pour l'Observation de la Terre (SPOT) sensor of the French Centre National d'études Spatiales (CNES). Olmanson *et al.*, (2008) used Landsat archive for mapping lake water clarity of over 10,000 Minnesota lakes. Tebbs *et al.*, (2013) mapped high biomass cyanobacteria blooms in lake Bogoria using Landsat-derived chl-a. Moreover, the long-term data archive from the Landsat satellite series provide an opportunity to study long-term changes taking place in lakes. Kutser (2012), for example, evaluated suitability of Landsat archive for mapping CDOM changes in Swedish lakes over the last 30 years. The later launch of sensors with improved

radiometric and/or spectral capabilities led to improvements in our ability to retrieve information on in-water constituents. For example, the NASA Advanced Land Imager (ALI) onboard the Earth Observing-1 Mission (EO-1) was used to estimate CDOM absorption in boreal lakes (Kutser *et al.*, 2005), while the first civilian hyperspectral sensor in space, Hyperion, also onboard EO-1, was used to retrieve chl-a and tripton (Giardino *et al.*, 2007).

Similarly, many remote sensing investigations of lakes made use of sensors intended for ocean colour applications. Early examples include Bukata *et al.*, (1981) who used NASA Coastal Zone Color Scanner (CZCS) imagery and model simulations to show that green-to-red instead of blue-to-green ratios were necessary for the retrieval of chl-a in optically complex waters, particularly those with high phytoplankton biomass. Mortimer (1988) used CZCS thermal data to identify bar fronts and upwelling zones. Binding *et al.*, (2007) merged CZCS and NASA Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) data to obtain long time series of water clarity (Secchi depth) for the lower Laurentian Great Lakes. SeaWiFS data have also been used for chl-a retrieval for lakes (Heim *et al.*, 2005; Witter *et al.*, 2009), as well as chl-a, dissolved organic carbon (DOC) and suspended matter retrieval (Korosov *et al.*, 2007; Pozdnyakov *et al.*, 2005) for further use in spatiotemporal analysis (Pozdnyakov *et al.*, 2013; Shuchman *et al.*, 2006), in very large lakes (Baikal, Lagoda). NASA Moderate Resolution Imaging Spectroradiometer (MODIS) data have been used over a number of lakes, particularly for the retrieval of chl-a (Bergamino *et al.*, 2010; Chavula *et al.*, 2009; de Moraes Novo *et al.*, 2006; Wang and Shi, 2008; Wang *et al.*, 2011), TSM, turbidity and Secchi depth (Tarrant *et al.*, 2010; Zhang *et al.*, 2010; Knight and Voth, 2012; Chang *et al.*, 2012; and Kaba *et al.*, 2014;) and surface water temperature (Bresciani *et al.*, 2011a; Bresciani *et al.*, 2011b; Crosman and Horel, 2009; Reinart and Reinhold, 2008). These examples are by no means exhaustive, but do demonstrate the insight that has been possible to be gained through the use of ocean colour data despite their relatively coarse spatial resolutions and their limited spectral coverage.

The Medium Resolution Imaging Spectrometer (MERIS) aboard the European Space Agency (ESA) Envisat platform was also primarily intended for oceanic observation, but presented improved spatial resolution compared with previous ocean colour sensors, as well as additional spectral bands at key wavelengths. Both of these new capabilities were useful in the retrieval of concentrations of optically

active substances in lakes (Koponen *et al.*, 2008; Olmanson *et al.*, 2011), in identifying and in quantitative remote sensing of cyanobacterial blooms (Matthews *et al.*, 2012) as well as in developing bloom monitoring systems (Wynne *et al.*, 2013). Several studies presented (Lunetta *et al.*, 2015; Kallio *et al.*, 2015; Kutser *et al.*, 2015; Palmer *et al.*, 2015; Sterckx *et al.*, 2015) make use of MERIS imagery in lake research. Although no longer being acquired, MERIS data remain highly valuable in terms of its still under-exploited archive dataset and planned continuity through future missions (Sentinel-3 Ocean and Land Colour Instrument (OLCI) of ESA).

It should also be noted that many advance research in inland water remote sensing have been achieved through the use of hyperspectral data from airborne or hand held sensors. Vertucci and Likens (1989) proposed a lake classification scheme based on water reflectance spectra and also developed an algorithm for DOC retrieval. The peak near 700 nm, now recognised as vital to the relative success of MERIS chl-a retrievals compared with the preceding land and ocean colour sensors described above, was utilised in hyperspectral chl-a retrieval more than three decades ago (Vasilkov and Kopelevich, 1982; Gitelson, 1992). The first attempt to retrieve accessory pigments (and consequently dominant phytoplankton groups) from airborne data were also undertaken in a lake environment (Richardson *et al.*, 1994). More recent studies have used hyperspectral data to focus on phycocyanin retrieval for the identification and quantification of cyanobacteria blooms in lakes (Hunter *et al.*, 2010; Hunter *et al.*, 2008; Li *et al.*, 2012; Mishra *et al.*, 2009; Randolph *et al.*, 2008; Simis *et al.*, 2005; and Yang and Pan, 2006).

Band ratio type algorithms for estimating various lake water characteristics ranging from chl-a, CDOM, and suspended matter to water turbidity/transparency have been developed by many authors (Bukata *et al.*, 1981; Dekker *et al.*, 1991; Gitelson *et al.*, 1993; Kallio *et al.*, 2001; Koponen *et al.*, 2007; Kutser *et al.*, 1995; Kutser *et al.*, 2005 to name only a few; reviews by Matthews, 2011; Odermatt *et al.*, 2012) using multispectral satellite as well as hyperspectral images. Remote sensing had been used in mapping shallow water benthic habitat in inland waters (Giardino *et al.*, 2007; Hunter *et al.*, 2010; Shuchman *et al.*, 2013), and to estimate lake primary production using satellite observations (Bergamino *et al.*, 2010; Bergamino *et al.*, 2013; Shuchman *et al.*, 2013). However, while primary production models have been used relatively widely in ocean waters, and have more recently been adapted for

some optically-complex coastal waters, very few studies have attempted to adapt and validate these models for lakes or other inland waters.

More sophisticated neural network and physics-based inversion methods have also been used to estimate in-water inherent optical properties (IOPs) (Odermatt *et al.*, 2012). Hoogenboom *et al.*, (1998) used matrix inversion for retrieving chl-a and suspended matter. Arst and Kutser (1994) used a modelling approach described further in Kutser *et al.*, (2001), where chl-a, CDOM and suspended matter concentrations were estimated based on modelled spectra. Full measured hyperspectral lake reflectance spectra were compared with reflectance spectra generated through bio-optical modelling and was assumed that the concentrations used in the model simulation correspond to real concentrations if the modelled spectrum matched with the measured one. Later, this approach was developed into a spectral library or look-up-table approach (Yang *et al.*, 2011), as for large images it is computationally more efficient to model reflectance spectra in advance rather than run the model when interpreting the remote sensing spectrum from each pixel. Giardino *et al.*, (2012) developed a software package incorporating their Bio-Optical Model Based tool for Estimating water quality and bottom properties from Remote sensing images (BOMBER), originally intended to retrieve optical and benthic properties for lakes but also applicable in other optically-complex contexts (estuaries, coastal zones, etc.). Brando *et al.*, (2012) presented an adaptive implementation of the linear matrix inversion (LMI) method which accounts for variability in both IOPs and mass-specific IOPs (SIOPs) over space and time in wide ranging optically-complex waters. Several neural network inversion approaches have also been designed specifically for lake settings the Lakes processor (Doerffer and Schiller, 2008) within the Basic ERS and Envisat (A) ATSR and MERIS Toolbox (BEAM) (Fomferra and Brockmann, 2005) or have been demonstrated to be transferable to some lakes from coastal zone settings (the Case 2 Regional (C2R; Doerffer and Schiller, 2007) and FUBWater processor (Schroeder *et al.*, 2007), also BEAM plug-ins). SIOP coefficient tuning or approximation is then required to relate retrieved IOPs to the concentrations of water constituents such as chl-a and TSM.

The use of remote sensing techniques to the quantification and monitoring of a range of parameters is crucial to the quality and functioning of inland waters continues to be at the centre of concern in active and growing community of practice. The occurrence of a large number of meetings, workshops and collaborative,

international projects in recent years has inspired this special issue, “Remote Sensing of Inland Waters”, which is intended to harness this momentum highlight some of the current state-of-the-art and future priority directions of the community. Zilioli (2001) and the numerous contributions of the Science of the Total Environment special issue entitled “Lake water monitoring in Europe” highlighted advancements linking remote sensing technologies and approaches with limnology in the European context at that time, and culminated in an invitation to the research and lake management communities to continue furthering such applications, including within other geographic settings. The Monitoring freshwater, estuarine and near-shore benthic ecosystems with multi-sensor remote sensing (Goetz *et al.*, 2008) included several contributions focused on inland freshwater systems (Gons *et al.*, 2008; Olmanson *et al.*, 2008; Ruiz-Verdú *et al.*, 2008) in addition to applications to coastal, intertidal and estuarine zones. The recent highlighted research on the Great Lakes and large water bodies globally, including the use of both passive (optical) and active (radar, light detection and ranging (LiDAR) and acoustic) data, with applications ranging from coastal/shore zone characterisation, in-water constituent retrieval and fundamental optics, ice classification, underwater gliders and aquatic vegetation (Shuchman and Leshkevich, 2013).

Cyanobacteria detection and biomass quantification have been confirmed as a priority through several contributions on this topic, using both phycocyanin (Li *et al.*, 2015) and cell counts (Lunetta *et al.*, 2015), which are more consistently available from some conventional monitoring programmes, as proxies. Oyama *et al.*, (2015) made use of a sequence of spectral indices applied to Landsat TM and ETM+ data to distinguish dense cyanobacteria blooms from aquatic vegetation, which is often a challenge due to their similar signatures in the red and near-infrared (NIR) ranges. Li *et al.*, (2015) presented a new approach to partition light absorption, thereby was able to dictate phycocyanin. A substantial improvement over previous methods to assess low concentrations in particular was demonstrated, with implications for the sensitivity of bloom detection. The validation of an existing medium resolution imaging spectrometer cyanobacteria product by Lunetta *et al.*, (2015) use of an extensive ($n > 2000$) *in situ* dataset from across eight states of the United State of America, and confirmed its potential to complement and inform operational monitoring activities.

2.5 Lake dynamics

A lake is a terrain feature, a body of liquid on the upper surface of earth that localized to the bottom of a basin or a lake can be defined as any relatively large or small body of slowly moving or standing water that occupies an inland basin of appreciable size. Another definition is any body of fresh or salt water of different size that is surrounded on the land. On Earth, different bodies of water are considered to be lake when they are on the land, not part of the ocean, is larger and deeper than a pond. The word *lake* comes from Middle English *lake* ("lake, pond, waterway"), from Old English *lacu* ("pond, pool, stream"). There was considerable uncertainty about defining the difference between lakes and ponds, and no current internationally accepted definition of either term across scientific disciplines or boundaries exists. The word *lake* is also used to describe a feature which is a dry basin most of the time but may get filled under seasonal conditions of heavy rainfall. In lake ecology, the environment of a lake is referred to as lacustrine. Large lakes sometime referred to as "inland seas," and small seas are occasionally referred to as lakes, such as Lake Maracaibo in Venezuela, which is actually a bay. Larger lakes often invert the world order, as in the names of each of the Great lakes in North America (Paramita, 2012).

Lakes have numerous features such as drainage basin or catchment area, inflow and outflow, nutrient content, pH, dissolved gases, sedimentation, and pollutants. Changes in the volume of a lake are controlled by differences between input and output compared to the total volume of the lake. Significant input sources are precipitation into the water body, runoff from the streams and channels of the lake catchment, groundwater, aquifers and artificial sources. Output sources are evaporation in the lake, surface and groundwater flows, and any extraction of lake water by humans. As climate conditions and human water requirements vary, these will create fluctuations in the lake water levels (Kohil *et al.*, 1998).

Lakes can be also classified on the basis of their richness in nutrient status, which typically affect growth of chlorophyll bearing biomass. Lakes with poor nutrients are classified as oligotrophic which are clear, having low concentrations of plant life. Mesotrophic lakes have good clarity and an average level of nutrients. Eutrophic lakes are enriched with nutrients, resulting in good plant growth and possible algal blooms. Hypertrophic lakes are bodies of water that have been excessively enriched with nutrients. These lakes typically have poor clarity and are

subjected to very high algal blooms. Lakes typically reach this condition due to anthropogenic activities, such as heavy use of fertilizers and toxic wastes in the lake catchment area, such lakes are of little use to humans and have a degraded ecosystem due to lesser dissolved oxygen (Hutchinson 1975).

Due to the unusual relationship between water temperature and its density, lakes form layers called thermoclines, layers of drastically varying temperature relative to depth. Fresh water is most dense at about 4⁰C at sea level. Surface water of deep tropical lakes never reaches the temperature of maximum density, there is no process that makes the water mix. The deeper layer becomes oxygen starved and can become saturated with carbon dioxide, or other gases such as sulfur dioxide. The bottom of a *lake bed*, may be composed of a wide variety of inorganics, such as sand, silt or and organic material, such as decaying vegetative or animal organic matter. Composition of the lake bed has significant role on the flora and fauna found within the lake's environment by contributing to the amounts and the types of nutrients available.

The lakes of our world are places of loveliness, pleasure and inspiration. They have inspired us, provided us with fresh water to meet our many needs. Although increased demand for water restoring and saving lakes from further threats will depend on non-structural solution that is re-thinking the demands and current uses of lake water, and the river that flow into the lake. The solution to present and future problems will not be solved in new technological advances, instead they may through changing our attitudes and ways toward people use and manage water (Catley-Carlson, 2001).

Many modification has been done by man to the ecosystem to favour his needs which causes deterioration of aquatic organisms. Man has suffered a lot from the changes that occurs in the ecosystem. So many human activities like disposal of domestic and industrial sewage, recreational activities, excess fertilization of lands and use of pesticides has threatened environmental health of both surface and ground water. Water pollution now a day is considered not only in terms of public health but also in terms of its conservation, aesthetics and preservation of natural beauty and resources. Water pollution has, however, threatened to reduce the quantity available in ponds, lakes, rivers and reservoirs due to disposal of sewage, industrial water and due to other human activities (Trivedy and Chandrasekhar, 1999). Population explosion, industrialization, urbanization and developmental thrust

of man have created these problems of water pollution.

Lake dynamics shows that shallow eutrophic lakes exist in two states: turbid and dominated by phytoplankton, or clear and dominated by macrophytes (usually rooted aquatic plants, but sometimes attached macroalgae). The turbid state involves dense phytoplankton growth driven by nutrient recycling from sediments. Shading by phytoplankton blocks growth of attached plants. The plant-dominated state involves dense growths of attached plants that stabilize sediments (thereby slowing nutrient recycling) and that shelter phytoplankton grazers. The switch to the plant-dominated state can be triggered by a trophic cascade: piscivore stocking and/or planktivore removal to increase grazing and reduce phytoplankton (Jeppesen *et al.*, 1990; Moss *et al.*, 1996). The switch to the turbid state can be triggered by water-level fluctuations (Blindow *et al.*, 1993) or grazing of macrophytes by fish or birds. Lakes switch states several times, with intervals of years to decades passing between transition events (Blindow *et al.*, 1993), thus showing alternative states between resilience and restoration.

Wetlands are facing degradation all over the world, deterioration of water quality, loss of biodiversity and fast depletion of water resources are main challenges which need urgent attention. Though thorough study of all the wetlands in the country has not been done, several past studies on the subject give us the degree of deterioration of these resources (Kodarkar, 1999, Tekale and Kodarkar, 1999 and Diwan and Kodarkar, 2000). Deshmukh (1964) has studied the physico-chemical variables of Ambazari lake in Nagpur (Maharashtra). The quality of water and its conservation aspects of five water bodies in and around Hyderabad, Andhra Pradesh are discussed by Kodarkar (1995). In the last two decades it becomes a norms in the urban water bodies particularly in urban areas and linked to environmental degradation due to unprecedented urbanization and industrialization. (Kodarkar, 1995). Extensive limnological work of Powai lake was carried out by a number of workers (Thakhare, 1969; Bhagat, 1977; Singh, 1991; Kohil *et al.*, 1998). Reduction in total water spread and depth due to siltation, encroachment and reclamation; due to area development program considerable leveling of the hills around the Powai lake has taken place, which resulted in the soil erosion considerably. Finally it led to large scale siltation and sedimentation of the lake. It is estimated that 3000 m³ of silt has been deposited in the lake; pollution from untreated domestic sewage entering the lake from settlements in the catchments areas; deforestation along the catchments

areas of water resources resulted in increased run-off and soil loss and lack of adequate skilled workers and a strong institutional framework with political and legal status (Boyd, 1979).

2.6 Morpho-edaphic and hydrological factors influencing productivity of a lake

Climatic, morpho-edaphic and hydrological factors determine productivity of a lake. The climatic factors like air temperature, wind velocity, rainfall, *etc.* play important role in fish production from a lake or reservoir. The latitudinal location is another important factor that determines the quantum of solar radiation available at the water surface for primary productivity.

Morphometry of a lake is influenced by topography of the area. The mean depth, shoreline and volume development indices are the three important morphometric parameters which determine the productivity of a lake. Among the three morphometric measurements mentioned above, the mean depth does not have much bearing on reservoir productivity. Edaphic characters of a reservoir include physico-chemical properties of soil and sediment. Physico-chemical characteristics of soil that determine the fertility of water include texture, pH, water retention capacity, organic carbon, nitrogen, phosphorus *etc.* Hydrological factors include physico-chemical properties of water. These properties of water includes physical condition of water like depth, temperature, turbidity, transparency, light intensity *etc.* and chemical conditions of water such as pH, dissolved gases, alkalinity, hardness, dissolved and suspended solids and nutrients status. All these parameters of soil and water have a great bearing on the productivity of a water body, be it a large, medium or small lake. In case of a lentic habitat, soil property of the catchment area plays a vital role in determining its productivity status. The oligotrophic characteristic tendencies shown by some of the lakes are mainly due to the poor nutrient status and other chemical deficiencies in the soil. In most of the cases, poor water quality is a direct reflection of the catchment soil properties (Hutchinson 1975).

There are many natural and artificial ponds, reservoirs and lakes in the Indian subcontinent (Rao, 1975), and there are number of studies on hydrobiological aspects of reservoirs, lakes in India and abroad. Limnology of Sone lake in Cachar District of Assam has been studied by Kar (1984). Acharjee (1997) made a detailed

study on ecology and productivity of some *beels* in lower Brahmaputra valley of Assam.

Physico-chemical factors have profound effects on productivity of lakes and have been the subject of research for limnologists. Terms such as 'eutrophy', 'oligotrophy', 'atrophy' and others appeared 70 years ago as general denominations of the status of lakes. These concepts have been defined in a better way during last few years. Studies on aspects of limnology help to formulate a good management plan for lakes and reservoirs. Rawson (1951, 1952, 1955 and 1956) based on his studies on a number of lakes, concluded that morphometric features have the important bearing on productivity of lake, especially the mean depth, which is inversely related to it. Workers like Northcote and Larkin (1956), Hutchinson (1957) and Larkin (1964) concluded that edaphic features have a direct bearing upon fish production. Limnology productivity studies have also been carried out by Steeman-Nielson (1966), Moore (1950), Edmondson (1956), Vardin (1956), Waldicuk (1956), Teal (1957), Rodhe (1958), Ivlev (1961), Wright (1961), Goldman (1963), Talling (1965a, 1965b, 1966a, 1966b and 1966c), Beedle (1966), Phillipson (1966), Gerkin (1967) and many others. James *et al.*, (2009), made a comparative analysis of nutrients, chlorophyll and transparency in two large shallow lakes (Lake Taihu, P. R. China and Lake Okeechobee, USA).

Earliest work on limnological aspects of a fresh water body was perhaps by Pruthy (1933). Significant results were obtained by Ganapati (1955), in his work on the hydrology of Stanley Reservoir at Mettur Dam. This was followed by limnological works in Bhavanisagar Reservoir (Dorairajah, 1956; Sreenivasan, 1964b and Natarajan, 1976). Limnological and productivity studies were conducted on a number of reservoirs in Tamil Nadu by Ganapati (1956, 1957 and 1959) and Sreenivasan (1964a, 1964b, 1964c, 1964d, 1965, 1966a, 1966b, 1968a, 1968b, 1970, 1971, 1972 and 1977). Workers like Pankajan (1956), Raj (1958), David *et al.*, (1959), Govind (1963 and 1969), Krishnamurty (1966), Vasisht (1968), Ganapati and Pathak (1969), Natarajan (1972, 1977 and 1979), Mathew (1975), Kohli (1981), Pathak (1979), Pandey *et al.*, (1993), Jha and Barat (2003), Sharma and Sarang (2004) and many others studied the ecology, edaphic features and hydrological characteristics of a number of reservoirs from different parts of the country. Aswathi and Tiwari (2004) studied the seasonal trends of abiotic factors in lake Govindgarh, Rewa, Madhya Pradesh and reported an inverse relationship between dissolved oxygen and

temperature. Pandey and Verma (2004) studied the influence of catchment area on chemical and biological characteristics of Baghdara and Udai Sagar lake of Southern Rajasthan. The two lakes were of contrasting features and the study revealed that Udai Sagar lake was polluted and reaching eutrophic condition, whereas Baghdara lake was unpolluted. The study also showed that the dredging of sediment containing phosphorus as a restoration measure for eutrophic lakes was effective. The impact of urbanization on Bellandurlake, Bangalore was studied by Chandrasekhar *et al.*, (2003). Their study showed high values of alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and low levels of dissolved oxygen which indicated the polluted nature of the lake.

2.7 Physico-chemical parameters

Water is fundamental component of life and to human well-being. It is integral to the survival of organism, in terms of food, domestic and industrial production (Blackmore, 2000). Water is a major resource as well as an environment for aquatic organism. Thus water resources include both water as a food to offer living organisms it supply industries, irrigate land or dilute and degrade water, (Nwoko, 1991). Fresh water lakes are large masses of standing water created by impounding the run-off, major streams or rivers as a reservoir. Building a dam at the end or toward the end of river valley. The lakes form in undulating large tract of land, (Boney, 1975). The creation of a large dam in a river environment may affect the socio-economic status both at upstream and downstream sectors of the catchments basin (Blackmore, 2000).

The quality of water plays an important role in the productivity of aquatic ecosystem. The productivity of water is related to its chemical properties and understanding of water chemistry serves as basis indicator for considering whether the water is poor or rich in production. The physical and chemical properties of water greatly influence the uses, the distribution and richness of plant and animal (Courtney and Clement 1998). Further more, techniques of using physico-chemical variables to assess water bodies are essential. They also reveal the concentrations of known environmental contaminants which could render such water unfit for human consumption, domestic, industrial, etc. Parameters such as high level dissolved oxygen in water is an essential pre-requisite for satisfactory aquatic life, while presence of dissolved oxygen and carbon dioxide in water for industrial purposes

constitute corrosive agents and threatens the life of most metallic plants (Akpan 1995).

Freshwater environment is a habitat, where water is the principal external and internal medium component. Ecosystem consists of categories of components which interfere between both physical (nonliving) and biotic (living) components of the environment to form a self sustaining system that is dynamic in nature.

The seasonal variation of productivity is related to variation in temperature and the photic conditions (Senthilkumar and Sivakumar, 2008). It plays a prime role in the productivity of water by influencing the abundance of primary producers on which the primary consumers depend for food source and it not only affects the metabolic activities of plankton, but also their proliferation, thus also affecting biogeochemical activities in the aquatic environment. (Shukla *et al.*,1991). Prasad (1956) stated that temperature is the determining factor in the seasonal distribution of organisms. Similar findings was also reported by Sondergaard and Sand Jensen (1979) and Spencer and King (1989).

Light penetration in water depends upon the quantity of suspended particulate matter (Odum, 1971). Variation in light penetration may cause more drastic changes in plankton production. Hart (1988) correlated changes in zooplankton composition with changes in water transparency in a turbid subtropical reservoir.

Conductivity is a degree of the total amount of ions present in a water body (Welcomme, 1976). It affects the degree of mineralization in water bodies (Junk, 1973). According to Jhingran (1988), the electrical conductance of a water body reflects the total quantity of dissolved solids and serves as a reliable indication of the edaphic characteristics.

According to Reynolds and Allen (1968), pH is the most important factor regulating plankton density. George (1997) pointed out that the variation in pH is an important parameter in a water since most of the aquatic organisms are adapted to the average pH and do not withstand abrupt changes.

Depth is the most important parameter among the various morphometric factors which are correlated with productivity. Shallower water bodies have a large proportion of their substrates available in the euphotic zone (Dale and Gillespie, 1977; Purohit and Singh, 1981). Shallower lakes provide greater mixing and circulation of heat and nutrients and hence, have greater productivity. Consequently,

populations of bottom fauna and sustained production of commercial fish are inversely correlated with mean depth (Rawson, 1955).

The main sources of dissolved oxygen (DO) are dissolution from the atmosphere and photosynthesis. DO is removed from the natural waters through the respiration by the biota and the decomposition of organic matter. The DO depends on factors like temperature, salinity and the density of phytoplankton (Kadam *et al.*, 2005). Nandan and Patel (1991) stated that DO shares a direct relation to algal periodicity. It has also been established that there exists no better general indicator of water quality than DO.

Biochemical oxygen demand (BOD) has been used as a measure of the quantity of organic matter present in an aquatic solution, which supports the growth of microorganisms (Nandan and Patel, 1991). Higher values of BOD indicate higher consumption of oxygen and a higher pollution load. BOD is a chemical procedure for determining the quantity of dissolved oxygen needed by aerobic biological organisms in any body of water to break down organic material present in a given water sample at certain temperature over a specific period of time.

Total organic carbon (TOC) provides a speedy and convenient way of determining the degree of organic contamination. TOC in waters comes from decaying natural organic matter (NOM) and from synthetic sources. Humic acid, fulvic acid, amines and urea are types of NOM. Detergents, pesticides, fertilizers, herbicides, industrial chemicals and chlorinated organics are examples of synthetic sources. Organic carbon provides an important role in quantifying the amount of organic contamination in water (Hendricks, 2007).

It is reported that alkaline pH is favourable for good plankton growth and indicates its unpolluted nature (Mahajan and Kanhere, 1995). Higher values of total alkalinity might be due to the presence of excess free carbon dioxide produced as a result of decomposition process coupled with the mixing of sewage and industrial effluents (Mohanta and Patra, 2000).

The nitrogen-containing organic compounds are usually broken down by a series of microbial enzymatic actions resulting in the formation of ammonia, carbon dioxide and other end products. It was reported that ammonia is the most reliable single parameter ($> 0.1\text{ppm NH}_3\text{--N}$) for measuring the quality of river water (Loster, 1975). Higher concentration of ammonia is harmful to fish and other biota (Jhingran, 1991). The acidic condition of water may reduce the toxicity of ammonia due to the

conversion of unionized ammonia to ammonium ions (Schmittou *et al.*, 1998).

Excess concentration of nitrates and phosphates brings eutrophication, and it stimulates algal bloom (Bahura, 1998), the process that sets a chain of destruction events leading to the gross pollution of a water body (Kodarkar, 1999). The determination of phosphate level is useful in measuring the water quality since it is an important plant nutrient and may play the role of a limiting factor among all the other essential plant nutrients (Thirumala *et al.*, 2006). Nitrate is one among the most important nutrients in an aquatic ecosystem; generally water bodies polluted by organic matter exhibit higher values of nitrate (Shanti *et al.*, 2002).

2.8 Heavy metals

Pollution of the aquatic ecosystem with heavy metals has become a worldwide problem in recent years, because they are indestructible and most of them have toxic effects on organisms (MacFarlane and Burchett, 2000). Among environmental pollutants, metals are of particular concern, due to their potential toxic effect and ability to bio-accumulate in aquatic ecosystems (Censi *et al.*, 2006).

Heavy metal concentrations in aquatic ecosystems are usually monitored by measuring their concentrations in water, sediments and biota (Camusso *et al.*, 1995), which generally exist in low levels in water and attain considerable concentration in sediments and biota (Namminga and Wilhm, 1976). Heavy metals including both essential and non-essential elements have a particular significance in eco-toxicology, since they are highly persistent and all have the potential to be toxic to living organisms (Storelli *et al.*, 2005).

Studies on heavy metals in rivers, lakes, fish and sediments (Özmen *et al.*, 2004; Begüm *et al.*, 2005; Fernandes *et al.*, 2008; Öztürk *et al.*, 2008; Pote *et al.*, 2008 and Praveena *et al.*, 2008) have been a major environmental focus especially during the last decade. Sediments are important sinks for various pollutants like pesticides and heavy metals and also play a significant role in the remobilization of contaminants in aquatic systems under favorable conditions and in interactions between water and sediment. Fish samples can be considered as one of the most significant indicators in freshwater systems for the estimation of metal pollution level (Rashed, 2001). The commercial and edible species have been widely investigated in order to check for those hazardous to human health (Begüm *et al.*, 2005).

Heavy metals such as copper, iron, chromium and nickel are essential metals

since they play an important role in biological systems, whereas cadmium and lead are non-essential metals, as they are toxic, even in trace amounts (Fernandes *et al.*, 2008). For the normal metabolism of the fish, the essential metals must be taken up from water, food or sediment (Canli and Atli 2003). These essential metals can also produce toxic effects when the metal intake is excessively elevated (Tüzen, 2003).

2.9 Biotic communities determining the productivity of lake water

Numerous factors, including species interactions, productivity, habitat type, colonization types and the number of species occur in a specific environment and all these are interrelated with diversity (Dodds, 2002). Planktonic organisms in temperate lakes commonly show distinct seasonal dynamics that have been attributed mainly to changes in ambient physico-chemical parameters (light, temperature and nutrients), which in turn, govern phytoplankton primary production and autotroph herbivore interactions (Hessen *et al.*, 2005). Plankton (both phyto and zooplankton), benthos, periphyton, ichthyofauna and all other types of flora and fauna comprise the biotic communities of a lake. Energy flow from producer to consumer is the basic pathway through which biotic communities play a pivotal role in productivity of a lake. Among the biological communities that influence the productivity of a lake or reservoir ecosystem, producers (chlorophyll bearing biomass) fix chemical energy and transform it into carbon (organic matter), thus constituting the major link in the trophic structure in an aquatic ecosystem. According to Sugunan (1995), a rich plankton community with well-marked serial succession is the hallmark of Indian reservoirs, and this also holds true for lakes.

2.10 Phytoplankton

Phytoplankton form the base of most of the lake food-webs and fish production is linked to phytoplankton production. Moreover, the number and species of phytoplankters serve to determine the quality of a water body (Ryder *et al.*, 1974). The physico-chemical, geomorphological and sedimentary natures are always correlated with the density of plankton (Yeragi and Yeragi, 2003). The study of plankton also serves as an index of water quality in respect of industrial, municipal and domestic sewage pollution (Pati and Sahu, 1993; Acharjee *et al.*, 1995; Baruah *et al.*, 1997). Study of plankton is a very useful tool for assessment of water quality in any type of water body and also contributes to the understanding of the basic nature and general economy of the lake (Pawar *et al.*, 2006). Lehman (2000) determined

the direct role of climate variation on phytoplankton community bio-volume. Hambright and Tamar (2000) concluded that disturbances can enhance phytoplankton species diversity. Goldman and Horne (1983) have reported that the dynamic features of lakes such as colour, clarity, trophic state, zooplankton and fish production depend to a large degree on the phytoplankton. The phytoplankton community on which whole aquatic population depends is largely influenced by the interaction of a number of physico-chemical factors. Davis (1955) showed that a number of physical, chemical and biological factors acting simultaneously must be taken into consideration in understanding the fluctuations of phytoplankton population.

Several workers have studied plankton dynamics in lakes and reservoirs. Sugunan (1980, 1995) indicated the seasonal fluctuation of plankton in Nagarjuna Sagar reservoir. Sreenivasan (1969) reported the dominance of blue green algae and diatoms in the South Indian reservoirs. Jepachandramohan *et al.*, (2009) showed the influence of spatial and temporal variations on phytoplankton community structure in Pechiparai reservoir. Other workers like Sreenivasan (1964a), Govind (1969), Ganapati and Pathak (1969), Fernando and Kanduru (1984), Salim and Ahmed (1985), Khan (1986), Saha (1990), Rao and Choubey (1990), Deorari (1993) reported about plankton communities of Indian reservoirs. Cheng and Tayler, 1973; Tilzer *et al.*, 1977; Duncan and Gulati, 1981; Krzanowski, 1986; Pollinger, 1986; Hanzato and Yasuno, 1987; James and Forszh, 1990; Vasconcelos, 1990; Melao and Rocha, 2000; Ariyadej *et al.*, 2004; Sendacz *et al.*, 2006; Sebetich, 2009, Parameta, 2012 have studied plankton and productivity of various lakes around the world.

2.11 Zooplankton

Zooplankton species inhabit all freshwater habitats of the world, including industrial and municipal waste water (Mukhopadhyay *et al.*, 2007), and they play a very important role in the food chain as primary consumers and also serving as food for the higher trophic levels (Qasim, 1997). However, because the zooplankton are closely linked to the environment and they tend to respond to changes more rapidly than do larger aquatic animal such as fish, they have proved valuable indicators of apparent and subtle alterations in the quality of aquatic environment, Marine Biology Organization, (MBO, 2007). They indicate the effect of low level of chemical pollution

in a water body and are good indicators of pollution in biological monitoring (Rutherford *et al.*, 1999; Soberon *et al.*, 2000; MBO 2007).

According to Wallance and Snell (1991), the freshwater zooplankton comprises three major groups of invertebrate animals; the rotifers, copepods, and cladocerans. The rotifers constitute a phylum found almost exclusively in freshwater. The copepods and cladocerans are both groups of the large subphylum crustaceans. Copepods constitute a class that is widespread in both freshwater and marine environment. Cladocerans constitute a group of four orders living primarily in freshwater environments. All three of these major groups have species adapted to Pelagic (open water), or littoral (vegetated), and benthic (bottom) environment. However, Soil Water Conservation Society of Metro Halifax (SWCSMH), (2007) pointed out that freshwater zooplankton are dominated by four major groups of animals; protozoa, rotifers, and two sub-classes of the crustacean, the cladocerans and copepods. The planktonic protozoa have limited locomotion, but the rotifers, cladoceran and copepod micro crustaceans, and certain immature insects larvae often move extensively in quiescent water.

Zooplankton productivity is generally tightly coupled with phytoplankton productivity (Mallin and Pearl, 1994) in that phytoplankton serve as food for zooplankton which in turn serves as food for fish. According to Suantama (2004), an advantage of zooplankton as fish food is that they contain lower amount of environmental toxin than organisms higher up the food chain. This is because environmental toxins accumulate as they move up the food chain.

Some measures of diversity of the freshwater zooplankton communities, for example their abundance, richness, diversity, and vertical distribution, has been explained by abiotic and biotic factors such as nutrient limitation, temperature, ultraviolet radiation, food availability, and predation avoidance in temperate and tropical aquatic systems (Williamson *et al.*, 1996; Plath and Boersma 2001; Winder *et al.*, 2004). In tropical systems, physical and chemical variables are quite similar in different seasons; additionally, the notion that low variability of water temperature in tropical regions favours environmental stability in freshwater systems is widely accepted (Lewis, 1996). However, the processes related to zooplankton abundances

and its possible natural variability in tropical (Lugo, 2000) and subtropical systems (Mazumder and Havens, 1998) are not well understood.

The variation in abundance, biomass (Torres-Orozco and Zanatta, 1998), communities (Deevey *et al.*, 1980; Haberyan *et al.*, 1995), and vertical distribution (Cervantes-Martínez *et al.*, 2005) of zooplankton in tropical systems during annual cycles has been described. However, the causes of these changes remain vague (Crisman and Streever, 1996). Similarly the zooplankton communities in small, tropical lakes (such as the sinkholes of the Yucatan Peninsula) and the factors related to their dynamics, have received limited attention (Lewis, 1990; Crisman and Streever, 1996).

Based on samples collected in two distinct sinkholes, we described the influence of abiotic and biotic variables on the abundance, richness, and diversity of limnetic zooplankton in one oligotrophic and one mesotrophic sinkholes. We considered one annual cycle and spatial scales (related to different depth layers in the sinkholes) to test the hypothesis that seasonal changes in environmental factors and predator abundance influence succession of zooplankton species in these tropical systems.

2.12 Pollution indices

Naganandini and Hosmani (1990) reported pollution-tolerant algae and suggested the use of algae as indicators of organic pollution. Nygaard (1949) introduced five indices for the biological monitoring of aquatic habitat based on individual population of Myxophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae and a mixture of all these proportions together. According to him, certain algal groups are indicative of the levels of nutrient enrichment. Nygaard's indices are used to get a meaningful evaluation of the extent of eutrophication by many workers (Vaishali and Madhuri, 2004). Palmer (1969) has also proposed an index which is based on the presence or absence of selected taxa of algae in the water sample. A definite score is assigned to each taxon and depending upon the total score, the water bodies are classified as oligotrophic, mesotrophic or eutrophic. Many ecologists calculated and determined the status of organic pollution in various aquatic ecosystems quite successfully with the help of Palmer's algal pollution index.

2.13 Eutrophication and degradation of aquatic ecosystems

The process of nutrient over-enrichment of a water body is known as eutrophication. Eutrophication (Greek: *eutrophia*—healthy, adequate nutrition, development; German: *Eutrophie*) or more precisely hypertrophication, is the ecosystem response to the addition of artificial or natural substances, such as nitrates and phosphates, through fertilizers or sewage, to an aquatic system. One example is the "bloom" or excessive increase of phytoplankton in a water body as a response to increased levels of nutrients. Negative environmental effects include hypoxia, the depletion of oxygen in the water, which induces reductions in specific fish and other animal populations. Eutrophication can be human-caused or natural. Untreated sewage effluent and agricultural run-off carrying fertilizers are examples of human-caused eutrophication. However, it also occurs naturally in situations where nutrients accumulate (e.g. depositional environments), or where they flow into systems on an ephemeral basis. Eutrophication generally promotes excessive plant growth and decay, favouring simple algae and plankton over other more complicated plants, and causes a severe reduction in water quality (Paramita, 2012).

Phosphorus is a necessary nutrient for plants to live, and is the limiting factor for plant growth in many freshwater ecosystems. The addition of phosphorus enhances algal growth. These algae assimilate the other necessary nutrients needed for plants and animals. When algae die they sink to the bottom where they get decomposed and the nutrients contained in organic matter are converted into inorganic forms by bacteria. The decomposition process uses oxygen and deprives the deeper waters of oxygen which can kill fish and other organisms. Also the necessary nutrients are all at the bottom of the aquatic ecosystem and if they are not brought up closer to the surface, where there is more available light allowing for photosynthesis for aquatic plants, a serious strain is placed on algae populations. Enhanced growth of aquatic vegetation or phytoplankton and algal blooms disrupts normal functioning of the ecosystem, causing a variety of problems such as a lack of oxygen needed for fish and shellfish to survive.

Eutrophication also reduces the value of rivers, lakes, and estuaries for recreation, fishing, hunting, and aesthetic enjoyment. Health problems can occur where eutrophic conditions interfere with drinking water treatment. Climate changes, habitat fragmentation and biotic exploitation of waters lead to loss of resilience and

accelerate eutrophication. Lake eutrophication is manifested essentially in the poor under-water light climate with high turbidity usually by cyanobacterial blooms (e.g. *Oscillatoria* sp.) and loss of littoral vegetation. Eutrophication can also modify water clarity (typically coloured a shade of green, yellow, brown, or red) and food web structure and it is probably the best understood type of lake degradation. Agriculture and urban development increase phosphorus transport to lakes. Loss of vegetation and wetlands increase the phosphorus flows. External phosphorus inputs and inputs from non-point sources, as well as nitrogen from agriculture, often constitute a major challenge to the lake restorers. Lake recovery is also invariably afflicted by in-lake nutrient sources. These include phosphorus loading from the P-rich sediments, mineralization in the water and release by the foraging and metabolic activities of benthivorous and planktivorous fish (Harper, 1992, Edmondson, 1969).

Pollution is the introduction of contaminants into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem that is physical systems or living organisms. Pollution can take the form of chemical substances or energy, such as noise, heat or light. Pollutants, the components of pollution, can be either foreign substances/energies or naturally occurring contaminants. Pollution is often classified as point source or nonpoint (diffuse) source pollution. The Blacksmith Institute issues an annual list of the world's worst polluted places. Water pollution is the contamination of water bodies' examples lakes, rivers, oceans, aquifers and groundwater). Water pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds. Water pollution affects plants and organisms living in these bodies of water. In almost all cases, the effect is damaging not only to individual species and populations, but also to the natural biological communities. Water is typically referred to as polluted when it is impaired by anthropogenic contaminants and either does not support a human use, such as drinking water, and/or undergoes a marked shift in its ability to support its constituent biotic communities, such as fish. Natural phenomena such as volcanoes, algae blooms, storms, and earthquakes also cause major changes in water quality and the ecological status of water (Boyd 1984).

2.14 Influence of physico-chemical parameters and nutrients on biodiversity

In general, aquatic ecosystems such as lakes are among the most vulnerable and diverse ecosystems types in the world. Biodiversity of aquatic ecosystems is largely responsible for maintaining and supporting overall health and sustainability of the environment. Urbanisation is one of the biggest drivers of environmental change and ecological damage of aquatic ecosystems due to unchecked incorporation of untreated solid and liquid wastes and other anthropogenic activities in the name of development. The rapidly expanding human population within the catchment areas of lakes has brought changes in its biotic components (Pandit, 2002). In recent years, the biologically rich habitats have been destroyed mainly due to habitat destruction, over-harvesting, pollution and inappropriate introduction of exotic plants and animals (Kulshrestha *et al.*, 1989). In this process, the valuable ecosystem services contributed by water bodies, including biodiversity support, nutrient cycling, bioremediation, etc. are being irreplaceably lost. Changes in the water quality are reflected in the biotic community structure as shown by the occurrence, diversity and abundance pattern of species (Sanjar and Sharma, 1995). Hence understanding the ecology and biodiversity of such an ecosystem helps in adopting proper management measures. Freshwater systems are estimated to contain about 10% of all animal species on earth (Balian *et al.*, 2008), but community and species diversity estimates mostly refer to the macro-biological level of fishes and it is likely that the species richness of microorganisms, which greatly contribute to the functional biodiversity of freshwater ecosystems, has been underestimated (Johns and Maggs, 1997; Gessner and Van Ryckegem, 2003).

There are numerous natural and artificial ponds, reservoirs and lakes in the Indian subcontinent (Rao, 1975). Several workers have attempted to study the hydro-biological profile and biodiversity of the flora and fauna in these lakes (Singh 2000; Patil and Kkarikal, 2001; Sukand and Patil, 2003). Phytoplankton serve as the producers in the food chain in an aquatic ecosystem and their productivity depends upon the quality of water. The abundance of zooplankton depends upon the availability of phytoplankton and they form the second trophic level in the aquatic food chain.

Over the last few decades, there has been growing interest in determining

heavy metal levels in the freshwater environment and attention was drawn to the measurement of contamination levels in public food supplied, particularly fish (Tariq *et al.*, 1993; kalay *et al.*, 1999; Rose *et al.*, 1999). Although heavy metal is a loosely defined term (Duffus, 2002), it is widely recognized and usually applied to the wide spread contaminants of terrestrial and fresh water ecosystems. Some examples of heavy metal include lead, zinc, cadmium, copper and manganese. Many of these heavy metals are toxic to organisms at low concentration (Galloway *et al.*, 1982).

The concentration of metals in bioavailable form is not necessarily proportional to the total concentration of the metal. The concentration of various elements in the air, water and land may be increased beyond their natural level due to the agricultural, domestic and industrial effluents. These substances are described as “contaminants” when discharged to the environment (Madu *et al.*, 2008). In water, insoluble heavy metals may be bound to small silt particles. Metals and other fluvial contaminants in suspension or solution, do simply flow down the stream, they form complexes with other compounds settle to the bottom and ingested by plants and animals or adsorbed to sediments (Odiete, 1999). Consequently, aquatic organisms may acquire heavy metals in body directly from the water via gills or food chain mechanisms (Collison and Shrimp, 1972).

Biological phenomena can be understood adequately with knowledge of hydrological factors (water and sediment characteristics), because they reveal much about general hydrobiological interrelationships. According to Reynolds (1984), physical factors (such as temperature, depth and light intensity), being the most important, influence seasonal appearance of plankton more than the chemical factors (dissolved oxygen, hydrogen ion concentration, salinity, alkalinity, electrical conductivity and nutrient level). The relation between physico-chemical parameters and diversity of organisms in the Indian context has been studied by Hedge (1985), Pollinger *et al.*, (1988), Kulshreshtha *et al.*, (1989), Adholia (1991) *etc.* The biodiversity of phytoplankton, zooplankton and benthos in the water body shows a correlation with respect to their occurrences, physico-chemical factors and level of nutrients (Pai and Vikrant, 2005). Nutrients over-enrichment of a water body, better known as eutrophication, is accompanied by structural changes in the food-webs of lakes and it causes substantial changes in floral and faunal communities, such as fish, plankton, benthos and macrophytes (Rognerud and Kjellberg, 1984; Wright and Shapiro, 1984; Bosselmann and Riemann, 1986; Persson *et al.*, 1991). Increase in

freshwater biodiversity due to the increase in nutrient concentration had been discussed by Leibold, 1999; Dodson *et al.*, 2000 and Dudgeon *et al.*, 2006). Changes in the water quality are reflected in the biotic community structure as revealed by occurrence, diversity and abundance pattern of species (Sanjar and Sharma, 1995). Hence, knowledge of ecology and biodiversity of such an ecosystem helps in taking proper management measures.

3. MATERIAL AND METHODS

This study was broadly divided into two categories: (a) conventional method or field based data collection, and (b) laboratory based data aggregation, processing and model development that is GIS and remote sensing application.

3.1 Field-based work

3.1.1 Study area

The Maharashtra is the third largest state of India which covers 307,713 km² areas and found to be one of the major maritime states in India with a coastline of 720 Km makes Maharashtra fourth longest coastal line state of India. There are 6 maritime districts that is Palghar, Raigad, Thane, Greater Mumbai, Ratnagiri and Sindhudurg in the state comes under Konkan coast. About 15 rivers 30 backwater regions and 5 major creeks have been reported along the Konkan coast (Kohil *et al.*, 1998). Though Maharashtra lacks major upstream freshwater flowing rivers or estuaries besides few small rivers like Savitri, Vashishti, Shastri, Kundalika and few creeks like Ulhas-Thane complex, Vaitarna, Karanja-Dharmatar complex, Dabhol, Jaigad, Sakhartar, Bhatye, Purnagad, Vijaydurga, Devgarh, Achra and Karli creeks drains in East-west direction and merges with Arabian sea.

Mumbai, situated in the state of Maharashtra along the west coast of India, is a coastal megacity (with population more than 10 million), as well as the commercial capital of the country. Along with the elevated population level, the region is also heavily industrialized, which adds other pollutant loading to the region (Paramita 2012). Heavy industrialization and urbanization in the city have deleterious effects on the environment, especially the aquatic ecosystems. Powai is an artificial lake situated in northern Mumbai. Powai name after Farmaji Kavasji Powai Estate created for drinking water purpose by constructing dams between two hillocks across Mithi River. Powai- Kanheri hill range forms the catchment area of the lake. Powai Lake is situated in the suburban area and the water is used only for non-potable purposes, that is, gardening and industrial purposes as the water quality has deteriorated. It is located between latitude 19° 17' N and longitude 72° 54' E with total surface area of 2.10km² and 35 meters above the mean sea level. It is a man-made lake build in 1891 and known as 'Anglers Paradise' with catchment area of 6.61km², maximum

depth of 12m and surface elevation of 58.5m. It is meant exclusively for angling and sports and is located about 27 Km away in the north- east of Mumbai city. This lake came into existence in the year 1891, when Mumbai Municipality got constructed a masonry dam of 10 meter height between two hillocks across Powai basin to conserve the rain water for drinking purpose, which later commonly known as Powai lake, since it impounded in Powai area. However, the water in the lake was found inpotable because of indiscriminate use of the lake for various purposes by the local people and also due to the addition of domestic sewage. This lake was open for the general utilization of the natives and it is leased out to Maharashtra State Angling Association, Mumbai for angling in addition to conservation. The conservation of Powai Lake is in the interest of man as it's ecological, aquacultural and tourist value. One of the most important steps in the conservation of the lake is to restore the water quality by controlling the pollution through different remedial measures. This lake has been included in the Central Government National Lake conservation Plan. So this lake which has been build since 100 years ago has changed its form now (Fig. 3).

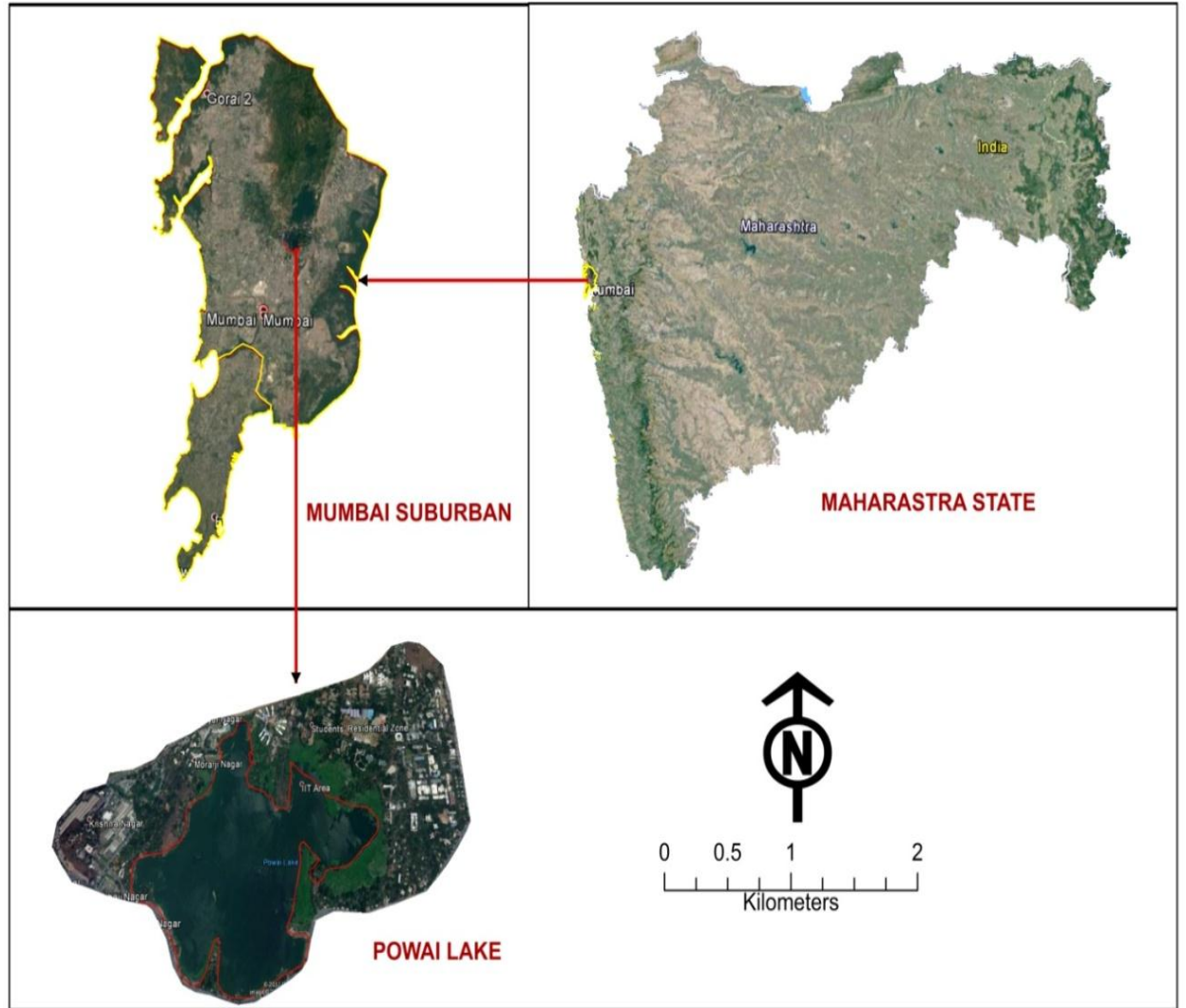


Fig. 3: Google map of Maharashtra State, Mumbai suburban and Powai lake

3.1.2 Sampling stations

Five sampling stations were chosen based on preliminary surveys of the lake and factors such as average depth, volume of water, accessibility, security and various activities taking place in and around the lake. GPS was used to locate the coordinates of the station A (19.1259 N and 72.8979 E), station B (19.1330 N and 72.9030 E), station C (19.1263 N and 72.9032 E), station D (19.1285 N and 72.9108 E) and station E (19.1213 and 72.9047) respectively (Fig. 4).

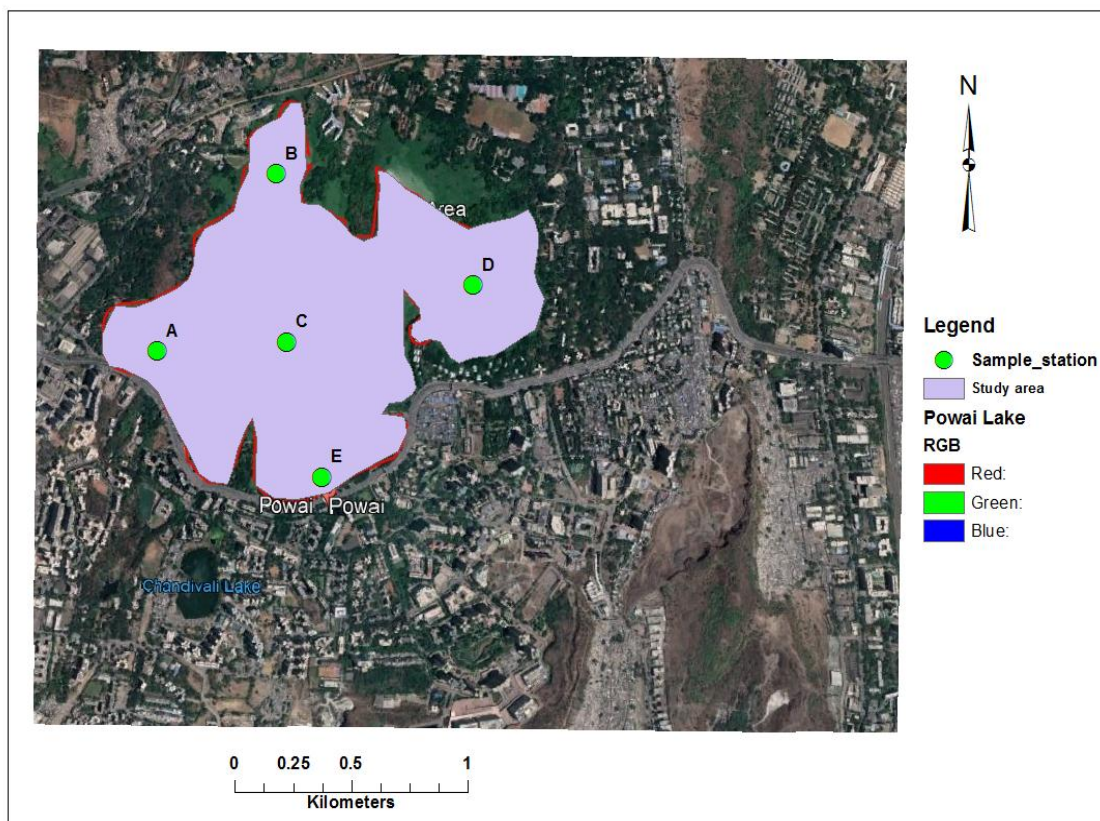


Fig. 4: Map of Powai lake showing the sampling stations

3.1.3 Sampling frequency and duration of study

The period of the study was from November 2016 to October 2017. Monthly Water, Plankton, Fish and Sediment samples were collected in the morning before 9:00am. Water sample was collected in one litre capacity sampling bottles in triplicate from five stations. A paddle boat was used for the sample collections.

3.1.4 Fish sample collection

Fish samples of Tilapia (*Oreochromis mossambicus*), Catla (*Catla catla*) and Clarias (*Clarias gariepinus*) were collected from anglers operating in the lake, package in polythene and preserved in deep fridge.

3.1.5 Sediment sample collection

Ekman grab was used to collect sediment samples from the bottom of the five selected sampling stations of the lake, following which, vegetative and animal matters were removed from the sediment samples. The collected samples were

mixed thoroughly to obtain a representative sediment sample, packed in plastic bag and brought to the laboratory for further analysis.

3.1.6 Determination of water quality characteristics

The water samples were subjected to the following analysis after collection as described by APHA (2012).

3.1.6.1 Temperature

Air temperature and surface water temperature of each station was determined using Dissolved Oxygen/Temperature meter model (FB 61317) fitted with thermometer. For each station, air temperature was initially taken before immersing the probes in water. And this was then followed by water temperature with the probes in water. Air temperature and water temperature reading on the Liquid Crystal Display (LCD) dial was recorded for each station.

3.1.6.2 Transparency

A secchi disc with graduated rope was used to obtain the degree of transparency of sampling points. The disc was lowered in water, until it disappeared and the depth recorded, the disc was then raised until it reappeared and the depth at which it reappeared was recorded. The average of the two measurements was considered as secchi disc visibility.

3.1.6.3 Turbidity

Nephelometer (NTU) was used for measuring the size and concentration of suspended particles.

3.1.6.4 Depth

While the grab was operated to collect the sediment samples from different stations, depth was also measured.

3.1.6.5 Hydrogen Ion Concentration (pH)

A portable field pH meter auto digital Model LT-II was used to take pH value. For each station, the probe was inserted in water and reading displayed on the LCD dial was recorded. Subsequent readings for the remaining stations were recorded after rinsing the probe in distilled water.

3.1.6.6 Dissolved Oxygen (DO)

A portable field Dissolved Oxygen/Temperature meter (model FB 61317) was used to measure the DO of each station. The probe was inserted in water and reading displayed on the LCD dial was recorded and subsequently same procedure was applied for the remaining stations after rinsing the probe in distilled water. The DO levels were later confirmed using Winkler's modified method in the laboratory.

Winkler's modified method

Materials used

- i. Manganous sulphate (Winkler's- A) solution (Dissolve 480g of $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$ or 400g of $\text{MnSO}_4 \cdot 2\text{H}_2\text{O}$ or 364g of $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ in one litre of distilled water)
- ii. Alkaline potassium iodide (Winkler's- B) solution (Dissolve 500g of NaOH, 150g of KI (Potassium iodide) and 20g of sodium azide in one litre of distilled water)
- iii. Standard sodium thiosulphate (0.025 N or N/40) solution (Dissolve 6.205g of $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ in one litre of distilled water).
- iv. Starch indicator (Make a thin paste of about 1g of starch in cold water, pour 200 ml of boiling water in it and stir, Add 0.1g of salicylic acid or 0.5g of sodium chloride or 0.5 ml of formalin as a preservative).

Procedure

The stopper was carefully removed and 1 ml of manganous sulphate reagent and 1 ml of alkaline iodide reagent was added by means of one ml pipette dipped to the bottom of the bottle and slowly drawing out as the reagent was added. The stopper was replaced and bottle was inverted, three or four times for a thorough mixing of reagent. A flocculent precipitate was formed which was settled at the

bottom. If the precipitate is whitish in colour, oxygen is very poor, light brown colour indicates high dissolved oxygen. For quantitative estimation, 1 ml of concentrated H_2SO_4 was added to dissolve the precipitate.

Titration

50 ml sample was taken in a beaker and two drops of starch indicator was added, then it was titrated with sodium thiosulphate (0.025N) N/40 to a colourless end point.

Calculation

DO in ppm = Burette reading $\times$ 4

3.1.6.7 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand was measured by Winkler's modified method. 1000 ml of distilled water was taken in beaker, 1 ml each of phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride was added. Then 2 ml of sewage sample was added aerated for 10 minutes. One full sample was taken in DO bottle and analysed DO of diluted water. 100 ml of sample water was taken in DO bottled and filled the top with diluted water, and incubated at 35°C for three (3) days in closed BOD incubator. After incubation, same procedure of DO determination was followed as described above and obtained the final DO.

- i. Dob= DO of blank (Dilution water).
- ii. Doi= DO of mixture after incubation.
- iii. Dos= DO of undiluted water.

Calculation

$$\text{BOD in ppm} = (\text{Dob} - \text{Doi}) \frac{\text{volume of bottle}}{\text{volume of sample}} - (\text{Dob} - \text{Dos})$$

3.1.6.8 Chemical Oxygen Demand (COD)

50 ml of water sample was taken in a 250 ml conical flask. 5 ml of KMnO_4 (0.1 N) solution and 1:3 sulphuric acid each was added and heat on a water bath at boiling point ($75\text{--}90^\circ\text{C}$) for 30 minutes and then cool to room temperature. 5 ml of

ammonium oxalate solution was added. The samples were titrated with potassium permanganate for COD. However, the burette reading was recorded. Calculate the COD as below:

Calculation

$$\text{COD in ppm} = \frac{\text{Burette reading} \times 1000}{\text{sample volume in ml}}$$

3.1.6.9 Alkalinity

Materials used

- i. Sulphuric acid (N/50) - First, prepare 1N H_2SO_4 by adding 35 ml distilled water in one ml of cone. H_2SO_4 . Now take 10ml of this 1N H_2SO_4 (stock solution) and add into it 49 ml of distilled water.
- ii. Phenolphthalein indicator (Dissolve 5 g of phenolphthalein in one litre of 50% alcohol ($\text{C}_2\text{H}_5\text{OH}$)).
- iii. Methyl orange indicator (Dissolve 5 g of methyl orange in one litre of distilled water).

Procedure

50 ml of sample was placed conical flasks. Two drops of phenolphthalein indicator was added (if a slight pink colour appears) and titrated with H_2SO_4 and then two drops of methyl orange was added, and is titrated again with H_2SO_4 from yellow to orange colour.

Calculation

$$\text{Total Alkalinity in ppm} = \frac{\text{Burette reading} \times 1000}{\text{ml of sample}}$$

3.1.6.10 Hardness

Materials used

- i. Eriochrome black-T indicator- Dissolve 0.1 g of Eriochrome black-T in 20 ml of ethyl alcohol).

- ii. Ammonia buffer (Dissolve 6.75 g of ammonium chloride (NH_4Cl) in 58 ml of liquid ammonia and dilute to 100 ml with distilled water).
- iii. Standard EDTA solution (dissolve 4 g of sodium salt of EDTA and 0.1 g of MgCl_2 in 800 ml of distilled water).

Procedure

50ml of sample was taken in a conical flask, 1 ml of ammonia buffer and 3 drops of Erichrome black T indicator was added. This was titrated with standard EDTA solution for hardness till the colour changes from wine red to blue. Record the volume of EDTA solution used.

Calculation

$$\text{Total Hardness in ppm} = \frac{\text{No. of ml of EDTA solution used} \times 1000}{\text{ml of sample}}$$

3.1.6.11 Chlorides

Materials used

Silver nitrate solution of N/35 (Dissolve 4.78 g of AgNO_3 in one litre of distilled water), and potassium chromate was used as indicator.

Procedure

50 ml of water sample was taken in conical flasks and two drops of potassium chromate indicator was added. This was titrated with silver nitrate solution for chloride. The end point is from yellowish to big red.

Calculation

$$\text{Chlorides in ppm} = \frac{\text{Burette reading} \times 1000}{\text{ml of sample}}$$

3.1.6.12 Ammonia-nitrogen

Ammonia in the water samples was estimated colorimetrically using the Indo-phenol blue method; 1 ml of phenol-nitroprusside solution and 1.5 ml of alkaline hypochloride solution were added to 2.5ml sample in test tube. The samples were

then kept in dark place at room temperature. After one hour, the colour developed was measured with spectrophotometer (UV/VIS spectrophotometer 2080 system) at 640nm.

3.1.6.13 Nitrite-nitrogen

Nitrite-nitrogen was determined using colorimetric method (APHA, 2012). Nitrite is determined by taking 25ml sample in Nesler's tube. 0.5ml of sulphanilamide solution, N1 nathyl-ethylene diamine dihydrochloride solution was added. The content was firmly shaken and the absorbance was measured at 543nm using spectrophotometer (UV/VIS spectrophotometer 2080 system).

3.1.6.14 Nitrate-nitrogen

Nitrate-nitrogen was determined using colorimetric method (APHA, 2012). 25ml of the sample was taken in Nessler's tube. 0.5ml of each hydrazine sulphate solution, copper sulphate solution, phenol solution and sodium hydroxide solution were added and kept in dark cabin for 24 hours. Then 1ml of acetone and 0.5ml of each sulphanilamide solution and N1 nyphthal solution was added. The present of pink colour indicate the availability of nitrate. The optical density was measured at 540nm using spectrophotometer (UV/VIS spectrophotometer 2080 system).

3.1.6.15 Phosphate

Phosphate in the water samples was estimated colorimetrically. 50ml of the sample was taken in Nessler tubes, 1ml of acid ammonium molybdate and 0.2 ml of stannous chloride solution (freshly prepared) were added. The samples were then covered and shake thoroughly. The colour developed was measured in spectrophotometer (UV/VIS spectrophotometer 2080 system) at 690nm.

3.1.6.16 Total solid

Materials used

Porcelain dish, silica crucible, corning or pyrex beaker (500 ml capacity) funnel, oven with thermostatic control, Whatman filter paper No.44, physical balance and analytical balance, etc.

Procedure

- i. 50 ml beaker was washed and oven dried for 5 minutes.
- ii. Initial weight of the beaker was taken using sensitive weighing balance and recorded.
- iii. 50 ml water sample was evaporated to dryness in an oven at 103°C to 105°C
- iv. The beakers was allowed to cool and dry in a desiccator
- v. Increase in weight was recorded

$$\text{Total solids (ppm)} = \frac{\text{Final weight} - \text{Initial weight} \times 1000}{\text{Volume of sample}}$$

3.1.6.17 Total dissolved solids

Material used

- i. 50 ml beaker was washed and oven dried for 5 minutes.
 - ii. Initial weight of the beaker was taken using sensitive weighing balance and recorded.
 - iii. Water sample was filtered through Whatman filter paper number 44
 - iv. Then water sample evaporated to dryness in an oven at 103°C to 105°C
 - v. The beakers allowed to cool and dryness in a desiccator
 - vi. Increase in weight was recorded
- Calculation

$$\text{Total dissolved solids (ppm)} = \frac{\text{Final weight of filtered sample} - \text{Initial weight} \times 1000}{\text{Volume of sample}}$$

3.1.6.18 Total suspended solids

Total suspended solids (ppm) = Total solids - Total dissolved solids

3.1.6.19 Conductivity

Conductivity value of each station was determined using conductivity /TDS/ pH meter model (PC 510) for each station. The probe was inserted in water and the reading displayed on the LCD dials was recorded. Subsequent reading for the remaining stations was recorded after rinsing the probe in distilled water and dried.

3.1.7 Primary productivity

Estimation of aquatic primary productivity

The primary productivity of the lake was estimated through oxygen production and consumption by phytoplankton through light and dark bottle method given by Adoni (1985).

3.1.7.1 Computations for primary production

Computation for primary production of the lake was done following the method given by Adoni (1985). Primary productivity values obtained through light and dark bottle method expressed in $\text{g C m}^{-3} \text{ d}^{-1}$. The following conversion was used for the same:

1 g of oxygen = 0.375 g carbon

Gross primary productivity (GPP), net primary productivity (NPP) and rate of community respiration (RR) are converted to $\text{g C m}^{-3} \text{ d}^{-1}$ by multiplying gross oxygen production (GOP), net oxygen production (NOP) and respiration (R) with a factor 0.375 and dividing the products by the period of incubation (t in days/ hours). The photosynthetic quotient for phytoplankton is typically 1.2 and therefore, the gross biomass productivity (GBP) in $\text{mg C l}^{-1} \text{ d}^{-1}$ are calculated as

$$\text{GBP} = (0.375 * \text{GOP}) / 1.2$$

Now, Gross biomass productivity is calculated from GBP by multiplying it with 7.47 and expressed in $\text{mg C m}^{-3} \text{ d}^{-1}$.

$$(\text{GBP wet weight}) = (\text{GBP mg C l}^{-1} \text{ d}^{-1}) * 7.47$$

3.1.8 Water quality index

Water quality index (WQI) created by Canadian water quality guideline for the protection of aquatic life (CCME, 2001) was used for assessment of water quality in the lake. The WQI is a mathematical instrument used to transform large

quantities of water quality data into a single number which summarize different quality parameters. The WQI is an index of water quality for a particular use. Mathematically, the index is an arithmetic weighting of normalized water quality measurements.

WQI is calculated using the following equation:

F_1 (**Scope**) represents the percentage of variables that do not meet their objectives at least once during the time period under consideration (“failed variables”), relative to the total number of variables measured:

$$F_1 = \frac{\text{Number of failed variable}}{\text{Total number of variable}} \times 100 \dots \dots \dots (1)$$

F_2 (**Frequency**) represents the percentage of individual tests that do not meet objectives (“failed tests”):

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \dots \dots \dots (2)$$

F_3 (**Amplitude**) represents the amount by which failed test values do not meet their objectives. F_3 is calculated in three steps.

The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an “excursion” and is expressed as follows. When the test value must not exceed the objective:

$$\text{excursion } i = \frac{\text{Failed Test Value}}{\text{Objective } i} - 1 \dots \dots \dots (3a)$$

For the cases in which the test value must not fall below objectives:

$$\text{excursion } i = \frac{\text{Objective } i}{\text{Failed Test Value } i} - 1 \dots \dots \dots (3b)$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions, or *nse*, is calculated as:

$$nse = \sum \frac{\sum_{i=1}^{excursion\ i}}{Number\ of\ tests} - 1 \dots \dots \dots (4)$$

F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (*nse*) to yield a range between 0 and 100.

$$F_3 = \frac{nse}{0.01nse + 0.01} \dots \dots \dots (5)$$

Once the factors have been obtained, the index itself was calculated by summing the three factors as if they were vectors. The sum of the squares of each factor is therefore equal to the square of the index. This approach treats the index as a three-dimensional space defined by each factor along one axis. With this model, the index changes in direct proportion to changes in all three factors.

The CCME Water Quality Index (CCME WQI):

$$CCME\ WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \dots \dots \dots (6)$$

The divisor 1.732 normalises the resultant values to a range between 0 and 100, where 0 represents the ‘worst’ water quality and 100 represents the ‘best’ water quality that has been most important for aquatic life preservation.

3.1.9 Metals analysis

Water, sediment and fish sample were prepared and taken to Sophisticated Analytical Instrument Facility of Indian Institute of Technology (IIT), Bombay for the heavy metals analysis using Inductively Coupled Plasma Mass Spectrometer (ICP-MS), model Element XR, Thermo Fisher Scientific.

3.1.9.1 Water sample

Typically water sample was acidified before analysis to ensure stability and comparability with calibration standards. Water sample (10 ml) was collected and placed in 15 ml centrifuge tube, 1 ml of nitric acid was added and the reading was taken using ICP-MS.

3.1.9.2 Sediment sample

Sediment sample for total elemental analysis was digested using acid digestion procedure in order to dissolve most silicate minerals. This digestion is carried out in open vessels on a hot-plate. The sample was dried in ovum for 3-4 hours and 0.1g sample was taken then 4 ml nitric acid and 2 ml of hydrochloric acid was added and heated at 80-90°C. The total volume sample was make to 15 ml with distilled water and reading was taken using ICP-MS.

3.1.9.3 Fish sample

Fish sample was generally digested using closed-vessel microwave digestion. The high temperature and pressures reached in the microwave digestion system can dissolve most fish flesh, including fatty tissues. This is also the best method for digesting organic samples, including crude oils. 0.15g of the fish sample was taken, and 3-4 ml of concentrated nitric acid was added then put in a hot plate at 80-90°C. Distilled water was added to make a total volume of 15 ml.

3.1.10 Determination of Plankton abundance, composition and distribution

3.1.10.1 Sampling and plankton analysis

The sampling was done monthly from November 2016 to October 2017, in the morning before 9:00am. Pour- through method was used to collect the samples. A 10-liter graduated bucked was used to collect water at a depth of about 30cm below the water surface, and pour into a plankton net of mesh size 150µm for zooplankton and 60µm for phytoplankton, these was done 10 times to make a total volume of 100 litres of filtered water. This was then transferred into labeled collecting bottles and

preserved in 5% formalin. The samples were taken to the laboratory for further analysis.

Each preserved plankton sample was poured into a graduated centrifuge tube and centrifuged using a 'Gallen Kamp- Medico' model (90) centrifuge this was allowed to settle and the Supe-natant decanted. After decanting the concentrated plankton was analyzed. A dropping pipette was used to place the concentrated plankton on a glass slide with a cover slip and then viewed under a binocular microscope model BH2 and a Olympus microscope model AH2 Vanox 7. The plankton was therefore counted (quantitative analysis) and then identified (qualitative analysis) using standard identification keys and Chart to identify them to species level in addition the taxonomic guide according to Pennak (1978), Jeje and Fernando (1986). The above processes were repeated four times, in order to determine the abundance and diversity of plankton at the five stations.

The estimation of species abundance and diversity of planktons was done using Margalef's Diversity Index (D), Shannon-Wiener Diversity Index(H') and Simpson's Index(D) methods (1949).

The faunal similarities at different sites based on nominal data, were analyzed using indices of Jackson (1989). The relative abundance of taxa that were common among the tributaries was calculated using Renkonen similarity (1975). Simpson index (d) and Jackknife Estimator (S) were employed to evaluate species richness. The Shannon-Weiner index (H) and evenness index (E) of Shannon and Weiner (1963) were used to evaluate species diversity. Jackknife index (S) estimate was employed to account for the probability of missing some of the actual total number of species present in any count based on a sample population.

3.1.10.2 Estimation of species abundance and diversity

a). Margalef's Diversity Index (d): is a species richness index that measures the diversity in the community structure. This was estimated using the formula as reported by Clifford and Stephenson (1975):

$$d = \frac{(S - 1)}{\ln N}$$

Where:

d = Species richness index

S = Number of species in a population

N = Total number of individuals in S species

b). Shannon-Wiener diversity index (H'): This measures faunal diversity and gives the degree of uncertainty involved in predicting the species identified from randomly selected individuals. It was calculated using the following equation as given by Magurran (2004):

$$H' = - \sum \left[\left(\frac{n_i}{N} \right) \times \ln \left(\frac{n_i}{N} \right) \right]$$

Where

n_i = number of individuals or amount of each species (the i^{th} species)

N = total number of individuals for the site

c). Simpson's Index (D): is a measure of dominance and was calculated using the formula of Simpson (1949):

$$D = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$$

Where:

n_i = number of individuals or amount of each species (i.e., the number of individuals of the i^{th} species) and

N = total number of individuals for the site.

This was then transformed into a measure of species heterogeneity using the complement of D as recommended by Lande (1996): $1 - D$.

d). Species Equitability or evenness Index (J): refers to the degree of relative dominance of each species in the dam. It was calculated according to Pielou (1966) as:

$$J = \frac{H'}{\ln S}$$

3.1.11 Physico-chemical properties of sediments

The samples were air-dried, ground to fine powder and sieved through a 2mm sieve. Sieved samples were further air-dried. Laboratory analysis for further determination of sediment and soil quality was done with these air-dried and powder sediment as given by Piper (1950) and Jhingran *et al.*, (1988) and the results were expressed on dry weight basis.

3.1.11.1 Texture of sediment

The sediment texture was determined by mechanical analysis using a Bouyocos hydrometer (graduated in g l^{-1}) and the results were expressed in percentage. Sediment texture was estimated by international pipette method (Muthuvel and Udayasooian, 1999) wherein 20g of air-dried sediment sample was placed in a 500 ml beaker and 60 ml of 6% hydrogen peroxide was added to it. It was stirred well and kept on a water-bath till the frothing stopped. After that, 200 ml of 0.5 N HCl was added to destroy CaCO_3 which act as a binder agent. The content were then filtered through Whatman (no. 5) filter paper till the filtrate was free from chloride. The sediment from the filter paper was transfer to a beaker and 400 ml of water and 8 ml of 1 N NaOH were added. The content was placed in mechanical shaker for 10 minutes, then transfer to a 1000 ml measuring cylinder and the volume was made up to 1000 ml with water. The content were mixed thoroughly and kept aside undisturbed. The silt and clay fraction were pipette out after 4 minutes and 5 seconds (at 27°C) by withdrawing 20 ml of suspension from 10 cm depth. The clay fraction was pipetted out after 6 hours 45 minutes in the same manner. The content was repeatedly wash with water and the residue was collected. All these were transfer into petri dishes and dried in an oven at 105°C , cooled in desiccators and weighed. The result was expressed in percentage of sand, silt and clay. The sediment textural class was obtained using USDA textural triangle.

3.1.11.2 Sediment pH

Sediment pH was estimated in a suspension by glass electrode method after shaking the soil with distilled water (soil to water ratio 1.0:2.5) for half an hour using a WTH pH meter. Organic carbon was estimated by wet oxidation method of Walkley and Black (1934) and the results were expressed in percentage.

3.1.11.3 Available Nitrogen

Available nitrogen was determined by the alkaline permanganate distillation method (Subbiah and Asija, 1956), using a micro-Kjeldahl unit (KEL plus-Classic DX VA, Pelican Equipments, India). About 5g of finely powdered sediment samples were used for estimation following manufacturer's instruction.

3.1.11.4 Available Phosphorus

The available phosphorus in the sediment samples was estimated according to Olsen's method (Olsen *et al.*, 1954). 2.5g scoop of sediment sample were taken in 100 ml conical flasks, to which a pinch of activated charcoal (Dargo-G) and 50 milliliters of 0.5 M sodium bicarbonate (pH 8.5) solution and then mechanically shaken for 30 minutes. The mixture is then filtered through Whatman (no. 40) filter paper and the ortho-phosphate in the filtered extract is determined colorimetrically (at 630nm) by reacting it with ammonium molybdate using ascorbic acid as the reducing agent. After the frothing completely ceased, distilled water was added, washing down the sides, to bring the volume to about 22 ml; 1 ml of freshly diluted ascorbic acid solution was added to the samples and the volume was made up to 25 ml. At about 10 minutes the blue colour intensity was read at 660nm using spectrophotometer (UV/VIS spectrophotometer 2080 system). The absorbance value was plotted on a standard curve to obtain the concentration of available phosphorus as parts per million (ppm) of phosphorus (P) in the sediment.

3.2 Hardware

3.2.1 Computer system

All laboratory-based work was carried out within the facilities of the Geographical Information Systems and Statistic lab of the Social Science/ Fisheries Economics, Extension and Statistics Division, ICAR-CIFE, Deemed University. The computer system used was a Dell workstation, model T5400, containing a Intel Xeon 3.16Ghz CPU with 8 Gb RAM running 64-bit Windows 7 operating system. Laboratory PCs are connected to the Local Area Network (LAN) of the Central Institute of Fisheries Education and to other devices such as printers, digitizer, storage systems, etc.

3.2.2 Storage facilities

High resolution spatial data (30 m x 30 m) was used for the whole catchment area of the Powai Lake (6.61 square kilometres). This required large local storage (2Tb + 2 Tb HDD) and access to the research group's network attached storage (NAS) systems (QNAP16 Tb active and LaCie 4Tb archive).

3.2.3 Output facilities

To enable high quality work, every workstation PC is equipped with twin high

resolution 21” monitors supported by a high capacity integrated graphic card with up to 4 Gb display capacity. Printing was done via a networked Epson Aculaser C1900 device.

3.2.4 Software

The main spatial modelling software (Geographic Information System – GIS) used in the study was Sentinel 2A. The software is specifically designed for both GIS and remote sensing operations and is particularly suitable for environmental modelling, natural resources management, multi criteria and multi objective decision support, risk analysis, spatial or surface interpolation, and statistical characterization. The software comprises almost 300 program modules to allow users to input, display and analyse the spatial information (Eastman 1999, 2006). Besides, the main software use was made of Google Earth (Google Corp, USA, 2012) which is one of the most popular programs for visualising topographic and land-use data and to support land cover classification. Subject to checking image date and quality, this data portal is widely used to verify ground-truth user data against current satellite information.

3.2.5 Acquisition and processing of data

Satellite images used in this study was downloaded free of charge from the USGS website (*United States Geological Survey: [http:// earthexplorer.usgs.gov](http://earthexplorer.usgs.gov)*) through the Sentinel 2A. The downloaded products was chosen from the period of November, 2016 to October, 2017 and covering the entire catchment area of Powai Lake. SNAP-6 in Sentinel 2 box was used and run in iCOR.

3.2.6 GPS support

To locate a sample point in the field, a hand held GPS (Global Positioning System) device was used. Garmin orgon@650 used was able to receive signals from up to 12 satellites to calculate the position and planning the route to approach a target, therefore approaching a target mainly relied upon compass and distance calculation functions generated from GPS.

3.2.7 Spatial data sets

Not all spatial data downloaded from different resources was in a similar projection system and so the geo-referencing of data sets needed to be unified prior to use in the spatial database and models. The PROJECT module was used to transform all raster and vector layers from their current referencing system to the

UTM-48N system (Universal Transverse Mercator- Zone 48). The process uses a re-sampling procedure with the options of bilinear analysis. The computation process adopts a value based on the distance-weighted average of the values of the four nearest cells in the input image. This option was chosen because the input image was quantitative (Eastman, 2006). In some cases, low resolution images after re-projection subjected to distortion and not matching the reference image template (usually the study area image). To correct them, the RESAMPLE module was called to correct the geo-coordinates by matching the ground control points (GCPs) between the template image and the distorted one (Salam *et al.*, 2003; Maria, 2002).

3.2.8 Arc GIS 10.3

Arc GIS developed by Environmental System Research Institute (ESRI) Redlands, California was used for analyzing the geographic data. It was used for making thematic maps, build up and edit geographic data, analyzed map information, sharing and discovering geographic information, using maps and geographic information in a range of various applications, and managing geographic information in a database. The Arc GIS 10.3 was used for the present study.

3.2.9 QGIS

QGIS is a free and open source desktop geographic information system application that is used to edit and analyze geographic information and represent the analyzed data. Like other GIS software, it is also used for creating and editing maps with many layers using different map projection. Maps can be assembled in different layers using different map projection. Maps can be assembled in different formats and for different uses. It was used for making raster and vector layers in the present study. In this software, vector data can be saved in point, line or polygon features and URLs directly used for mapping. QGIS ESSEN (2.14.3) was used in this study.

3.2.10 Corel draw 12

Corel draw is a vector graphic editor tool. It was used to draw the scale diagram of Dol net.

3.2.11 Microsoft excel 2013

Microsoft Excel 2013 was used for calculation of monthly water, sediment, heavy metals, plankton species composition data sets, and also for conversion of GPS location points into degree decimals.

3.3 Statistical analysis

All data on the physico-chemical and biological studies were statistically analysed using one-way analysis of variance (ANOVA-IBM SPSS version 22), and the significant differences between the means were determined by Duncan's Multiple Range Test (DMRT). The significance level was made at $P < 0.05$. Data are as mean $\pm$ standard error of the mean.

4. RESULTS

4.1 Physico-chemical Parameters

4.1.1 Air Temperature

The monthly variations of water quality parameters of Powai lake are presented in Table 1. The results showed that air temperature varied across the months and it ranged from 24.51 to 32.39⁰C in the months of December and May. Other higher values were recorded in the months of July, August and February. There was significant difference ($P>0.05$) among all the study months, except in November and January; March and June; April, July, August and October ($P<0.05$).

The variations in water quality parameters across stations studied in Powai lake are presented in Table 3. It showed air temperature across the stations were relatively within closely related range of 23.33 to 27.33⁰C at station B and station A respectively. For the month of December, it ranged from 23.73 to 25.66⁰C in station C and station A. There were no significant differences ($P<0.05$) between station B and C; station D and E, while it is significantly different with station A. In the month of January, station A had the highest (28.63⁰C) and lowest value in station E (25.33⁰C), there was significant difference ($P<0.05$) between all the stations except in station C and D; and station A and B respectively. 30.83⁰C was recorded in station C as highest while 27.26⁰C was lowest in station A for the month of February, there is significant difference ($P>0.05$) between all the stations except in station C and D. However, station E (30.66⁰C) was highest and station C (26.60⁰C) was the lowest in March, there is significant difference ($P>0.05$) in all the stations except station C, D and E.

Table 1: Monthly mean variation in physico-chemical parameters of Powai lake (November, 2016 to October, 2017)

Month	A/temperature (°C)	W/temperature (°C)	Transparency (cm)	Turbidity (NTU)	Depth (m)	pH	DO (ppm)	CO ₂ (ppm)	Alkalinity (ppm)	Hardness (ppm)	Chloride (ppm)
November	26.33±0.25 ^b	25.94±0.09 ^c	38.26±1.41 ^g	47.46±2.12 ^d	4.26±0.28 ^a	7.12±0.01 ^a	5.49±0.17 ^b	0.00±0.00 ^a	133.46±2.56 ^e	138.80±1.80 ^g	64.00±2.46 ^g
December	24.51±0.19 ^a	23.75±0.12 ^a	28.60±0.86 ^d	34.33±1.37 ^c	4.27±0.22 ^a	7.18±0.01 ^b	6.29±0.21 ^{cd}	0.00±0.00 ^a	127.73±0.80 ^d	20.93±1.30 ^a	32.00±0.43 ^a
January	26.36±0.32 ^b	24.31±0.03 ^b	34.90±0.80 ^f	47.26±1.73 ^d	4.16±0.30 ^a	7.18±0.02 ^b	7.09±0.21 ^e	0.00±0.00 ^a	128.13±0.94 ^d	22.66±1.50 ^a	34.00±0.55 ^{ab}
February	29.31±0.38 ^d	29.12±0.33 ^d	24.46±0.45 ^c	57.33±1.13 ^f	4.20±0.37 ^a	7.32±0.01 ^c	6.32±0.34 ^{cd}	6.80±1.01 ^b	109.06±2.63 ^b	113.20±3.93 ^c	45.20±0.54 ^f
March	28.19±0.42 ^c	31.34±0.12 ^h	17.80±0.49 ^a	85.66±1.68 ^h	3.36±0.33 ^a	7.38±0.00 ^e	6.72±0.29 ^{de}	0.00±0.00 ^a	107.20±1.54 ^{ab}	98.13±1.78 ^b	44.00±0.64 ^{ef}
April	29.76±0.22 ^d	31.24±0.03 ^{gh}	20.10±0.31 ^b	79.33±1.75 ^g	3.28±0.32 ^a	7.44±0.02 ^{fg}	5.70±0.18 ^{bc}	0.00±0.00 ^a	106.80±0.69 ^{ab}	99.20±1.24 ^b	46.13±0.56 ^f
May	32.39±0.16 ^f	32.92±0.04 ⁱ	16.96±0.29 ^a	88.33±1.59 ^h	2.83±0.35 ^a	7.47±0.01 ^{fg}	3.46±0.18 ^a	0.00±0.00 ^a	116.26±2.22 ^c	122.66±3.54 ^d	67.73±1.89 ^h
June	27.66±0.15 ^c	29.42±0.03 ^{de}	28.33±0.33 ^d	52.53±0.55 ^e	4.19±0.38 ^a	7.18±0.01 ^b	5.86±0.22 ^{bc}	13.20±4.52 ^d	102.66±1.46 ^a	152.26±5.44 ^b	40.93±0.64 ^{de}
July	29.92±0.25 ^d	29.66±0.04 ^{ef}	31.18±0.35 ^e	33.93±1.49 ^c	6.90±2.93 ^b	7.38±0.01 ^{de}	10.80±0.31 ^g	0.00±0.00 ^a	120.13±2.06 ^c	135.73±2.61 ^f	38.53±0.60 ^{cd}
August	29.82±0.22 ^d	29.39±0.03 ^{de}	26.10±1.01 ^c	45.33±1.88 ^d	4.06±0.36 ^a	7.40±0.00 ^{ef}	9.25±0.25 ^f	0.00±0.00 ^a	110.40±0.94 ^b	145.06±2.40 ^{gh}	38.26±0.61 ^{cd}
September	31.16±0.18 ^e	30.94±0.09 ^g	42.36±0.81 ^h	24.93±0.72 ^a	3.95±0.37 ^a	7.50±0.01 ^g	13.81±0.29 ^h	0.00±0.00 ^a	149.06±2.08 ^f	126.40±1.99 ^{de}	36.80±1.87 ^{bc}
October	29.66±0.27 ^d	29.82±0.04 ^f	34.40±0.44 ^f	29.73±0.81 ^b	3.69±0.34 ^a	7.34±0.01 ^{cd}	6.72±0.24 ^{de}	9.73±1.27 ^c	215.73±1.40 ^g	132.53±1.98 ^{ef}	32.53±0.56 ^a
Objective	25-32	24-27	20-35	<30		6.7-9.5	5-10	<3	50-300	30-180	31-50

Means (±SE) in the same column having different superscripts are significantly (P<0.05) different

For April, it ranged from 28.96⁰C to 30.90⁰C in station D and C. Other higher value was recorded in station B and there is no significant difference ($P < 0.05$) in station A, D and E; and station B and C. In the month of May, lowest value was recorded in station E (31.20⁰C) and highest in station A (32.76⁰C). There was significant difference ($P > 0.05$) in all the stations except station B and C. For the month of June, highest temperature was recorded in station D (28.70⁰C), while lowest in station B (27.10⁰C). There is significant difference ($P > 0.05$) in all the stations except station B, C and D. 30.80⁰C was highest in station B and 28.10⁰C was lowest in station E for the month of July, other higher values were recorded in stations A, C and D. There is significant difference between all the stations ($P > 0.05$). In August, lowest value was recorded in station E (28.48⁰C) while highest value in station A (30.86⁰C). There is significant difference across all the stations ($P > 0.05$). 30.33⁰C to 31.93⁰C were recorded in station B and A as the lowest and highest reading of temperature for the month of September, other higher values were recorded in station D and E, there is significant difference in all the stations ($P > 0.05$). Highest temperature was recorded in station A (30.76⁰C) and lowest in station C (27.86⁰C) in the month of October, there is significant difference among all the stations ($P > 0.05$).

4.1.2 Water Temperature

The surface water temperature ranged between 23.75 and 32.92⁰C which shows a wide variation across the months of December and May (Table 1), although other higher values were recorded in the months of March and April with significant difference, ($P > 0.05$). Also, lower values were recorded in the months of November and January with significant difference ($P > 0.05$) Table 1.

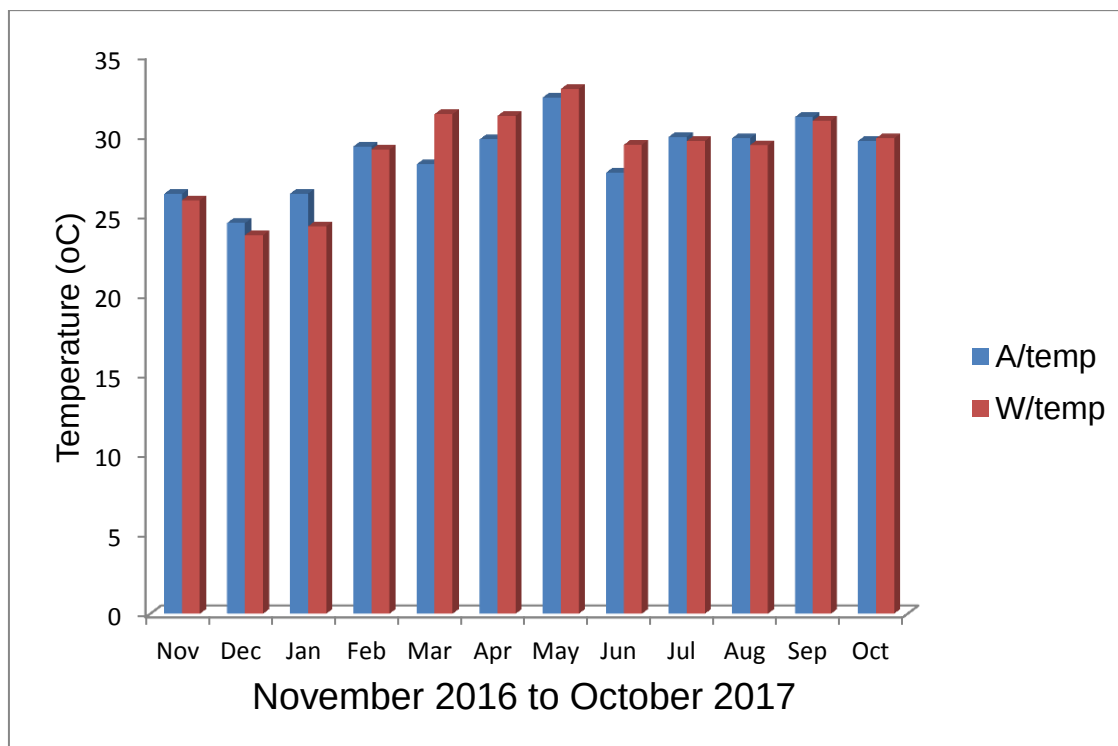


Fig. 5: Relationship of air temperature and water temperature (During post-monsoon there is corresponding increase in water temperature as the air temperature increases, but in pre-monsoon and monsoon water temperature increases higher than air temperature).

In terms of stations, 25.46 to 26.30°C ranged was recorded throughout the study for the month of November (Table 4). There was significant difference among stations A, D and E, with stations B and C ($P>0.05$). For the month of December, it ranged from 23.26 to 24.33°C in station C and station E. There was no significant difference ($P<0.05$) between station A and E; station B and C while it is significantly different with station D. In the month of January, station D had the highest (24.43°C) and lowest value was recorded in station B (24.23°C); there was no significant difference ($P<0.05$) among all the stations. 31.16°C was recorded in station A as highest while 27.63°C was lowest in station B for the month of February, there was significant difference ($P>0.05$) among all the stations except in station B and C. Table 4, showed station A (32.13°C) was highest and station E (30.83°C) was the lowest in March, there was significant difference ($P>0.05$) in all the stations except station B and D. For April, it ranged from 31.06°C to 31.36°C in station E and D. Other higher value was recorded in station A, B and C. There was no significant difference ($P<0.05$) in station B, C and D; and significantly difference ($P>0.05$) in station A and E.

Table 2: Monthly mean variation in water quality parameters of Powai lake (November, 2016 to October, 2017)

Month	NH ₄ ⁺ -N (ppm)	NO ₂ -N (ppm)	NO ₃ -N (ppm)	Phosphate (ppm)	TS (ppm)	TDS (ppm)	TSS (ppm)	BOD (ppm)	COD (ppm)	Conductivity (μS/cm)
November	0.41±0.02 ^{bc}	0.14±0.03 ^b	2.73±0.15 ^f	1.30±0.11 ^a	220±0.01 ^a	20±0.00 ^a	200±0.03 ^c	3.70±0.36 ^b	44.13±2.05 ^{bc}	244.33±0.58 ^d
December	0.28±0.01 ^b	0.06±0.00 ^{ab}	0.20±0.02 ^a	0.17±0.03 ^a	230±0.00 ^a	170±0.01 ^c	60±0.01 ^a	4.38±0.44 ^{bc}	14.26±2.63 ^a	253.00±0.47 ^e
January	0.06±0.00 ^a	0.05±0.01 ^{ab}	0.63±0.03 ^{bc}	0.49±0.00 ^b	190±0.00 ^a	140±0.01 ^c	50±0.00 ^a	2.29±0.39 ^a	12.80±0.47 ^a	292.26±0.67 ^g
February	0.37±0.07 ^{bc}	0.03±0.00 ^{ab}	0.76±0.01 ^c	2.46±0.11 ^e	200±0.00 ^a	140±0.01 ^c	60±0.01 ^a	6.25±0.52 ^d	42.66±3.74 ^{bc}	288.86±1.19 ^g
March	0.40±0.06 ^{bc}	0.12±0.03 ^{ab}	1.85±0.23 ^e	0.17±0.00 ^a	300±0.01 ^a	220±0.01 ^d	80±0.02 ^{ab}	7.63±0.31 ^e	121.06±0.67 ^h	283.13±1.23 ^f
April	0.40±0.06 ^{bc}	0.11±0.02 ^{ab}	1.91±0.22 ^e	0.18±0.00 ^a	230±0.00 ^a	170±0.01 ^c	60±0.01 ^a	5.33±0.53 ^{cd}	123.46±0.49 ^h	321.00±1.55 ^h
May	0.43±0.03 ^{bc}	0.02±0.00 ^a	1.39±0.07 ^d	2.09±0.07 ^d	380±0.06 ^b	170±0.00 ^c	110±0.06 ^c	5.62±0.20 ^d	112.53±2.77 ^g	480.80±2.83 ^j
June	0.36±0.02 ^{bc}	1.29±0.10 ^d	3.00±0.00 ^f	0.45±0.01 ^b	250±0.01 ^a	90±0.01 ^b	160±0.01 ^{bc}	6.41±0.23 ^d	83.06±2.42 ^e	370.46±2.01 ⁱ
July	0.66±0.09 ^d	0.03±0.00 ^{ab}	0.35±0.02 ^{ab}	0.59±0.02 ^b	190±0.00 ^a	100±0.00 ^b	90±0.01 ^{ab}	6.36±0.37 ^d	39.60±2.90 ^b	602.73±4.33 ^k
August	0.33±0.06 ^{bc}	0.28±0.03 ^c	2.73±0.15 ^f	0.47±0.03 ^b	410±0.01 ^b	90±0.01 ^b	320±0.02 ^d	8.42±0.44 ^{ef}	59.33±4.91 ^d	177.26±2.11 ^c
September	0.48±0.08 ^c	0.04±0.01 ^{ab}	0.56±0.10 ^{bc}	0.53±0.01 ^b	220±0.03 ^a	90±0.12 ^b	130±0.02 ^{ab}	9.02±0.44 ^f	97.73±4.13 ^f	157.20±1.26 ^b
October	0.47±0.03 ^c	0.01±0.00 ^a	0.67±0.03 ^{bc}	5.00±0.00 ^f	180±0.00 ^a	100±0.00 ^b	80±0.01 ^{ab}	5.92±0.53 ^d	48.66±2.58 ^c	142.13±2.22 ^a
Objective	0-1	0-0.5	0.1-3	0.05-0.4	<500	<500	30-200	<10	<50	150-500

Means (±SE) in the same column having different superscripts are significantly (P<0.05) different

Table 3: Air temperature ($^{\circ}\text{C}$) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	27.33 $\pm$ 0.93 ^a	23.33 $\pm$ 0.68 ^a	25.70 $\pm$ 0.50 ^a	26.16 $\pm$ 0.06 ^a	26.13 $\pm$ 0.08 ^a
December	25.66 $\pm$ 0.14 ^c	23.83 $\pm$ 0.06 ^a	23.73 $\pm$ 0.03 ^a	24.76 $\pm$ 0.08 ^b	24.56 $\pm$ 0.08 ^b
January	28.63 $\pm$ 0.03 ^c	25.36 $\pm$ 0.14 ^a	26.30 $\pm$ 0.11 ^b	26.16 $\pm$ 0.03 ^b	25.33 $\pm$ 0.06 ^a
February	27.26 $\pm$ 0.06 ^a	28.06 $\pm$ 0.03 ^b	30.83 $\pm$ 0.03 ^d	30.76 $\pm$ 0.03 ^d	29.63 $\pm$ 0.03 ^c
March	28.03 $\pm$ 0.08 ^b	29.00 $\pm$ 0.65 ^c	26.60 $\pm$ 0.10 ^a	26.66 $\pm$ 0.08 ^a	30.66 $\pm$ 0.06 ^a
April	29.13 $\pm$ 0.33 ^a	30.46 $\pm$ 0.06 ^b	30.90 $\pm$ 0.05 ^b	28.96 $\pm$ 0.29 ^a	29.36 $\pm$ 0.14 ^a
May	32.76 $\pm$ 0.03 ^c	32.63 $\pm$ 0.03 ^b	32.63 $\pm$ 0.03 ^b	32.73 $\pm$ 0.03 ^{bc}	31.20 $\pm$ 0.05 ^a
June	27.53 $\pm$ 0.03 ^b	27.10 $\pm$ 0.00 ^a	27.13 $\pm$ 0.03 ^a	28.70 $\pm$ 0.00 ^a	27.86 $\pm$ 0.03 ^c
July	30.60 $\pm$ 0.00 ^d	30.80 $\pm$ 0.00 ^e	30.10 $\pm$ 0.00 ^c	30.03 $\pm$ 0.03 ^b	28.10 $\pm$ 0.10 ^a
August	30.86 $\pm$ 0.03 ^e	30.06 $\pm$ 0.03 ^c	29.33 $\pm$ 0.03 ^b	30.36 $\pm$ 0.03 ^d	28.46 $\pm$ 0.03 ^a
September	31.93 $\pm$ 0.03 ^c	30.33 $\pm$ 0.38 ^a	30.56 $\pm$ 0.03 ^{ab}	31.10 $\pm$ 0.05 ^b	31.86 $\pm$ 0.08 ^c
October	30.76 $\pm$ 0.03 ^e	29.36 $\pm$ 0.03 ^b	27.86 $\pm$ 0.03 ^a	30.43 $\pm$ 0.03 ^d	29.86 $\pm$ 0.03 ^c

Means ($\pm$ SE) in the same row followed by different superscripts differ significantly ($P>0.05$)

In the month of May (table 4), lowest value was recorded in station E (32.63 $^{\circ}\text{C}$) and highest in station C and D (32.93 $^{\circ}\text{C}$) respectively. There was no significant difference ($P<0.05$) in all the stations except station E. For the month of June, highest temperature was recorded in station A (29.60 $^{\circ}\text{C}$), while lowest was in station D (29.26 $^{\circ}\text{C}$). There was significant difference ($P>0.05$) among all the stations except station A and B. 29.86 $^{\circ}\text{C}$ was highest in station A and 29.46 $^{\circ}\text{C}$ was lowest in station C for the month of July, other higher values were recorded in station B and D. There was significant difference among all the stations ($P>0.05$) except station B and D; and station C and E. In August, lowest value was recorded in station A (29.23 $^{\circ}\text{C}$) while highest value was in station C and D (29.53 $^{\circ}\text{C}$). There was significant difference ($P>0.05$) across all the stations except station A and E; and station C and D. A variation of 30.66 $^{\circ}\text{C}$ to 31.63 $^{\circ}\text{C}$ was recorded in station D and A as the lowest and highest reading of temperature for the month of September, other higher values were recorded in station B, C and E; and there was significant difference among all the stations ($P>0.05$). Highest temperature was recorded in station A (30.10 $^{\circ}\text{C}$) and

lowest in station E (29.60°C) in the month of October, there was significant difference ($P>0.05$) among all the stations, except station B, C and D.

Table 4: Water temperature (°C) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	26.30±0.05 ^b	25.46±0.14 ^a	25.66±0.03 ^a	26.16±0.12 ^b	26.13±0.08 ^b
December	24.26±0.08 ^c	23.30±0.10 ^a	23.26±0.03 ^a	23.60±0.05 ^b	24.33±0.14 ^c
January	24.36±0.06 ^a	24.23±0.06 ^a	24.26±0.03 ^a	24.43±0.08 ^a	24.26±0.08 ^a
February	31.16±0.03 ^e	27.63±0.03 ^a	27.96±0.03 ^a	29.16±0.03 ^c	29.66±0.08 ^d
March	32.13±0.08 ^d	31.06±0.06 ^b	31.50±0.05 ^c	31.16±0.03 ^b	30.83±0.06 ^a
April	31.23±0.03 ^{ab}	31.26±0.08 ^b	31.26±0.06 ^b	31.36±0.03 ^b	31.06±0.03 ^a
May	33.06±0.08 ^b	33.03±0.03 ^b	32.93±0.03 ^b	32.93±0.03 ^b	32.63±0.03 ^a
June	29.60±0.00 ^c	29.53±0.03 ^c	29.40±0.00 ^b	29.26±0.03 ^a	29.33±0.03 ^{ab}
July	29.86±0.03 ^c	29.76±0.03 ^b	29.46±0.03 ^a	29.70±0.00 ^b	29.50±0.00 ^a
August	29.23±0.03 ^a	29.40±0.00 ^b	29.53±0.06 ^c	29.53±0.03 ^c	29.26±0.03 ^a
September	31.63±0.03 ^d	30.70±0.00 ^{ab}	30.83±0.03 ^{bc}	30.66±0.06 ^a	30.90±0.05 ^c
October	30.10±0.00 ^c	29.80±0.00 ^b	29.80±0.00 ^b	29.83±0.03 ^b	29.60±0.00 ^a

Means (±SE) in the same row followed by different superscripts differ significantly ($P<0.05$)

4.1.3 Transparency

16.96 to 42.36cm was recorded as the lowest and highest transparency values in the months of May and September. Other higher value were recorded in November, January and October with significant difference ($P>0.05$) across all the months except in January and October; February and August; and March and May, (Table 1).

The transparency was fluctuated from 32.66 to 47.66 cm in November (table 5). There was significant difference ($P>0.05$) among all the stations except station B and E. For the month of December, it ranged from 27.00 to 30.16 cm in station C and station A. There was no significant differences ($P<0.05$) among all the stations.

Table 5: Transparency (cm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	32.66±0.72 ^a	35.66±0.60 ^b	39.83±0.16 ^c	47.66±0.72 ^d	35.50±0.00 ^b
December	30.00±3.75 ^a	27.80±1.36 ^a	27.00±0.76 ^a	30.16±1.64 ^a	28.00±1.73 ^a
January	34.66±0.72 ^a	33.83±0.44 ^a	32.50±1.25 ^a	33.33±1.20 ^a	40.16±0.60 ^b
February	23.66±0.16 ^a	23.83±0.44 ^a	26.66±0.88 ^a	24.16±0.88 ^a	24.00±1.52 ^a
March	15.00±0.28 ^a	17.33±0.44 ^b	19.66±0.44 ^c	17.33±0.44 ^b	19.66±0.44 ^c
April	19.83±1.16 ^a	19.66±0.44 ^a	19.50±0.57 ^a	21.16±0.66 ^a	20.33±0.44 ^a
May	17.00±0.28 ^b	16.66±0.33 ^b	18.16±0.44 ^c	17.66±0.16 ^{bc}	15.33±0.44 ^a
June	28.33±0.44 ^b	27.83±0.44 ^{ab}	27.00±0.28 ^a	30.50±0.28 ^c	28.00±0.00 ^{ab}
July	31.83±0.33 ^c	33.16±0.33 ^d	29.66±0.16 ^a	30.93±0.52 ^{bc}	30.33±0.44 ^{ab}
August	24.50±0.28 ^{ab}	33.50±0.28 ^c	25.16±0.33 ^b	24.00±0.28 ^{ab}	23.33±0.72 ^a
September	40.16±0.33 ^a	41.50±0.50 ^b	40.66±0.16 ^{ab}	48.33±0.16 ^c	41.16±0.33 ^{ab}
October	35.00±0.28 ^c	37.33±0.16 ^d	32.83±0.16 ^a	33.16±0.16 ^{ab}	33.66±0.33 ^b

Means (±SE) in the same row followed by different superscripts differ significantly (P>0.05)

In the month of January, station E had the highest (40.16 cm) and lowest value in station C (32.50 cm), there was no significant difference (P<0.05) among all the stations except in station E. A value of 26.66 cm was recorded in station C as highest while 23.66 cm was lowest in station A for the month of February, there was no significant difference (P<0.05) among all the stations. Station C and E (19.66 cm) are highest and station A (15.00 cm) is the lowest recorded during March, there was significant difference (P>0.05) in all the stations except station B and D; and station C and E. For April, it ranged from 19.50 to 21.16 cm in station C and D. Other higher value was recorded in station E. There was no significant difference (P<0.05) among all the stations. In the month of May, lowest value was recorded in station E (15.33 cm) and highest in station C (18.16 cm). There was significant difference (P>0.05) in all the stations except in station A and B. For the month of June, highest transparency was recorded in station D (30.50 cm), while lowest in station C (27.00 cm). There was significant difference (P>0.05) in all the stations. 33.16 cm was highest in station B and 29.66 cm was lowest in station C for the month of July, there

was significant difference ($P>0.05$) among all the stations. In August, station E (23.33 cm) recorded the lowest value while station B (33.50 cm) was noted the highest. There was significant difference ($P>0.05$) across all the stations, except station A and D. Fluctuation of 40.16 to 48.33 cm was recorded in station A and D as the lowest and highest values of transparency for the month of September, other higher values were recorded in station B and E, there was significant difference ($P>0.05$) among all the stations. Highest transparency was recorded in station B (37.33 cm) and lowest in station C (32.83 cm) during the month of October, there was significant difference ($P>0.05$) among all the stations.

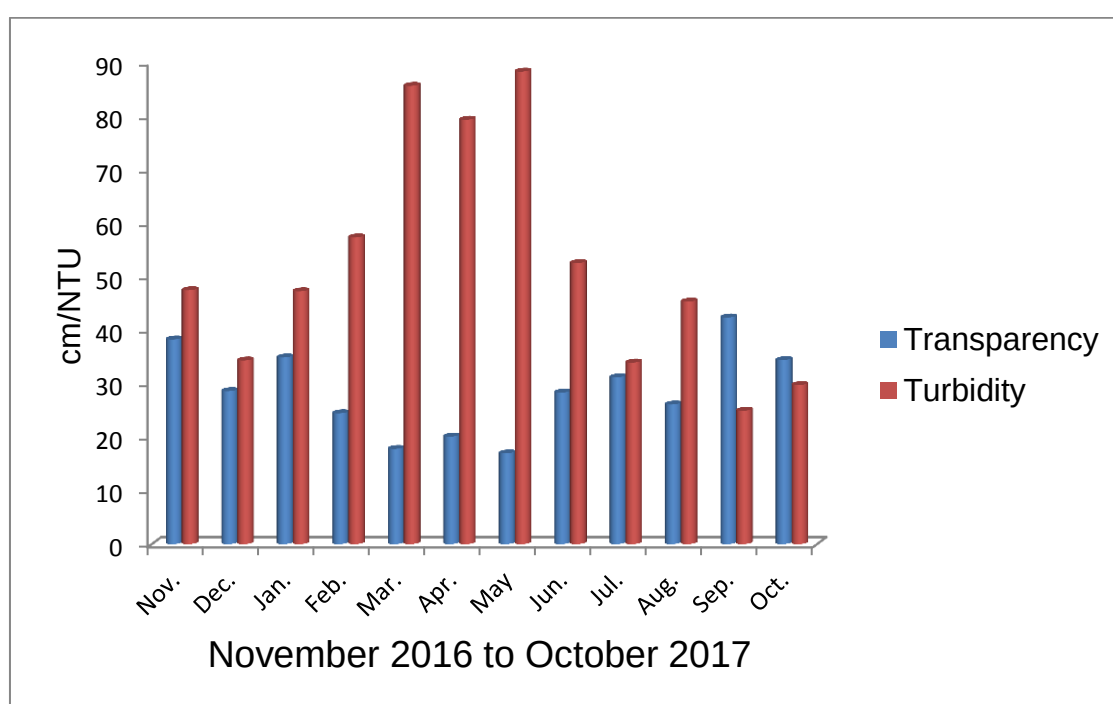


Fig. 6: Correlative account of turbidity and transparency (During post-monsoon and pre-monsoon, there is corresponding increase of turbidity to every increase in transparency while in monsoon, transparency decline considerably and turbidity increased to reach a peak).

4.1.4 Turbidity

The turbidity of Powai lake ranged from 24.93 to 88.33 NTU during the months of September and May, other higher values were recorded in March and April (table 1). There was significant difference ($P<0.05$) among all the months except in November and January; December and July; and March and May.

In terms of stations, 37.66 to 55.66 NTU was recorded in station D and B, as the lowest and highest values in the month of November (table 6). There was significant difference ($P>0.05$) among all the stations. For the month of December, it ranged from 29.00 to 41.66 NTU in station E and station C. There was no significant difference ($P<0.05$) among all the stations, except B and C. In the month of January, station D had the highest (54.33 NTU) and lowest value in station A (35.66 NTU), there was significant difference ($P>0.05$) among all the stations, except station C and E. The value of 60.00 NTU was recorded in stations A and B as highest while 51.66 NTU was lowest in station C for the month of February, there was significant difference ($P>0.05$) among all the stations except in station A and B; and station D and E.

Table 6: Turbidity (NTU) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	53.00±0.57 ^{bc}	55.66±0.66 ^c	47.66±5.48 ^{abc}	37.66±1.45 ^a	43.33±4.48 ^{ab}
December	30.33±1.45 ^a	37.67±1.45 ^b	41.66±2.02 ^b	33.00±1.00 ^a	29.00±1.00 ^a
January	35.66±1.20 ^a	46.00±1.00 ^b	49.66±0.88 ^c	54.33±0.66 ^d	50.66±0.66 ^c
February	60.00±2.88 ^b	60.00±2.88 ^b	51.66±1.66 ^a	57.33±0.33 ^{ab}	57.66±1.45 ^{ab}
March	85.00±2.88 ^{ab}	86.66±1.66 ^b	91.66±1.66 ^b	76.66±4.40 ^a	88.33±1.66 ^b
April	76.66±1.66 ^{ab}	76.66±4.40 ^{ab}	83.33±1.66 ^{ab}	73.33±4.40 ^a	86.66±1.66 ^b
May	81.66±1.66 ^a	98.33±1.66 ^c	86.66±1.66 ^{ab}	88.33±1.66 ^b	86.66±1.66 ^{ab}
June	55.33±0.33 ^d	54.00±0.57 ^{cd}	50.66±0.66 ^{ab}	50.33±0.33 ^a	52.33±0.66 ^{bc}
July	25.33±0.33 ^a	40.66±0.66 ^d	36.00±1.00 ^c	37.66±0.66 ^c	30.00±0.00 ^b
August	35.66±0.66 ^a	52.00±1.15 ^d	54.33±0.66 ^d	40.66±0.66 ^b	44.00±1.00 ^c
September	29.33±0.33 ^d	26.33±0.33 ^c	24.00±0.00 ^b	21.66±0.33 ^a	23.33±0.66 ^b
October	35.33±0.33 ^d	28.33±0.33 ^b	30.00±0.00 ^c	28.66±0.33 ^b	26.33±0.33 ^a

Means (±SE) in the same row followed by different superscripts differ significantly ($P>0.05$)

Table 6, shows station C (91.66 NTU) had the highest and station D (76.66 NTU), the lowest turbidity in March. There was significant difference ($P > 0.05$) in all the stations except station B, C and E. For April, it ranged from 73.33 to 86.66 NTU in station D and E. Other higher value was recorded in station C. There was no significant different ($P < 0.05$) in stations A, B and C; and significantly different ($P > 0.05$) in stations D and E. In the month of May, lowest value was recorded in station A (81.66 NTU) and highest in station B (98.33 NTU) respectively. There was significant difference ($P > 0.05$) among all the stations except station C and E. For the month of June, highest turbidity was recorded in station A (55.33 NTU), while lowest was recorded in station D (50.33 NTU). There was significant difference ($P > 0.05$) among all the stations. The 40.66 NTU was highest in station B and 25.33 NTU was lowest in station A for the month of July; other higher values were recorded in station C and D. There was significant difference among all the stations ($P > 0.05$) except stations C and D. In August, lowest value was recorded in station A (35.66 NTU) while highest value was in station C (54.33 NTU). There was significant difference ($P > 0.05$) across all the stations, except stations B and C. 21.66 and 29.33 NTU was recorded in station D and A as the lowest and highest values of turbidity for the month of September, other higher value was recorded in station B, there was significant difference ($P > 0.05$) in all the stations, except stations C and E. Highest turbidity was recorded in station A (35.33 NTU) and lowest in station E (26.33 NTU) in the month of October, there was significant difference ($P > 0.05$) among all the stations, except stations B and D.

4.1.5 Depth

2.83 to 6.90 m was the minimum and maximum depth observed during the months of May and July. Other higher values were recorded in the month of November, December and July. There was no significant difference ($P < 0.05$) across the months of present study except in the month of February (table 1).

In terms of stations (table 7), 3.38 to 6.26 m was recorded in station D and A, as the lowest and highest values in the month of November. There was significant difference ($P > 0.05$) among all the stations. For the month of December, it ranged from 3.46 to 5.77 m in station C and A. There was significant difference ($P > 0.05$) among all the stations. In the month of January, station A had the highest (5.91 m)

and lowest value in station E (2.78 m), there was significant difference ($P>0.05$) among all the stations. 6.37 m was recorded in station A as highest while 2.24 m was lowest in station E for the month of February, there was significant difference ($P>0.05$) among all the stations.

Table 7: Depth (m) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	6.26±0.01 ^d	3.65±0.08 ^b	3.60±0.11 ^{ab}	3.38±0.79 ^a	4.43±0.03 ^c
December	5.77±0.14 ^d	3.77±0.05 ^{ab}	3.46±0.08 ^a	3.96±0.07 ^b	4.41±0.17 ^c
January	5.91±0.03 ^e	4.21±0.05 ^c	3.17±0.04 ^b	4.72±0.10 ^d	2.78±0.17 ^a
February	6.37±0.03 ^d	3.84±0.08 ^c	3.20±0.12 ^b	3.52±0.14 ^{bc}	2.24±0.18 ^a
March	5.39±0.00 ^e	3.37±0.02 ^c	2.76±0.04 ^b	3.68±0.04 ^d	1.59±0.01 ^a
April	5.25±0.05 ^e	3.33±0.03 ^c	2.68±0.05 ^b	3.58±0.01 ^d	1.56±0.02 ^a
May	5.02±0.01 ^d	3.03±0.00 ^c	2.07±0.01 ^b	3.03±0.01 ^c	1.02±0.01 ^a
June	6.46±0.03 ^d	3.76±0.03 ^b	2.16±0.03 ^a	3.70±0.05 ^b	4.86±0.03 ^c
July	6.46±0.03 ^d	3.73±0.03 ^b	2.18±0.01 ^a	3.76±0.03 ^b	4.86±0.03 ^c
August	6.16±0.12 ^d	3.63±0.08 ^b	2.13±0.06 ^a	3.60±0.05 ^b	4.80±0.05 ^c
September	6.10±0.20 ^d	3.46±0.03 ^b	1.93±0.03 ^a	3.56±0.03 ^b	4.70±0.05 ^c
October	5.70±0.05 ^d	3.26±0.03 ^b	1.73±0.06 ^a	3.46±0.03 ^b	4.30±0.11 ^c

Means ($\pm$ SE) in the same row followed by different superscripts differ significantly ($P>0.05$)

Table 7, shows station A (5.39 m) was the highest depth value and station E (1.59 m) is the lowest during March, there was significant difference ($P>0.05$) in all the stations. For April, it ranged from 1.56 to 5.25 m in station E and A. Other higher value was recorded in station D. There was significant difference ($P>0.05$) among all the stations. In the month of May, lowest value was in station E (1.02 m) and highest in station A (5.02 m). There was significant difference ($P>0.05$) among all the stations except stations B and D. For the month of June, highest depth was recorded in station A (6.46 m), while lowest in station C (2.16 m). There was significant difference ($P>0.05$) among all the stations, except stations B and D. 6.46 m was highest value in station A and 2.18 m was lowest in station C for the month of July, other higher

values were recorded in station D and E. There was significant difference ($P>0.05$) among all the stations except stations B and D.

In August (table 7), lowest value was recorded in station C (2.13 m) while highest value was in station A (6.16 m). There was significant difference ($P>0.05$) across all the stations, except stations B and D. A ranged of 1.93 to 6.10 m was recorded in station C and A as the lowest and highest depth for the month of September, other higher value was recorded in station E, there was significant difference ($P>0.05$) in all the stations, except stations B and D. Highest depth was recorded in station A (5.70 m) and lowest in station C (1.73 m) in the month of October, there was significant difference ($P>0.05$) among all the stations, except stations B and D.

4.1.6 Hydrogen Ion Concentration (pH)

The pH ranged between 7.12 and 7.50 in the months of November and September respectively. The value then continued on the downward trend to neutral level again as shown in Table 1. There was significant difference ($P<0.05$) across the months studied, except in December, January and June; and April and May.

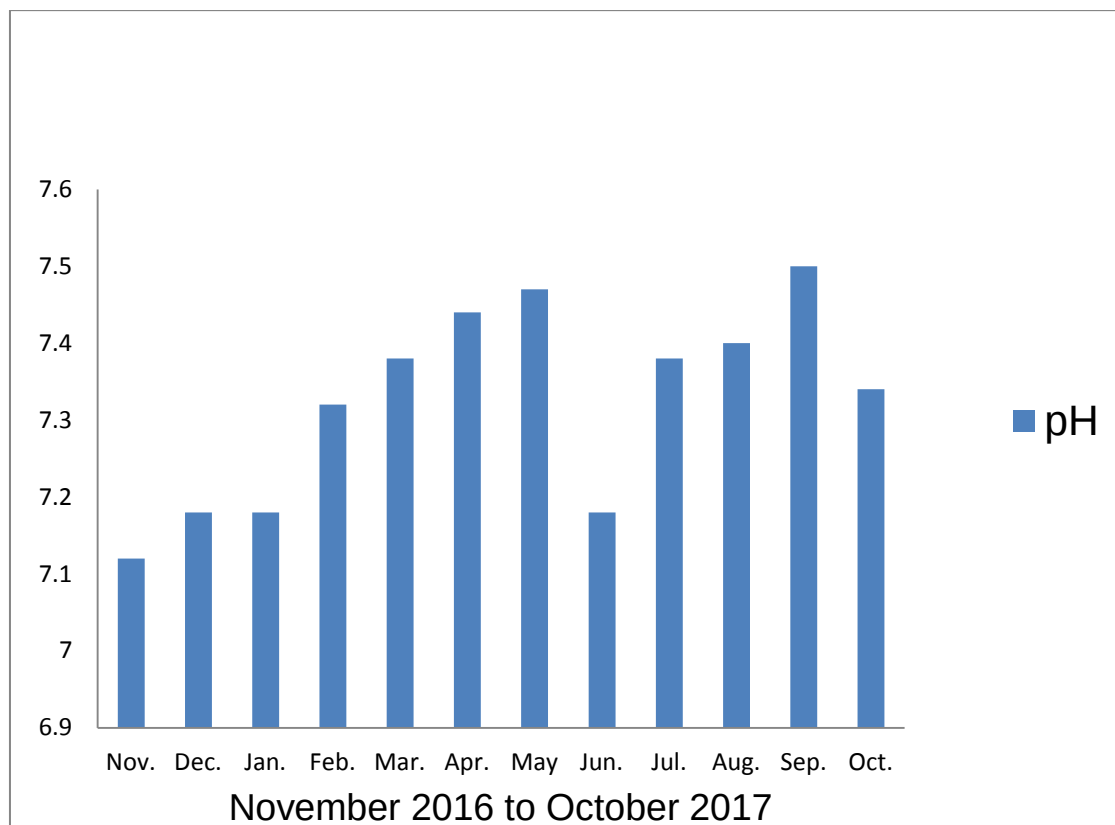


Fig. 7: Variation of pH across the months (pH value was low in post-monsoon, gradually increased in pre-monsoon with a sharp decline in June, reach a peak during monsoon).

For the stations (table 8), 7.10 and 7.16 pH values were recorded in station A and D respectively. There was no significant differences ($P < 0.05$) among all the stations of the study for the month of November. During the month of December, it ranged from minimum of 7.16 to maximum of 7.23 in station C and station B respectively. There was no significant differences ($P < 0.05$) among all the stations. In the month of January, station B had the highest value of (7.26) and lowest values was recorded in station E (7.13), there was no significant difference ($P < 0.05$) among all the stations. 7.36 pH was recorded in station C as highest value while 7.30 was lowest values in station B, D and E for the month of February, there was no significant difference ($P < 0.05$) among all the stations. Station A, C, D and E (7.40) as highest and station B (7.33) was the lowest in the month of March, there was no significant difference ($P < 0.05$) in all the stations except station B. For April, it ranged from 7.26 to 7.50 in station B and A respectively. Other higher value was recorded in station C, D and E. There was no significant difference ($P < 0.05$) among all the stations, except station B. In the month of May, lowest value of pH was recorded in

stations A, B, C and E (7.46) and highest value was recorded in station D (7.50). There was no significant different ($P<0.05$) in all the stations.

Table 8: pH at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	7.10±0.00 ^a	7.10±0.00 ^a	7.13±0.03 ^a	7.16±0.03 ^a	7.13±0.03 ^a
December	7.20±0.00 ^a	7.23±0.03 ^a	7.16±0.03 ^a	7.16±0.03 ^a	7.16±0.03 ^a
January	7.16±0.03 ^a	7.26±0.12 ^a	7.16±0.03 ^a	7.16±0.03 ^a	7.13±0.03 ^a
February	7.33±0.03 ^a	7.30±0.00 ^a	7.36±0.03 ^a	7.30±0.00 ^a	7.30±0.00 ^a
March	7.40±0.00 ^b	7.33±0.03 ^a	7.40±0.00 ^b	7.40±0.00 ^b	7.40±0.00 ^b
April	7.50±0.05 ^b	7.26±0.06 ^a	7.50±0.00 ^b	7.46±0.03 ^b	7.46±0.03 ^b
May	7.46±0.03 ^a	7.46±0.03 ^a	7.46±0.03 ^a	7.50±0.00 ^a	7.46±0.03 ^a
June	7.16±0.03 ^a	7.16±0.03 ^a	7.16±0.03 ^a	7.20±0.05 ^a	7.23±0.03 ^a
July	7.40±0.00 ^a	7.30±0.00 ^a	7.40±0.00 ^a	7.40±0.00 ^a	7.40±0.00 ^a
August	7.40±0.00 ^a	7.40±0.00 ^a	7.40±0.00 ^a	7.40±0.00 ^a	7.40±0.00 ^a
September	7.50±0.00 ^b	7.50±0.00 ^b	7.60±0.00 ^c	7.50±0.00 ^b	7.43±0.03 ^a
October	7.30±0.00 ^a	7.30±0.00 ^a	7.40±0.00 ^a	7.30±0.00 ^a	7.40±0.00 ^a

Means ($\pm$ SE) in the same row followed by different superscripts differ significantly ($P>0.05$)

For the month of June (table 8), highest pH value was recorded in station E (7.23), while lowest value was recorded in stations A, B and C (7.16). There was no significant difference ($P<0.05$) in all the stations. 7.40 pH value was highest recorded in stations A, C, D and E; and 7.30 was lowest recorded in station B for the month of July, there was no significant different among all the stations ($P<0.05$). In August, the stations were observed with same value (7.40) throughout the sampling. There was no significant different ($P<0.05$) across all the stations. The pH value of 7.43 to 7.60 was recorded in station E and C as the lowest and highest for the month of September, other higher values was recorded in station A, B and D, there was no significant difference ($P<0.05$) in all the stations, except in station C and E. Highest pH value was recorded in station C and E (7.40) and lowest value was recorded in station A, B and C (7.30) in the month of October, there was no significant difference ($P<0.05$) among all the stations.

4.1.7 Dissolved Oxygen (DO)

The DO ranged 3.46 and 13.81 ppm as lowest and highest values during the months of May and September; other higher values had been recorded in July and August. There was significant difference ($P>0.05$) among the months of this study, while no significant difference ($P<0.05$) was seen between December and February; March and October; and April and June (table 1).

In terms of stations (table 9), 5.06 and 6.13 ppm DO concentrations was recorded in stations B and E as the lowest and highest respectively during the month of November. There was no significant difference ($P<0.05$) among all the stations. For the month of December, it ranged from 5.73 to 7.20 ppm in station A and C. There was no significant difference ($P<0.05$) among all the stations. In the month of January, station D had the highest (7.73 ppm) and lowest value was recorded in station A (5.86 ppm), there was no significant difference ($P<0.05$) among all the stations, except station A. The DO value of 7.33 ppm was observed in station A as highest while 5.20 ppm was lowest in station D for the month of February, there was no significant difference ($P>0.05$) among all the stations. Station A (8.13 ppm) was recorded highest and station C (5.73 ppm) was the lowest during March, there was significant difference ($P>0.05$) in all the stations except station B and C. For April, it noticed 5.20 and 6.13 ppm in stations C and A. There was no significant difference ($P<0.05$) across the entire stations. In the month of May, lowest value was recorded in station C (2.80 ppm) and highest in station A (3.86 ppm). There was no significant difference ($P<0.05$) in all the stations.

Table 9: Dissolved oxygen (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	5.20±0.46 ^a	5.06±0.26 ^a	5.46±0.35 ^a	5.60±0.40 ^a	6.13±0.35 ^a
December	5.73±0.26 ^a	6.40±0.40 ^a	7.20±0.61 ^a	5.86±0.58 ^a	6.26±0.13 ^a
January	5.86±0.26 ^a	7.46±0.35 ^b	7.46±0.48 ^b	7.73±0.13 ^b	6.93±0.35 ^b
February	7.33±0.70 ^a	6.13±0.13 ^a	6.26±1.06 ^a	5.20±0.69 ^a	6.66±0.93 ^a
March	8.13±0.53 ^c	5.86±0.13 ^a	5.73±0.35 ^a	6.40±0.40 ^{ab}	7.46±0.53 ^{bc}
April	6.13±0.13 ^a	5.86±0.53 ^a	5.20±0.40 ^a	5.46±0.58 ^a	5.86±0.35 ^a
May	3.86±0.13 ^a	3.20±0.61 ^a	2.80±0.00 ^a	3.73±0.35 ^a	3.73±0.58 ^a
June	5.20±0.40 ^a	4.80±0.00 ^a	6.40±0.46 ^b	6.40±0.23 ^b	6.53±0.35 ^b
July	9.86±0.87 ^a	10.53±0.58 ^a	10.80±0.23 ^a	11.60±0.92 ^a	11.20±0.83 ^a
August	9.06±0.13 ^a	8.26±0.93 ^a	9.33±0.35 ^a	9.60±0.69 ^a	10.00±0.00 ^a
September	13.73±0.48 ^{ab}	14.66±0.81 ^b	14.00±0.46 ^{ab}	12.53±0.81 ^a	14.13±0.26 ^{ab}
October	7.06±0.48 ^b	6.53±0.13 ^{ab}	7.73±0.53 ^b	5.46±0.13 ^a	6.80±0.46 ^b

Means (±SE) in the same row followed by different superscripts differ significantly (P>0.05)

For the month of June, highest DO was recorded in station C (6.40 ppm), while lowest was in station B (4.80 ppm). There was no significant difference (P<0.05) among all the stations, except in station A and B. A concentration of 11.60 ppm was highest in station D and 9.86 ppm was lowest in station A for the month of July, other higher values were recorded in station C and E. There was no significant difference (P<0.05) among all the stations. In August, lowest value was recorded in station B (8.26 ppm), while highest in station E (10.00 ppm). There was no significant difference (P<0.05) across all the stations. The DO concentrations of 12.53 and 14.66 ppm was noticed in station D and B respectively as the lowest and highest for the month of September, other higher values were recorded in station C and E, there was significant difference (P>0.05) in all the stations, except stations A, C and E. Highest DO was recorded in station C (7.73 ppm) and lowest in station D (5.46 ppm) in the month of October, there was significant difference (P>0.05) among all the stations, except station A, C and E.

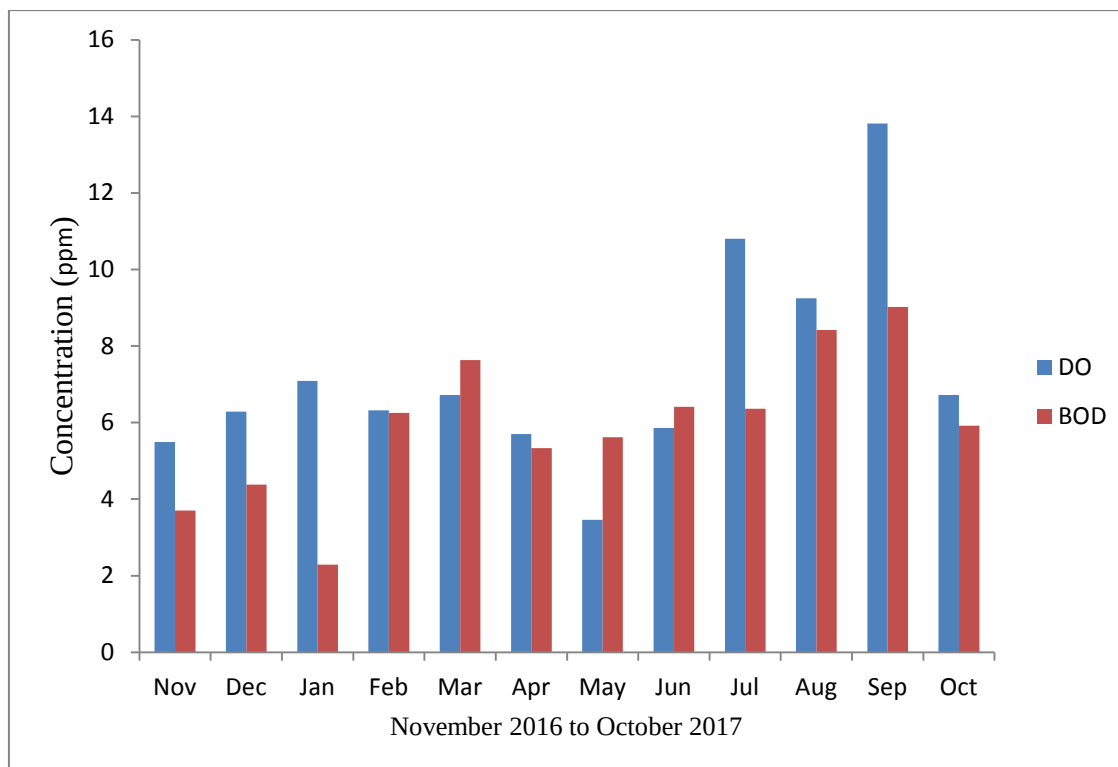


Fig. 8: Correlative account of DO and BOD (During monsoon and post-monsoon, there is corresponding increase of BOD to every increase of DO while in pre-monsoon, BOD fluctuate considerably and even high than DO in some months).

4.1.8 Carbon dioxide (CO₂)

Free dissolved carbon dioxide was available only during the months of February, June and October. The minimum value of 6.80 ppm was noticed in the month of February and the maximum value of 13.20 ppm was also noticed in the month of June. Other value recorded only in the month of October. There was significant difference ($P>0.05$) among all the study months (table 2).

Table 10: Carbon dioxide (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
December	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
January	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
February	6.33±0.00 ^a	8.03±0.00 ^a	8.00±0.00 ^a	6.30±0.00 ^a	6.00±0.00 ^a
March	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
April	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
May	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
June	12.66±1.76 ^{ab}	10.00±2.00 ^a	12.66±1.33 ^{ab}	11.33±0.66 ^a	19.33±3.52 ^b
July	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
August	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
September	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
October	8.66±0.66 ^a	10.66±0.66 ^a	9.33±0.66 ^a	10.00±1.15 ^a	10.00±0.00 ^a

Means (±SE) in the same row followed by different superscripts differ significantly (P>0.05)

Station E was recorded the lowest value of 6.00 ppm while the highest value of 8.03 ppm was observed in station B for the month of February (table 10). There was no significant difference (P<0.05) among the stations. In June, it ranged from 10.00 to 19.33 ppm in stations B and station E. There was no significant difference (P<0.05) among all the stations, except in station E. In the month of October, station B had the highest (10.66 ppm) concentration and lowest value in station A (8.66 ppm), there was no significant difference (P<0.05) among all the stations.

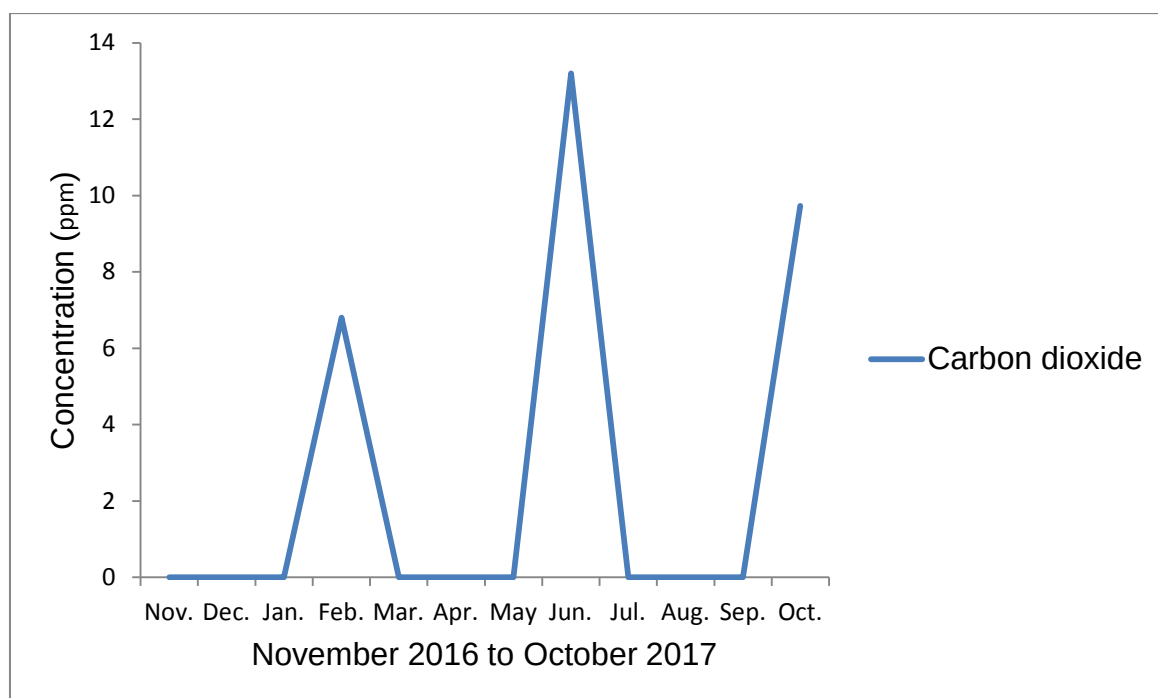


Fig. 9: Variation in carbon dioxide across the months (during post-monsoon carbon dioxide was only observed in October, while in pre-monsoon was noticed only in February and during monsoon, it reach a peak in June).

4.1.9 Alkalinity

The minimum value of 102 ppm was recorded in the month of June and the maximum value of 215 ppm was recorded in the month of October. The following months also recorded higher values, November, December, January and September, with no significant difference ($P < 0.05$) between December and January; February and August; March and April; and May and July (table 1).

Table 11: Alkalinity (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	144.00±8.08 ^b	123.33±0.66 ^a	134.00±5.03 ^{ab}	133.33±3.52 ^{ab}	132.66±4.37 ^{ab}
December	128.00±1.15 ^a	127.33±1.76 ^a	126.66±1.76 ^a	127.33±0.66 ^a	129.33±3.52 ^a
January	124.66±0.66 ^a	126.66±0.66 ^a	130.00±2.30 ^a	128.00±2.00 ^a	131.33±2.66 ^b
February	102.00±4.16 ^a	108.66±2.66 ^a	104.00±6.11 ^a	112.00±5.03 ^a	118.66±8.19 ^a
March	116.00±4.61 ^b	107.33±0.66 ^a	105.33±0.66 ^a	102.66±0.66 ^a	104.66±2.66 ^a
April	108.00±2.00 ^a	107.33±0.66 ^a	106.00±2.00 ^a	104.00±0.00 ^a	108.66±1.33 ^a
May	115.33±2.66 ^a	114.00±12.16 ^a	116.00±1.15 ^a	119.33±2.66 ^a	116.66±1.33 ^a
June	108.66±3.71 ^b	102.00±1.15 ^{ab}	97.33±0.66 ^a	101.33±0.66 ^{ab}	104.00±5.03 ^{ab}
July	114.00±1.15 ^a	115.33±1.33 ^a	118.00±1.15 ^a	121.33±0.66 ^a	132.00±6.42 ^b
August	107.33±0.66 ^a	112.66±1.76 ^a	109.33±1.33 ^a	112.00±3.05 ^a	110.66±2.66 ^a
September	150.00±6.42 ^a	146.66±1.76 ^a	144.66±2.66 ^a	147.33±6.35 ^a	156.66±4.05 ^a
October	213.33±1.76 ^a	220.00±1.15 ^a	212.66±2.90 ^a	219.33±3.33 ^a	213.33±4.37 ^a

Means (±SE) in the same row followed by different superscripts differ significantly (P>0.05)

Station B recorded the lowest value of 123.33 ppm while the highest value of 144.00 ppm was recorded in station A for the month of November (table 11). There was no significant difference (P<0.05) among the stations, except in station A and B. In December, it ranged from 126.66 to 129.33 ppm in station C and station E. There was no significant difference (P<0.05) among all the stations. In the month of January, station E had the highest value (131.33 ppm) and lowest value was observed in station A (124.66 ppm), there was no significant difference (P<0.05) among all the stations, except in station E. A value of 118.66 ppm was recorded in station E as highest while 102.00 ppm was noticed lowest in station A for the month of February, there was no significant difference (P<0.05) among all the stations. Station A (116.00 ppm) was highest and station D (102.66 ppm) was the lowest in March for alkalinity, there was no significant difference (P<0.05) in all the stations, except in station A. For April, it ranged from 104.00 to 108.66 ppm in station D and E respectively. There was no significant difference (P<0.05) across the entire stations. In the month of May, lowest value was recorded in station B (114.00 ppm) and

highest value was recorded in station D (119.33 ppm). There was no significant difference ($P < 0.05$) in all the stations.

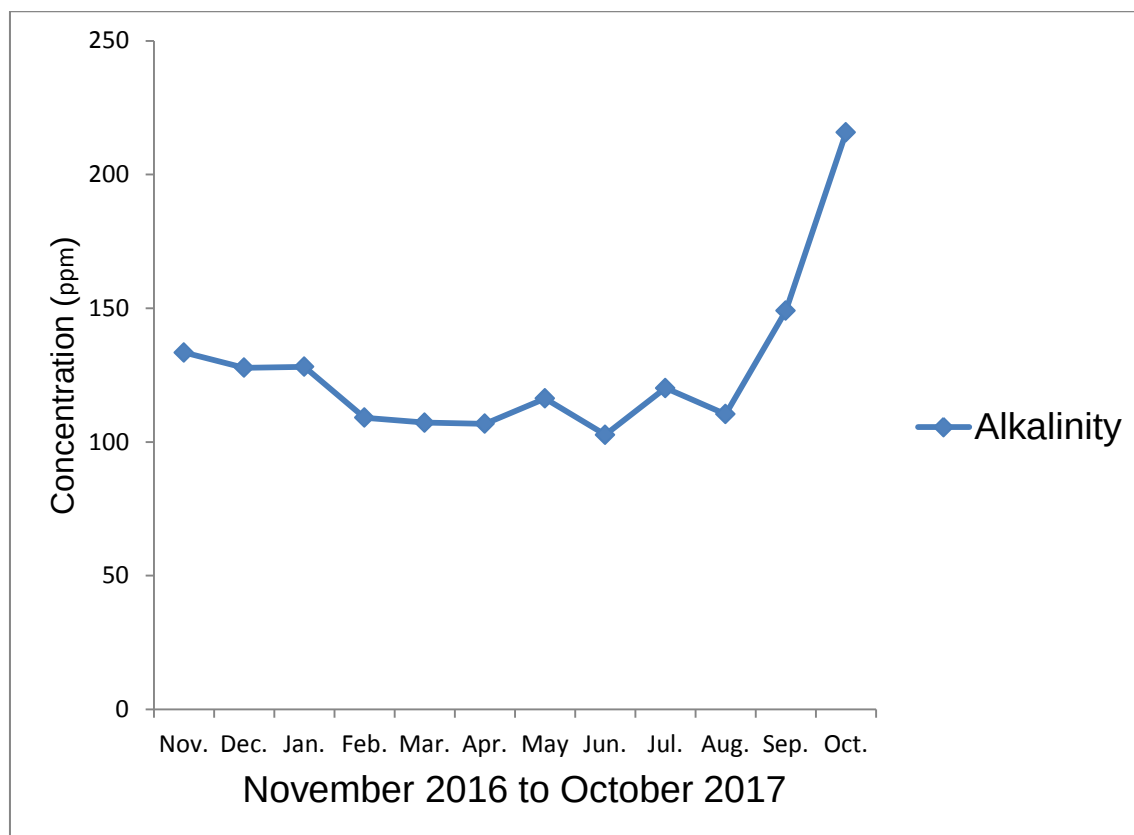


Fig. 10: Monthly scores variation of alkalinity (during pre-monsoon and monsoon, alkalinity concentration variation was less while in post-monsoon, variation was very wide considerably reaching a peak in October).

For the month of June (table 11), highest Alkalinity value was recorded in station A (108.66 ppm), while lowest value was recorded in station C (97.33 ppm). There was no significant difference ($P < 0.05$) among all the stations, except in stations A and C. 132.00 ppm alkalinity was highest in station E and 114.00 ppm was lowest in station A for the month of July, other higher values were recorded in stations C and D. There was no significant difference ($P > 0.05$) among all the stations, except in station E. In August, lowest value was recorded in station A (107.33 ppm) while highest value was recorded in station B (122.66 ppm). There was no significant difference ($P < 0.05$) across all the stations. 144.66 and 156.66 ppm values were recorded in station C and E as the lowest and highest respectively for the month of September, other higher value was recorded in station A, there was no significant difference ($P < 0.05$) among all the stations. Highest alkalinity was noticed

in station B (220.00 ppm) and lowest was recorded in station C (212.66 ppm) during the month of October, there was no significant difference ($P < 0.05$) among all the stations.

4.1.10 Hardness

The maximum water hardness value of 152.26 ppm was recorded in the month of June and the minimum value of 20.93 ppm was noticed in the month of December. However, other higher values were observed in November, July, August and October. There was significant difference ($P > 0.05$) among the study months, except in December and January; and March and April (table 1).

Table 12: Hardness (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	146.66±2.90 ^b	136.66±1.76 ^{ab}	132.66±0.66 ^a	138.66±7.05 ^{ab}	139.33±0.66 ^{ab}
December	24.66±4.66 ^a	21.33±4.05 ^a	20.66±1.76 ^a	19.33±0.66 ^a	18.66±2.66 ^a
January	30.66±5.33 ^b	20.66±1.76 ^a	19.33±0.66 ^a	20.00±1.54 ^a	22.66±1.76 ^{ab}
February	103.33±4.80 ^a	106.00±2.00 ^{ab}	102.00±9.86 ^a	126.00±7.21 ^{bc}	128.66±5.20 ^c
March	94.00±2.30 ^a	93.33±3.33 ^a	104.00±7.02 ^a	100.66±1.33 ^a	98.66±1.76 ^a
April	97.33±1.76 ^a	97.33±3.52 ^a	102.66±3.71 ^a	100.00±3.05 ^a	98.66±2.40 ^a
May	128.66±6.66 ^{ab}	114.66±2.90 ^a	111.33±1.33 ^a	118.66±5.69 ^a	140.00±9.01 ^b
June	164.66±13.48 ^a	158.66±5.92 ^a	144.66±12.66 ^a	142.66±13.38 ^a	150.66±17.48 ^a
July	144.66±8.81 ^a	138.66±6.96 ^a	130.00±3.05 ^a	130.00±3.05 ^a	135.33±4.05 ^a
August	146.66±2.40 ^b	132.66±4.66 ^a	152.66±5.69 ^b	150.00±3.05 ^b	143.33±3.52 ^{ab}
September	129.33±3.52 ^a	133.33±7.42 ^a	123.33±1.76 ^a	124.66±2.66 ^a	121.33±3.71 ^a
October	132.66±4.80 ^{ab}	125.33±1.33 ^a	140.66±4.05 ^b	134.00±4.00 ^{ab}	130.00±4.16 ^{ab}

Means ($\pm$ SE) in the same row followed by different superscripts differ significantly ($P > 0.05$)

In terms of stations (table 12), station C recorded the lowest value of 132.66 ppm, while the highest value of 146.66 ppm was seen in station A for the month of November. There was no significant difference ($P < 0.05$) between the stations, except in station A and C. In December, it ranged from 18.66 to 24.66 ppm in station E and station A. There was no significant difference ($P < 0.05$) among all the stations. In the

month of January, station A had the highest value (30.66 ppm) and lowest value was recorded in station C (19.33 ppm), there was no significant difference ($P < 0.05$) among all the stations, except in station A and E. 128.66 ppm was recorded in stations E as highest of hardness while 102.00 ppm was recorded as lowest in station C for the month of February, there was significant difference ($P > 0.05$) among all the stations, except A and C. Table 12, shows that station C (104.00 ppm) was having highest and station B (93.33 ppm) had the lowest value in March, there was no significant difference ($P < 0.05$) in all the stations.

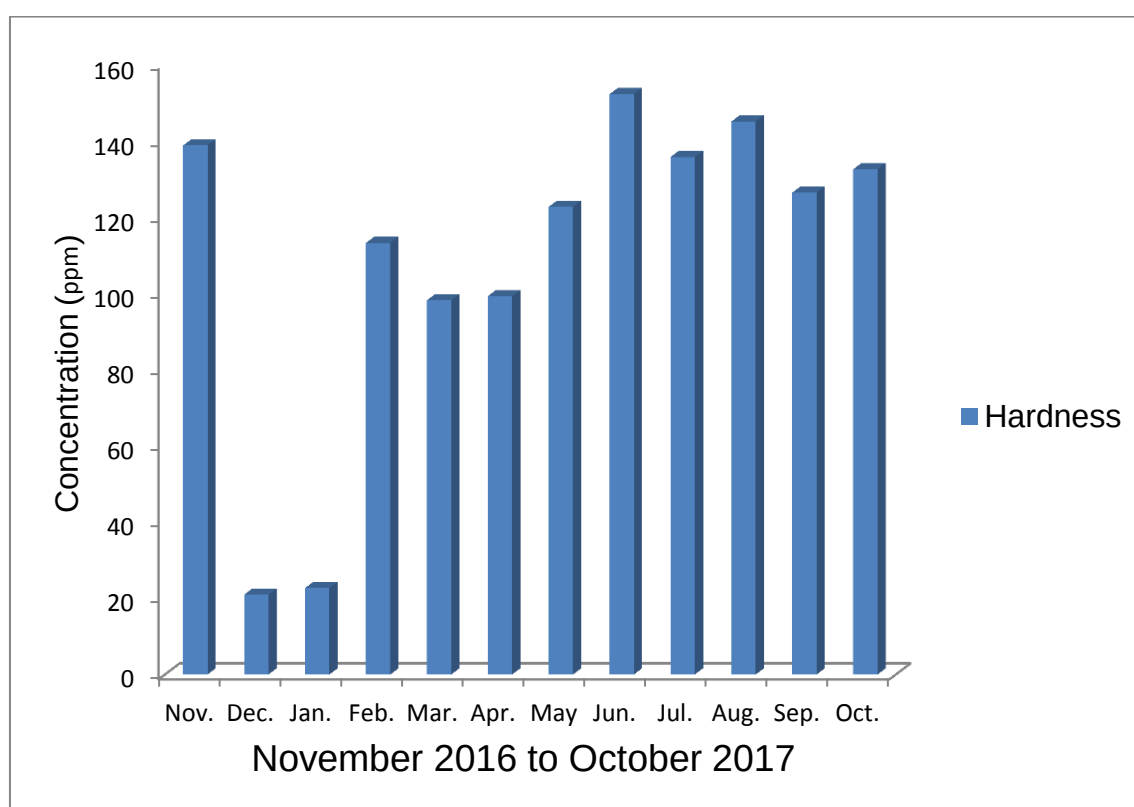


Fig. 11: Seasonal variation in hardness (during post-monsoon hardness fluctuation was relatively low, but in December and January there was very wide drop and increased in pre-monsoon; and subsequently increased in monsoon and reach a peak in June).

For April, it ranged from 97.33 to 102.66 ppm in station A and C, there was no significant difference ($P < 0.05$) across the entire stations. In the month of May, lowest value was recorded in station C (111.33 ppm) and highest value was recorded in station E (140.00 ppm). There was no significant difference ($P < 0.05$) in all the stations, except in station A and E. For the month of June, highest value of hardness

was recorded in station A (164.66 ppm), while lowest value was recorded in station D (142.66 ppm). There was no significant difference ($P < 0.05$) among all the stations. A value of 144.66 ppm was highest value recorded in station A and 130.00 ppm was the lowest value recorded in station C and D for the month of July, other higher values was recorded in station B and E. There was no significant difference ($P < 0.05$) among all the stations. In August, lowest value was recorded in station B (132.66 ppm) while highest value was recorded in station C (152.66 ppm). There was no significant difference ($P < 0.05$) across all the stations, except station B and E. 121.33 and 133.33 ppm values was recorded in station E and B as the lowest value and highest hardness for the month of September, other higher value was recorded in station A, there was no significant difference ($P < 0.05$) in all the stations. Highest hardness was recorded in station C (140.66 ppm) and lowest was recorded in station B (125.33 ppm) in the month of October, there was no significant difference ($P < 0.05$) among all the stations, except in station B and C.

4.1.11 Chloride

The chloride ranged between 32.00 and 67.73 ppm as lowest and highest values in the months of December and May respectively; other higher value was recorded in November (table 1). There was significant difference ($P > 0.05$) between the months of this study, while insignificant difference ($P < 0.05$) was in December and October; February and April; and July and August.

In terms of stations (table 13), 59.33 to 70.66 ppm was recorded in station A and B, as the lowest and highest values in the month of November. There was no significant difference ($P < 0.05$) among all the stations. For the month of December, it ranged from 31.33 to 33.33 ppm in station C and D as lowest and in station A the highest. There was no significant difference ($P < 0.05$) among all the stations. In the month of January, station D had the highest (34.66 ppm) and lowest value was recorded in station E (32.00 ppm), there was no significant difference ($P < 0.05$) among all the stations. 47.33 ppm was recorded in station D as highest while 43.33 ppm was lowest in station E for the month of February, there was significant difference ($P > 0.05$) among all the stations. Station A (46.00 ppm) was observed highest and station D (41.33 ppm) as the lowest in March, there was no significant difference ($P < 0.05$) in all the stations, except station A and D.

Table 13: Chloride (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	59.33±1.76 ^a	70.66±10.4 ^a	63.33±5.45 ^a	67.33±3.52 ^a	59.33±2.90 ^a
December	33.33±1.76 ^a	32.00±0.00 ^a	31.33±0.66 ^a	31.33±0.66 ^a	32.00±1.15 ^a
January	34.00±1.15 ^a	34.66±1.33 ^a	34.66±0.66 ^a	34.66±1.76 ^a	32.00±1.15 ^a
February	44.66±1.33 ^{abc}	44.00±1.15 ^{ab}	46.66±0.66 ^{bc}	47.33±0.66 ^c	43.33±0.66 ^a
March	46.00±1.15 ^b	42.66±0.66 ^{ab}	44.66±1.33 ^{ab}	41.33±1.76 ^a	45.33±0.66 ^{ab}
April	47.33±1.33 ^a	45.33±0.66 ^a	46.00±2.00 ^a	45.33±1.76 ^a	46.66±0.66 ^a
May	61.33±1.33 ^a	65.33±3.71 ^{ab}	75.33±5.92 ^b	66.66±1.76 ^{ab}	70.00±4.00 ^{ab}
June	40.66±0.66 ^{ab}	44.00±1.15 ^b	39.33±1.33 ^a	40.66±1.76 ^{ab}	40.00±1.15 ^{ab}
July	37.33±1.33 ^a	38.00±1.15 ^a	38.66±1.33 ^a	40.00±0.00 ^a	38.66±2.40 ^a
August	36.00±2.00 ^a	39.33±1.33 ^a	38.00±1.15 ^a	39.33±0.66 ^a	38.66±1.33 ^a
September	35.33±0.66 ^a	44.00±8.08 ^a	36.00±2.30 ^a	32.00±1.15 ^a	36.66±3.33 ^a
October	30.66±0.66 ^a	32.00±1.15 ^{ab}	31.33±0.66 ^{ab}	34.66±1.33 ^b	34.00±1.15 ^{ab}

Means (±SE) in the same row followed by different superscripts differ significantly (P>0.05)

For April (Table 13), it ranged from 45.33 to 47.33 ppm in station B and A. There was no significant difference (P<0.05) across the all stations. In the month of May, lowest value was recorded in station A (61.33 ppm) and highest in station C (75.33 ppm). There is no significant difference (P<0.05) in all the stations, except station A and C. For the month of June, highest chloride was found in station B (44.00 ppm), while lowest was in station C (39.33 ppm). There was no significant difference (P<0.05) among all the stations, except station B and C. 40.00 ppm was highest in station D and 37.33 ppm was lowest in station A for the month of July, there was no significant difference (P<0.05) among all the stations. In August, lowest value was recorded in station A (36.00 ppm) while highest value in station B (39.13 ppm). There was no significant difference (P<0.05) across all the stations. 32.00 to 44.00 ppm was recorded in station D and B as the lowest and highest values of chloride for the month of September, there was no significant difference (P<0.05) in all the stations. Highest chloride was noticed in station D (34.66 ppm) and lowest in

station A (30.66 ppm) in the month of October, there was no significant difference ($P < 0.05$) among all the stations, except station A and D.

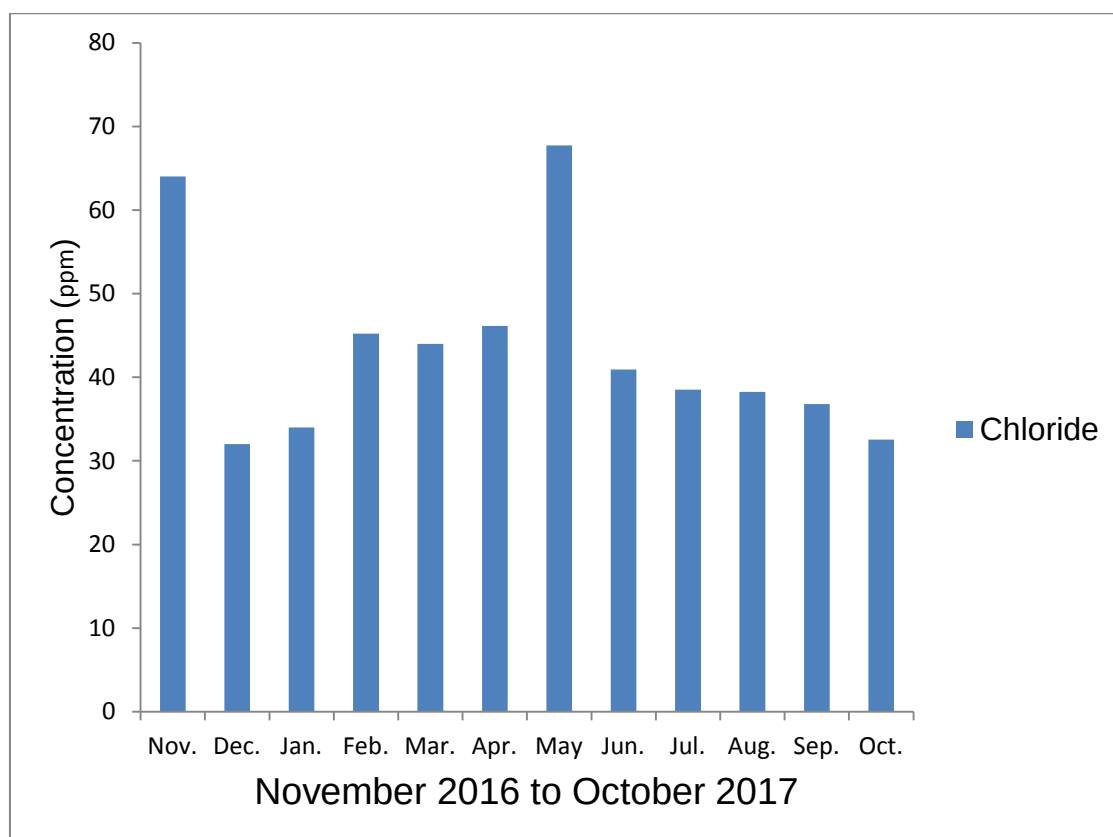


Fig. 12: Monthly variation in chloride (chloride was low during monsoon and post-monsoon except in November, there was corresponding increased in pre-monsoon and reach a peak in May).

4.1.12 Ammonia ($\text{NH}_4^+\text{-N}$)

The ammonia ranged between 0.06 and 0.66 ppm as lowest and highest values in the months of January and July (table 2), other higher values were recorded in November, March, April, May, September and October. There was no significant difference ($P < 0.05$) between the months of this study, except in December, January, July; and September and October.

In terms of stations (table 14), 0.28 to 0.53 ppm was recorded in station A and E, as the lowest and highest values in the month of November. There was significant difference ($P > 0.05$) among stations A and B with stations C, D and E. For the month of December, it ranged from 0.24 to 0.33 ppm in station C and A, as lowest and highest values respectively. There was no significant differences ($P < 0.05$) among the

stations, except in station A. In the month of January, same value was recorded in all the stations (0.06 ppm), there was no significant difference ($P < 0.05$) among all the stations. 0.72 ppm was recorded in stations A as highest while 0.25 ppm was recorded as lowest in both stations D and E for the month of February, there was no significant difference ($P < 0.05$) among all the stations. Ammonia (0.76 ppm) was highest in station A, and (0.27 ppm) was the lowest in stations C and E for the month of March, there was no significant difference ($P < 0.05$) in all the stations, except in station A.

Table 14: Ammonia (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	0.28±0.02 ^a	0.32±0.03 ^a	0.49±0.00 ^b	0.46±0.06 ^b	0.53±0.01 ^b
December	0.33±0.03 ^b	0.25±0.01 ^a	0.24±0.02 ^a	0.30±0.01 ^{ab}	0.27±0.00 ^{ab}
January	0.06±0.00 ^a	0.06±0.00 ^a	0.06±0.00 ^a	0.06±0.00 ^a	0.06±0.00 ^a
February	0.72±0.30 ^a	0.31±0.08 ^a	0.33±0.07 ^a	0.25±0.00 ^a	0.25±0.00 ^a
March	0.76±0.14 ^b	0.29±0.00 ^a	0.27±0.11 ^a	0.41±0.06 ^a	0.27±0.00 ^a
April	0.77±0.14 ^b	0.26±0.03 ^a	0.28±0.12 ^a	0.43±0.06 ^a	0.29±0.00 ^a
May	0.43±0.13 ^a	0.35±0.05 ^a	0.53±0.05 ^a	0.46±0.00 ^a	0.39±0.04 ^a
June	0.42±0.06 ^a	0.35±0.05 ^a	0.35±0.06 ^a	0.39±0.09 ^a	0.29±0.00 ^a
July	0.37±0.14 ^a	0.52±0.15 ^a	0.89±0.32 ^a	0.71±0.23 ^a	0.80±0.08 ^a
August	0.15±0.03 ^a	0.13±0.03 ^a	0.22±0.00 ^a	0.52±0.14 ^b	0.64±0.02 ^b
September	0.37±0.14 ^{ab}	0.18±0.00 ^a	0.40±0.12 ^{ab}	0.85±0.20 ^b	0.58±0.19 ^{ab}
October	0.53±0.08 ^a	0.32±0.05 ^a	0.42±0.04 ^a	0.55±0.06 ^a	0.55±0.10 ^a

Means (±SE) in the same row followed by different superscripts differ significantly ($P > 0.05$)

For the month of April, it ranged from 0.26 to 0.77 ppm in station B and A. There was no significant difference ($P < 0.05$) across all the stations, except in station A. In the month of May, lowest value was recorded in station B (0.35 ppm) and highest in station C (0.53 ppm). There was no significant difference ($P < 0.05$) in all the stations. For the month of June, lowest value was in station E (0.29 ppm) and highest value was recorded in station A (0.42 ppm). There was no significant difference ($P < 0.05$) among all the stations. 0.37 and 0.89 ppm ammonia concentration got

recorded as lowest and highest station A and C, for the month of July (table 14), there was no significant difference ($P < 0.05$) among all the stations. In August, lowest value was recorded in station B (0.13 ppm) while highest value in station E (0.64 ppm). There was no significant difference ($P < 0.05$) across all the stations, except in station D and E. 0.18 to 0.85 ppm values was recorded in station B and D as the lowest and highest concentrations of ammonia for the month of September, there was no significant difference ($P < 0.05$) in all the stations, except in station B and D. Highest value of 0.55 ppm in station E and lowest value of 0.32 ppm was recorded in station B in the month of October, there was no significant difference ($P < 0.05$) among all the stations.

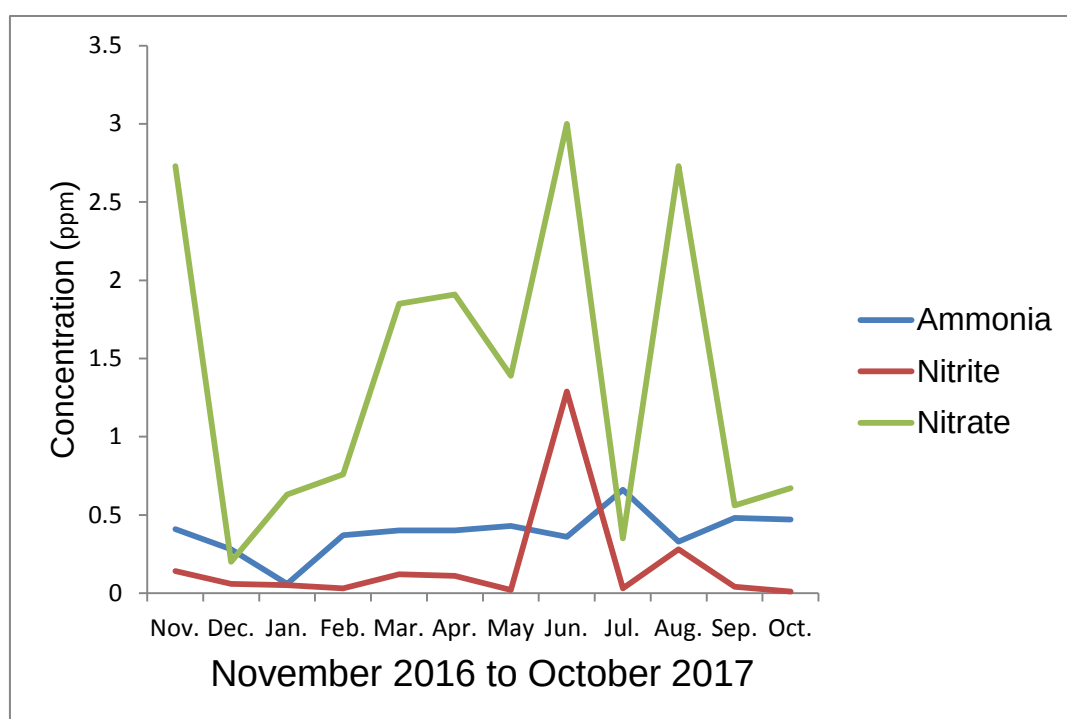


Fig. 13: Scores in sampling months of ammonia, nitrite and nitrate (The value of ammonia was relatively same throughout the year with a peak in July, nitrite and nitrate values fluctuate reach peak in the month of June).

4.1.13 Nitrite ($\text{NO}_2\text{-N}$)

The nitrite ranged between 0.01 and 1.29 ppm as lowest and highest values in the months of October and June, (table 2). There was no significant difference ($P < 0.05$) between the months of this study, except in November and August while insignificant difference ($P < 0.05$) was noticed in December, January, February, March, April, July and September; and May and October.

In terms of stations (table 15), 0.02 and 0.38 ppm concentrations were recorded in station E and A, as the lowest and highest values during the month of November (table 3). There was no significant difference ($P < 0.05$) among all the stations, except in station A and B. For the month of December, it ranged from 0.05 to 0.08 ppm in station C and A, as lowest and highest values. There was no significant difference ($P < 0.05$) among all the stations, except in station A and C. In the month of January, station E had the highest (0.10 ppm) and lowest value was recorded in station A and B (0.01 ppm), there was no significant difference ($P < 0.05$) among all the stations. Nitrite concentration of 0.04 ppm was recorded in stations A as highest while 0.03 ppm was lowest in station B, C, D and E for the month of February, there was significant difference ($P > 0.05$) among all the stations. Station C (0.27 ppm) had highest and station B and E (0.05 ppm) were the lowest in March, there was no significant difference ($P < 0.05$) in all the stations. For April, it ranged from 0.05 to 0.18 ppm in station B and A. There was no significant difference ($P < 0.05$) across the stations. In the month of May, lowest value was recorded in station B and C (0.02 ppm) and highest in station D (0.03 ppm). There is no significant difference ($P < 0.05$) in all the stations.

For the month of June, highest nitrite was recorded in station C and D (1.50 ppm), while lowest was in station E (0.79 ppm). There was significant difference ($P > 0.05$) among all the stations, except in station A and B; and station C and D. The concentration of 0.03 ppm was recorded across all the stations for the month of July, there was no significant difference ($P < 0.05$) among all the stations. In August, lowest value was recorded in station D (0.15 ppm) while highest value in station B (0.37 ppm). There was no significant difference ($P < 0.05$) across all the stations. The values of 0.02 and 0.12 ppm was recorded in station B and A as the lowest and highest respectively of nitrite for the month of September, there was no significant difference ($P < 0.05$) in all the stations. Highest value of nitrite (0.02 ppm) was recorded in station A and lowest value of 0.01 ppm was recorded in station B, C, D and E in the month of October, there was no significant difference ($P < 0.05$) among all the stations, except station A and D.

Table 15: Nitrite (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	0.38±0.05 ^c	0.23±0.00 ^b	0.04±0.00 ^a	0.03±0.01 ^a	0.02±0.00 ^a
December	0.08±0.01 ^b	0.06±0.00 ^a	0.06±0.00 ^{ab}	0.05±0.00 ^a	0.05±0.00 ^a
January	0.01±0.00 ^a	0.01±0.00 ^a	0.05±0.04 ^a	0.09±0.04 ^a	0.10±0.04 ^a
February	0.04±0.00 ^a	0.03±0.00 ^a	0.03±0.00 ^a	0.03±0.00 ^a	0.03±0.00 ^a
March	0.17±0.09 ^a	0.05±0.01 ^a	0.27±0.12 ^a	0.09±0.04 ^a	0.05±0.01 ^a
April	0.18±0.09 ^a	0.05±0.01 ^a	0.18±0.04 ^a	0.10±0.04 ^a	0.06±0.02 ^a
May	0.02±0.01 ^a	0.02±0.00 ^a	0.02±0.00 ^a	0.03±0.00 ^a	0.02±0.01 ^a
June	1.30±0.19 ^{ab}	1.36±0.13 ^{ab}	1.50±0.00 ^b	1.50±0.00 ^b	0.79±0.35 ^a
July	0.03±0.00 ^a	0.03±0.00 ^a	0.03±0.00 ^a	0.03±0.00 ^a	0.03±0.00 ^a
August	0.30±0.05 ^a	0.37±0.09 ^a	0.36±0.00 ^a	0.15±0.03 ^a	0.22±0.09 ^a
September	0.12±0.09 ^a	0.02±0.00 ^a	0.02±0.00 ^a	0.02±0.00 ^a	0.02±0.00 ^a
October	0.02±0.00 ^b	0.01±0.00 ^{ab}	0.01±0.00 ^{ab}	0.01±0.00 ^a	0.01±0.00 ^{ab}

Means (±SE) in the same row followed by different superscripts differ significantly (P>0.05)

4.1.14 Nitrate (NO₃-N)

The nitrate ranged between 0.20 and 3.00 ppm as lowest and highest value during the months of December and June respectively (table 2), other higher values were recorded in November and August. There was significant difference (P>0.05) among the months of this study, except in November, June and August; March and April; and September and October.

In terms of stations (table 16), 1.84 and 3.00 ppm values was recorded in station D and A, as the lowest and highest respectively in the month of November. There was no significant difference (P<0.05) among all the stations. For the month of December, it ranged from 0.13 to 0.32 ppm in station E and A, as lowest and highest value. There was no significant difference (P<0.05) among all the stations. In the month of January, station C had the highest (0.70 ppm) concentration and lowest value was recorded in station E (0.51 ppm), there was no significant difference (P<0.05) among all the stations. 0.79 ppm was recorded in stations A as highest

while 0.72 ppm was lowest amount in station C for the month of February, there was significant difference ($P>0.05$) among all the stations, except in station A and C. Station A (2.76 ppm) represented highest and (0.88 ppm) was the lowest in station E for the month of March, there was no significant difference ($P<0.05$) in all the stations, except in station E. For April month, it ranged from 0.97 to 2.80 ppm in station E and A. There was significant difference ($P>0.05$) across the entire stations.

Table 16: Nitrate (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	3.00±0.00 ^a	3.00±0.00 ^a	3.00±0.00 ^a	1.84±0.61 ^a	2.82±0.08 ^a
December	0.32±0.04 ^b	0.18±0.01 ^a	0.22±0.04 ^a	0.16±0.01 ^a	0.13±0.01 ^a
January	0.62±0.05 ^a	0.66±0.07 ^a	0.70±0.08 ^a	0.68±0.08 ^a	0.51±0.00 ^a
February	0.79±0.00 ^b	0.78±0.00 ^{ab}	0.72±0.03 ^a	0.78±0.00 ^{ab}	0.74±0.02 ^{ab}
March	2.76±0.23 ^b	1.42±0.18 ^{ab}	2.41±0.59 ^b	1.80±0.60 ^{ab}	0.88±0.10 ^a
April	2.80±0.20 ^c	1.47±0.18 ^{ab}	2.47±0.52 ^{bc}	1.84±0.58 ^{abc}	0.97±0.11 ^a
May	1.63±0.11 ^b	1.24±0.21 ^{ab}	1.58±0.12 ^b	1.38±0.02 ^{ab}	1.13±0.08 ^a
June	3.00±0.00 ^a	3.00±0.00 ^a	3.00±0.00 ^a	3.00±0.00 ^a	3.00±0.00 ^a
July	0.37±0.02 ^a	0.26±0.11 ^a	0.42±0.04 ^a	0.37±0.02 ^a	0.31±0.07 ^a
August	3.00±0.00 ^b	3.00±0.00 ^b	3.00±0.00 ^b	3.00±0.00 ^b	1.67±0.32 ^a
September	1.08±0.34 ^b	0.57±0.22 ^{ab}	0.38±0.07 ^a	0.37±0.09 ^a	0.39±0.00 ^a
October	0.79±0.08 ^a	0.65±0.03 ^a	0.59±0.00 ^a	0.65±0.07 ^a	0.66±0.08 ^a

Means (±SE) in the same row followed by different superscripts differ significantly ($P>0.05$)

In the month of May, lowest value was recorded in station B (1.24 ppm) and highest in station A (1.63 ppm). There was significant difference ($P>0.05$) in all the stations, except in station A and C; and station B and D. For the month of June, uniform value of nitrate was observed in all the stations (3.00 ppm). There was no significant difference ($P<0.05$) among all the stations. The nitrite concentration of 0.26 and 0.42 ppm was recorded as lowest and highest station B and C respectively, for the month of July, there was no significant difference ($P<0.05$) among all the stations. In August, lowest value was noticed in station E (1.67 ppm) while highest values in stations A, B, C and D (3.00 ppm) respectively. There was no significant

difference ($P < 0.05$) across all the stations, except in station E. The values of 0.37 and 1.08 ppm were observed in station D and A as the lowest and highest respectively of nitrate for the month of September, there was no significant difference ($P < 0.05$) in all the stations, except in station A and B. Highest value of 0.79 ppm was recorded in station A and lowest same value of 0.59 ppm was recorded in station C in the month of October, there was no significant difference ($P < 0.05$) among all the stations.

4.1.15 Phosphate

The phosphate ranged between 0.17 and 5.00 ppm as lowest and highest values respectively during the months of December, March and October; other higher values were recorded in November, February and May (table 2). There was significant difference ($P > 0.05$) among the months of this study in February, May and October, while insignificant difference ($P < 0.05$) was noticed in November, December, March and April; and January, June, July, August and September.

Table 17: Phosphate (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	1.28±0.23 ^a	1.08±0.30 ^a	1.53±0.48 ^a	1.41±0.10 ^a	1.20±0.04 ^a
December	0.13±0.00 ^a	0.15±0.01 ^a	0.11±0.00 ^a	0.13±0.01 ^a	0.34±0.18 ^a
January	0.51±0.01 ^a	0.51±0.01 ^a	0.50±0.01 ^a	0.48±0.00 ^a	0.48±0.00 ^a
February	2.33±0.08 ^{ab}	2.65±0.20 ^{ab}	2.86±0.18 ^b	2.54±0.02 ^{ab}	1.94±0.40 ^a
March	0.17±0.01 ^a	0.17±0.01 ^a	0.18±0.00 ^a	0.18±0.00 ^a	0.15±0.05 ^a
April	0.18±0.01 ^a	0.18±0.01 ^a	0.20±0.00 ^a	0.20±0.00 ^a	0.16±0.04 ^a
May	2.06±0.15 ^a	2.28±0.21 ^a	2.28±0.10 ^a	1.87±0.21 ^a	1.95±0.11 ^a
June	0.48±0.04 ^a	0.47±0.01 ^a	0.42±0.02 ^a	0.42±0.02 ^a	0.47±0.02 ^a
July	0.52±0.02 ^a	0.63±0.01 ^a	0.62±0.02 ^a	0.56±0.02 ^a	0.63±0.08 ^a
August	0.38±0.01 ^a	0.38±0.04 ^a	0.45±0.04 ^a	0.53±0.07 ^a	0.60±0.13 ^a
September	0.51±0.03 ^a	0.53±0.03 ^a	0.56±0.01 ^a	0.52±0.05 ^a	0.52±0.05 ^a
October	5.00±0.00 ^a	5.00±0.00 ^a	5.00±0.00 ^a	5.00±0.00 ^a	5.00±0.00 ^a

Means (±SE) in the same row followed by different superscripts differ significantly (P>0.05)

In terms of stations (table 17), 1.08 to 1.53 ppm was recorded in station B and C respectively, as the lowest and highest values in the month of November. There was no significant difference (P<0.05) among all the stations. For the month of December, it ranged from 0.11 to 0.34 ppm in station C and A, as lowest and highest value. There was no significant differences (P<0.05) among all the stations. In the month of January, stations A and B had the highest (0.51 ppm) and lowest value (0.48 ppm) was recorded in station D and E, there was no significant difference (P<0.05) among all the stations. Phosphate concentration of 2.86 ppm was recorded in station C as highest, while 1.94 ppm was lowest in station E for the month of February, there was significant difference (P>0.05) among all the stations, except in station A, B and D. Stations C and D (0.18 ppm) were highest representations and station E (0.15 ppm) expressed the lowest in March, there was no significant difference (P<0.05) in all the stations.

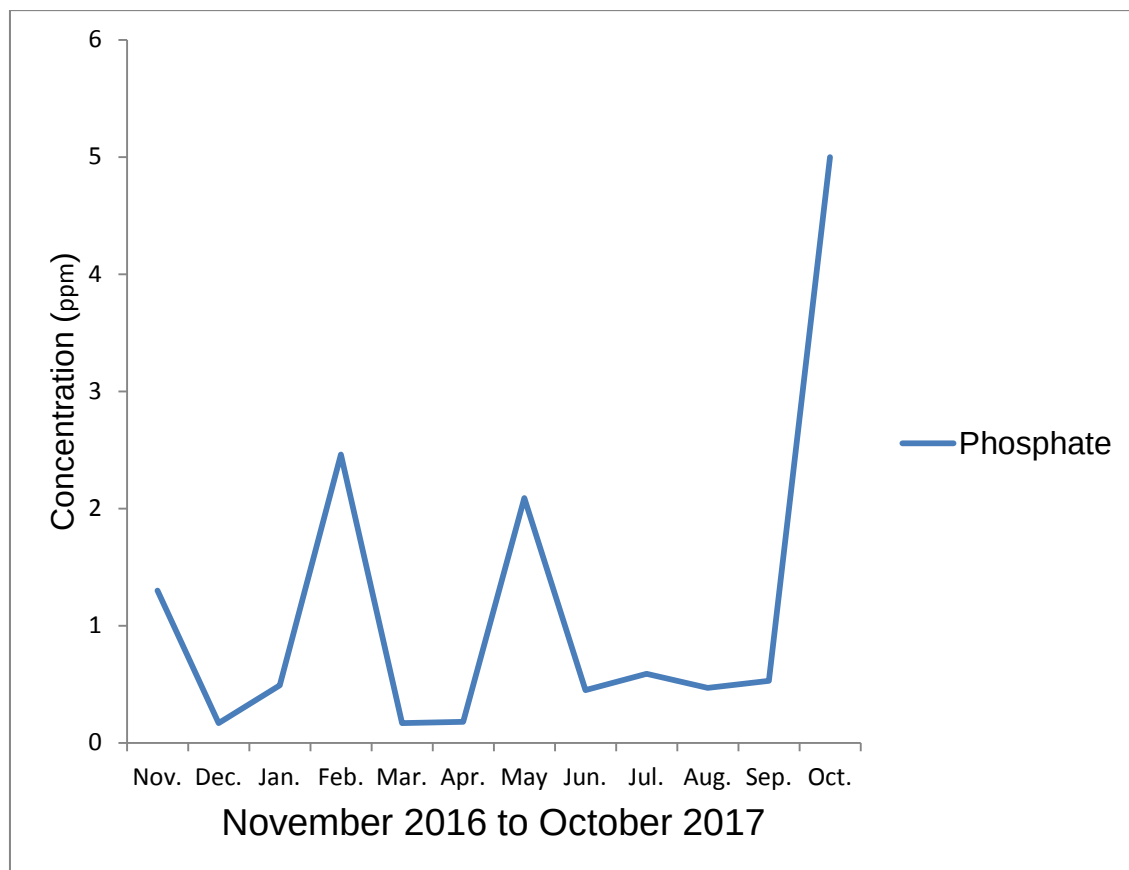


Fig. 14: Phosphate concentration in sampling months (phosphate reach a peak in post-monsoon and thereby declined considerably in December, during pre-monsoon and monsoon there was a relatively even distribution across the months).

For April, it ranged from 0.16 to 0.20 ppm in station E and C. There was no significant difference ($P < 0.05$) across the entire stations. In the month of May, lowest value was recorded in station D (1.87 ppm) and highest in station B (2.28 ppm). There was no significant difference ($P < 0.05$) in all the stations. For the month of June, highest phosphate was noticed in station A (0.48 ppm), while lowest in stations C and D (0.42 ppm). There was no significant difference ($P < 0.05$) among all the stations. The 0.63 ppm value was highest in station E and 0.52 ppm was lowest in station A for the month of July, there was no significant difference ($P < 0.05$) among all the stations. In August, lowest value was recorded in station A (0.38 ppm), while highest value in station E (0.60 ppm). There was no significant difference ($P < 0.05$) across all the stations. The phosphate concentration of 0.51 and 0.56 ppm was recorded in station A and C as the lowest and highest for the month of September, there was no significant difference ($P < 0.05$) in all the stations. The same value of

phosphate was noticed in all the stations (5.00 ppm) in the month of October, there was no significant difference ($P<0.05$) among all the stations.

4.1.16 Total Solid (TS)

The TS ranged between 180 to 410 ppm as lowest and highest value in the months of October and August (table 2), other higher value was recorded in May. There was no significant difference ($P<0.05$) between the months of this study, except in May and August.

In terms of stations, 150 to 260 ppm was recorded in station E and A, as the lowest and highest values in the month of November (table 18). There was significant difference ($P>0.05$) among all the stations, except in station E. For the month of December, it ranged from 200 to 220 ppm in station E and A, as lowest and highest value. There was no significant difference ($P<0.05$) among all the stations. In the month of January, 210 ppm was recorded in station E as highest while 170 ppm was lowest in station A, there was no significant difference ($P<0.05$) among all the stations. 200 ppm was recorded in stations D as highest while 180 ppm was lowest in both station A and E for the month of February, there was no significant difference ($P<0.05$) among all the stations. Station A (300 ppm) was highest, and (180 ppm) was the lowest is in station D for the month of March, there was no significant difference ($P<0.05$) among all the stations, except in station A and D. For April, it ranged from 200 to 220 ppm in station E and A. There was no significant difference ($P<0.05$) across entire stations. In the month of May, lowest value was in station A (280 ppm) and highest in station E (570 ppm) respectively. There was no significant difference ($P<0.05$) in all the stations.

For the month of June, lowest value was in station D (220 ppm) and highest in station B (300 ppm). There was no significance difference ($P<0.05$) among the stations, except in station B and C. 180 to 200 ppm was recorded as lowest and highest in station A and C respectively, for the month of July, there was no significant difference ($P<0.05$) among all the stations. In August, lowest value was recorded in station E (350 ppm) while highest value in station B (500 ppm). There was no significant difference ($P<0.05$) across the stations, except in station B. The values of 140 and 290 ppm were recorded in station E and C as the lowest and highest of TS for the month of September, there was no significant difference ($P<0.05$) in all the

stations. Highest value of 200 ppm in station A and lowest same value of 170 ppm was recorded in station E in the month of October, there was no significant difference ($P<0.05$) among all the stations.

Table 18: Total solid (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	260±0.11 ^c	240±0.11 ^c	200±0.00 ^b	180±0.00 ^b	150±0.01 ^a
December	220±0.02 ^a	220±0.00 ^a	220±0.01 ^a	210±0.01 ^a	200±0.01 ^a
January	170±0.02 ^a	200±0.00 ^a	200±0.00 ^a	190±0.00 ^a	210±0.01 ^a
February	180±0.00 ^a	180±0.01 ^a	190±0.00 ^a	200±0.01 ^a	180±0.00 ^a
March	300±0.05 ^b	290±0.03 ^{ab}	290±0.01 ^{ab}	240±0.02 ^a	250±0.01 ^{ab}
April	220±0.02 ^a	220±0.00 ^a	220±0.01 ^a	210±0.01 ^a	200±0.01 ^a
May	280±0.01 ^a	350±0.10 ^a	330±0.02 ^a	330±0.03 ^a	370±0.32 ^a
June	240±0.01 ^a	300±0.01 ^b	260±0.01 ^{ab}	220±0.01 ^a	220±0.02 ^a
July	180±0.01 ^a	180±0.02 ^a	200±0.01 ^a	200±0.00 ^a	180±0.01 ^a
August	370±0.00 ^a	500±0.05 ^b	430±0.04 ^{ab}	400±0.02 ^{ab}	350±0.03 ^a
September	210±0.04 ^a	120±0.04 ^a	290±0.12 ^a	240±0.05 ^a	140±0.01 ^a
October	200±0.02 ^a	190±0.01 ^a	180±0.01 ^a	190±0.01 ^a	170±0.03 ^a

Means ($\pm$ SE) in the same row followed by different superscripts differ significantly ($P>0.05$)

4.1.17 Total Dissolved Solid (TDS)

The TDS ranged between 20 to 220 ppm as lowest and highest values in the months of November and March (table 2), other higher values were recorded in December, April and May. There was significant difference ($P>0.05$) between November and March with rest of the months of this study, while insignificant difference ($P<0.05$) was seen in months of December, January, February, April and May; and June, July, August, September and October.

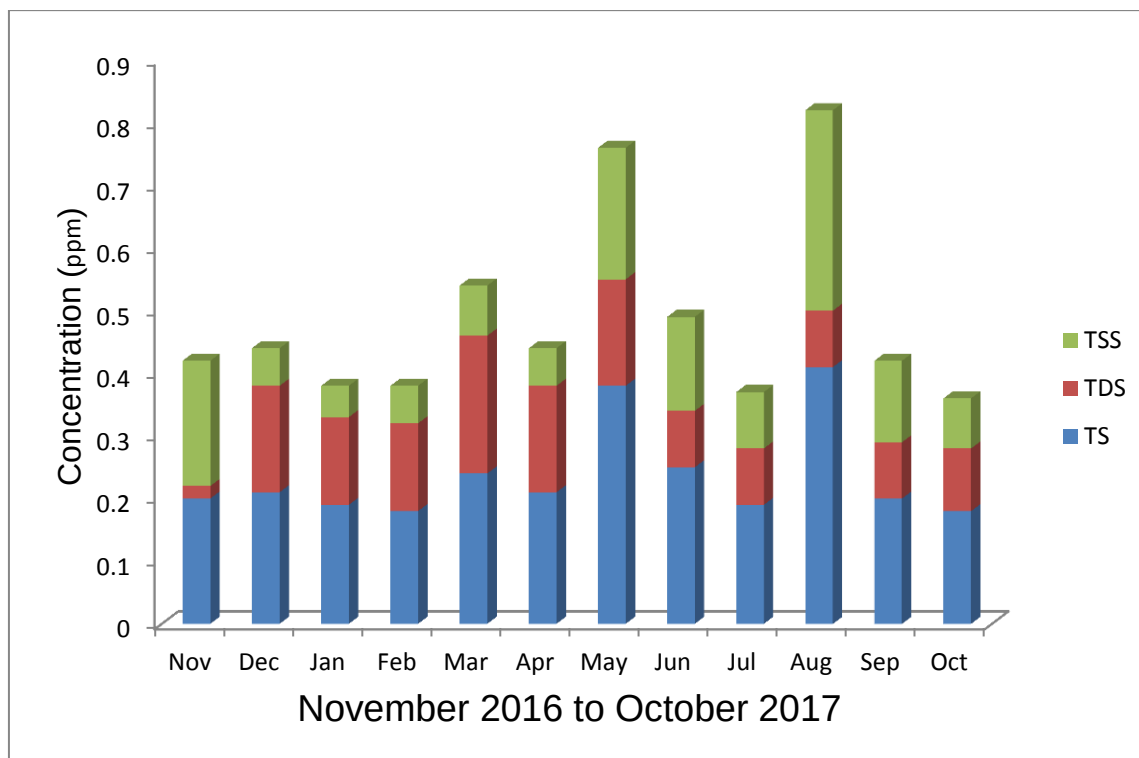


Fig. 15: Variations in TS, TDS and TSS (TDS increases during monsoon and post-monsoon, and decreases in pre-monsoon. TS and TSS reach a peak during monsoon and subsequently decline in post-monsoon and pre-monsoon).

In terms of stations (table 19), 10 and 40 ppm was recorded in station D and B, as the lowest and highest values in the month of November. There was no significant difference ($P < 0.05$) among all the stations. For the month of December, it ranged from 100 to 220 ppm in station E and C, as lowest and highest value. There was no significant difference ($P < 0.05$) between station A and B; and station C and D, while station E is significantly different ($P > 0.05$).

In the month of January, 180 ppm was recorded in stations E as highest while 130 ppm was lowest in station B, C and D. There was no significant difference ($P < 0.05$) among all the stations. 140 ppm was recorded in stations D as highest while 100 ppm was lowest in both stations C and D for the month of February, there was no significant difference ($P < 0.05$) between station A and E; and station C and D, while station B was significantly different ($P > 0.05$). Station B (290 ppm) was highest, and lowest was in station E (140 ppm) for the month of March, there was significant difference ($P > 0.05$) in all the stations, except in station A, C and D. For the month of April, it ranged from 100 to 220 ppm in station E and C. There was no significant difference ($P < 0.05$) across entire stations, except station E. In the month of May,

lowest value was in station C (150 ppm) and highest in station E (180 ppm). There was no significant difference ($P<0.05$) in all the stations. For the month of June, lowest value was in station C (60 ppm) and highest in station D (120 ppm). There was no significant difference ($P<0.05$) among the stations. 70 and 110 ppm of TDS was recorded as lowest and highest in station B and C, for the month of July, there was no significant difference ($P<0.05$) among all the stations. In August, lowest value was recorded in station B (70 ppm), while highest value was in station E (100 ppm). There was no significant difference ($P<0.05$) across the stations. 60 and 140 ppm were recorded in station A and B as the lowest and highest values of TDS for the month of September, there was no significant difference ($P<0.05$) in all the stations. Highest value of 110 ppm in station C and lower value of 90 ppm was recorded in station D in the month of October, there was no significant difference ($P<0.05$) among all the stations.

Table 19: Total dissolved solid (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	40±0.00 ^a	40±0.04 ^a	20±0.02 ^a	20±0.01 ^a	20±0.02 ^a
December	170.03 ^{ab}	170±0.02 ^{ab}	200±0.01 ^b	170±0.01 ^b	100±0.01 ^a
January	130±0.03 ^a	130±0.02 ^a	130±0.02 ^a	130±0.02 ^a	180±0.01 ^a
February	130±0.01 ^{ab}	140±0.05 ^b	110±0.02 ^a	110±0.02 ^a	140±0.01 ^{ab}
March	210±0.04 ^{ab}	260±0.05 ^b	250±0.02 ^{ab}	200±0.02 ^{ab}	150±0.02 ^a
April	170±0.03 ^{ab}	170±0.02 ^{ab}	200±0.01 ^b	180±0.01 ^b	150±0.01 ^a
May	180±0.00 ^a	230±0.00 ^a	190±0.01 ^a	180±0.00 ^a	220±0.01 ^a
June	100±0.02 ^a	70±0.01 ^a	60±0.00 ^a	120±0.02 ^a	110±0.04 ^a
July	100±0.01 ^a	70±0.02 ^a	110±0.00 ^a	100±0.00 ^a	80±0.01 ^a
August	90±0.00 ^a	80±0.02 ^a	110±0.01 ^a	90±0.01 ^a	100±0.05 ^a
September	70±0.01 ^a	40±0.05 ^a	90±0.00 ^a	60±0.01 ^a	100±0.01 ^a
October	90±0.01 ^a	90±0.01 ^a	110±0.01 ^a	90±0.00 ^a	110±0.01 ^a

Means (±SE) in the same row followed by different superscripts differ significantly ($P>0.05$)

4.1.18 Total Suspended Solid (TSS)

The TSS ranged between 50 and 320 ppm as lowest and highest values during the months of January and August (table 2), other higher values were recorded in November and June. There was significant difference ($P>0.05$) between June and August with rest of the months of this study, while insignificant difference ($P<0.05$) was noticed in months of November and May; and December, January, February and April; and March, July, September and October.

In terms of stations, 120 to 320 ppm values of TDS was recorded in station E and D, as the lowest and highest values in the month of November (table 20). There was no significant difference ($P<0.05$) among all the stations. For the month of December, it ranged from 20 to 100 ppm in station C and E, as lowest and highest values. There was no significant difference ($P<0.05$) among all the stations. In the month of January, 70 ppm was recorded in station B as highest while 20 ppm was lowest in station E. There was no significant difference ($P<0.05$) among all the stations. 90 ppm was recorded in station D as highest value while 30 ppm was recorded lowest in station E for the month of February, there was no significant difference ($P<0.05$) among the stations. Station A (100 ppm) was highest, and (50 ppm) as the lowest was in station C for the month of March, there was no significant difference ($P<0.05$) in all the stations. For April, it ranged 10 and 80 ppm in station E and A respectively. There was no significant difference ($P<0.05$) across the entire stations. In the month of May, lowest value was recorded in station A (100 ppm) and highest value was in station E (390 ppm). There was no significant difference ($P<0.05$) in all the stations. For the month of June, lowest value was recorded in station D (100 ppm) and highest value was recorded in station B (230 ppm). There was significant difference ($P>0.05$) between station B with the rest of the stations and insignificant difference ($P<0.05$) between station A and C; and station D and E. 70 and 110 ppm TSS values was recorded as lowest and highest in station A and B, for the month of July, there was no significant difference ($P<0.05$) among all the stations. In August, lowest value was recorded in station E (200 ppm) while highest value was recorded in station B (420 ppm). There was no significant difference ($P<0.05$) across the stations. 40 and 200 ppm TSS were noticed in station E and C as the lowest and highest values for the month of September, there was no significant difference ($P<0.05$) in all the stations. Highest value of 100 ppm in station A and B; and lower

value of 60 ppm was recorded in station E in the month of October, there was no significant difference ($P < 0.05$) among all the stations.

Table 20: Total suspended solid (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	220±0.01 ^a	200±0.04 ^a	180±0.03 ^a	160±0.16 ^a	130±0.01 ^a
December	50±0.02 ^a	50±0.03 ^a	20±0.01 ^a	40±0.02 ^a	100±0.00 ^a
January	40±0.00 ^a	70±0.03 ^a	70±0.00 ^a	60±0.01 ^a	30±0.02 ^a
February	50±0.01 ^a	40±0.03 ^a	80±0.03 ^a	90±0.02 ^a	40±0.01 ^a
March	90±0.09 ^a	30±0.05 ^a	40±0.00 ^a	40±0.03 ^a	100±0.03 ^a
April	50±0.02 ^a	50±0.03 ^a	20±0.01 ^a	30±0.02 ^a	50±0.00 ^a
May	100±0.00 ^a	120±0.10 ^a	140±0.04 ^a	150±0.03 ^a	150±0.33 ^a
June	140±0.04 ^{ab}	230±0.02 ^b	200±0.01 ^{ab}	100±0.03 ^a	110±0.04 ^a
July	80±0.02 ^a	110±0.04 ^a	90±0.01 ^a	100±0.01 ^a	100±0.03 ^a
August	280±0.00 ^a	420±0.07 ^a	320±0.05 ^a	310±0.00 ^a	250±0.08 ^a
September	140±0.03 ^a	80±0.04 ^a	200±0.12 ^a	180±0.04 ^a	40±0.01 ^a
October	110±0.03 ^a	100±0.03 ^a	70±0.02 ^a	100±0.02 ^a	60±0.03 ^a

Means ($\pm$ SE) in the same row followed by different superscripts differ significantly ($P > 0.05$)

4.1.19 Biochemical Oxygen Demand (BOD)

The BOD ranged between 2.29 and 9.02 ppm as lowest and highest values in the months of January and September; other higher value was recorded in March and August. There was significant difference ($P > 0.05$) among the months of this study, while insignificant difference ($P < 0.05$) was found in February, May, June, July and October (table 1).

In terms of stations (table 21), 2.77 and 4.66 ppm was recorded in stations A and D, as the lowest and highest values respectively in the month of November. There was no significant difference ($P < 0.05$) among all the stations. For the month of December, it ranged from 3.04 to 6.13 ppm in station E and station C. There was significant differences ($P > 0.05$) among all the stations, except A, B and D. In the

month of January, station C had the highest value (3.22 ppm) while lowest in station E (1.62 ppm), there was no significant difference ($P<0.05$) among all the stations, except station C and E. The BOD value of 8.29 ppm was recorded in station E as highest while 3.81 ppm was seen as lowest in station A for the month of February, there was no significant difference ($P<0.05$) among all the stations, except in station A. Station A (9.07 ppm) was highest and station B (6.58 ppm) was the lowest in BOD values during March, there was no significant difference ($P<0.05$) in all the stations.

Table 21: Biochemical oxygen demand (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	2.77±0.50 ^a	3.06±0.52 ^a	3.46±1.08 ^a	4.66±0.75 ^a	4.56±0.90 ^a
December	4.45±0.61 ^{ab}	4.82±0.18 ^{ab}	6.13±1.89 ^b	3.49±0.32 ^{ab}	3.04±0.16 ^a
January	2.40±1.43 ^{ab}	1.70±0.58 ^{ab}	3.22±1.20 ^b	2.50±0.57 ^{ab}	1.62±0.71 ^a
February	3.81±1.15 ^a	5.60±0.48 ^b	6.66±0.80 ^b	6.90±1.03 ^b	8.29±0.85 ^b
March	9.07±0.50 ^a	6.58±0.13 ^a	6.82±0.42 ^a	7.30±0.51 ^a	8.37±0.64 ^a
April	6.21±1.27 ^a	5.57±1.60 ^a	5.28±1.33 ^a	4.98±1.40 ^a	4.64±1.08 ^a
May	5.94±0.13 ^a	5.65±0.69 ^a	5.25±0.18 ^a	5.44±0.64 ^a	5.81±0.58 ^a
June	6.34±0.83 ^a	6.13±0.18 ^a	6.24±0.72 ^a	6.42±0.43 ^a	6.93±0.55 ^a
July	6.10±0.37 ^a	7.14±0.35 ^a	5.92±0.60 ^a	7.28±0.52 ^a	5.38±1.64 ^a
August	7.78±0.85 ^a	8.10±0.61 ^{ab}	10.66±0.42 ^b	7.20±0.86 ^a	8.34±1.13 ^{ab}
September	11.22±1.08 ^b	8.42±0.17 ^a	8.13±0.39 ^a	7.60±0.76 ^a	9.76±0.77 ^{ab}
October	8.32±1.02 ^c	6.98±1.41 ^{bc}	6.02±0.47 ^{abc}	3.76±0.16 ^a	4.53±0.31 ^{ab}

Means ($\pm$ SE) in the same row followed by different superscripts differ significantly ($P>0.05$)

For the month of April, it ranged from 4.64 to 6.21 ppm in station E and A respectively. There was no significant difference ($P<0.05$) across the entire stations. In the month of May, lowest value was recorded in station C (5.25 ppm) and highest in station A (5.94 ppm). There was no significant difference ($P<0.05$) in all the stations. For the month of June, highest BOD was recorded in station E (6.93 ppm), while lowest was recorded in station B (6.13 ppm). There was no significant difference ($P<0.05$) among all the stations. The BOD value of 7.28 ppm was highest in station D and 5.38 ppm was lowest in station E for the month of July, other higher

values were recorded in station A and B. There was no significant difference ($P < 0.05$) among all the stations. In August, lowest value was recorded in station D (7.20 ppm), while highest value in station C (10.66 ppm). There was no significant difference ($P < 0.05$) across all the stations, except in station B and E. 7.60 and 11.22 ppm were recorded in stations D and A as the lowest and highest values of BOD for the month of September, other higher value was recorded in station E, there was no significant difference ($P < 0.05$) in all the stations, except station A, and E. Highest BOD was recorded in station A (8.32 ppm) and lowest in station D (3.76 ppm) in the month of October, there was significant difference ($P > 0.05$) among all the stations.

4.1.20 Chemical Oxygen Demand (COD)

The COD ranged between 12.80 and 123.46 ppm as lowest and highest value in the months of January and April respectively, other higher value was recorded in March and May (table 2). There was significant difference ($P > 0.05$) among the months of this study, while insignificant difference ($P < 0.05$) was noticed in November and February; December and January; and March and April.

In terms of stations, 36.66 and 51.33 ppm was recorded in stations A and E, as the lowest and highest values during the month of November (table 22). There was no significant difference ($P < 0.05$) among station A and E; and station B, C and D. For the month of December, it ranged from 8.66 to 28.66 ppm in stations D and A as lowest and station A as highest. There was no significant difference ($P < 0.05$) among all the stations, except in station A. In the month of January, station E had the highest (13.33 ppm) value, while the lowest value was recorded in station B (12.66 ppm), there was no significant difference ($P < 0.05$) among all the stations.

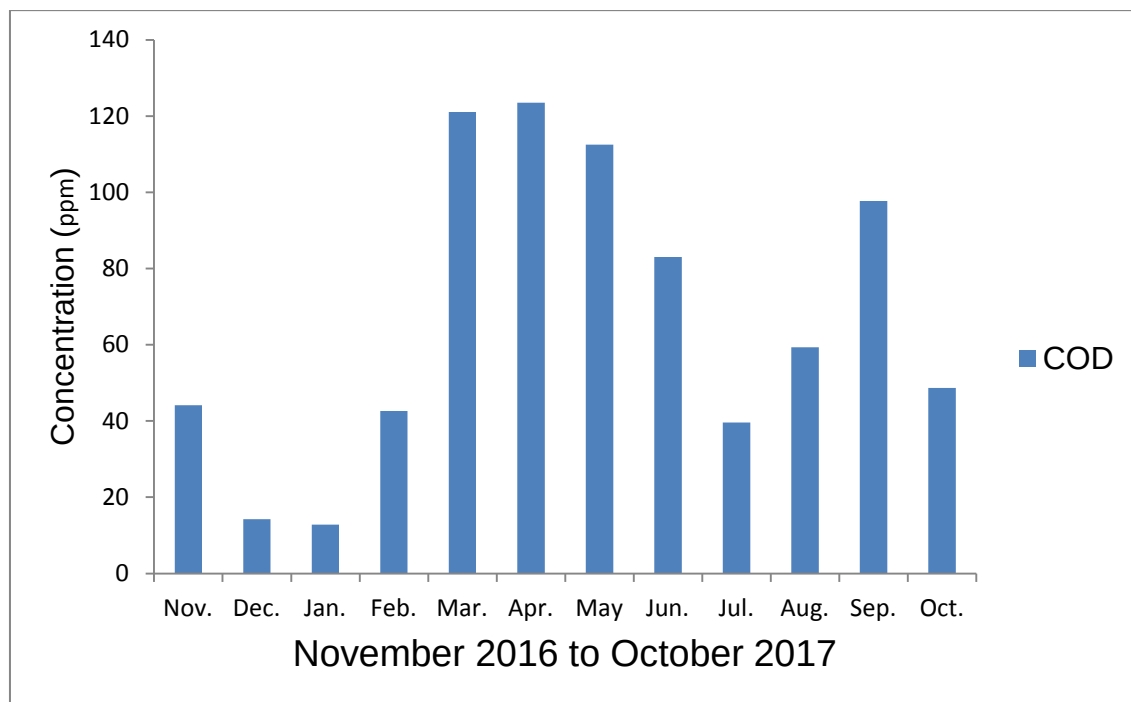


Fig. 16: Monthly variation in COD (COD was very low during post-monsoon but increased to a peak in pre-monsoon, and subsequently declined during monsoon).

Table 22: Chemical oxygen demand (ppm) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	36.66±3.71 ^a	41.33±2.66 ^{ab}	43.33±0.66 ^{ab}	48.00±4.00 ^{ab}	51.33±6.66 ^a
December	28.66±9.82 ^b	12.00±2.00 ^a	12.66±1.76 ^a	8.66±0.66 ^a	9.33±1.76 ^a
January	12.66±1.76 ^a	12.66±0.66 ^a	13.33±0.66 ^a	12.00±1.15 ^a	13.33±1.33 ^a
February	38.00±14.42 ^a	41.33±12.01 ^a	42.00±5.03 ^a	44.00±8.71 ^a	48.00±3.05 ^a
March	122.00±2.00 ^a	122.00±0.00 ^a	122.00±2.00 ^a	120.00±1.15 ^a	119.33±1.76 ^a
April	123.33±1.33 ^a	125.33±0.66 ^a	124.00±1.15 ^a	122.00±1.15 ^a	122.66±0.66 ^a
May	107.33±8.70 ^a	122.00±0.00 ^a	109.33±6.56 ^a	104.66±4.80 ^a	119.33±2.90 ^a
June	72.66±1.33 ^a	74.66±0.66 ^a	86.66±2.40 ^b	89.33±6.65 ^b	92.00±0.00 ^b
July	22.00±2.30 ^a	34.00±3.46 ^b	43.33±1.76 ^c	49.33±1.33 ^c	49.33±0.66 ^c
August	44.66±10.72 ^a	72.66±15.33 ^a	68.66±7.68 ^a	64.66±2.90 ^a	46.00±9.16 ^a
September	101.33±8.81 ^a	91.33±5.20 ^a	114.66±6.96 ^a	86.00±3.05 ^a	95.33±13.87 ^a
October	54.66±8.19 ^a	40.00±1.15 ^a	47.33±5.81 ^a	56.00±6.00 ^a	45.33±2.66 ^a

Means (±SE) in the same row followed by different superscripts differ significantly (P>0.05)

The COD value of 48.00 ppm was recorded in station E as highest while 38.00 ppm was lowest in station A for the month of February, there was significant difference ($P>0.05$) among all the stations. Stations A and C (122.00 ppm) were noted as highest and station E (119.33 ppm) as the lowest in March, there was no significant difference ($P<0.05$) in all the stations. For April, it ranged from 122.00 to 125.33 ppm in stations D and B. There was no significant difference ($P<0.05$) across the entire stations. In the month of May, lowest value was recorded in station D (104.66 ppm) and highest in station B (122.00 ppm). There was no significant difference ($P<0.05$) in all the stations. For the month of June, highest COD was recorded in station E (92.00 ppm), while lowest in station A (72.66 ppm). There was no significant difference ($P<0.05$) among all the stations, except station A and B. The 49.33 ppm was highest value in station D and 22.00 ppm was lowest in station A for the month of July, there was no significant difference ($P<0.05$) among all the stations, except in station A and B. In August, lowest value was recorded in station E (46.00 ppm) while highest value was in station B (72.66 ppm). There was no significant difference ($P<0.05$) across all the stations. 86.00 and 114.66 ppm values of COD was recorded in stations D and C as the lowest and highest respectively for the month of September, there was no significant difference ($P<0.05$) in all the stations. Highest COD was recorded in station D (56.00 ppm) and lowest in station B (40.00 ppm) during the month of October, there was no significant difference ($P<0.05$) among all the stations.

4.1.21 Conductivity

The minimum value of 142.13 $\mu\text{S}/\text{cm}$ was recorded in the month of October and the maximum value of 602.73 $\mu\text{S}/\text{cm}$ was observed in the month of July. Other months that recorded higher values are May and June. There was significant difference ($P>0.05$) among all the months, except in January and February, (table 2).

Station B was recorded the lowest value of 243.66 $\mu\text{S}/\text{cm}$, while the highest value of 246.33 $\mu\text{S}/\text{cm}$ was noticed in station D for the month of November (table 23). There was no significant difference ($P<0.05$) among the stations. In December, it ranged from 251.00 to 254.33 $\mu\text{S}/\text{cm}$ in stations E and C. There was no significant difference ($P<0.05$) among all the stations, except in station E. In the month of January, station B had the highest (294.33 $\mu\text{S}/\text{cm}$) and lowest value (290.66 $\mu\text{S}/\text{cm}$)

was in station E, there was no significant difference ($P<0.05$) among all the stations. The 290.33 $\mu\text{S}/\text{cm}$ value was observed in stations B as highest, while 285.33 $\mu\text{S}/\text{cm}$ was lowest in station E for the month of February, there was no significant difference ($P<0.05$) among all the stations.

Table 23: Conductivity ($\mu\text{S}/\text{cm}$) at five sampling stations in Powai lake during November 2016 to October 2017

Month	Station				
	A	B	C	D	E
November	244.00 $\pm$ 0.57 ^a	243.66 $\pm$ 1.20 ^a	243.66 $\pm$ 1.66 ^a	246.33 $\pm$ 1.33 ^a	244.00 $\pm$ 1.73 ^a
December	254.66 $\pm$ 0.88 ^b	252.33 $\pm$ 0.66 ^{ab}	254.33 $\pm$ 1.20 ^b	252.66 $\pm$ 0.66 ^{ab}	251.00 $\pm$ 0.57 ^a
January	292.66 $\pm$ 0.66 ^a	294.33 $\pm$ 1.76 ^a	292.33 $\pm$ 1.20 ^a	291.33 $\pm$ 1.20 ^a	290.66 $\pm$ 2.40 ^a
February	288.66 $\pm$ 3.84 ^a	290.33 $\pm$ 4.37 ^a	290.00 $\pm$ 1.15 ^a	290.00 $\pm$ 2.51 ^a	285.33 $\pm$ 0.33 ^a
March	276.66 $\pm$ 3.33 ^a	285.66 $\pm$ 1.20 ^{bc}	288.00 $\pm$ 0.57 ^c	284.33 $\pm$ 0.66 ^{bc}	281.00 $\pm$ 1.00 ^{ab}
April	319.00 $\pm$ 0.57 ^b	323.66 $\pm$ 0.66 ^c	320.33 $\pm$ 0.88 ^b	312.33 $\pm$ 0.88 ^a	329.66 $\pm$ 1.20 ^d
May	471.66 $\pm$ 2.02 ^a	474.33 $\pm$ 9.20 ^a	484.33 $\pm$ 2.72 ^a	483.00 $\pm$ 8.08 ^a	490.66 $\pm$ 0.66 ^a
June	381.66 $\pm$ 0.88 ^d	377.00 $\pm$ 0.57 ^c	363.66 $\pm$ 0.88 ^a	366.66 $\pm$ 0.88 ^b	363.33 $\pm$ 0.33 ^a
July	602.33 $\pm$ 19.18 ^a	614.66 $\pm$ 7.42 ^a	611.33 $\pm$ 2.96 ^a	591.66 $\pm$ 2.96 ^a	593.66 $\pm$ 2.40 ^a
August	187.66 $\pm$ 1.76 ^c	175.33 $\pm$ 2.96 ^{ab}	167.00 $\pm$ 3.00 ^a	176.66 $\pm$ 4.84 ^{ab}	179.66 $\pm$ 0.33 ^{bc}
September	159.00 $\pm$ 0.57 ^b	156.00 $\pm$ 1.15 ^b	151.00 $\pm$ 0.57 ^a	164.33 $\pm$ 2.02 ^c	155.66 $\pm$ 1.20 ^b
October	153.33 $\pm$ 3.17 ^c	140.66 $\pm$ 4.09 ^{ab}	144.66 $\pm$ 3.38 ^{bc}	140.66 $\pm$ 1.45 ^{ab}	131.33 $\pm$ 2.60 ^a

Means ($\pm$ SE) in the same row followed by different superscripts differ significantly ($P<0.05$)

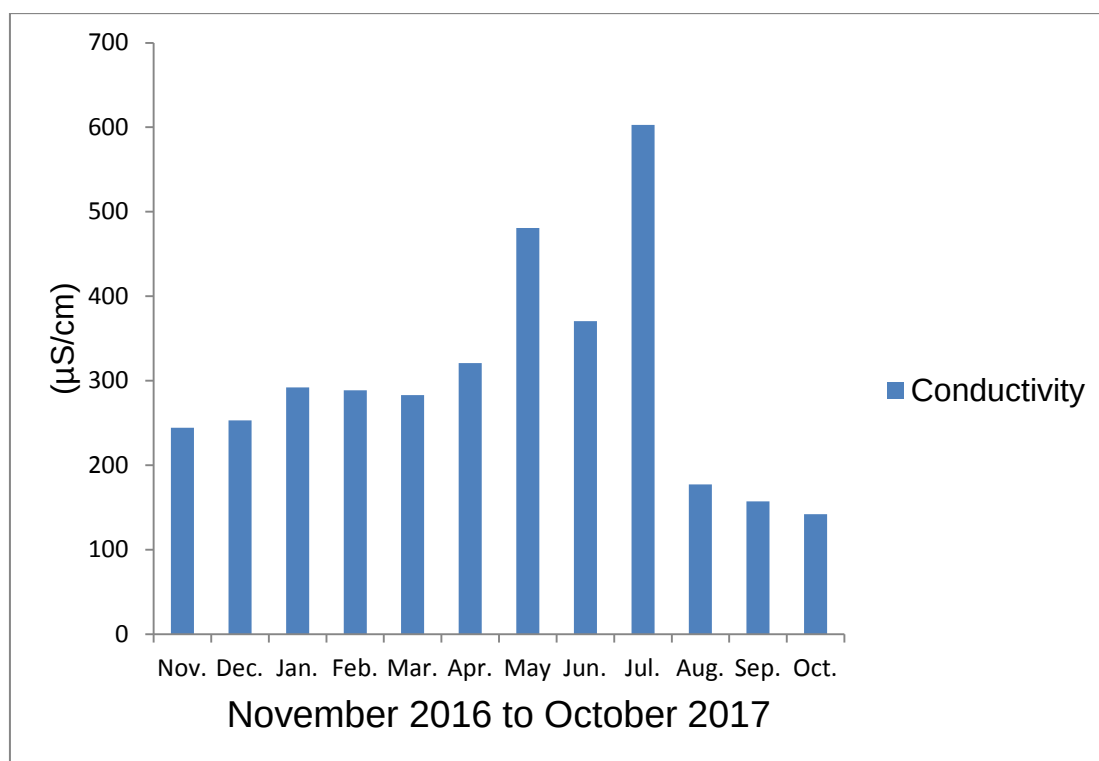


Fig. 17: Monthly variation in conductivity (lowest conductivity values were observed during post-monsoon and pre-monsoon while in monsoon, there was tremendous increased to reach a peak in July).

Station C (288.00 $\mu\text{S/cm}$) was highest and station A (276.66 $\mu\text{S/cm}$) was the lowest in March for conductivity values, there was significant difference ($P>0.05$) in all the stations, except in station B and D. For April, it ranged from 312.33 to 329.66 $\mu\text{S/cm}$ in station D and E. There was significant difference ($P>0.05$) across the entire stations, except in station A and C. In the month of May, lowest value was recorded in station A (471.66 $\mu\text{S/cm}$) and highest in station E (490.66 $\mu\text{S/cm}$). There was no significant difference ($P<0.05$) in all the stations. For the month of June, highest conductivity was recorded in station A (381.66 $\mu\text{S/cm}$), while lowest was recorded in station E (363.33 $\mu\text{S/cm}$). There was significant difference ($P>0.05$) among all the stations, except in station C and E. The 614.66 $\mu\text{S/cm}$ value was highest in station B and 591.66 $\mu\text{S/cm}$ was lowest in station D for the month of July, other higher values was recorded in stations C and A. There was no significant difference ($P<0.05$) among all the stations. In August, lowest value was observed in station C (167.00 $\mu\text{S/cm}$) while highest value in station A (187.66 $\mu\text{S/cm}$). There was significant difference ($P>0.05$) across all the stations, except in station B and D. 151.00 to 164.33 $\mu\text{S/cm}$ was recorded in stations C and D as the lowest and highest readings

of conductivity for the month of September, other higher value was recorded in station A, there was no significant difference ($P < 0.05$) in all the stations, except in station C and D. Highest conductivity was recorded in station A (153.33 $\mu\text{S}/\text{cm}$) and lowest in station E (131.33 $\mu\text{S}/\text{cm}$) in the month of October, there was significant difference ($P > 0.05$) among all the stations, except in station B and D.

4.2.0 Productivity

4.2.1 Gross Primary Productivity (GPP)

The maximum value of 346.46 $\text{mg C}/\text{m}^3/\text{hr}$ was recorded in the month of May and the minimum value of 142.36 $\text{mg C}/\text{m}^3/\text{hr}$ was observed in the month of August. However, other higher values were recorded in December, January and February. There was significant difference ($P > 0.05$) among the study months, except in November, March, April, and September; and December, February and October (table 24).

Table 24: Monthly mean variation in productivity of Powai lake (November, 2016 to October, 2017)

Months	Gross primary productivity (GPP) (mg C/m ⁻³ /hr)	Net primary productivity (NPP) (mg C/m ⁻³ /hr)	NPP(wet weight) (mg/m ⁻³ /hr)	Tertiary productivity (TP) Kg/ha/yr)
November	264.75±0.06 ^{abc}	219.61±0.07 ^{bc}	1750.35±0.13 ^{bc}	5726.92±0.22 ^{bc}
December	312.50±0.99 ^{bc}	258.68±0.62 ^{cd}	2061.68±0.42 ^{cd}	6745.54±0.46 ^{cd}
January	336.80±0.27 ^c	287.33±0.10 ^d	2289.99±0.62 ^d	7492.53±0.28 ^d
February	320.31±0.00 ^{bc}	282.98±0.59 ^d	2255.39±0.60 ^d	7379.35±0.77 ^d
March	297.74±0.44 ^{abc}	258.68±0.05 ^{cd}	2062.01±0.31 ^{cd}	6745.54±0.72 ^{cd}
April	274.58±0.68 ^{abc}	248.33±0.64 ^{cd}	1979.21±0.72 ^{cd}	6475.71±0.74 ^{cd}
May	346.87±0.63 ^c	166.66±0.33 ^{ab}	1328.33±0.56 ^{ab}	4346.11±0.92 ^{ab}
June	180.00±0.77 ^{ab}	150.00±0.14 ^{ab}	1434.60±0.01 ^{ab}	4693.80±0.55 ^{ab}
July	184.02±0.18 ^{ab}	193.47±0.88 ^{abc}	1466.70±0.21 ^{ab}	4798.84±0.55 ^{ab}
August	142.36±0.66 ^a	131.94±0.85 ^a	1134.61±0.44 ^a	3712.31±0.60 ^a
September	215.27±0.26 ^{abc}	204.86±0.19 ^{bc}	1632.74±0.55 ^{bc}	5342.11±0.75 ^{bc}
October	220.00±0.14 ^{bc}	193.33±0.63 ^{abc}	1753.16±0.23 ^{bc}	5736.87±0.24 ^{bc}

Means (±SE) in the same column followed by different superscripts differ significantly (P>0.05)

4.2.2 Net Primary Productivity (NPP)

The minimum value of 131.94 mg C/m⁻³/hr was recorded in the month of August and the maximum value of 287.33 mg C/m⁻³/hr was observed in the month of January. However, other higher values were noticed in December, February, March and April. There was significant difference (P>0.05) among the study months, except in November and September; December, March and April; January and February; and May, June and July.

4.2.3 NPP (wet weight)

2289.99 mg/m⁻³/hr was recorded as highest in the month of January and 1134.61 mg/m⁻³/hr was recorded as lowest in the month of August. However, other lower value was observed in May, June and July. There was significant difference

($P>0.05$) among the study months, except in September, October and November; December, March and April; January and February; and May, June and July.

4.2.4 Tertiary Productivity (TP)

The maximum value of 7492.53 Kg/ha/yr was noted in the month of January and the minimum value of 3712.31 Kg/ha/yr was recorded in the month of August. However, other higher values were recorded in February, March, April and December. There was significant difference ($P>0.05$) among the study months, except in November, September and October; December, March and April; January and February; and May, June and July.

4.3.0 Water Quality Index (WQI)

All the twenty one parameters observed under this study were present except free dissolved carbon dioxide (CO_2) that was available only in the months of February, June and October. pH, biochemical oxygen demand (BOD), alkalinity, ammonia ($\text{NH}_4^+\text{-N}$), nitrate ($\text{NO}_3^-\text{-N}$), total solid (TS), total dissolved solid (TDS) and total suspended solid (TSS) were within the recommended level for aquatic life (table 1). High level in ambient temperature (A/T), surface water temperature (W/T), transparency (Trans), turbidity, dissolved oxygen (DO), chloride, phosphorus phosphate ($\text{PO}_4\text{-P}$), nitrite ($\text{NO}_2^-\text{-N}$), chemical oxygen demand (COD), conductivity and CO_2 were recorded while low in ambient temperature, water temperature, transparency, turbidity, DO, hardness, COD and conductivity across the months. Lowest ambient temperature was noticed in the month of December and highest during May, there was no significant difference ($p<0.05$) in November and January; March and June; February, April, July, August and October while significant difference ($p>0.05$) in December, September and May. Lowest water temperature was recorded in December while highest value in March, there was significant difference ($p>0.05$) between all the study months. Highest transparency was seen in September and lowest in May, November, September, and October and it was significantly difference ($P>0.05$) also with the rest of the months. Highest turbidity was noticed in May while lowest in September, there was significant difference ($p>0.05$) within the months

except in November, January and August; December and July; and March and May.

TS, TDS and TSS were low in February, November and January while they were high in August and March. No significant difference ($p < 0.05$) between May and August; November and March; and April was observed as compared with rest of the months for TS, TDS and TSS. pH was highest in September and lowest in November, significant difference ($p > 0.05$) was observed in all the months except in December, January and June; and April and May. Alkalinity was lowest in August and highest in October, there was no significant difference ($p < 0.05$) in December and January; February and August; March and April; May and July while rest of the months were significantly different ($p > 0.05$). Highest value of hardness was recorded in June and lowest in December, months of December and January; March and April were not significantly different ($p < 0.05$), while there was significant difference ($P > 0.05$) in rest of the months. Chloride and phosphorus phosphate were low in December while high in May and October (table 2), no significant difference ($p < 0.05$) was seen in February and April for chloride and significant difference ($p > 0.05$) in May and October.

In term of $\text{NH}_4^+\text{-N}$, lowest value was recorded in January and highest in September, there was significant difference ($p > 0.05$) in December, January and July with rest of the months. NO_2^-N was low in October and high in June, there was a significant difference ($p > 0.05$) in June, August and October; with no different in rest of the months. NO_3^-N was highest in June and lowest in December, significant difference ($p > 0.05$) was observed in December, February and May, while there was insignificant difference ($p < 0.05$) in rest of the months. In term of phosphate, highest value was recorded in October and lowest in March, there was no significant difference ($P < 0.05$) across the study months except in February and October. Lowest DO was available in May and highest in September, there was no significant difference ($p < 0.05$) in the month of December and February; March and October; and April and June. For CO_2 , high concentration was present in June and low in February, there was no significant difference ($P < 0.05$) was seen in February, June and October. Highest BOD was observed in September and lowest in January, and no significant difference

($p < 0.05$) in February, May, June, July and October, while rest of the months were significantly different ($p > 0.05$). COD was high in April and low in January, and a significant difference ($P > 0.05$) was observed in May, June, July, August, September and October as compared to other months. Conductivity was low in October and high in July, with insignificant difference ($P < 0.05$) in months of January and February; and significantly different with rest of the months.

4.4.0 Heavy metal, Metalloid and Active metal concentration in fish, water and sediment

4.4.1 Fish samples

Calcium was present in *Catla catla* (0.01 ppm), *Clarias gariepinus* (0.04 ppm) and very low in *Oreochromis mossambicus*, there was no significant difference ($P < 0.05$) across the species (table 25). For potassium, *Catla catla* had the highest (0.28 ppm), followed by *Clarias gariepinus* (0.25 ppm) and lowest in *Oreochromis mossambicus* (0.24 ppm), there was no significant difference ($P < 0.05$) in among the species.

Table 25: Variation in metals in three fish species of Powai lake (November, 2016 to October, 2017)

Parameter (ppm)	<i>Oreochromis mossambicus</i>	<i>Catla catla</i>	<i>Clarias gariepinus</i>
Calcium**	0.00±0.0 ^a	0.01±0.00 ^a	0.04±0.00 ^a
Cadmium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Chromium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Copper*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Iron*	0.01±0.00 ^a	0.01±0.00 ^a	0.01±0.00 ^a
Arsenic*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Potassium**	0.24±0.04 ^a	0.28±0.02 ^a	0.25±0.01 ^a
Magnesium**	0.01±0.0 ^a	0.01±0.00 ^a	0.01±0.00 ^b
Manganese*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Sodium**	0.04±0.01 ^a	0.04±0.00 ^a	0.05±0.01 ^a
Silicon***	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Zinc*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a

Means (±SE) in the same column having different superscripts are significantly different (P<0.05). *Heavy metals, **Active metals and ***Metalloid

For magnesium, 0.01 ppm was present in all the three species, there was no significant difference (P<0.05). 0.05 ppm value of sodium was present in *Clarias gariepinus*, while 0.04 ppm value was present in both *Oreochromis mossambicus* and *Catla catla*, there was no significant difference (P<0.05) among the species. Iron was present in relatively same proportion (0.01 ppm) in all the three species, there was no significant difference (P<0.05). Cadmium, chromium, copper, arsenic, manganese, silicon and zinc were less than 0.01 ppm.

Metal concentration in Water

4.4.2 Pre-monsoon season of Powai lake

Calcium was highest in station D (28.82 ppm) and lowest in station C (26.40 ppm) as shown in table 26, there was significant difference (P>0.05) across all the stations studied. Lowest potassium concentration was recorded in station A (1.02 ppm) while highest value in station C (1.38 ppm), there was no significant difference

($P < 0.05$) in station A and E; and station B and C, and significantly different ($P > 0.05$) with station D. For magnesium, 9.82 ppm was highest in station A and 9.67 ppm was lowest in station D, there was no significant difference ($P < 0.05$) across the stations. The 16.68 ppm value of sodium was recorded as the highest in station D, while 16.00 ppm value was lowest in station C, there was no significant difference ($P < 0.05$) between station A and D; and station B and D, and significantly different ($P > 0.05$) with station C.

Manganese was highest in station D (0.02 ppm), and lowest in station B (0.01 ppm). There was no significant difference ($P < 0.05$) between station C and D; and significantly different ($P > 0.05$) with stations A, B and C. Iron was only present in station D (0.01 ppm) and E (0.01 ppm) which was significantly different ($P > 0.05$). Lowest amount of copper was recorded in station A and C (0.01 ppm) and highest in station D (0.01 ppm), while stations B and E had lesser than 0.01 ppm. There was significant difference ($P > 0.05$) between station D with station A and C. Tin was highest in station D (0.21 ppm) and lowest in station B (0.11 ppm), other higher value was recorded in station A. There was significant difference ($P > 0.05$) across all the stations. Chromium, cobalt, nickel, zinc, arsenic, cadmium, antimony, mercury and lead were less than 0.01 ppm.

Table 26: Metals concentration across the stations of Powai lake in pre-monsoon

Parameter (ppm)	Station				
	A	B	C	D	E
Chromium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Manganese*	0.01±0.00 ^b	0.01±0.00 ^a	0.01±0.00 ^c	0.01±0.00 ^c	0.02±0.00 ^d
Iron*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.01±0.00 ^b	0.01±0.00 ^c
Cobalt*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Nickel*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Copper*	0.01±0.00 ^b	0.00±0.00 ^a	0.01±0.00 ^b	0.01±0.00 ^c	0.00±0.00 ^a
Zinc*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Arsenic*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Cadmium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Tin*	0.14±0.00 ^b	0.11±0.00 ^a	0.16±0.00 ^c	0.21±0.00 ^e	0.16±0.00 ^d
Antimony*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Mercury*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Lead*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Calcium**	27.45±0.05 ^b	27.86±0.03 ^c	26.40±0.03 ^a	28.82±0.05 ^d	27.68±0.20 ^{bc}
Potassium**	1.02±0.00 ^a	1.32±0.02 ^c	1.38±0.01 ^c	1.23±0.02 ^b	1.09±0.03 ^a
Magnesium**	9.82±0.01 ^a	9.68±0.02 ^a	9.79±0.02 ^a	9.67±0.03 ^a	9.76±0.01 ^a
Sodium**	16.67±0.06 ^c	16.34±0.03 ^b	16.00±0.00 ^a	16.68±0.07 ^c	16.26±0.03 ^b

Means (±SE) in the same row having different superscripts are significantly different (P<0.05). *Heavy metals and **Active metals

4.4.3 Monsoon season of Powai lake

Calcium was highest in station E (28.56 ppm) and lowest in station B (27.63 ppm) as shown in table 27, there was no significant difference (P<0.05) in stations C, D and E, and significantly different (P>0.05) in A and B. Potassium lowest value was recorded in station A (1.50 ppm), while highest value in station E (1.73 ppm), there was no significant difference (P<0.05) in station A and D; and station C and E, and significantly different (P>0.05) with station B. For magnesium, 9.82 ppm was highest in station D and 9.15 ppm was lowest in station C, there was no significant difference (P<0.05) across the stations. The 16.59 ppm value of sodium was recorded as the highest in station C, while 16.16 ppm value was recorded as lowest in station B, there was significant difference (P>0.05) in all the stations except in station C and D.

Table 27: Metals concentration across the stations of Powai lake in monsoon

Parameter (ppm)	Station				
	A	B	C	D	E
Chromium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Manganese*	0.01±0.01 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Iron*	0.01±0.00 ^a	0.02±0.00 ^a	0.01±0.00 ^a	0.01±0.00 ^a	0.01±0.00 ^a
Cobalt*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Nickel*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Copper*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Zinc*	0.01±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.01±0.00 ^a
Arsenic*	0.28±0.07 ^b	0.10±0.00 ^a	0.07±0.00 ^a	0.06±0.00 ^a	0.06±0.00 ^a
Cadmium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Tin*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Antimony*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Mercury*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Lead*	0.00±0.00 ^a	0.00±0.00 ^a	0.08±0.08 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Calcium**	28.18±0.05 ^{ab}	27.63±0.14 ^a	28.52±0.09 ^b	28.46±0.04 ^b	28.56±0.38 ^b
Potassium**	1.50±0.01 ^a	1.72±0.02 ^c	1.61±0.00 ^b	1.55±0.02 ^a	1.73±0.00 ^c
Magnesium**	9.63±0.00 ^a	9.67±0.06 ^a	9.15±0.01 ^a	9.82±0.04 ^a	9.51±0.01 ^a
Sodium**	16.31±0.03 ^{ab}	16.16±0.00 ^a	16.59±0.11 ^c	16.57±0.01 ^c	16.37±0.03 ^b

Means (±SE) in the same row having different superscripts are significantly different (P<0.05). *Heavy metals and **Active metals

Manganese was present only in station A (0.01 ppm). There was no significant difference (P<0.05) among the stations. Iron was highest in station B (0.02 ppm), and lower in stations A, C, D and E (0.01 ppm), there was no significant difference (P>0.05) across the stations. The lowest amount of zinc was recorded in station A and E (0.01 ppm), while stations B, C and D had lesser than 0.01 ppm. There was no significant difference (P<0.05) between station A and E. Arsenic was highest in station A (0.28 ppm) and lowest in station D and E (0.06 ppm), other higher value was recorded in station B. There was significant difference (P>0.05) between station A and the rest of the stations. Lead was present only in station C (0.08 ppm) while lesser than 0.01 ppm in stations A, B, D and E. There was no significant difference (P<0.05) among the studied stations. Chromium, cobalt, nickel, copper, cadmium, tin, antimony and mercury were lesser than 0.01 ppm.

4.4.4 Post-monsoon season of Powai lake

Calcium was highest in station E (28.53 ppm) and lowest in station B (27.84 ppm) as depicted in table 28, there was no significant difference ($P < 0.05$) in stations C, D and E, and got significantly different ($P > 0.05$) in A and B. Potassium lowest value was observed in station A (1.52 ppm) while highest value in station B (1.76 ppm), there was no significant difference ($P < 0.05$) in station A and D; and station B and E, and significantly different ($P > 0.05$) noticed with station C. For magnesium, 9.74 ppm was highest in station D and 9.13 ppm was lowest in station C, there was significant difference ($P > 0.05$) across the stations, except in station B and D. 16.71 ppm value of sodium was noticed as the highest in station C, while 16.17 ppm value was lowest in station B, there was significant difference ($P > 0.05$) in all the stations. Chromium, manganese, iron, cobalt, nickel, copper, zinc, arsenic, cadmium, tin, antimony, mercury and lead were lesser than 0.01 ppm.

Table 28: Metals concentration across the stations of Powai lake during post-monsoon in water

Parameter (ppm)	Station				
	A	B	C	D	E
Chromium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Manganese*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Iron*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Cobalt*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Nickel*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Copper*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Zinc*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Arsenic*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Cadmium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Tin*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Antimony*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Mercury*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Lead*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Calcium**	28.17±0.08 ^b	27.84±0.07 ^a	28.51±0.07 ^c	28.49±0.12 ^c	28.53±0.08 ^c
Potassium**	1.52±0.01 ^a	1.76±0.01 ^c	1.61±0.00 ^b	1.54±0.02 ^a	1.72±0.01 ^c
Magnesium**	9.60±0.01 ^c	9.74±0.00 ^d	9.13±0.01 ^a	9.74±0.01 ^d	9.53±0.00 ^b
Sodium**	16.33±0.02 ^b	16.17±0.00 ^a	16.71±0.01 ^e	16.55±0.01 ^d	16.42±0.02 ^c

Means (±SE) in the same row having different superscripts are significantly different (P<0.05). *Heavy metals and **Trace metals

4.4.5 Seasonal variation in water of Powai lake

Calcium was highest in post-monsoon (28.31 ppm) and lowest in pre-monsoon (27.64 ppm) as shown in table 29, there was no significant difference (P<0.05) in monsoon and post-monsoon; and got significantly different (P>0.05) in pre-monsoon. Potassium lowest value was recorded in pre-monsoon (1.21 ppm) while highest value in post-monsoon (1.63 ppm), there was no significant difference (P<0.05) in monsoon and post-monsoon; and significantly different (P>0.05) with pre-monsoon. For magnesium, 9.74 ppm was highest in pre-monsoon and 9.42 ppm was lowest in monsoon, there was no significant difference (P<0.05) across the seasons. 16.44 ppm value of sodium was recorded as the highest in post-monsoon, while 16.39 ppm

value was lowest in pre-monsoon, there was no significant difference ($P < 0.05$) in all the seasons.

Table 29: Metals concentration across the seasons of Powai lake water

Parameter (ppm)	Pre-monsoon	Monsoon	Post-monsoon
Chromium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Manganese*	0.01±0.00 ^b	0.00±0.00 ^a	0.00±0.00 ^a
Iron*	0.00±0.00 ^a	0.01±0.00 ^b	0.00±0.00 ^a
Cobalt*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Nickel*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Copper*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Zinc*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Arsenic*	0.00±0.00 ^a	0.11±0.00 ^b	0.00±0.00 ^a
Cadmium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Tin*	0.16±0.00 ^b	0.00±0.00 ^a	0.00±0.00 ^a
Antimony*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Mercury*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Lead*	0.00±0.00 ^a	0.01±0.00 ^b	0.00±0.00 ^a
Calcium**	27.64±0.21 ^a	28.27±0.11 ^b	28.31±0.08 ^b
Potassium**	1.21±0.03 ^a	1.62±0.02 ^b	1.63±0.02 ^b
Magnesium**	9.74±0.02 ^a	9.42±0.08 ^a	9.55±0.06 ^a
Sodium**	16.39±0.07 ^a	16.41±0.04 ^a	16.44±0.04 ^a

Means ($\pm$ SE) in the same column having different superscripts are significantly different ($P < 0.05$). *Heavy metals and **Active metals

Manganese was only present during pre-monsoon (0.01 ppm), and it was significantly different ($P > 0.05$) with the rest of the seasons. Iron was also only present in monsoon (0.01 ppm), and lesser than 0.01 ppm in pre-monsoon and post-monsoon, there was significant difference ($P > 0.05$) between monsoon and the rest of the seasons. Arsenic was recorded in monsoon (0.01 ppm), while pre-monsoon and post-monsoon had lesser than 0.01 ppm. There was significant difference ($P > 0.05$) between monsoon and the rest of the seasons. Tin was available in pre-monsoon (0.16 ppm) and lesser than (0.01 ppm) in monsoon and post-monsoon. There was

significant difference ($P>0.05$) between pre-monsoon and the rest of the seasons. Lead was present in monsoon (0.01 ppm) while lesser than 0.01 ppm in pre-monsoon and post-monsoon. There was significant difference ($P>0.05$) in monsoon and the rest of the seasons. Chromium, cobalt, nickel, copper, zinc, cadmium, antimony and mercury were lesser than 0.01 ppm.

4.4.6 Seasonal variation in sediment of Powai lake

Calcium was highest in pre-monsoon (22.10 ppm) and lowest in post-monsoon (14.42 ppm) as shown in table 30, there was no significant difference ($P<0.05$) in monsoon and post-monsoon; and got significantly different ($P>0.05$) in pre-monsoon. Lowest chromium value was recorded in monsoon and post-monsoon (0.01 ppm), while highest value in pre-monsoon (0.02 ppm), there was no significant difference ($P<0.05$) in monsoon and post-monsoon; and significantly different ($P>0.05$) in pre-monsoon. For copper, 0.01 ppm was highest in pre-monsoon and 0.01 ppm was lowest in post-monsoon, there was significant difference ($P>0.05$) across the seasons. 10.01 ppm value of iron was recorded as the highest in pre-monsoon, while 7.64 ppm value was lowest in post-monsoon, there was no significant difference ($P<0.05$) across the seasons, except in pre-monsoon.

Potassium was highest during pre-monsoon (0.15 ppm) and lowest in monsoon (0.06 ppm), there was significant difference ($P>0.05$) between pre-monsoon and the rest of the seasons. Magnesium was lowest in post-monsoon (0.26 ppm) and highest in pre-monsoon (0.37 ppm), there was no significant difference ($P<0.05$) across the seasons. Manganese was highest in pre-monsoon (0.20 ppm), while lowest value was observed in monsoon (0.10 ppm). There was significant difference ($P>0.05$) between pre-monsoon and the rest of the seasons. Sodium availability was highest in pre-monsoon (0.39 ppm) and lowest in post-monsoon. There was significant difference ($P>0.05$) between pre-monsoon and the rest of the seasons. Silicon was highest in pre-monsoon (1.77 ppm) while lowest in post-monsoon. There was no significant difference ($P<0.05$) in the studied seasons. Zinc was present only in pre-monsoon (0.01 ppm) and lesser than 0.01 ppm in monsoon and post-monsoon, there was significant difference between pre-monsoon and the rest of the season. Arsenic was less than 0.01% ppm throughout the studied seasons.

Table 30: Metals concentration across the seasons of Powai lake sediment

Parameter (ppm)	Pre-monsoon	Monsoon	Post-monsoon
Calcium**	22.10±0.60 ^b	15.20±1.64 ^a	14.42±0.11 ^a
Cadmium*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Chromium*	0.02±0.00 ^b	0.01±0.00 ^a	0.01±0.00 ^a
Copper*	0.01±0.00 ^b	0.00±0.00 ^a	0.01±0.00 ^a
Iron*	10.01±0.31 ^b	7.90±0.48 ^a	7.64±0.10 ^a
Arsenic*	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Potassium**	0.15±0.01 ^b	0.06±0.02 ^a	0.11±0.00 ^a
Magnesium**	0.37±0.05 ^a	0.26±0.04 ^a	0.26±0.03 ^a
Manganese*	0.20±0.03 ^b	0.10±0.02 ^a	0.13±0.01 ^a
Sodium**	0.39±0.03 ^b	0.26±0.03 ^a	0.26±0.01 ^a
Silicon***	1.77±0.23 ^a	1.29±0.11 ^a	1.28±0.12 ^a
Zinc*	0.01±0.00 ^b	0.00±0.00 ^a	0.00±0.00 ^a

Means (±SE) in the same column having different superscripts are significantly different (P<0.05). *Heavy metals, **Active metals and ***Metalloid

4.5.0 Plankton

4.5.1 Plankton relative percentage

Plankton species recorded during the present study in relation to numbers per litre, and percentage is summarized in table 31. In total, eleven (11) species belonging to nine (9) families were identified. Phytoplankton comprise the greater proportion of about 95.09% with six (6) families and zooplankton was less dominant with only 4.91% coupled with three (3) families. The result shows dominance by family *Microcystaceae* comprising a significant fraction 84.91%, and there is the only one specie (*Microcystis aeruginosa*) in this family. This was followed by *Navicular sp.* (8.16%) which was the only specie from the family *Naviculaceae*. Other less prominent species in order of percentage were *Moina brachiata* (1.66%) in family *Moinidae*, *Keratella chochlearis* (1.30%) and *Brachionus calyciflorus* (0.95%) in family *Brachionidae* (2.25%). *Acartia clausi* (0.95%) was the only specie in family *Acartiidae*. The lower percentages were 0.59% (*Eudorina sp.*) and 0.37% (*Volvox sp.*) belong to family *Volvocaceae* (0.96%). Others include *Pediastrum sp.* (0.56%) in

family *Hydrodictyaceae*, *Nitzschia* sp. (0.41%) in family *Bacillariaceae*, and *Spirogyra* sp. (0.09%) in family *Zygnemataceae*.

Table 31: Monthly composition of plankton in Powai lake (No./litre) and percentage (November, 2016 to October, 2017)

Family	Species	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Total	%	%
<i>Microcystaceae</i>	<i>Microcystis</i>															
(Colony)	<i>aeruginosa</i>	9750	22090	8380	16330	56880	113430	217110	412130	815880	1615430	3173980	6234530	12695920	84.919	
<i>Naviculaceae</i>	<i>Navicula</i>															
	<i>sp.</i>	50	10	0	0	9810	9870	19690	39370	78740	157480	305150	600430	1220600	8.164	
<i>Hydrodictyceae</i>	<i>Pediastrum</i>															
	<i>sp.</i>	100	110	110	40	410	770	1440	2770	5430	10820	21230	41690	84920	0.568	
<i>Volvocaceae</i>	<i>Volvox sp.</i>	30	120	10	40	300	500	970	1820	3630	7220	14140	27780	56560	0.378	
	<i>Eudorina</i>															
	<i>sp.</i>	100	170	20	100	420	810	1520	2870	5720	11340	22260	43710	89040	0.595	
<i>Bacillariaceae</i>	<i>Nitzschia</i>															
	<i>sp.</i>	110	70	30	0	360	570	1030	1990	3950	7900	15440	30310	61760	0.413	
<i>Zygnemataceae</i>	<i>Spirogyra</i>															
	<i>sp.</i>	0	0	0	0	110	110	220	440	880	1760	3410	6710	13640	0.091	95.09
<i>Brachionidae</i>	<i>Keratella</i>															
	<i>chochlearis</i>	250	210	150	270	880	1760	3270	6330	12511	24753	48626	95492	194504	1.300	
	<i>Brachionus</i>															
	<i>calyciflorus</i>	240	150	130	140	660	1320	2400	4651	9173	18206	35752	70184	143009	0.956	
<i>Moinidae</i>	<i>Moina</i>															
	<i>brachiata</i>	330	270	310	220	1130	2260	4191	8112	15914	31609	62088	121916	248354	1.661	
<i>Acartiidae</i>	<i>Acartia</i>															
	<i>clausi</i>	150	200	110	130	690	1280	2410	4620	9130	18130	35570	69860	142280	0.951	4.91

4.5.2 Relative plankton species in station

The samples from the five stations showed relevant difference in number of taxa and relative abundance of plankton (Table 32). All the species occurred throughout the depth (30cm) except *Navicula sp.* which was absent in station E. The common species in all the stations were *Microcystis aeruginosa*, *Moina brachiata*, *Keratella chochlearis* and *Brachionus calyciflorus*. The highest value represented the peak was recorded in stations B and C which varied between 14050 and 24662 plankton per litre. The least concentration was observed in station C (4 plankton per liter). *Navicula sp.* was only 45 (number per liter) in station A, 8 (number per liter) in station B, 4 (number per liter) in station C, and 20 (number per liter) in station D.

Table 32: Composition of plankton (No. /litre) of Powai lake at different station

Family	Species	Station					Total
		A	B	C	D	E	
<i>Microcystaceae</i>	<i>Microcystis</i>						
(Colony)	<i>aeruginosa</i>	20066	24662	14050	14637	16685	90102
<i>Naviculaceae</i>	<i>Navicula sp.</i>	45	8	4	20	0	79
<i>Hydrodictyaceae</i>	<i>Pediastrum</i>						
	<i>sp.</i>	87	91	58	12	66	316
<i>Volvocaceae</i>	<i>Volvox sp.</i>	66	66	33	66	79	312
	<i>Eudorina sp.</i>	62	104	62	95	62	387
<i>Bacillariaceae</i>	<i>Nitzschia sp.</i>	200	262	150	175	183	970
<i>Zygnemataceae</i>	<i>Spirogyra sp.</i>	104	166	87	87	120	566
<i>Brachionidae</i>	<i>Keratella</i>						
	<i>chochlearis</i>	254	254	154	154	129	945
	<i>Brachionus</i>						
	<i>calyciflorus</i>	258	150	83	137	120	750
<i>Moinidae</i>	<i>Moina</i>						
	<i>brachiata</i>	329	391	233	179	179	1312
<i>Acartiidae</i>	<i>Acartia clausi</i>	104	166	87	87	120	566

4.5.3 Plankton diversity index

Table 33 show the monthly plankton diversity index of Powai lake for the months studied. The monthly trend of Shannon-Weiner index for the lake can be depicted as month of March had the highest, other higher index was observed in the month of August, followed by same index in July, September and October; followed by June, followed by April, followed by May, followed by November, followed by January, followed by December, and least in February. The maximum number (3337551) of plankton species was recorded in October whereas the minimum (4204) was observed in January. The concentration of dominance was highest in March, followed by August, followed by same trend in July, September and October; followed by June, followed by November, followed by May, followed by April, followed by January, followed by December, and least in February. The species richness index ranged from 0.632 (October) to 1.095 (January). The equitability or evenness index was highest in March (0.327) and lowest (0.143) in December. Species heterogeneity was in descending order as February, December, January, November, April, May, July, June having the same index with September and October; followed by August, and least in March.

Table 33: Monthly diversity indices of plankton species of Powai lake (November, 2016 to October, 2017)

Month	No. of sp.	No. of Individual per litre	Diversity indices				
			Species Richness Index (d')	Shannon-Weiner Index (H')	Equitability Index (J)	Simpson's Index (D)	Species Heterogeneity ($1 - D$)
November	10	5050	1.074	0.616	0.267	0.227	0.772
December	10	10636	0.994	0.329	0.143	0.108	0.891
January	9	4204	1.095	0.474	0.216	0.177	0.822
February	8	7850	1.025	0.307	0.148	0.105	0.894
March	11	32568	0.895	0.782	0.327	0.350	0.649
April	11	60309	0.848	0.655	0.274	0.262	0.737
May	11	115569	0.803	0.654	0.273	0.264	0.735
June	11	220502	0.763	0.665	0.278	0.270	0.729
July	11	436799	0.726	0.666	0.279	0.271	0.728
August	11	865749	0.692	0.669	0.280	0.273	0.726
September	11	1698931	0.660	0.666	0.278	0.271	0.728
October	11	3337551	0.632	0.666	0.279	0.271	0.728

The trend of Shannon-Weiner index for sampling stations in Powai lake (table 34) can be depicted in descending order as station A, D, C, B and then station E. The minimum number (15001) of plankton species was recorded in station B whereas the maximum number (26320) was observed for station C. The concentration of dominance was highest in station A, followed by D, followed by C, and followed by station B and E with the same value. The species richness index ranged from 0.983 (station B) to 1.040 (station C). The Equitability or evenness index was highest in station A (0.167) and least (0.153) in station B, C and E. Species heterogeneity was in the descending order as station E, B, C, D and then station A.

Table 34: Diversity indices of plankton at different stations in Powai lake (November, 2016 to October, 2017)

Station	No. of sp.	No. of Individual per litre	Diversity indices				
			Species Richness Index (d')	Shannon-Weiner Index (H')	Equitability Index (J)	Simpson's Index (D)	Species Heterogeneity ($1 - D$)
A	11	21575	1.003	0.400	0.167	0.134	0.865
B	11	26320	0.983	0.366	0.153	0.121	0.878
C	11	15001	1.040	0.367	0.153	0.122	0.877
D	11	15649	1.033	0.376	0.157	0.124	0.875
E	10	17743	1.022	0.353	0.153	0.115	0.884

4.5.4 Relative abundance

The species abundance data was plotted as a rank abundance curve following Whittaker (1965). Each species is represented by a point on the line graph proportional to its abundance. Fig. 18 shows the rank abundance plot. The long tail depicts rarer species, hence the plankton community of Powai lake can be said to have high to moderate evenness.

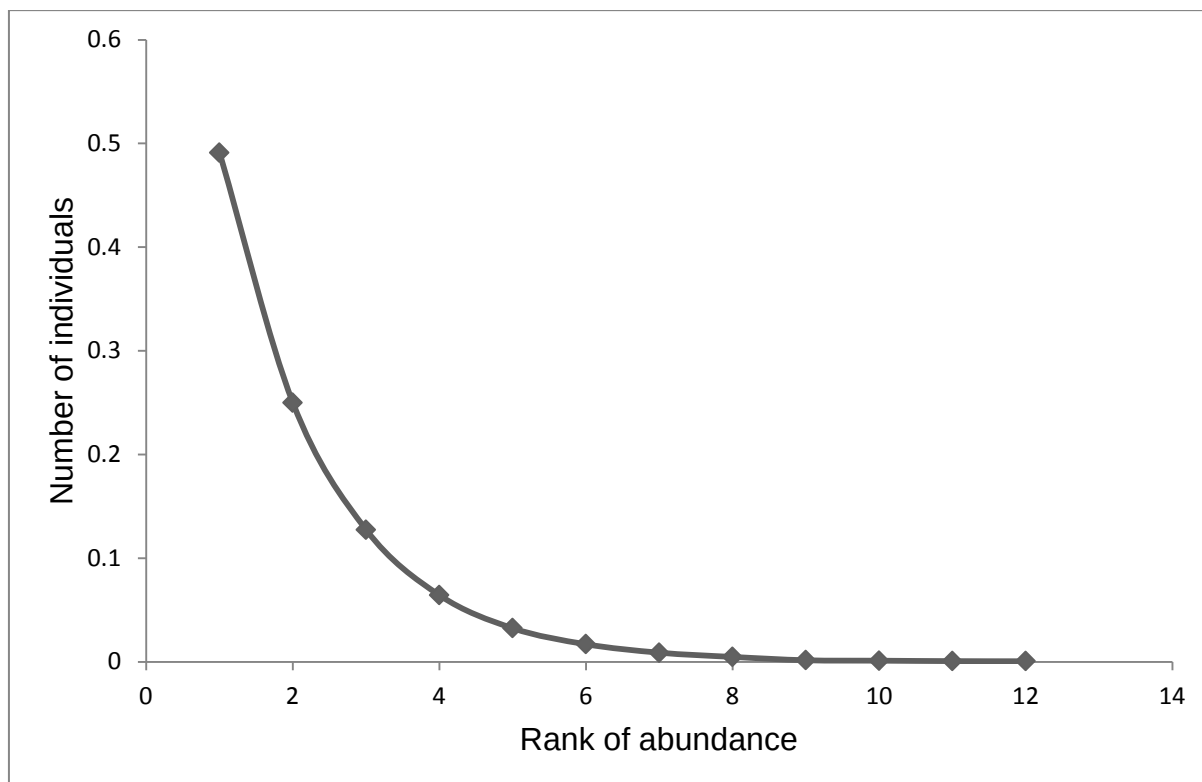


Fig. 18: Rank-abundance curve for the plankton community of Powai lake, Mumbai India

4.6.0 Sediment quality parameters

4.6.1 Texture

Results of the sediment texture analysis reveal that the sediment was clayey loam to silty loam in nature (Table 35). The sediment samples showed relative significant variation in texture. Monthly average percentage of clay component ranged from 51.40 to 54.60%. This was followed by silt component which varied from 30.60 and 33.80%. The sand component was found in small fraction which ranged from 12.80 to 14.60%. Thus soil texture analysis of the catchment area showed higher percentage of clay followed by silt and sand in the various stations (appendix I-XII).

Table 35: Monthly mean variation in sediment quality parameters of Powai lake (November, 2016 to October, 2017)

Month	Texture (%)			pH	Available nitrogen (mg 100g ⁻¹ sediment)	Available phosphorus (mg 100g ⁻¹ sediment)	Organic carbon (%)	Organic matter (%)
	Sand	Silt	Clay					
November	14.60±0.27 ^d	32.20±0.31 ^{cde}	51.40±1.90 ^a	7.50±0.08 ^a	299.26±0.75 ^a	7.18±0.25 ^a	2.97±0.10 ^a	5.16±0.17 ^a
December	13.80±0.10 ^b	32.40±0.21 ^{de}	53.80±0.20 ^b	7.48±0.06 ^a	310.33±0.64 ^a	7.44±0.15 ^a	3.08±0.06 ^a	5.33±0.11 ^a
January	12.80±0.31 ^a	33.80±0.35 ^f	53.40±0.36 ^b	7.45±0.05 ^a	321.13±0.58 ^a	7.70±0.13 ^a	3.19±0.05 ^a	5.50±0.09 ^a
February	13.20±0.31 ^{ab}	32.80±0.35 ^e	54.00±0.53 ^b	7.48±0.05 ^a	306.33±0.52 ^a	7.35±0.18 ^a	3.06±0.07 ^a	5.28±0.13 ^a
March	14.20±0.35 ^{cd}	32.20±0.45 ^{cde}	53.60±0.60 ^b	7.56±0.05 ^a	296.40±0.32 ^a	7.11±0.31 ^a	2.94±0.13 ^a	5.07±0.22 ^a
April	14.20±0.10 ^{cd}	32.20±0.31 ^{cde}	53.40±0.27 ^b	7.58±0.05 ^a	301.20±0.27 ^a	7.22±0.24 ^a	2.99±0.10 ^a	5.15±0.17 ^a
May	14.60±0.13 ^d	31.20±0.31 ^{ab}	54.00±0.23 ^b	7.56±0.05 ^a	314.01±0.54 ^a	7.53±0.22 ^a	3.14±0.09 ^a	5.41±0.16 ^a
June	14.20±0.10 ^{cd}	31.00±0.16 ^{ab}	54.60±0.13 ^b	7.56±0.03 ^a	316.42±0.83 ^a	7.59±0.21 ^a	3.16±0.08 ^a	5.45±0.15 ^a
July	14.60±0.13 ^d	30.60±0.13 ^a	54.60±0.32 ^b	7.56±0.03 ^a	320.86±0.65 ^a	7.70±0.20 ^a	3.20±0.08 ^a	5.53±0.14 ^a
August	14.40±0.13 ^{cd}	31.20±0.20 ^{ab}	54.20±0.26 ^b	7.55±0.04 ^a	310.42±0.81 ^a	7.45±0.21 ^a	3.10±0.08 ^a	5.35±0.15 ^a
September	14.20±0.20 ^{cd}	31.40±0.21 ^{abc}	54.20±0.31 ^b	7.56±0.05 ^a	305.83±0.08 ^a	7.34±0.21 ^a	3.05±0.09 ^a	5.27±0.15 ^a
October	14.20±0.35 ^{cd}	31.60±0.21 ^{bcd}	54.20±0.31 ^b	7.60±0.07 ^a	313.85±0.58 ^a	7.53±0.20 ^a	3.13±0.08 ^a	5.41±0.14 ^a

Means (±SE) in the same column followed by different superscripts differ significantly (P<0.05)

The texture of the sand showed significant difference ($P>0.05$) across the study months, except in November and July; and March, April, June, August, September and October. In term of silt, there was significant difference ($P>0.05$) across the study months, except in November, March and April; May, and June and August. There was no significant difference ($P<0.05$) across the study months for clay texture, except in the month of November.

4.6.2 Sediment pH

Highest value of the lake sediment pH was recorded in the month of October (7.60) and lowest value in January (7.45). Other lower values were observed in December and February. There was no significant difference ($P<0.05$) among the study months. However, the results reveal that the sediments were neutral to alkaline.

4.6.3 Available nitrogen

321.13 mg 100g⁻¹ of sediment was recorded as highest in the month of January and 296.40 mg 100g⁻¹ of sediment was observed as lowest in the month of March. However, other higher values were recorded in May, June and July. There was no significant difference ($P<0.05$) among the study months. There was negligible variation in season wise concentrations of available nitrogen in the lake sediments.

4.6.4 Available phosphorus

The minimum value of 7.11 mg 100g⁻¹ of sediment was recorded in the month of March and the maximum value of 7.70 mg 100g⁻¹ of sediment was observed in the month of July. However, other higher values were recorded in December, January, June and August. There was no significant difference ($P<0.05$) among the study months. The available sediment phosphorus exhibited comparatively higher values during monsoon period while low in pre-monsoon.

4.6.5 Organic carbon

The maximum value of 3.19% was recorded in the month of January and the minimum value of 2.94% was seen in the month of March. However, other higher values were recorded in May, June, July and August. There was no significant

difference ($P<0.05$) among the study months. Usually, the value was higher during monsoon.

4.6.6 Organic matter

The maximum value of 5.53% was recorded in the month of July and the minimum value of 5.07% was observed in the month of March. However, other higher values were also observed in January, May and June. There was no significant difference ($P<0.05$) among the study months.

4.7 GIS and remote sensing based using multi-criteria evaluation models

Resource and facility maps were prepared based on the toposheet and satellite data using interpolation model. A procedure was set up using GIS where the map of Powai lake was extracted from google map using geo-referencing showing the current area of the lake as 15,427 m².

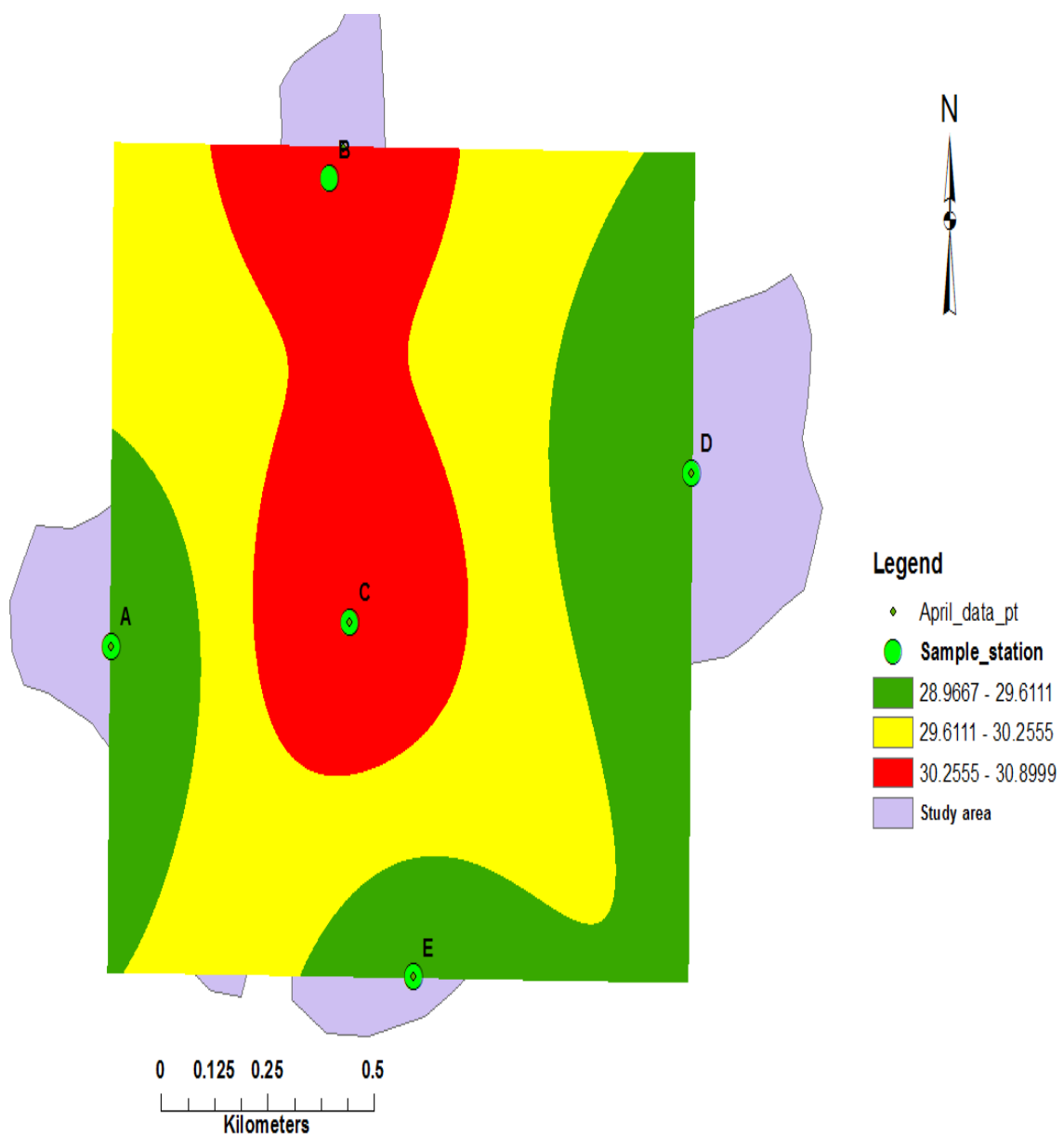


Fig. 19: Air temperature during pre-monsoon season across the stations

Air temperature of the lake fluctuates during pre-monsoon, monsoon and post-monsoon. Highest air temperature was in station B and C, and moderately at their radius, while least temperature was in station A, D and E during the pre-monsoon (Fig. 19).

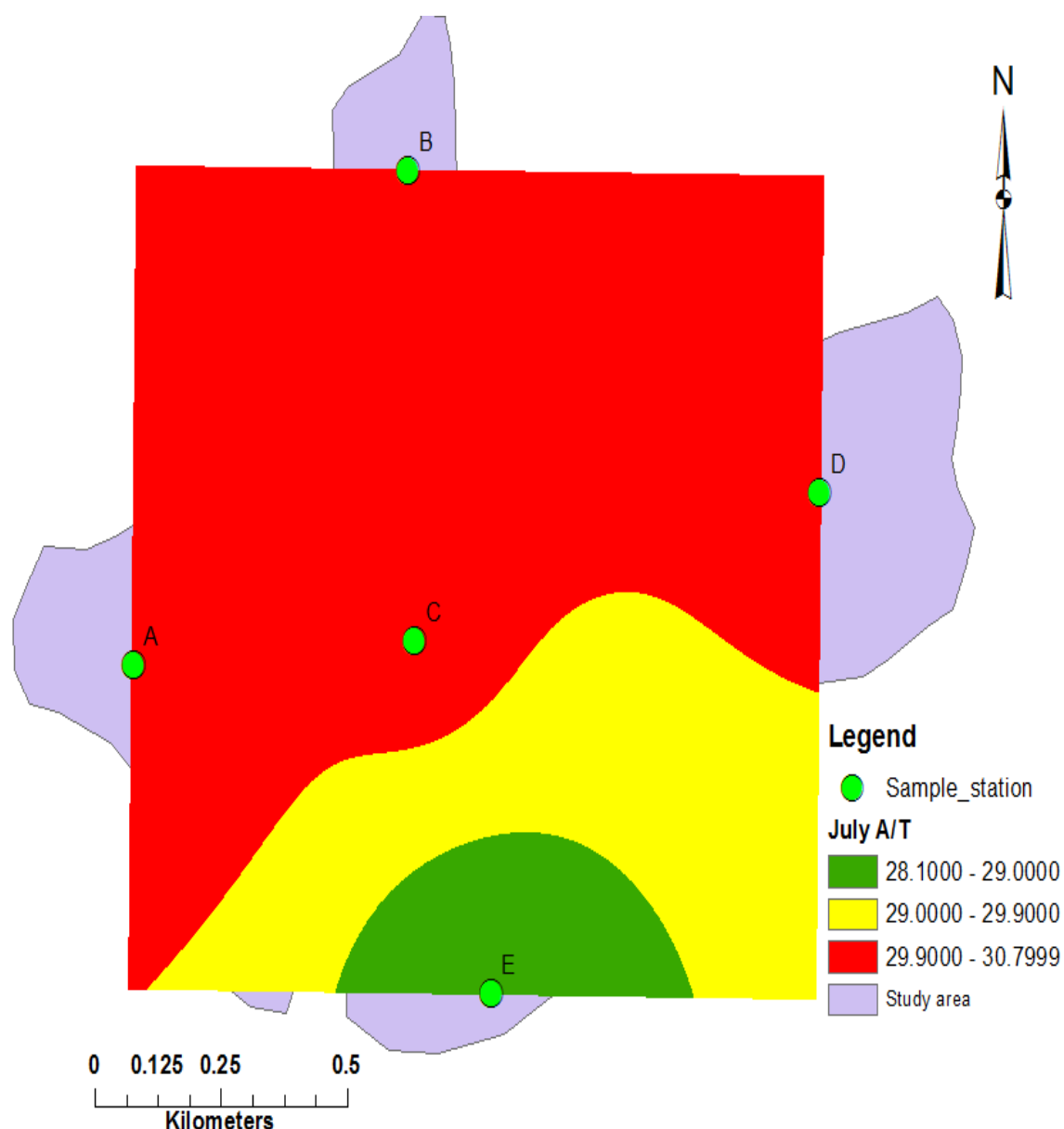


Fig. 20: Air temperature during monsoon season across the stations

During monsoon (Fig. 20), high air temperature were in station A, B, C and D with moderately suitable temperature at the radius of station E, in which the most suitable for aquatic life.

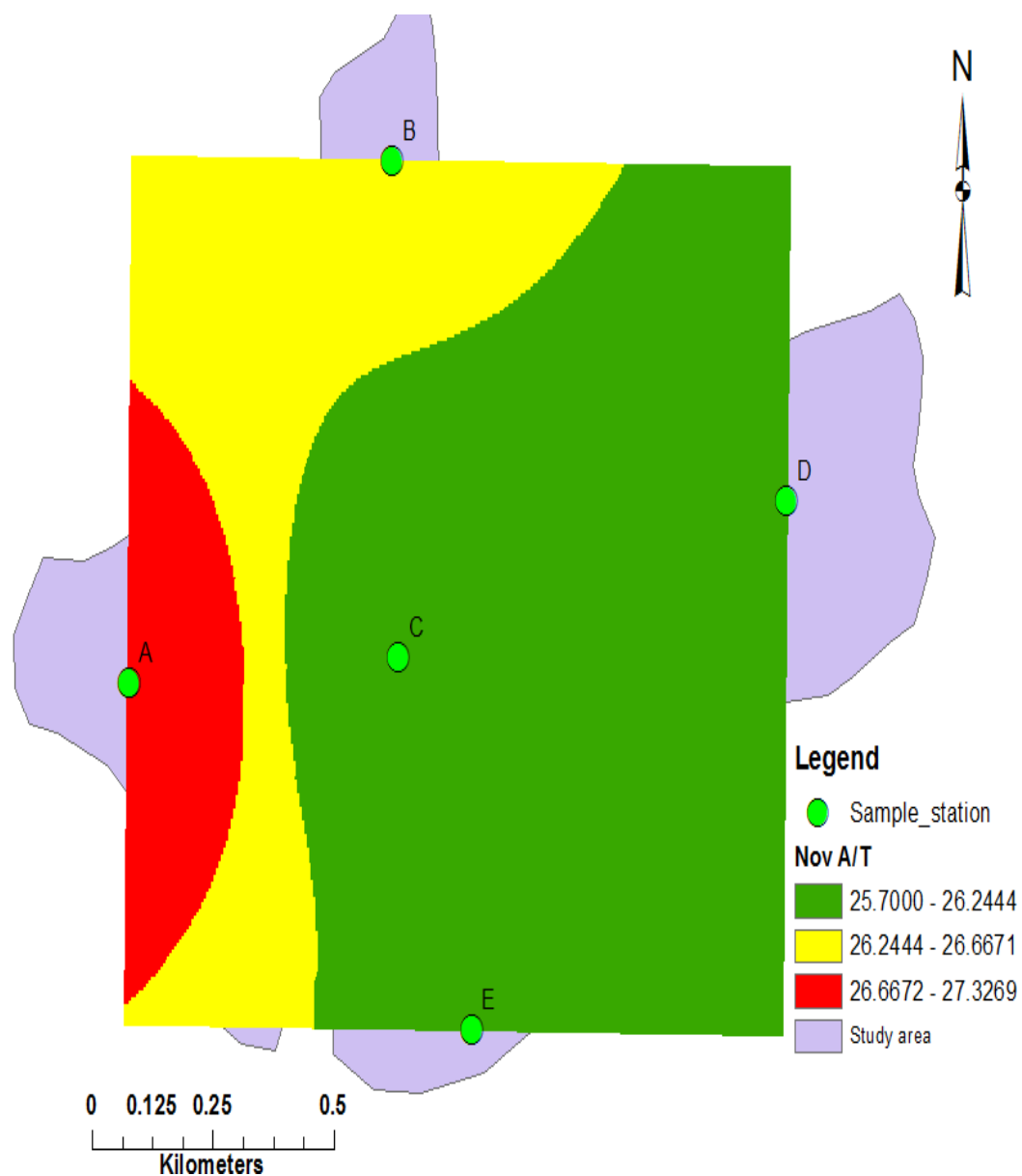


Fig. 21: Air temperature during post-monsoon season across the stations

Station C, D and E are the most suitable during the post-monsoon (Fig. 21) season, station B is moderately suitable, while station A and its radius are not suitable for aquatic life.

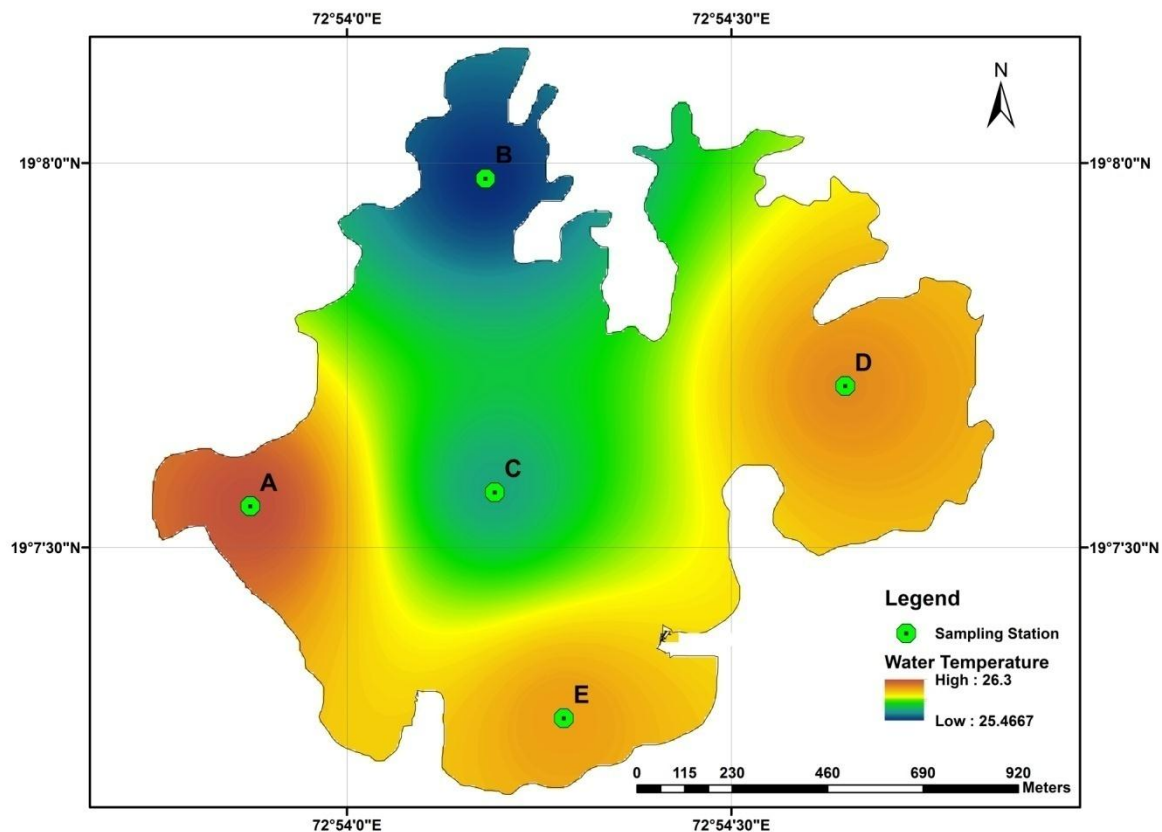


Fig. 22: Water temperature during post-monsoon season across the stations

Water temperature of the lake fluctuated during post-monsoon, monsoon and pre-monsoon season. Highest water temperature was in station A and D, and moderately at their radius, while least temperature was in station B, followed by station C and E (Fig. 22).

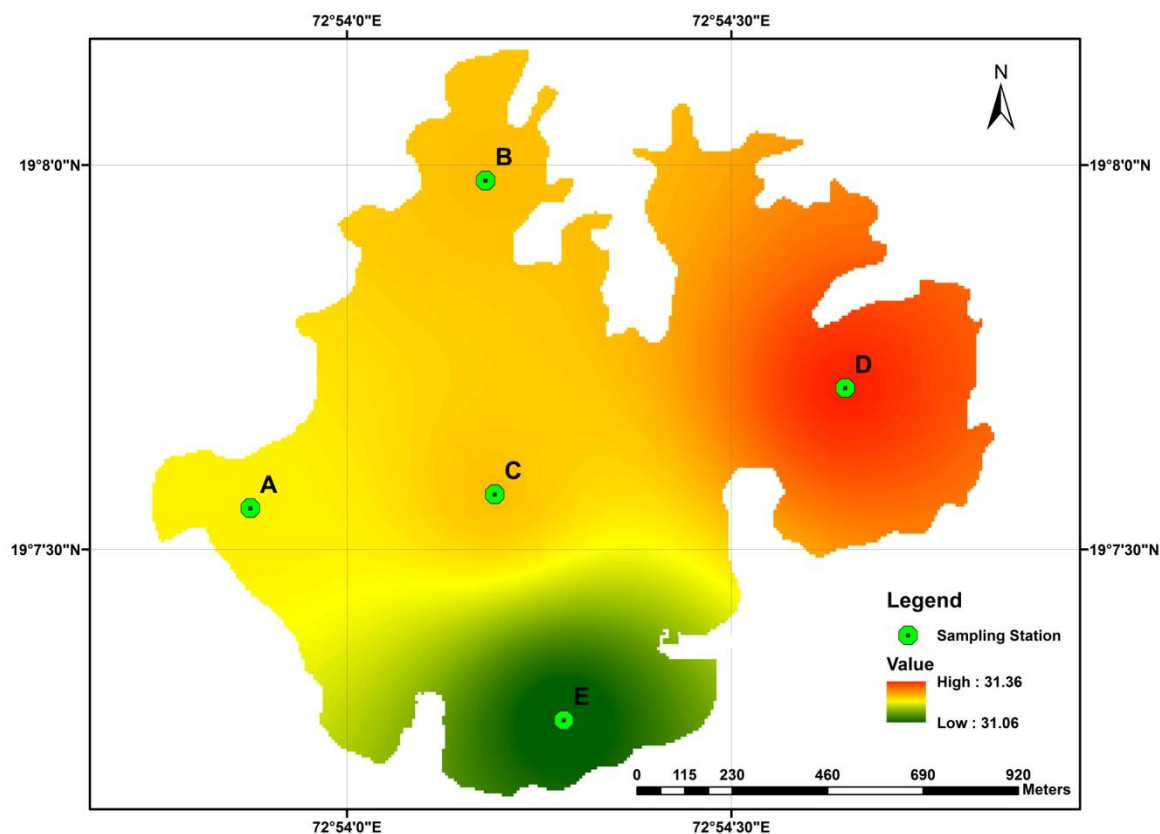


Fig. 23: Water temperature during pre-monsoon season across the stations

During pre-monsoon (Fig. 23), high water temperatures were in station D and low in station E, while station A, B and C are moderately suitable temperature, in the radius of station E in which the most suitable for aquatic life.

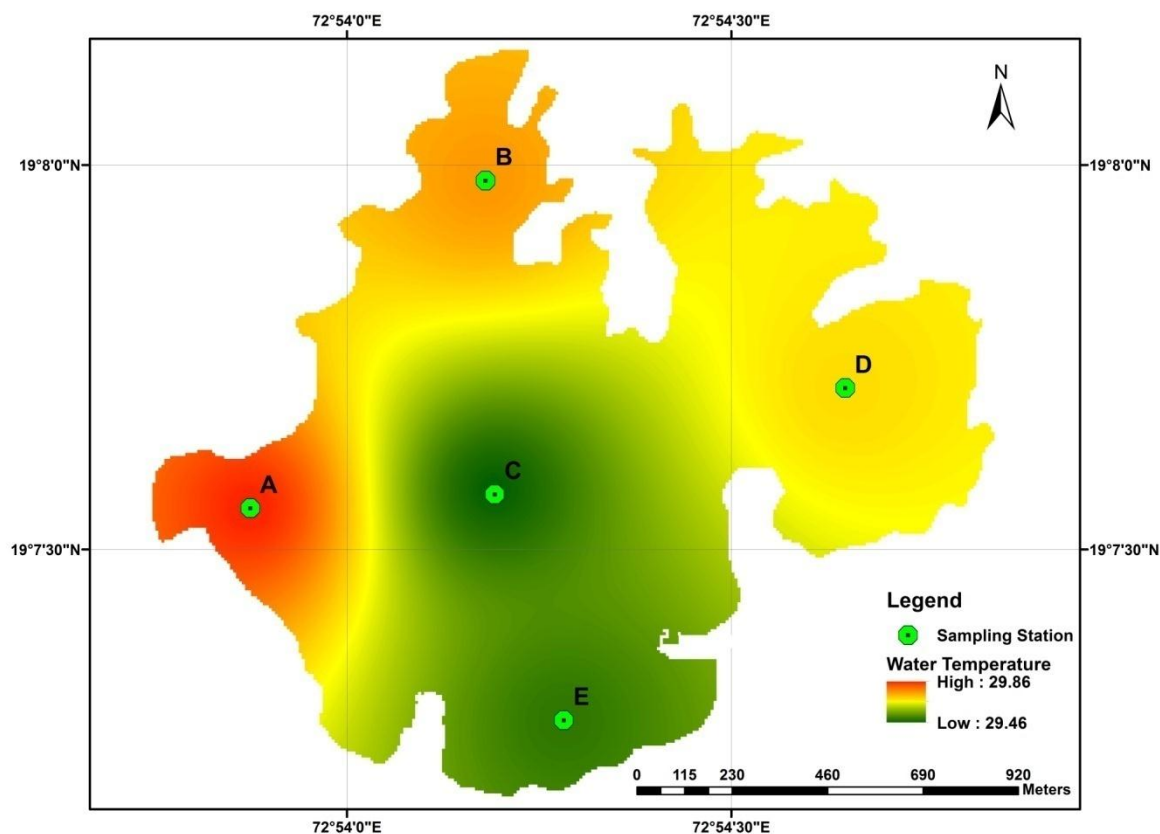


Fig. 24: Water temperature during monsoon season across the stations

In the monsoon (Fig. 24), high water temperature was in station A followed by station B, while station D was moderately suitable temperature, and lowest temperature was in station C and E, in which the most suitable for aquatic life.

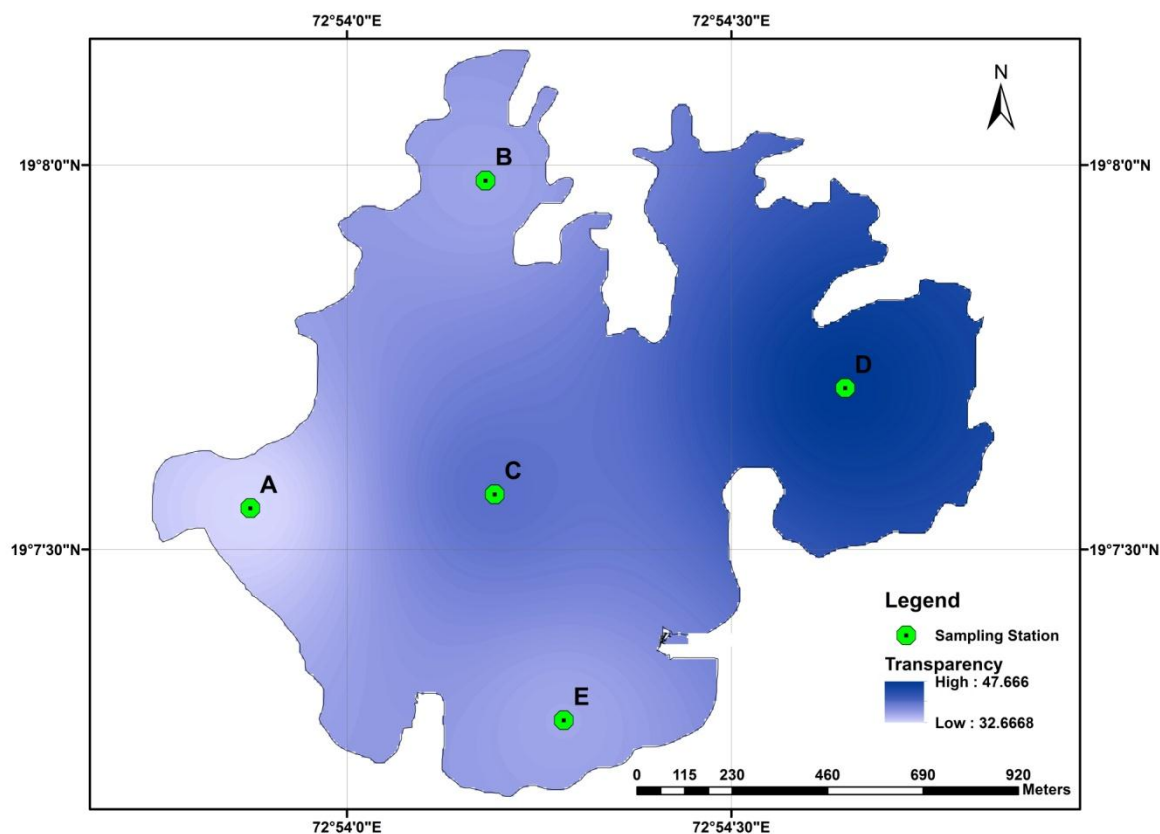


Fig. 25: Transparency during post-monsoon season across the stations

Transparency of the lake fluctuated during post-monsoon, monsoon and pre-monsoon seasons. Highest transparency was recorded in station D, and moderately in station B, C and E, while least transparency was in station A (Fig. 25). Transparency was highest across the seasons because of the high water influx immediately after monsoon rain.

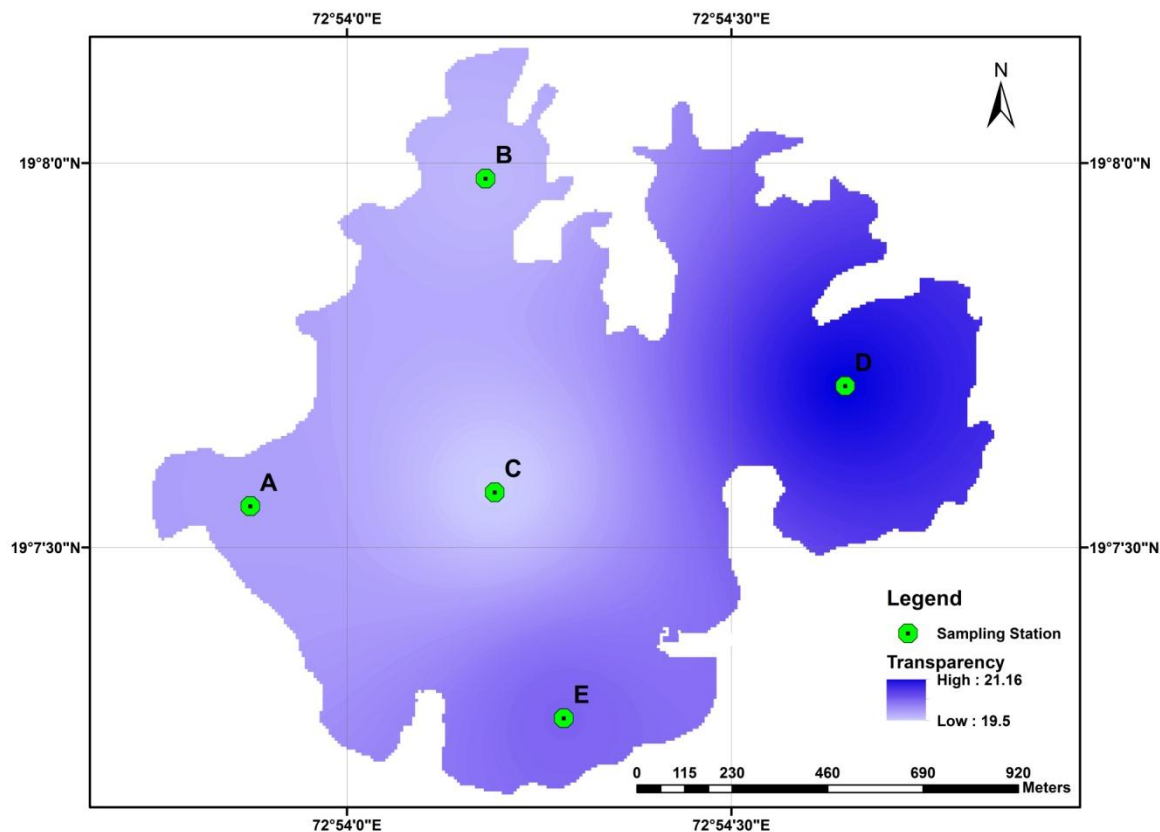


Fig. 26: Transparency during pre-monsoon season across the stations

During pre-monsoon (Fig. 26), highest transparency was recorded in station D and lowest in station A, while station B, C and E are moderate. This is the lowest across the season, and this can be attributed to the decrease in water level in pre-monsoon season.

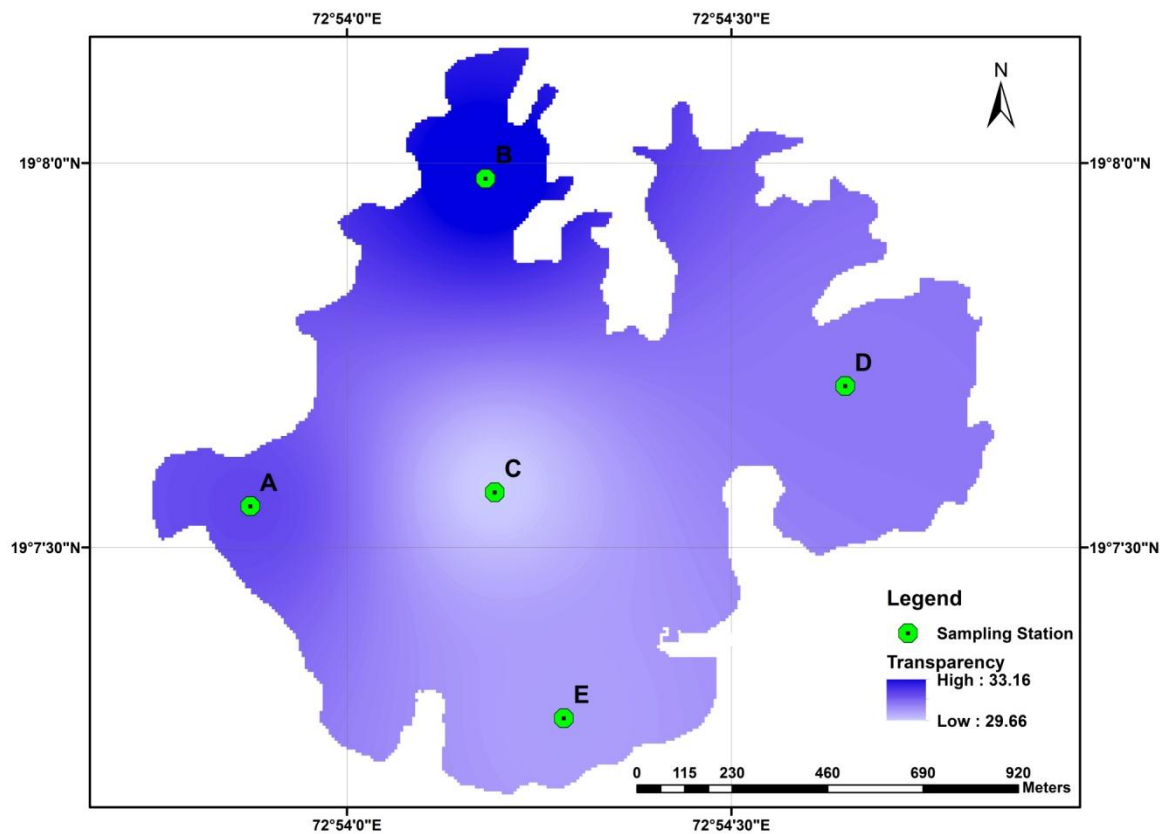


Fig. 27: Transparency during monsoon season across the stations

In monsoon (Fig. 27), highest transparency was recorded in station B and lowest in station E, while station A, C and E are moderate. This is moderate across the season, and this can be attributed to the increase in water level in monsoon season.

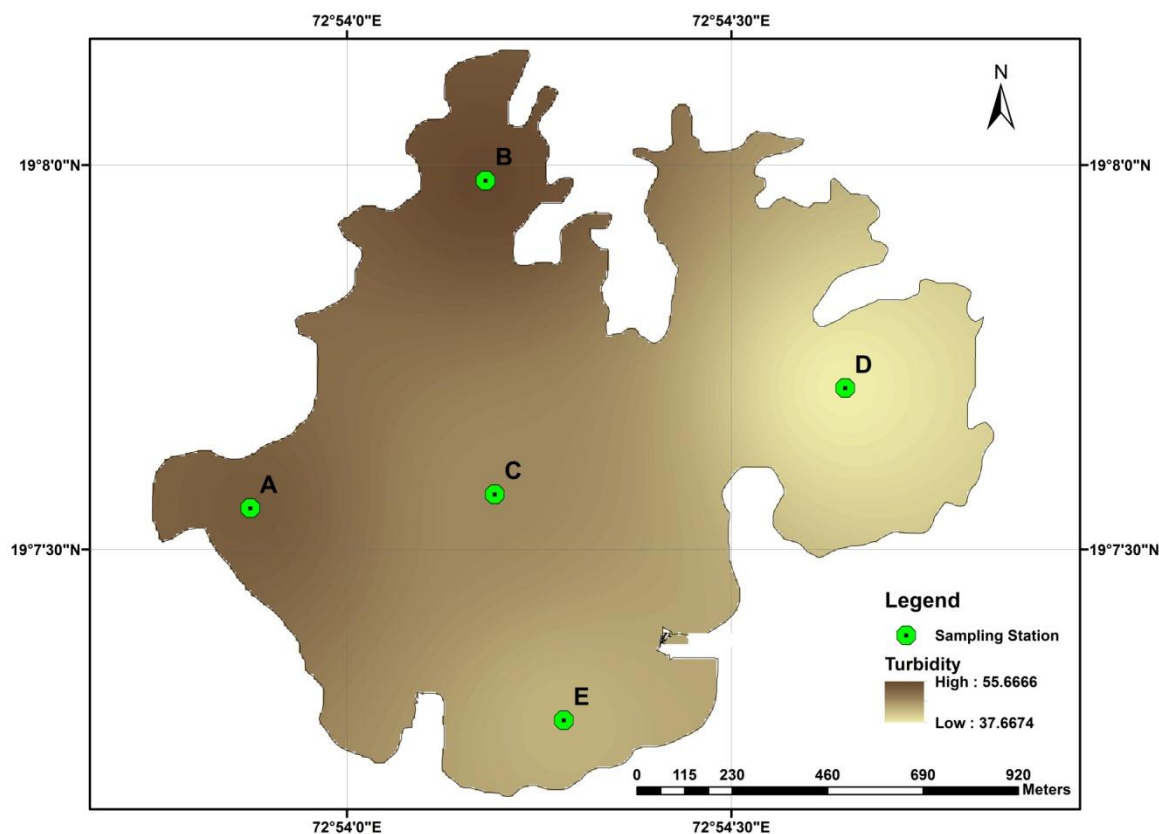


Fig. 28: Turbidity during post-monsoon season across the stations

Turbidity of the lake fluctuated during post-monsoon, monsoon and pre-monsoon seasons. Highest turbidity was recorded in station B followed by station A, and moderately in station C and E, while least turbidity was recorded in station D (Fig. 28). Turbidity was moderate across the seasons because of the relatively high water level immediately after monsoon rain.

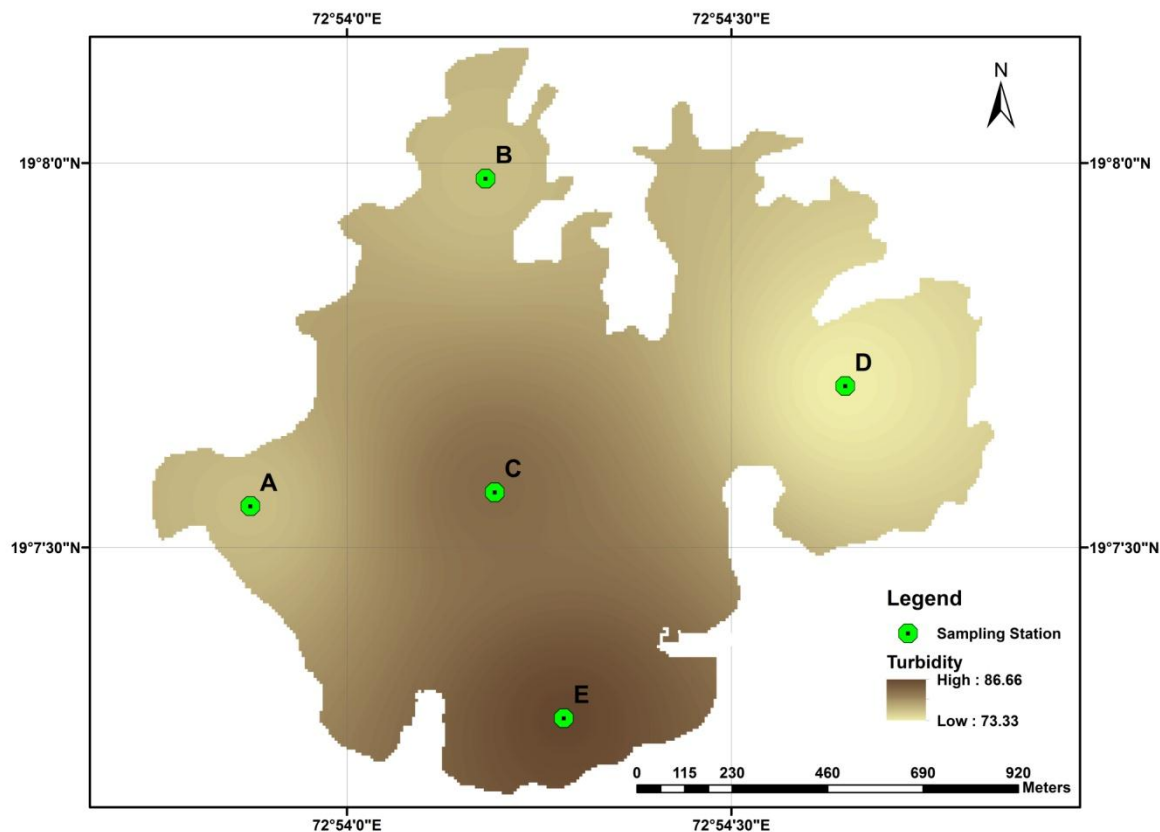


Fig. 29: Turbidity during pre-monsoon season across the stations

During pre-monsoon (Fig. 29), highest turbidity was recorded in station E and lowest in station D, while station A, B and C showed moderate turbidity. This was the highest turbidity across the season, and this can be attributed to the decrease in water level in pre-monsoon season.

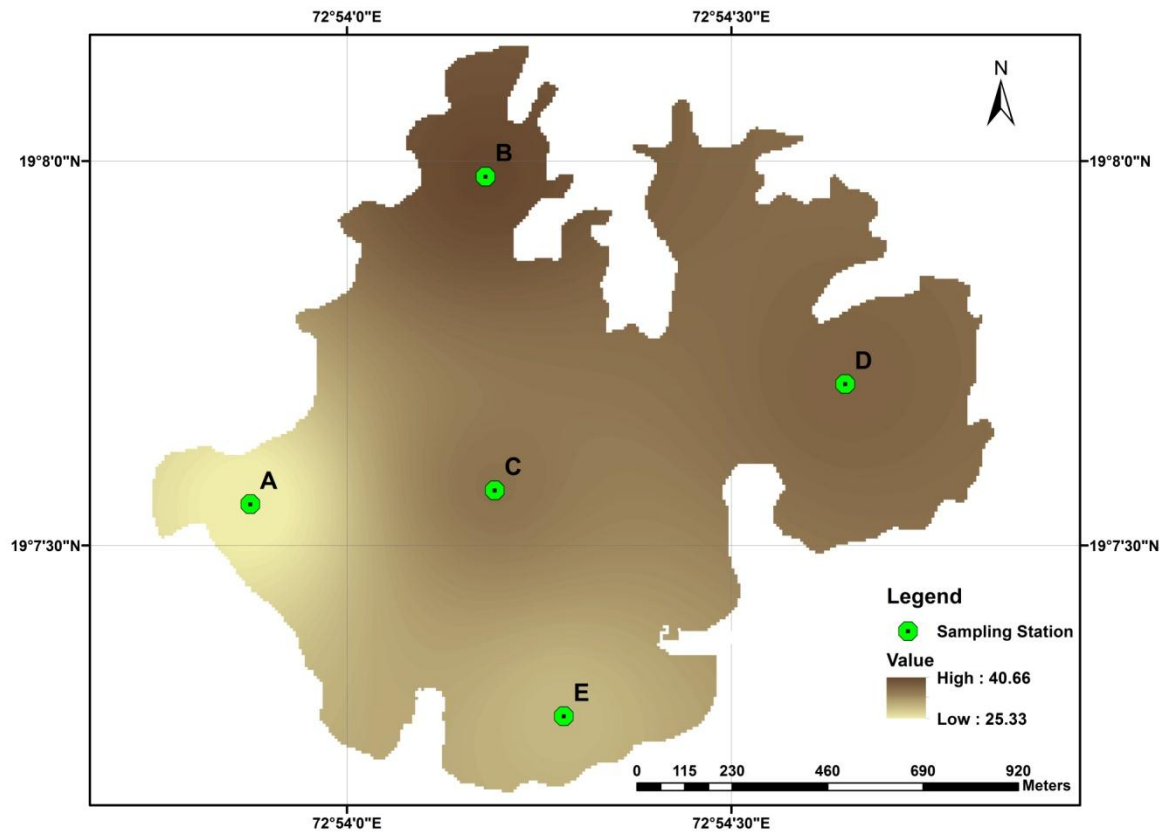


Fig. 30: Turbidity during monsoon season across the stations

In monsoon (Fig. 30), highest turbidity was recorded in station B followed by station D, and lowest in station A, while station C and E showed moderate values. This is the lowest turbidity across the season, and this can be attributed to the increase in water level and runoff discharge into the lake.

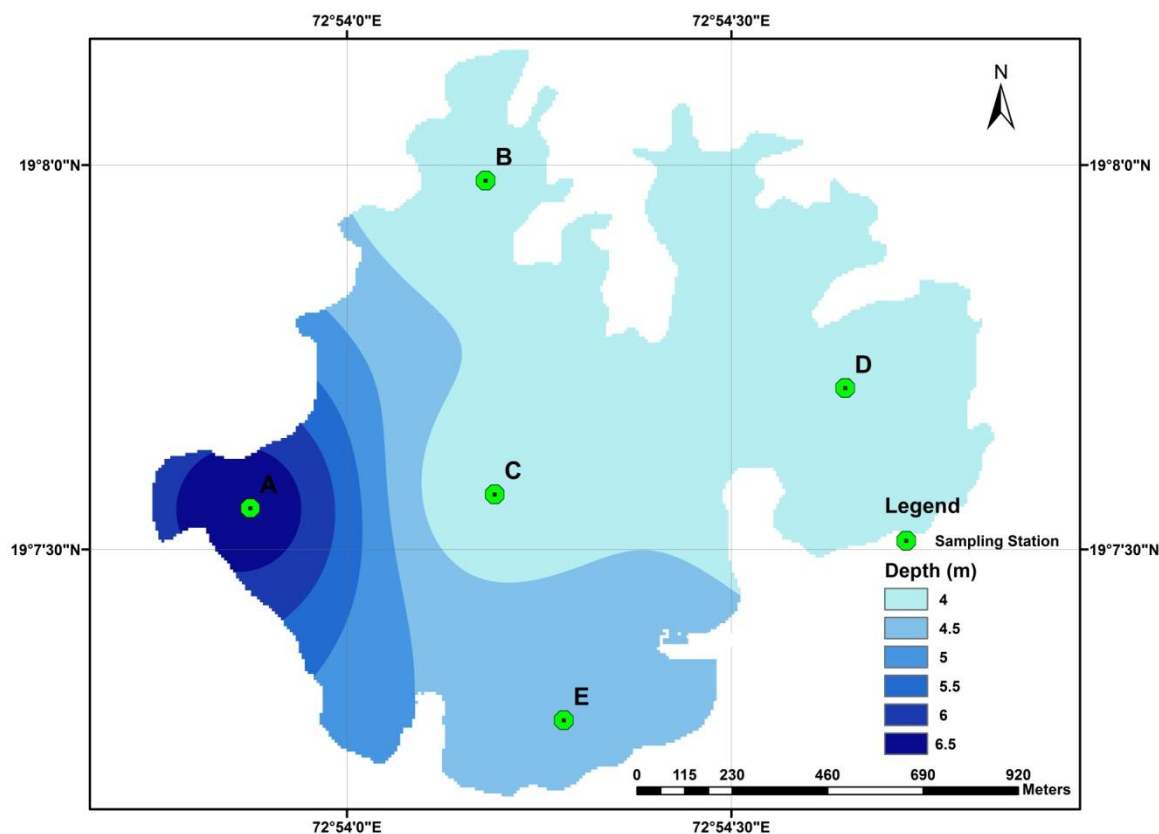


Fig. 31: Variation in depth during post-monsoon season across the stations

Depth of the lake fluctuated during post-monsoon, monsoon and pre-monsoon season. Highest depth was recorded in station A, followed by station E, and moderate in station C and E, while least depth was recorded in station B (Fig. 31). Depth was moderate across the post-monsoon seasons because of the relatively high water level immediately after monsoon rains.

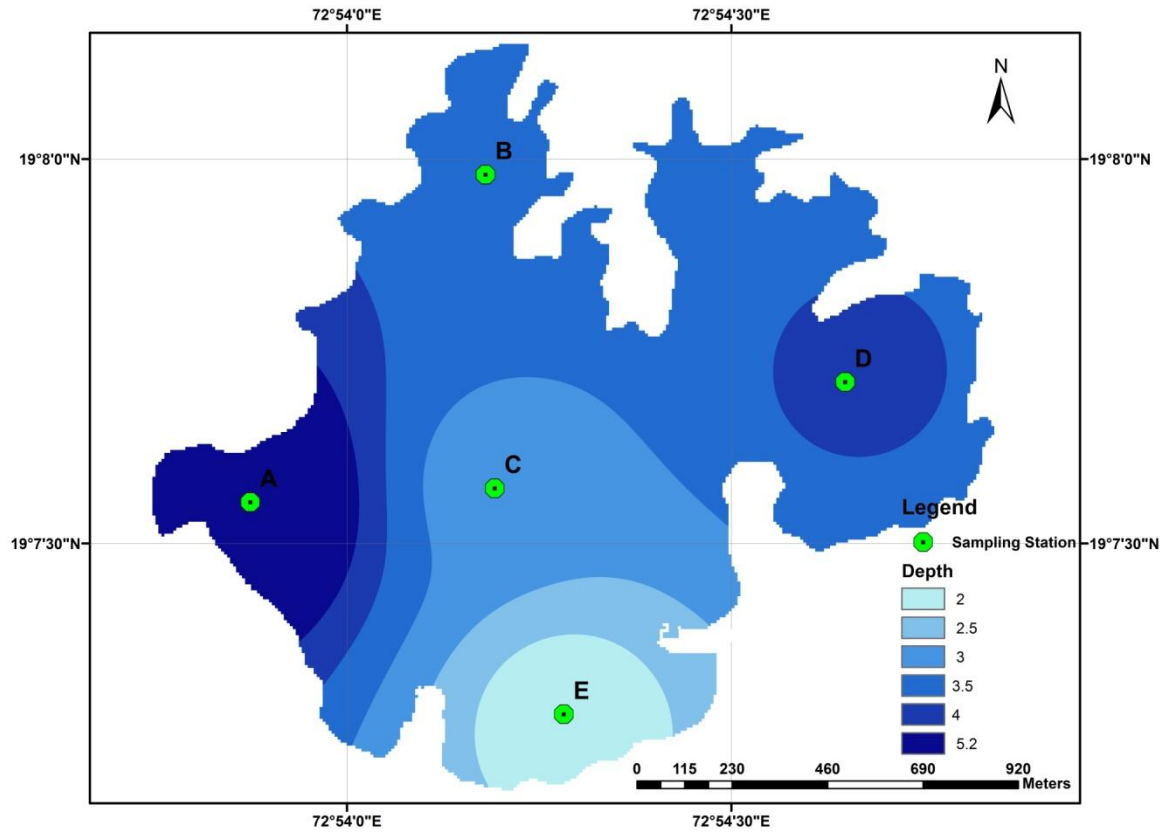


Fig. 32: Variation in depth during pre-monsoon season across the stations

During pre-monsoon (Fig. 32), highest depth was recorded in station A and lowest in station E, while station B, C and D were moderate. This was the lowest depth across the season, and this can be attributed to the decreased water level in pre-monsoon season.

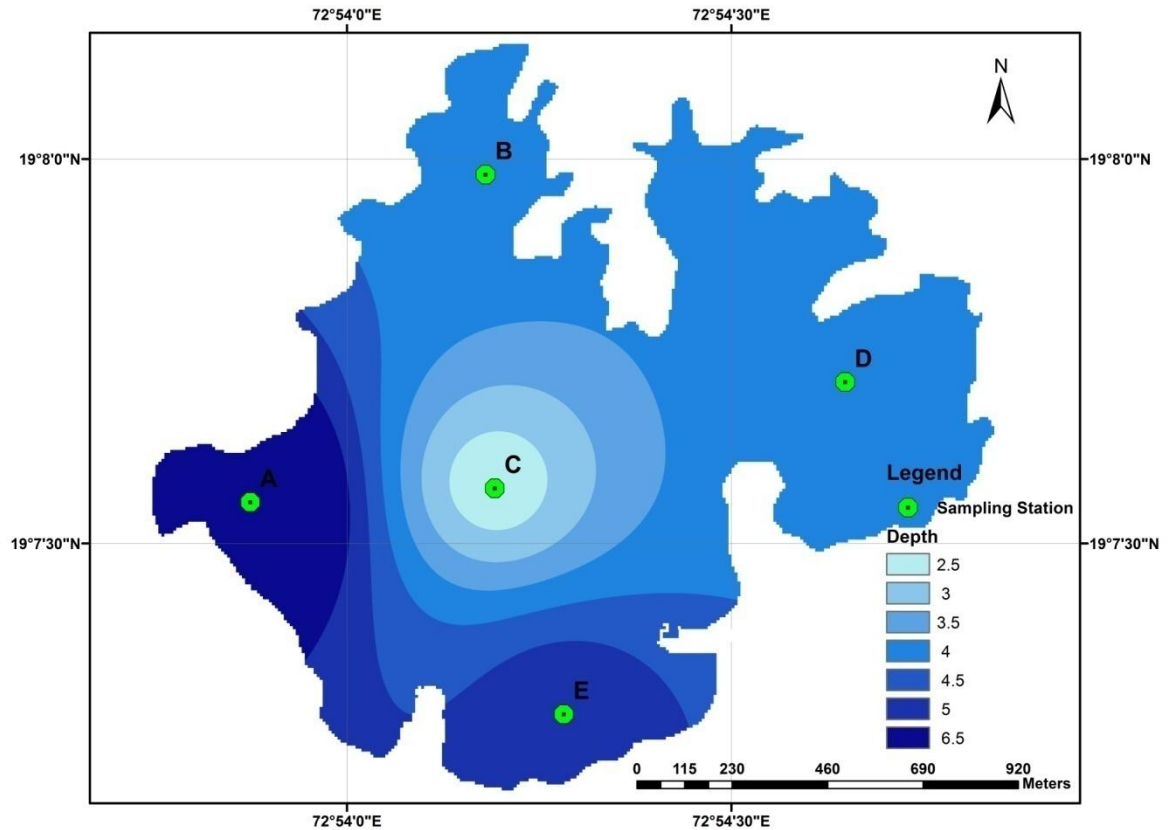


Fig. 33: Variation in depth during monsoon season across the stations

In monsoon (Fig. 33), highest depth was recorded in station A followed by station E, and lowest in station C, while station B and E were moderate. This is the highest depth across the season, and this can be attributed to the increased water level and runoff discharge into the lake.

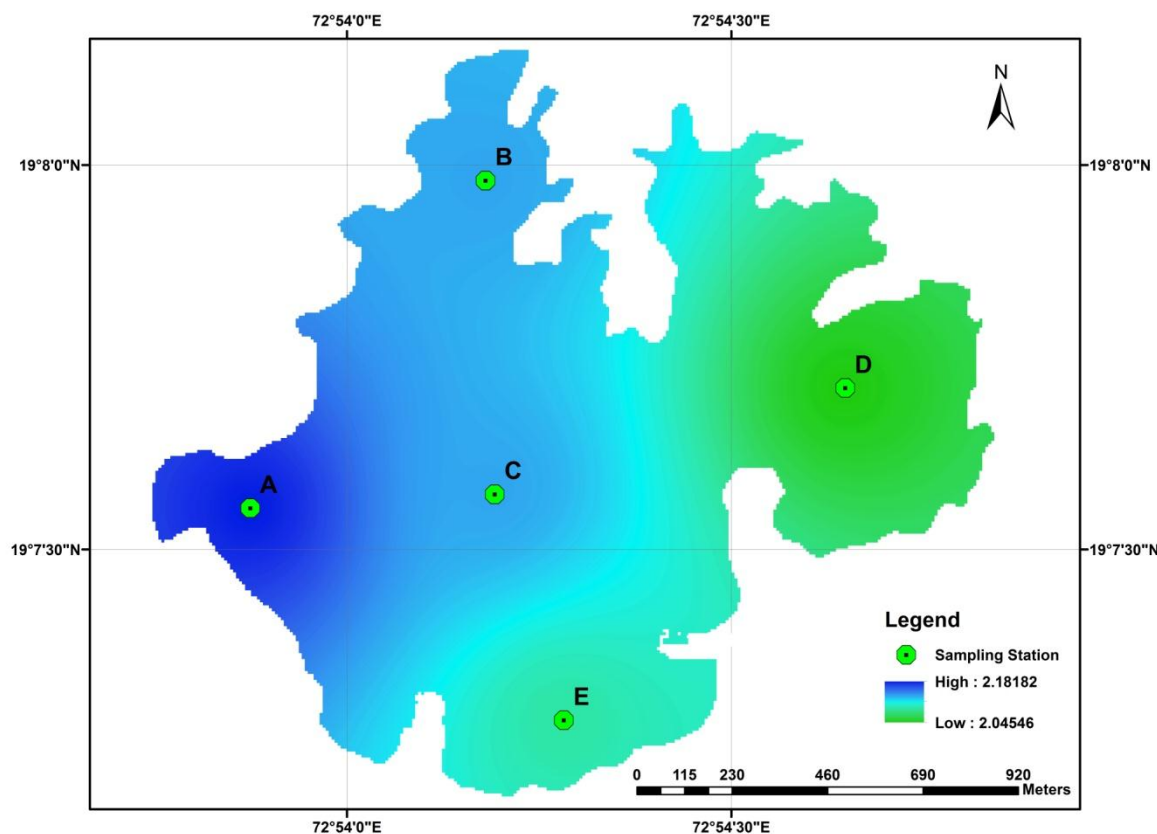


Fig. 34: Post-monsoon season suitability score of Powai lake

Three classes such as most suitable, moderately suitable and not suitable on the basis of requirements for aquaculture using twenty one (21) parameters, and the interpretation suitability classes for each factor was classified on a scale from 3 to 1. The result reveals that, decrease in productivity can be attributed to decrease in water level (Fig. 32). However, station E remain the most suitable site, station B as not suitable and stations A, C and D are moderately suitable (Fig. 34).

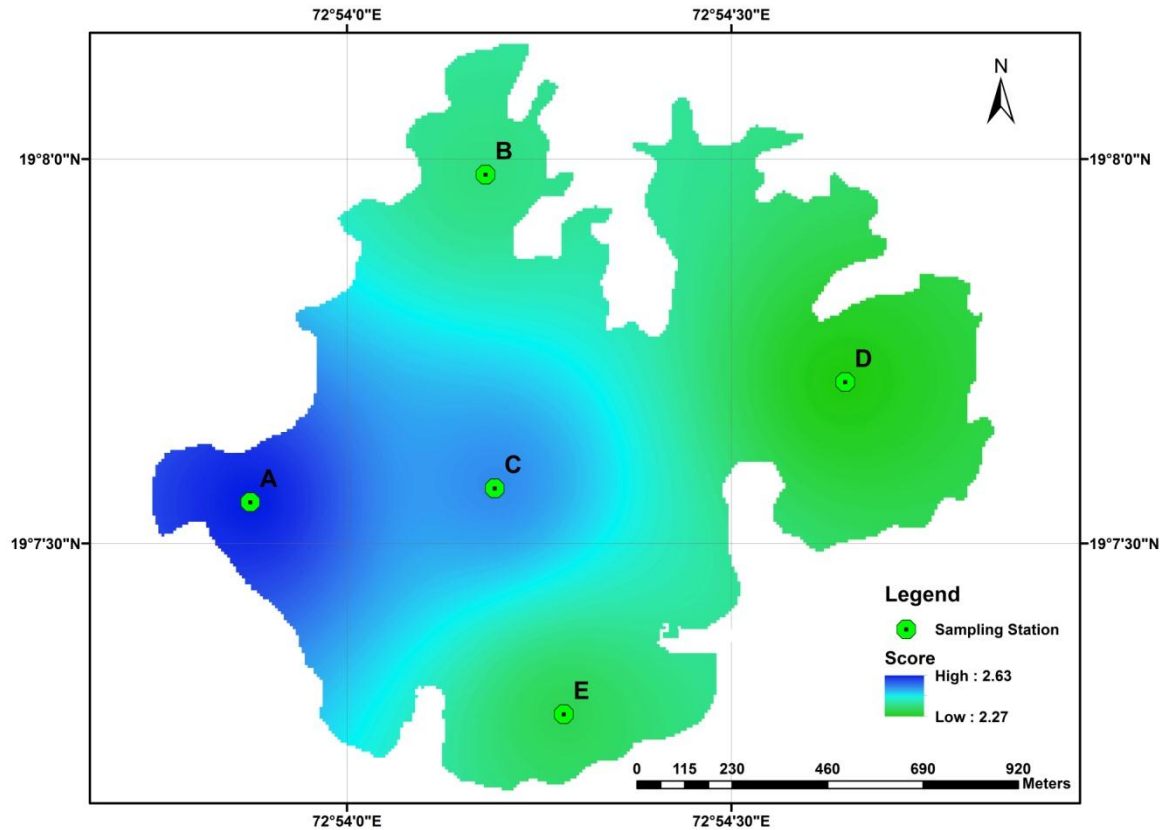


Fig. 35: Pre-monsoon season suitability score of Powai lake

Suitability score during pre-monsoon shows that water quality is moderately suitable in station B, C and E, with station A as the most suitable while station E as not suitable (Fig. 35). There was increase in the productivity leading to high accumulation of nutrients causing eutrophication thereby reducing its productivity.

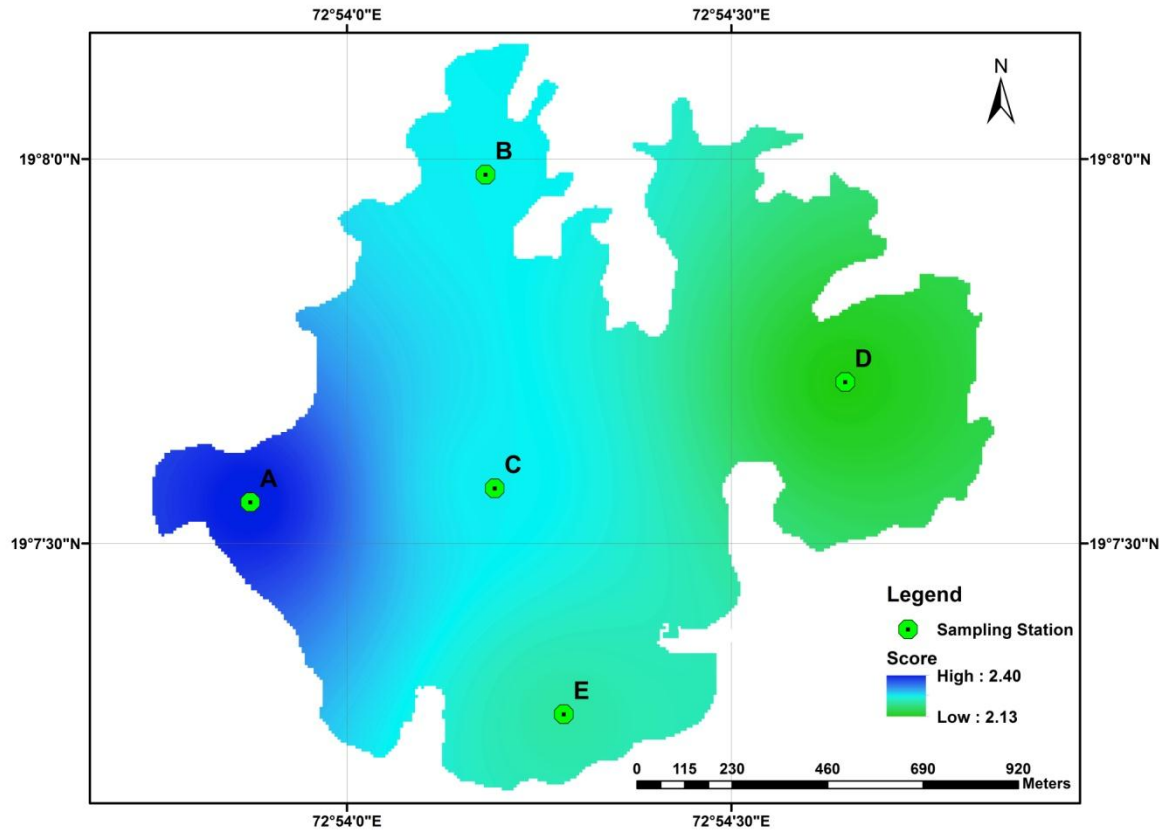


Fig. 36: Monsoon season suitability score of Powai lake

During monsoon season (Fig. 36), the water quality and the productivity improved covering the entire stations of the lake except station D, which may be due to runoff discharge into the lake from the metropolis. Station A, B and C were the most suitable while station E's greater radius was moderately suitable for aquatic life.

For the remote sensing, out of the eighteen (18) downloaded satellite images during present study (November, 2016 to October, 2017), two images each in the months of October, August, May, March, and February; one image each in September, July, June, April and January; three images in December; and no image was available in November. The downloaded images for the months of December, January, February and March were processed, while images for months of April, May, June, July, August, September, October and November are unable to show results after processing the data apparently due to cloudy nature and other factors.

Table 36: Remote sensing monthly variation in Chlorophyll-a and total suspended matter of Powai lake (November, 2016 to October, 2017)

Month	Parameter (mg m ⁻³)	Station				
		A	B	C	D	E
December	Chlorophyll	27.41	24.12	22.32	26.00	20.50
	TSM	8940	28770	26510	23770	22840
January	Chlorophyll	21.60	22.47	20.73	22.70	20.44
	TSM	38410	34810	32640	28290	33200
February	Chlorophyll	28.02	23.63	24.95	24.92	24.08
	TSM	32410	22610	27450	11730	35370
March	Chlorophyll	01.58	02.24	06.62	05.21	03.79
	TSM	11660	8480	2990	2990	2990

The monthly variation of chlorophyll in Powai lake was presented in table 36. The results showed that chlorophyll varied across the months and it ranged from 01.58 to 28.02 (mg m⁻³) during the months of March to February. Other higher values were recorded in the months of December and January.

The variation in chlorophyll across stations for the month of December studied in Powai lake as presented in table 36, show that chlorophyll values are relatively within closely related ranged from 20.50 to 27.41 (mg m⁻³) in stations E and A respectively. The average chlorophyll concentration was 20.39 (mg m⁻³) with 27.34 (mg m⁻³) observed as maximum and 0.01 (mg m⁻³) as minimum. For the month of January, it ranged from 20.44 to 22.70 (mg m⁻³) in stations E and D. The average chlorophyll concentration was 20.01 (mg m⁻³) with 26.06 (mg m⁻³) as maximum and

0.026 (mg m^{-3}) as minimum. In the month of February, station A had the highest concentration (28.02 mg m^{-3}), while lowest was in station B (23.63 mg m^{-3}). The average chlorophyll concentration was 22.63 mg m^{-3} with 27.73 mg m^{-3} as maximum and 0.0146 mg m^{-3} as minimum. 06.62 mg m^{-3} was noticed in station C as highest while 01.58 mg m^{-3} was observed as lowest in station A for the month of March. The average chlorophyll concentration was 10.79 mg m^{-3} with 29.91 mg m^{-3} as maximum and 0.0093 (mg m^{-3}) as minimum.

The monthly variation of Total Suspended Matter (TSM) in Powai lake was presented in table 36. The results showed that TSM varied across the months and it ranged from 2990 to 38410 mg m^{-3} in the months of March to January. Other higher values were recorded in the months of December and February.

The variation in TSM across stations for the month of December studied in Powai lake (table 36), were relatively within closely related ranged of 8940 to 28770 mg m^{-3} in stations A and B respectively. The average TSM concentration was 22809.80 mg m^{-3} with 40497.10 mg m^{-3} as maximum and 41.70 mg m^{-3} as minimum. For the month of January, it ranged from 28290 to 38410 mg m^{-3} in stations D and A. The average TSM concentration was 22549.20 mg m^{-3} with 130229.00 mg m^{-3} as maximum and 21.50 mg m^{-3} as minimum. In the month of February, station E had the highest concentration of 35370 mg m^{-3} and lowest in station D 11730 mg m^{-3} . The average TSM concentration was 24293.40 mg m^{-3} with 39765.00 mg m^{-3} as maximum and 108.70 mg m^{-3} as minimum. 11660 mg m^{-3} TSM was observed in station A as highest, while 2990 mg m^{-3} was lowest in stations C, D and E, for the month of March. The average TSM concentration was 17032.80 mg m^{-3} with 34548.60 mg m^{-3} as maximum and 79.00 mg m^{-3} as minimum.

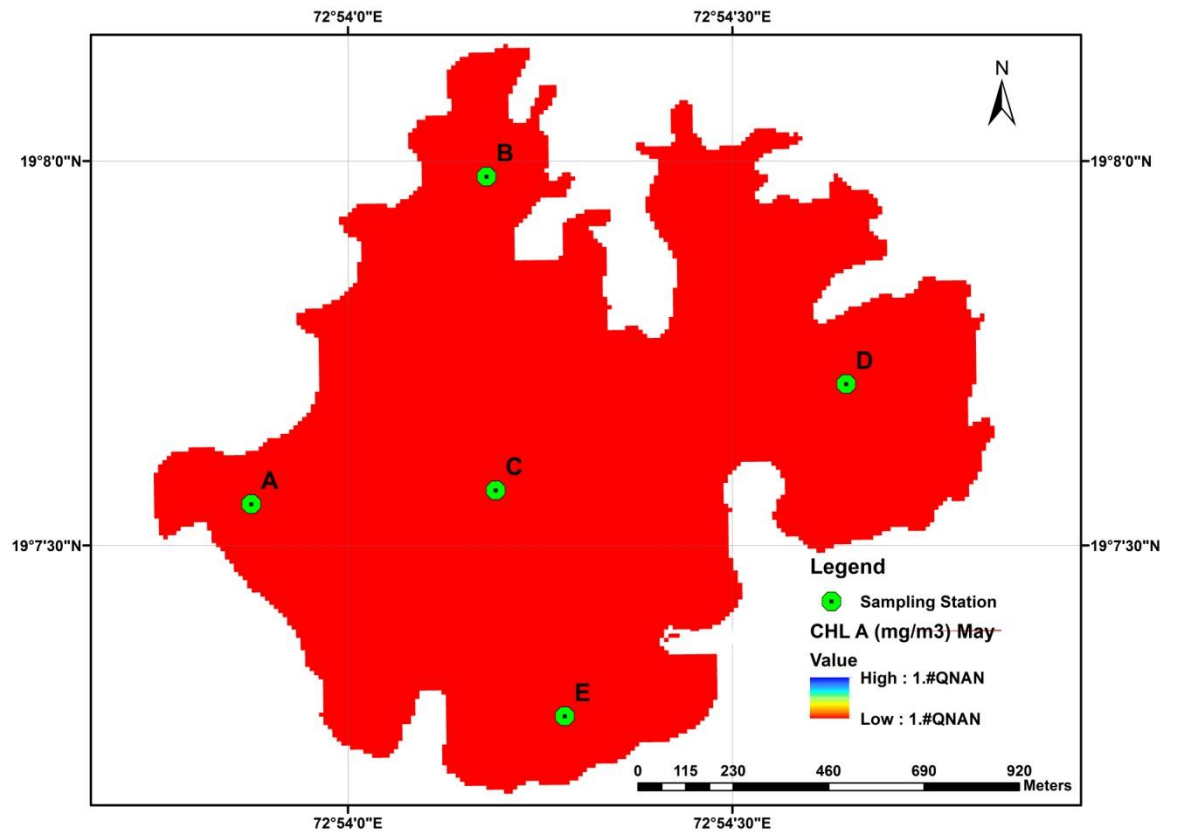


Fig. 37: Blank chlorophyll-a, and total suspended matter concentration in Powai lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions after processing.

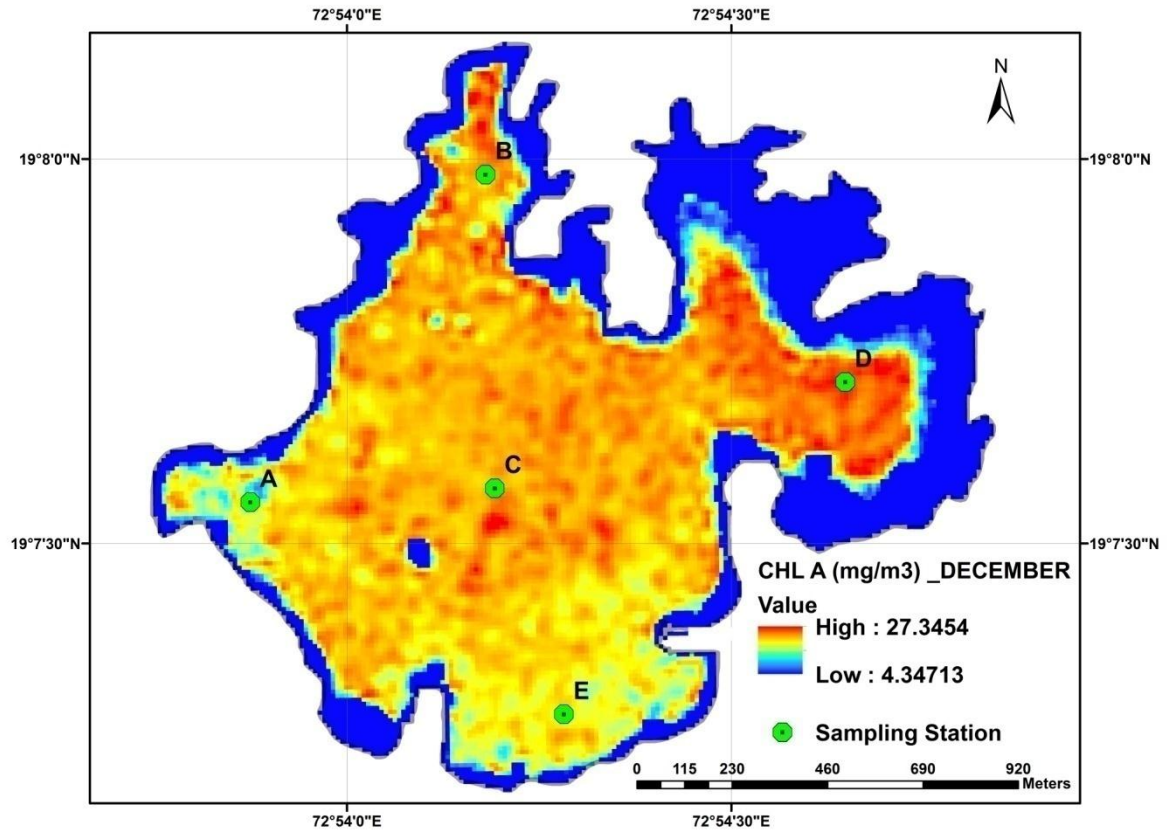


Fig 38: Chlorophyll-a distribution estimation and concentration in Powai Lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from blue to red for chlorophyll-a ranging from 20.50 to 27.41 mg m^{-3} for December, 2016.

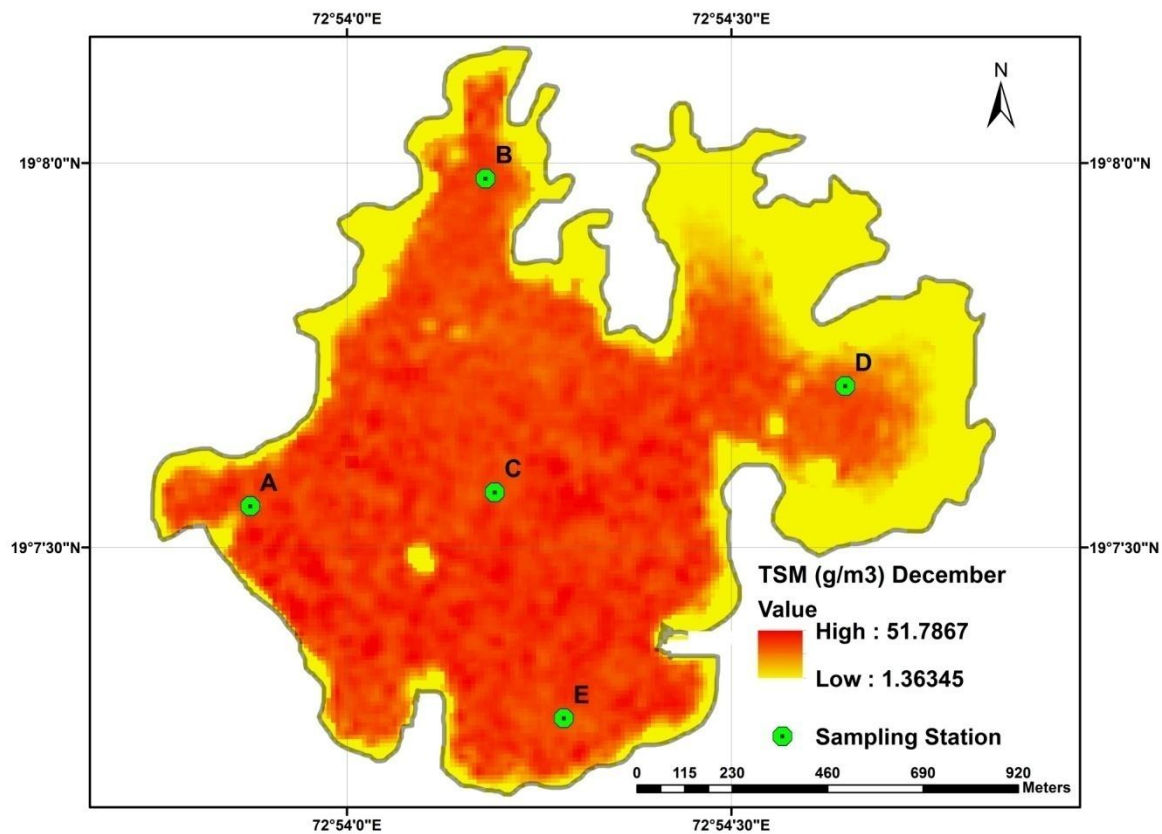


Fig 39: Total suspended matter concentration in Powai Lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from yellow for December, 2016.

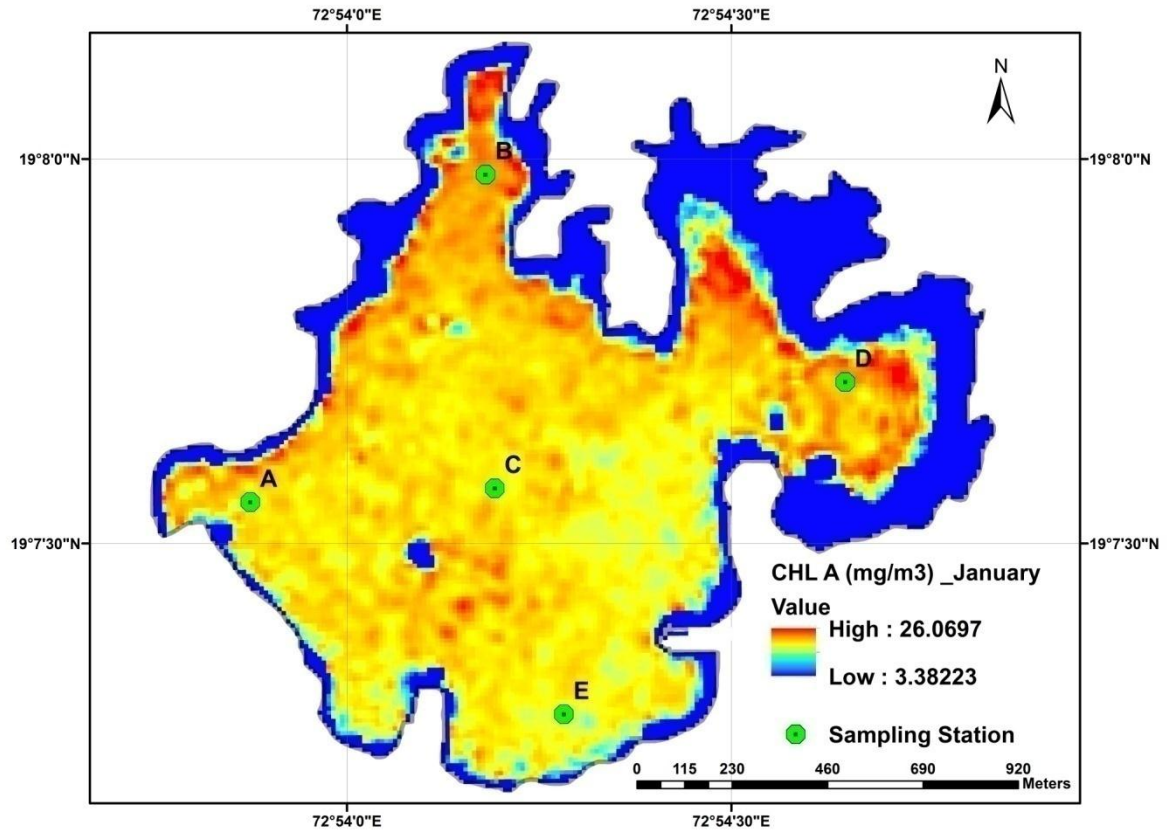


Fig 40: Chlorophyll-a distribution estimation and concentration in Powai Lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from blue to red for chlorophyll-a ranging from 20.44 to 22.70 mg m⁻³ for January, 2017.

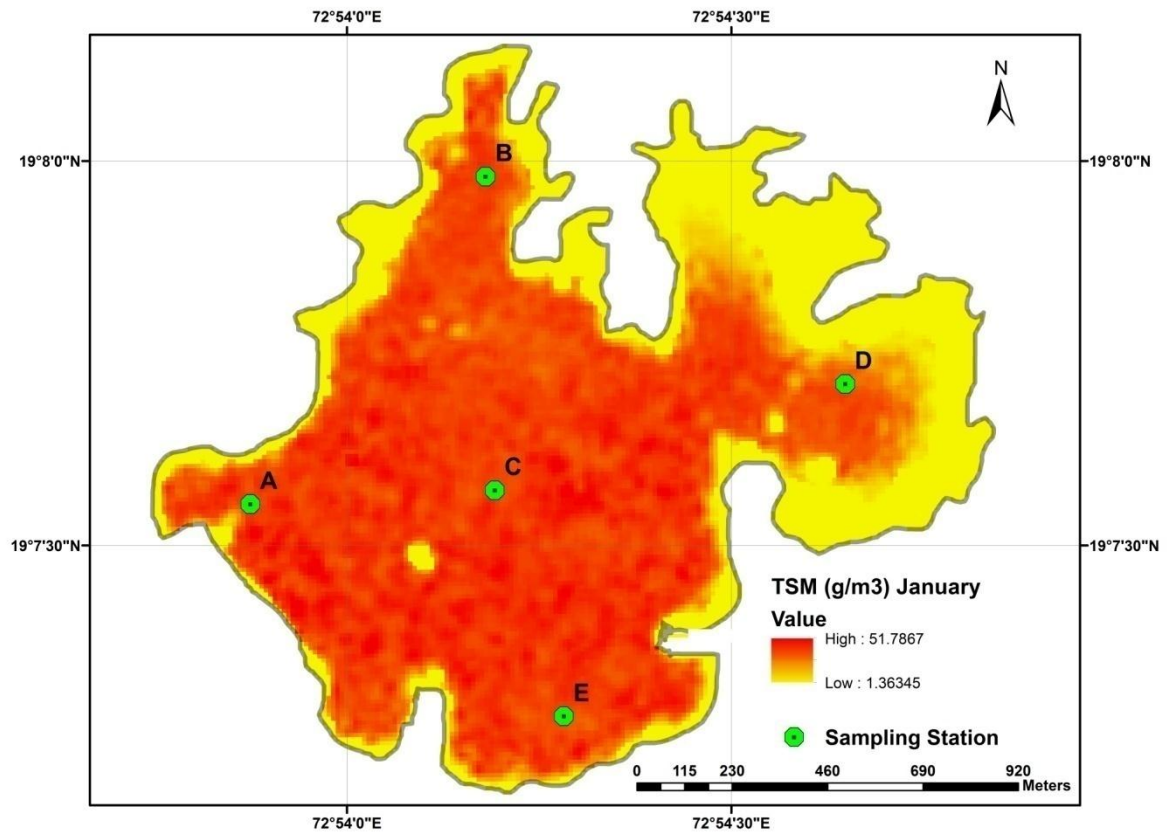


Fig 41: Total suspended matter concentration in Powai Lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from yellow for January, 2017.

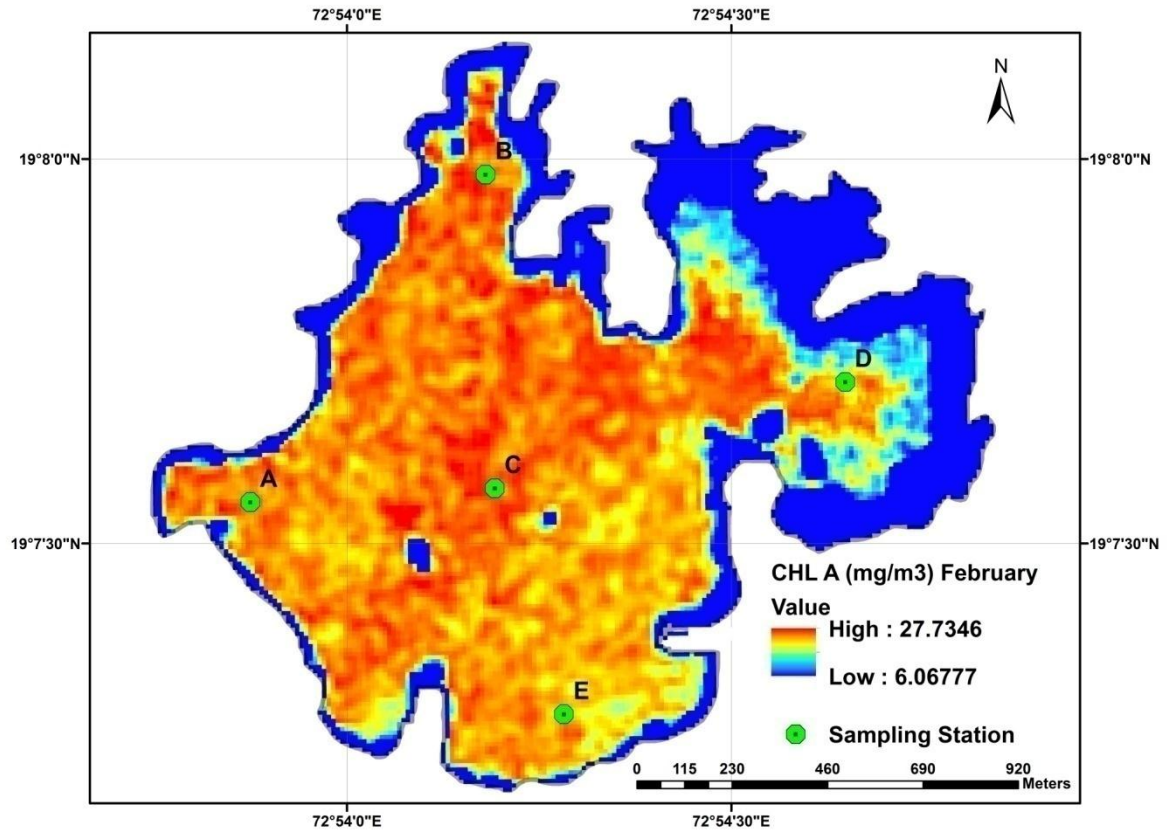


Fig 42: Chlorophyll-a distribution estimation and concentration in Powai Lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from blue to red for chlorophyll-a ranging from 23.63 to 28.02 mg m⁻³ for February, 2017.

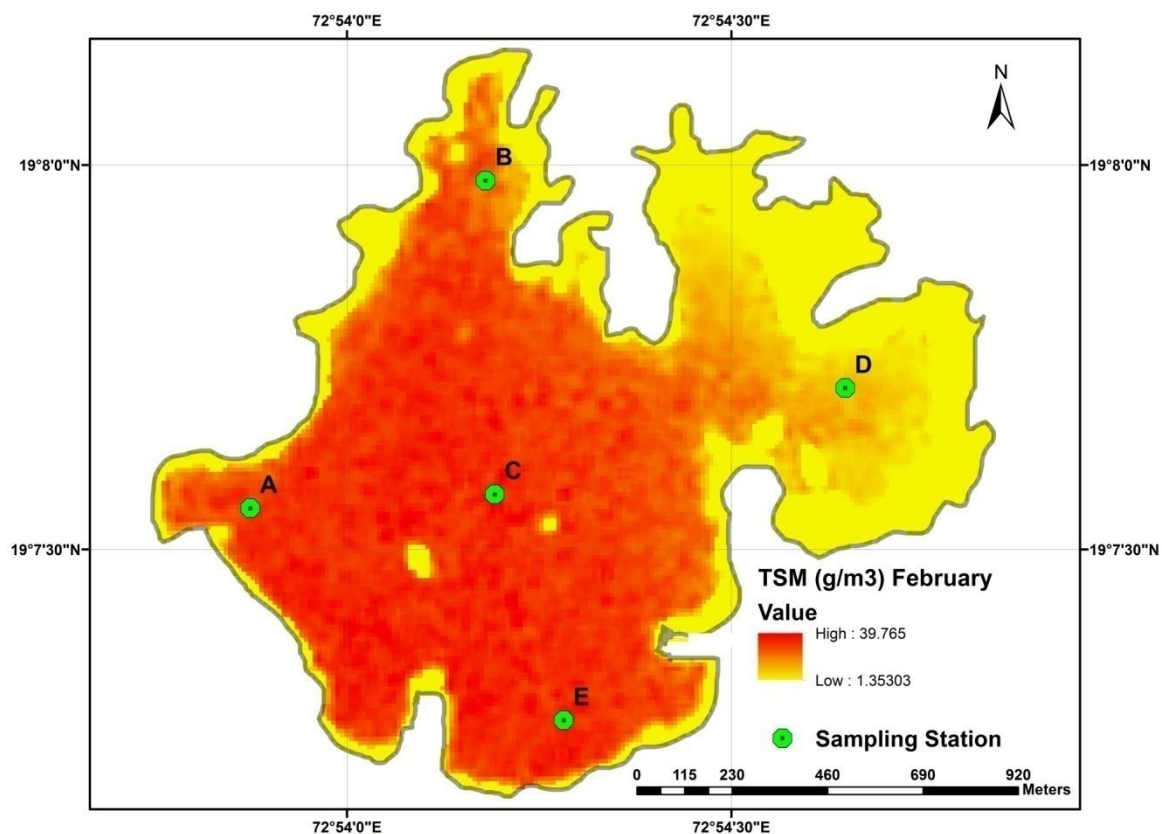


Fig 43: Total suspended matter concentration in Powai Lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from yellow for February, 2017.

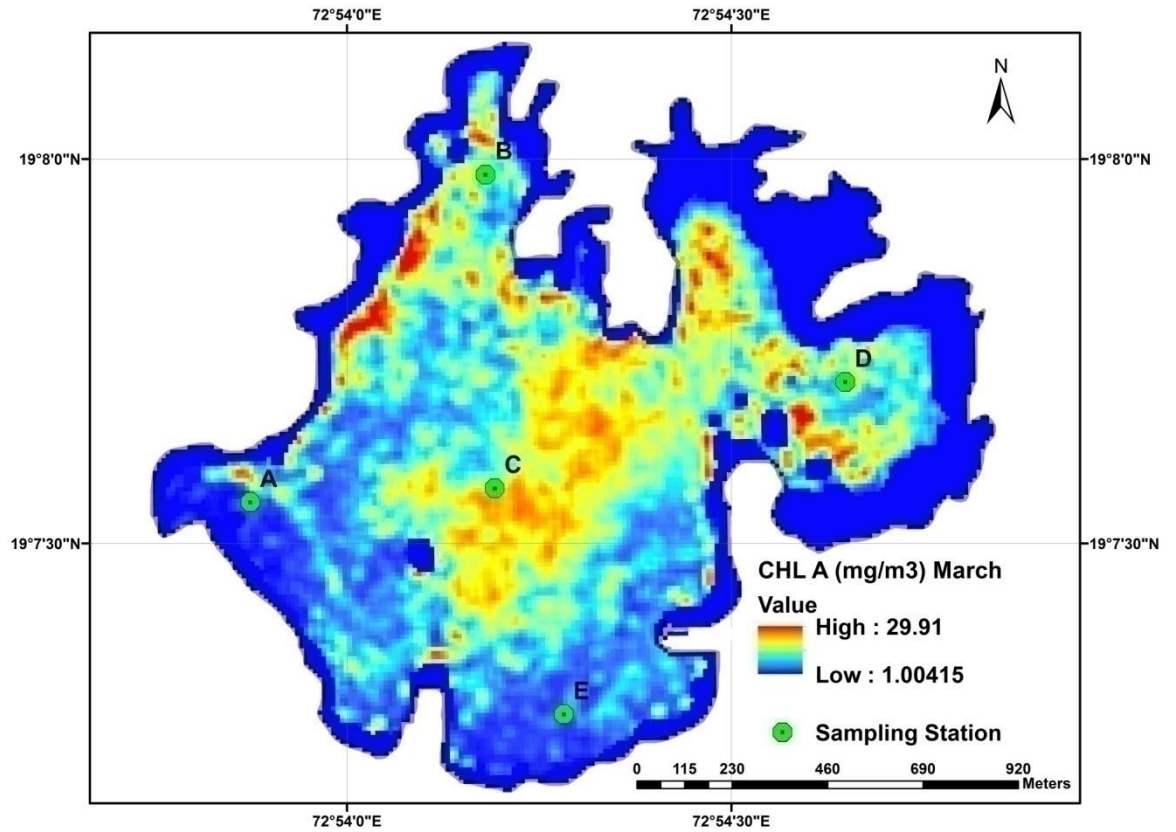


Fig 44: Chlorophyll-a distribution estimation and concentration in Powai Lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from blue to red for chlorophyll-a ranging from 01.58 to 06.62 mg m⁻³ for March, 2017.

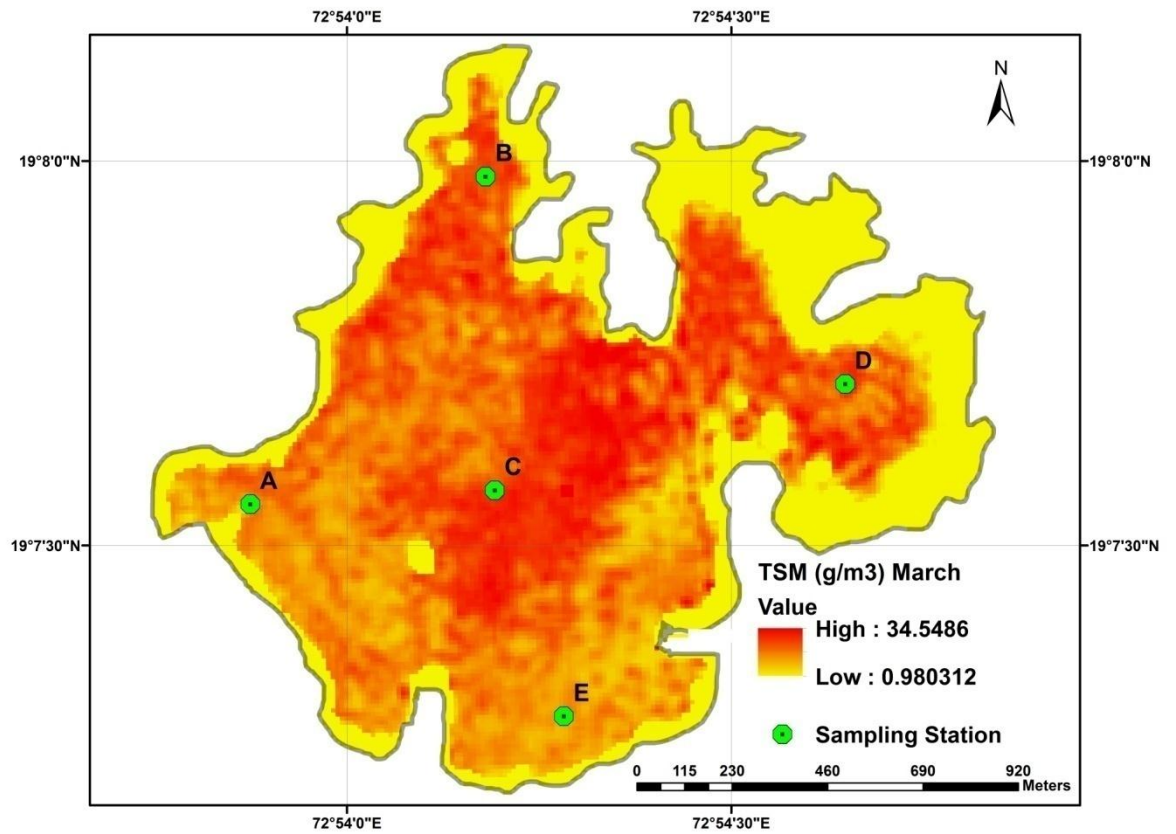


Fig 45: Total suspended matter concentration in Powai Lake from the Sentinel 2A (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from yellow for March, 2017.

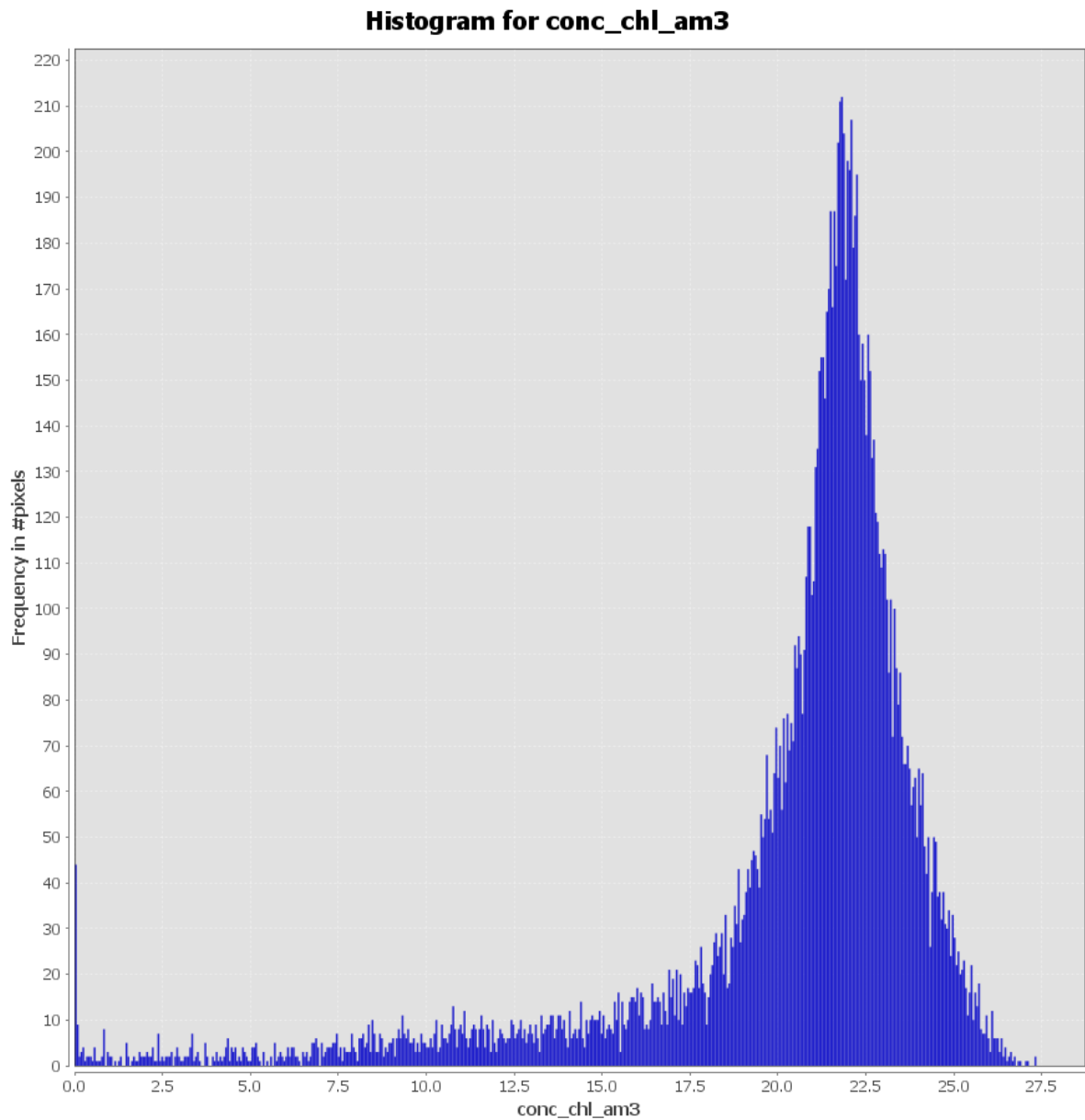


Fig. 46: Chlorophyll-a concentration and distribution (mg m^{-3}) on x-axis and fraction of total pixel on y-axis, indicate water framework directive boundaries for water quality status classification based on chlorophyll-a concentration, for December 2016, blue: high/good status, green: good/moderate, yellow: moderate/poor, red: poor/bad (Wolfram *et al.*, 2009).

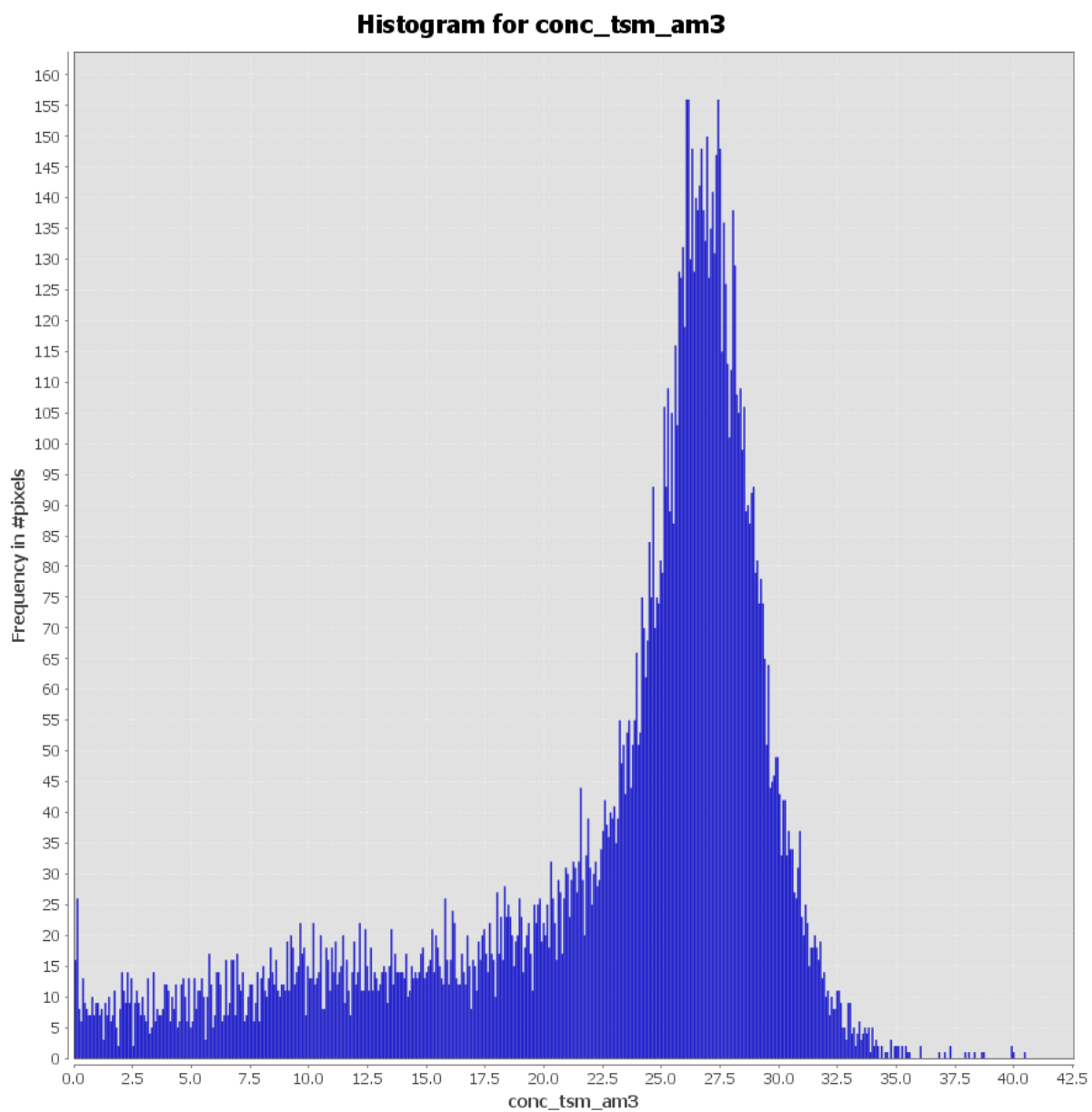


Fig. 47: Total suspended matter concentration (g m^{-3}) on x-axis and fraction of total pixel on y-axis, indicate frequency of pixels against the corresponding concentration value on x-axis for December, 2016.

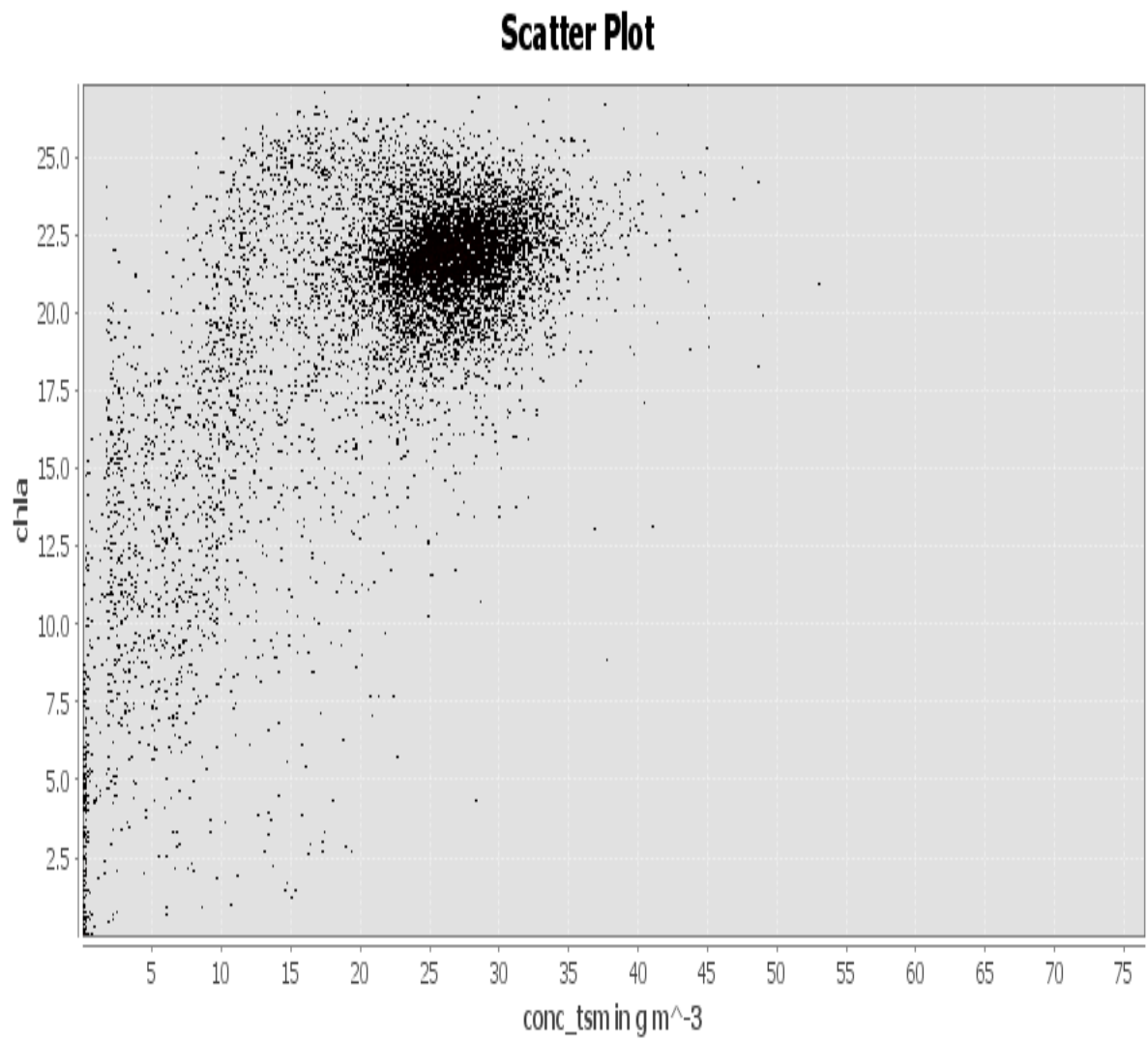


Fig. 48: Cross-relationships of chlorophyll-a, and total suspended matter characteristics of Sentinel 2A used in Powai lake for the month of December, 2016.

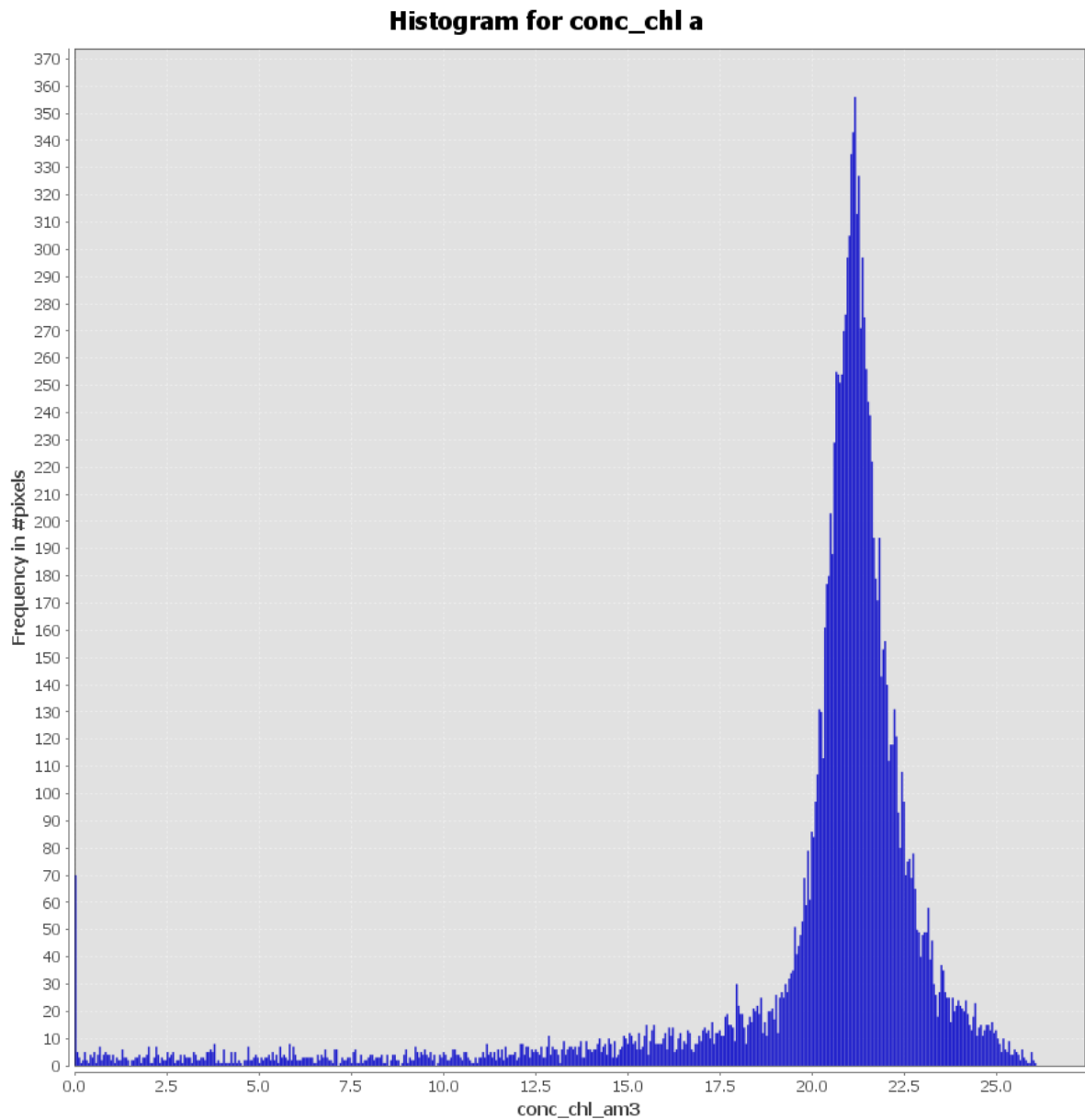


Fig. 49: Chlorophyll-a concentration and distribution (mg m^{-3}) on x-axis and fraction of total pixel on y-axis, indicate water framework directive boundaries for water quality status classification based on chlorophyll-a concentration, for January 2017, blue: high/good status, green: good/moderate, yellow: moderate/poor, red: poor/bad (Wolfram *et al.*, 2009).

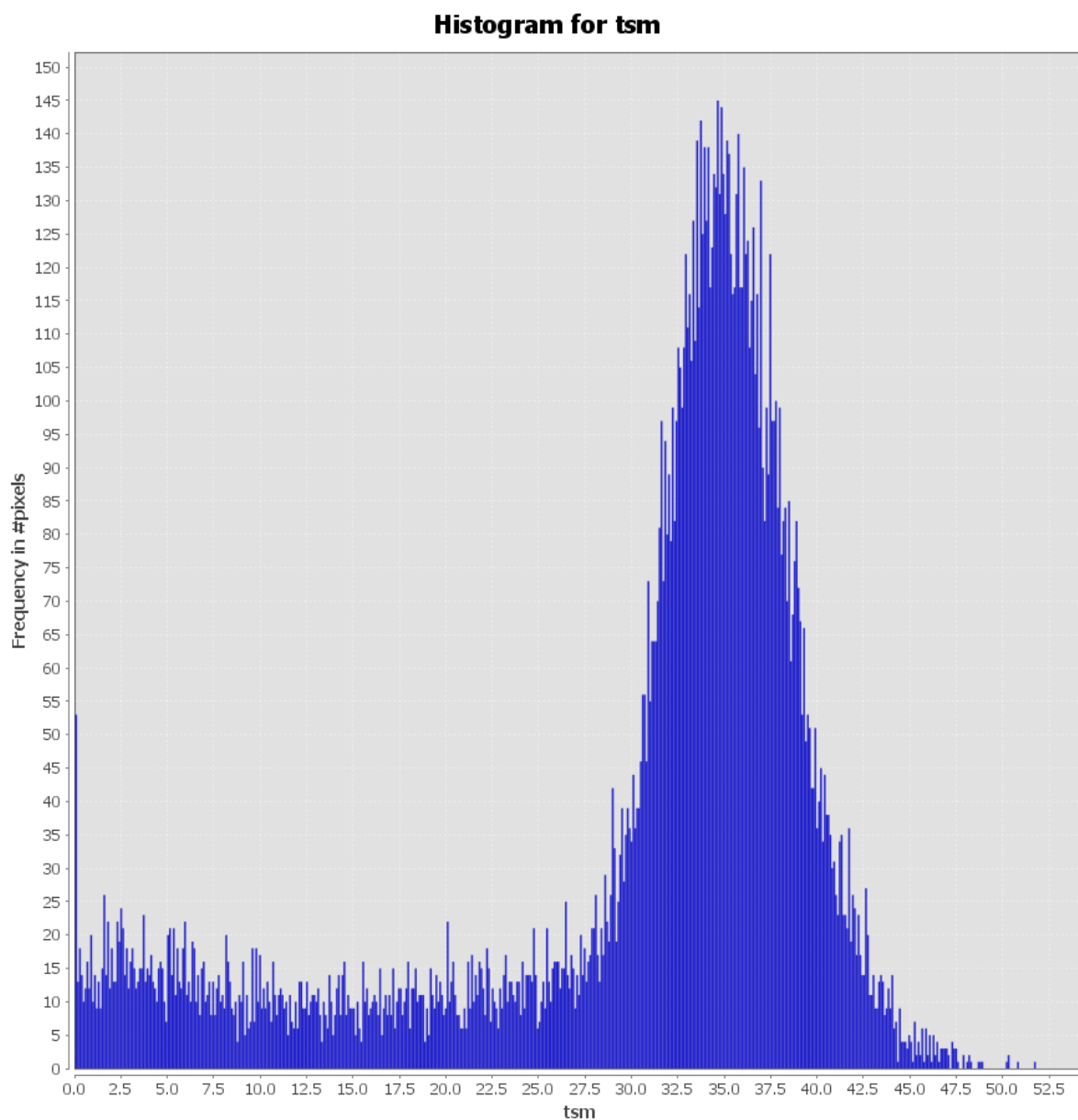


Fig. 50: Total suspended matter concentration (g m^{-3}) on x-axis and fraction of total pixel on y-axis, indicate frequency of pixels against the corresponding concentration value on x-axis for January, 2017.

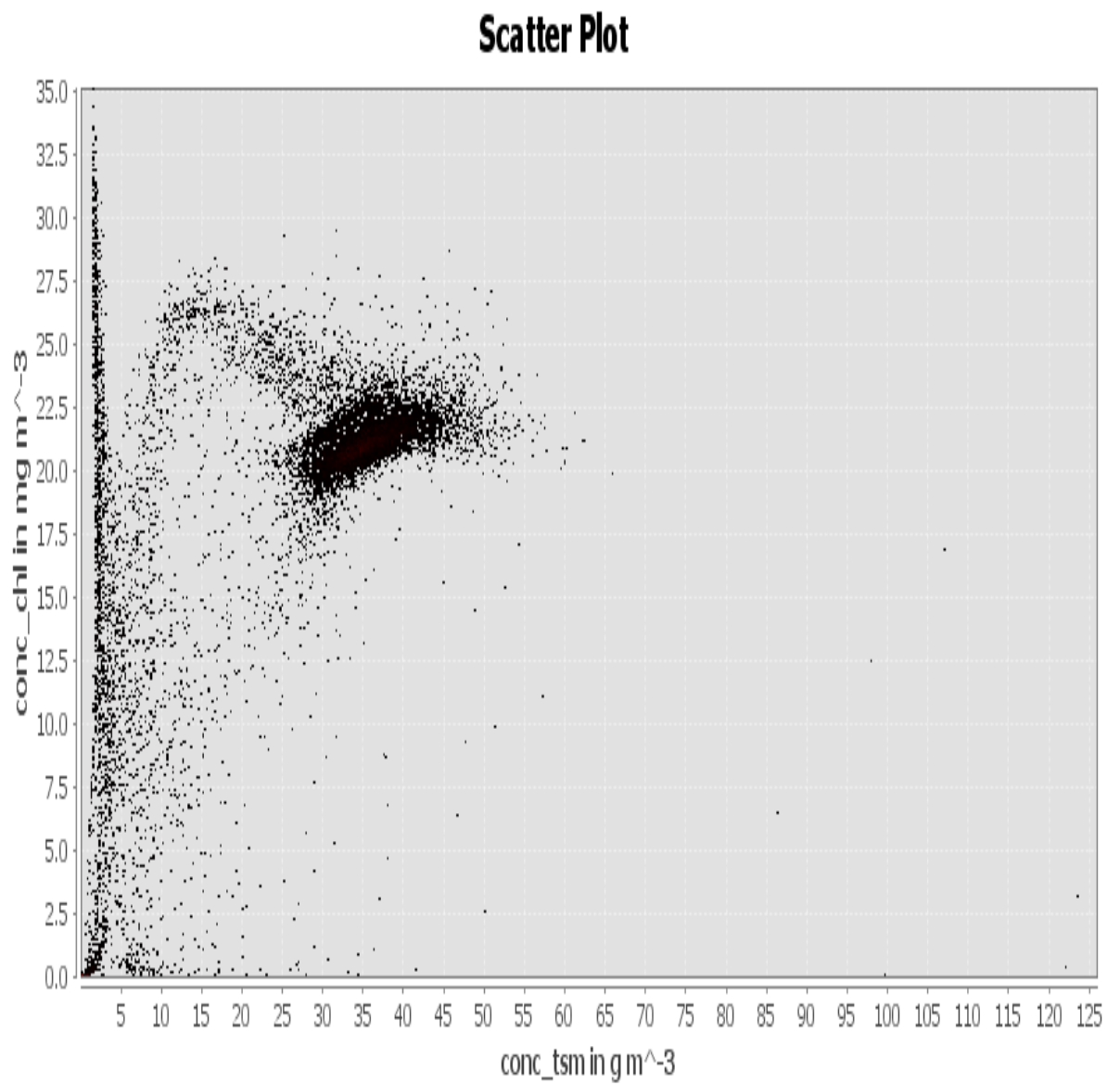


Fig. 51: Cross-relationships of chlorophyll-a, and total suspended matter characteristics of Sentinel 2A used in Powai lake for the month of January, 2017.

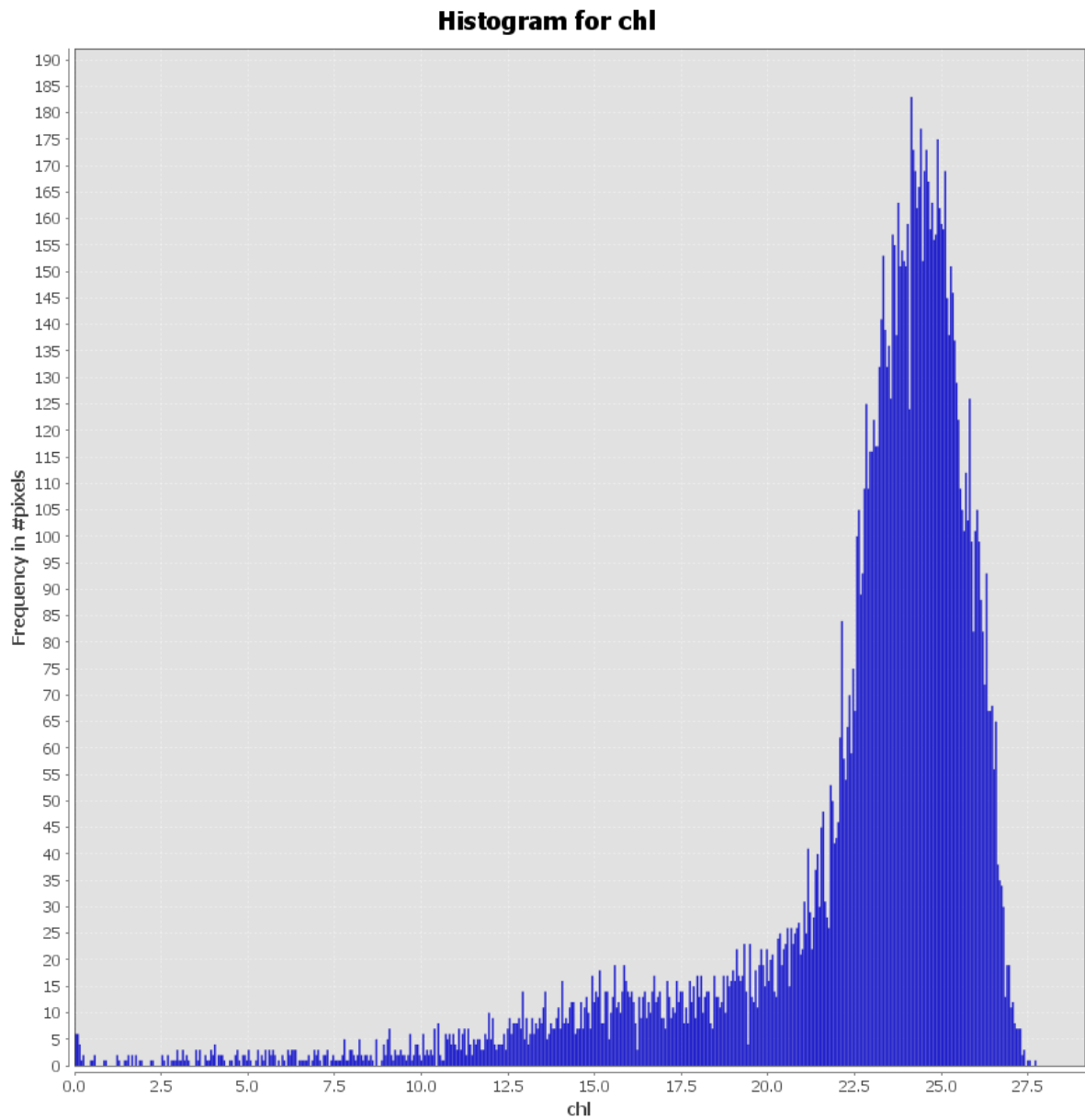


Fig. 52: Chlorophyll-a concentration and distribution (mg m^{-3}) on x-axis and fraction of total pixel on y-axis, indicate water framework directive boundaries for water quality status classification based on chlorophyll-a concentration, for February 2017, blue: high/good status, green: good/moderate, yellow: moderate/poor, red: poor/bad (Wolfram *et al.*, 2009).

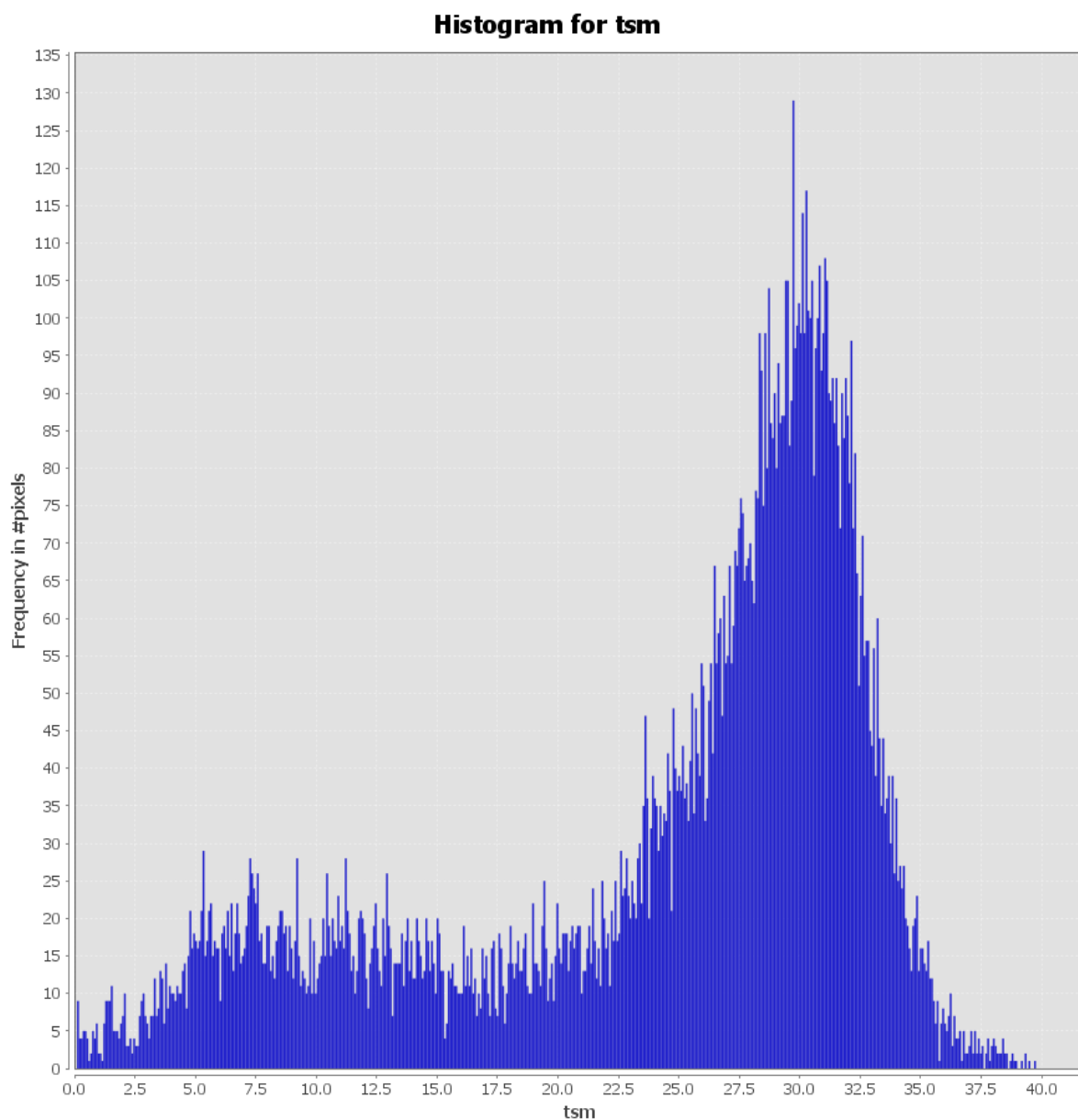


Fig. 53: Total suspended matter concentration (g m^{-3}) on x-axis and fraction of total pixel on y-axis, indicate frequency of pixels against the corresponding concentration value on x-axis for February, 2017.

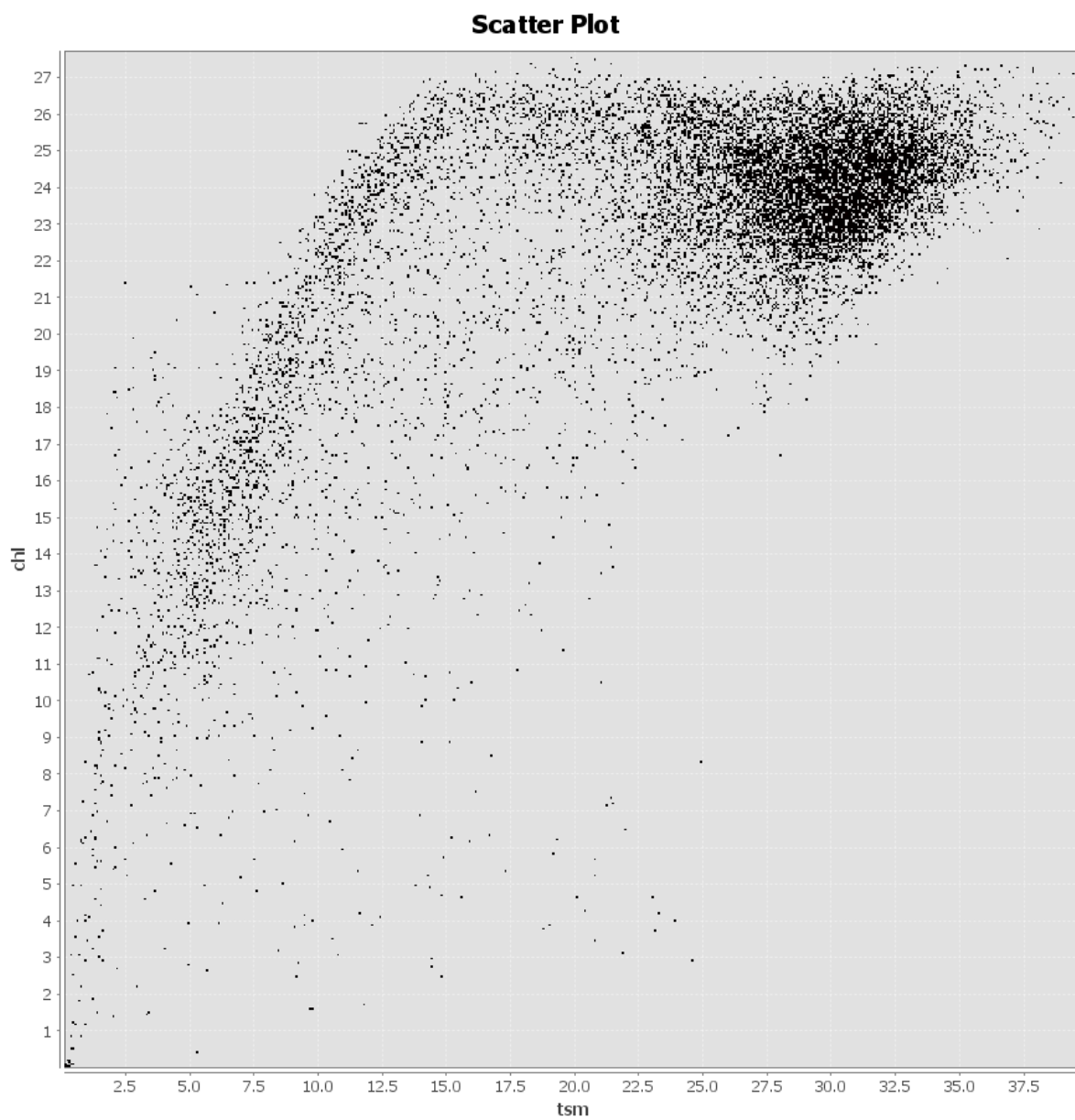


Fig. 54: Cross-relationships of chlorophyll-a, and total suspended matter characteristics of Sentinel 2A used in Powai lake for the month of February, 2017.

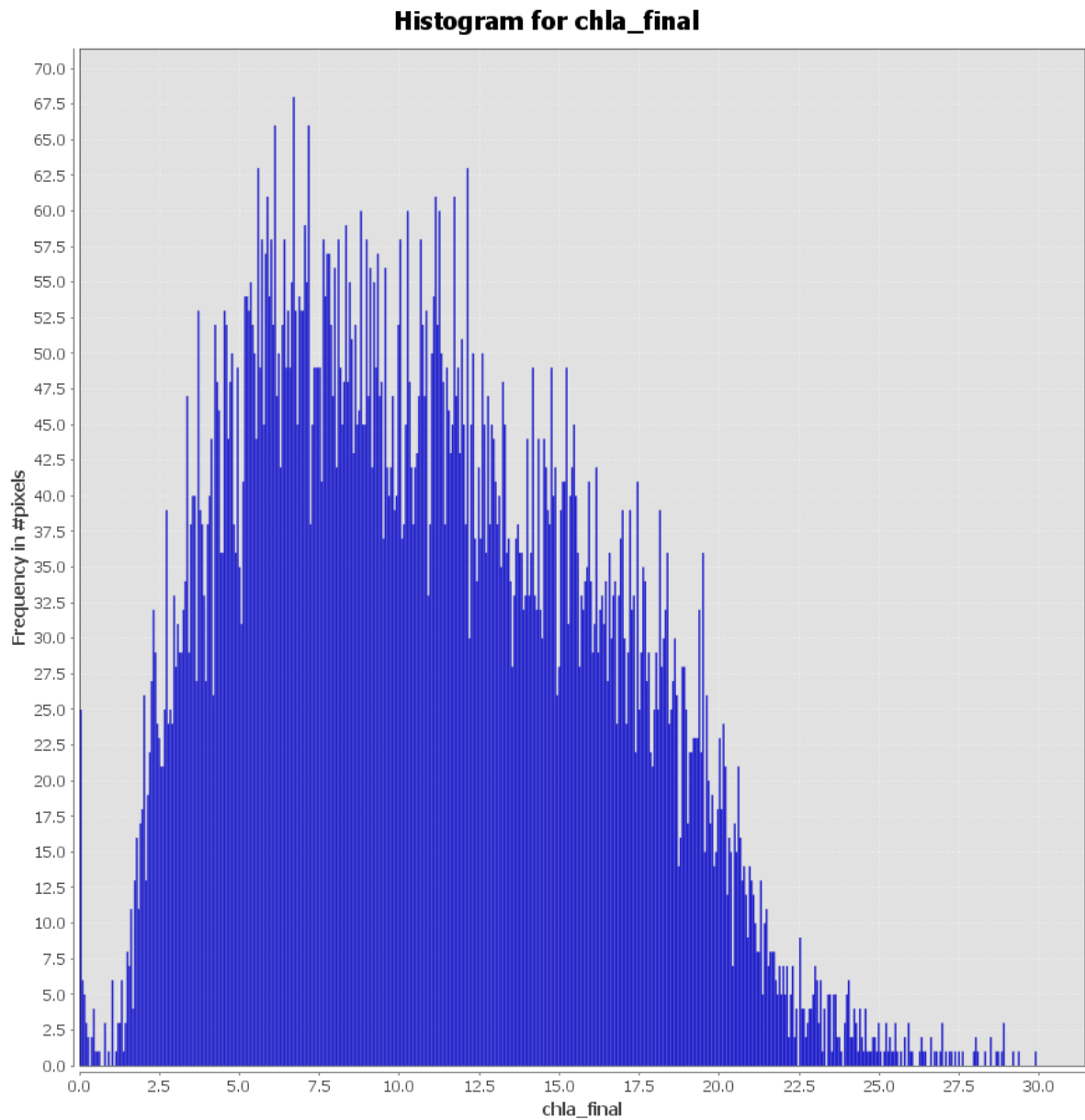


Fig. 55: Chlorophyll-a concentration and distribution (mg m^{-3}) on x-axis and fraction of total pixel on y-axis, indicate water framework directive boundaries for water quality status classification based on chlorophyll-a concentration, March 2017, blue: high/good status, green: good/moderate, yellow: moderate/poor, red: poor/bad (Wolfram *et al.*, 2009).

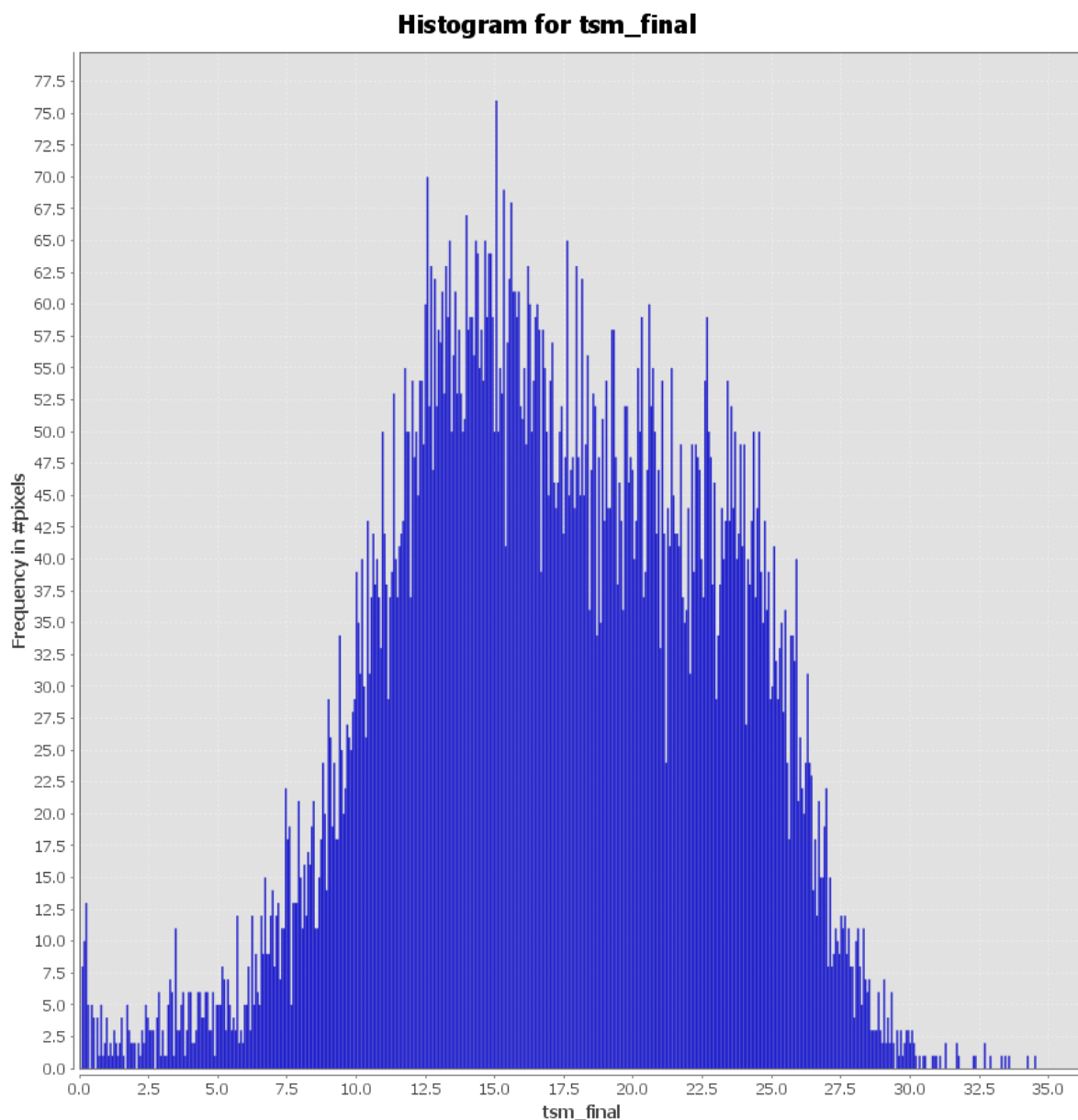


Fig. 56: Total suspended matter concentration (g m^{-3}) on x-axis and fraction of total pixel on y-axis, indicate frequency of pixels against the corresponding concentration value on x-axis for March, 2017.

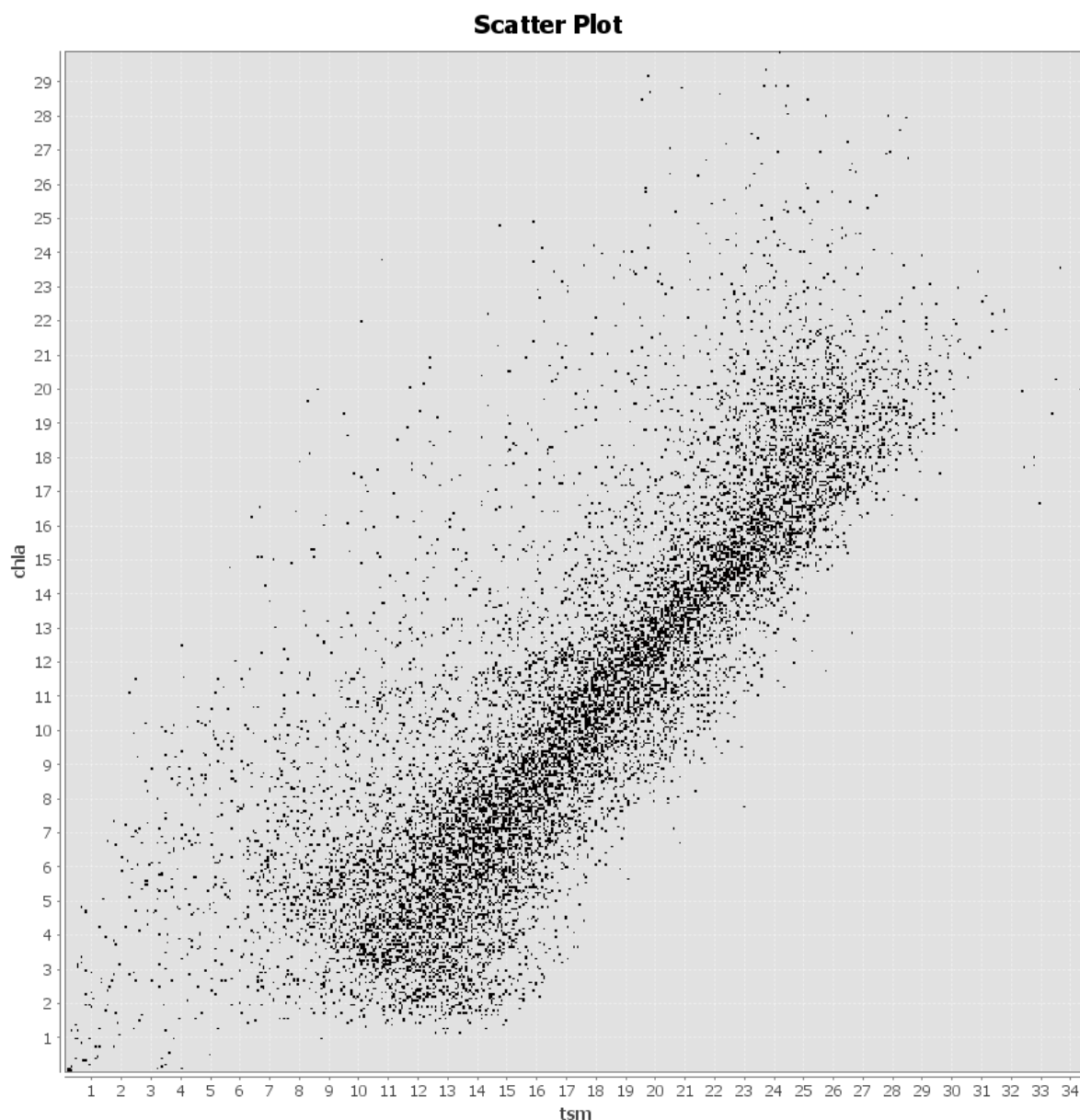


Fig. 57: Cross-relationships of chlorophyll-a, and total suspended matter characteristics of Sentinel 2A used in Powai lake for the month of March, 2017.

4.8 Conventional, GIS and remote sensing results

Finally, the conventional, GIS and remote sensing approach used in the present study revealed relatively similar results for water quality parameters, productivity and plankton concentration of Powai lake.

5. DISCUSSION

5.1 Physico-chemical parameter of Powai lake

The findings revealed that the physico-chemical components and plankton community of Powai lake varied with months, stations and seasons.

The temperature showed considerable fluctuation. The low temperatures recorded from November to early March were due to the winter and dry wind. In early June, July and August the rains and the associated cloudy weather caused the decrease in temperature. Similar types of fluctuations in air temperature were also observed by Bade *et al.*, (2009) and Sathe *et al.*, (2001). The air temperature determines the water temperature of a water body, which has a great bearing on its productivity. In the present investigation, a significant relationship was found between air and water temperature (Fig. 5). Timms (2001) suggested that climatic factors were the determining factor for increase or decrease in temperature in the tropics and Powai lake shares the climate of the southeast Asia. This is in accordance with Egborge (1972), Holden and Green (1960) who noted that climatic factors were the determining factors for water temperature. The water temperature range in this study falls within the normal temperature range (25-30⁰c) of natural tropical water (Alabaster and Boyd, 1980). The aquatic lives in the tropics are adapted to these changes (Wood *et al.*, 2002).

Water transparency varied from 15.00 cm to 47.66 cm in the five stations. This is low as compared to 0.45 to 2.8 meters obtained in Kainji lake (Adeniji, 1975). The progressive decrease in water transparency from February to May has relationship with increase in plankton production. The remarkable increase from July to September after the onset of rains indicates that water influx into the lake were responsible for the low water transparency within that period, rather than plankton production (Fig. 6). There are seasonal and regional variations of water transparency due to the differential quantities of suspended solids, algae, silt and illumination (Salim and Ahmed, 1985; Sharma, 2000). Moderate seasonal pattern of fluctuation in water transparency was observed. The low value of transparency in October may be due to the high silt load after monsoon runoff and the result of human activity in and around the lake (during Ganesh Festival in September); whereas, it could be

attributed to increased primary production resulting in high plankton density. Since the lake is a comparatively small ecosystem, it behaves like a lotic water body during the overflow of the dam and there is complete mixing of water between the lake and catchment surface run-off, which in turn increases the turbidity and decreases the transparency during monsoon (Paramita, 2012).

There are seasonal and regional variations of water transparency due to the differential quantities of suspended solids, algae, silt and illumination (Salim and Ahmed, 1985; Sharma, 2000). The low value of transparency in Powai compared to Vihar may be due to the high plankton density and silt load observed in Powai, which is the result of human activity in and around the lake unlike Vihar, which is isolated and protected inside the Sanjay Gandhi National Park (Ratheesh, 2011).

Biwas (1978) observed that in lake Volta Ghana, Secchi disc transparency decreased due to plankton. Olaniyan (1978) suggested that transparency vary directly with rainfall in fresh water habitats and it determines the depth to which light essential for photosynthesis can penetrate.

Turbidity of water was high in the pre-monsoon season, i.e March, April and May. Since turbidity had an inverse relationship with transparency, maximum turbidity can be correlated with the high density of plankton in pre-monsoon season up to May (Fig. 6).

The depth in Powai lake started increasing during the rainy season, i.e June to September and was lowest during the dry season. The highest value recorded in July is as a result of peak inflow into the lake. The increase in depth could influence turbidity and therefore light penetration for primary production, and affect feeding by biotic communities relying on sight. Stations A, B and E were deeper than station C and D. This could be as a result of natural feature of the lake. Alabaster and Boyd (1980) suggested that high depth might affect some aquatic life. The effect may include the reduction of their growth rate as well as reduction of food availability to the fauna.

The value and the status in the pH of Powai lake are in agreement with the observation of Hall *et al.*, (1977) in Zambezi river, Elemi, (1990) in Ona river, Atama (2003) in RIMCO reservoir, but in contradiction with the trend in some African lakes in

which pH is lower in the rainy season, but rises during dry season. The pH range of Powai lake were comparatively narrow and fell within the recommended range (6.5-9.0) as suitable for aquatic life (Boyd, 1979). Bell (1971) has stated that pH range between 6.5 and 9.0 provides adequate protection to the life of freshwater fishes, bottom-dwelling invertebrates and other aquatic organisms. Mishra *et al.*, (2003) have reported that a pH range of 7.2 to 8.5 favours the growth of plankton. According to Reynolds and Allen (1968), pH is the most important factor regulating plankton density. In the present study, a higher than neutral pH (7.12 to 7.60), observed in Powai lake can be correlated to the high plankton density in the lake.

The lake is shown to be slightly alkaline; this may be attributed to the influx of salts during the rains in previous months (Fig. 7). The value then continued on the downward trend to neutral level again. This is in agreement with Beadle (1981) that photosynthetic and respiratory process determines to a large extent the hydrogen ion concentration in an aquatic ecosystem. Hutchinson (1975), Walnis and Toemain (1979), Holden and Green (1960) noted that in African waters, alkaline conditions are not typical. It is in agreement with Steeman-Nilsson's (1966) observation, that decay of allochthonous and autochthonous organic material in the lake would decrease the pH below 7.0, the nature of the basement rocks of granite-biotite must be important in the buffering of the water pH above 7.8.

The patterns of dissolved oxygen varied between stations and months. Egborge (1979) observed similar pattern of variation in lake Asejire. Oxygen levels in the five stations sampled were statistically significant. The relatively low level of dissolved oxygen in the month of May, might have been due to the decomposition process of organic matter (Fig. 8). Duchane (1975) observed that whereas wind is a major oxygenator in large lakes, dissolved oxygen in smaller lakes is largely determined by photosynthetic action of plankton, in which Powai lake is the one. Complete oxygen depletion was not observed in any of the stations in the lake, apparently because of significant water movement in relatively same amplitude.

Ratheesh (2011), observed similar DO value in Powai lake, and further revealed that DO value was higher in Powai lake than in Vihar lake. Higher values of BOD indicate a higher level of consumption of oxygen and a higher pollution load. The increase in DO and decrease in BOD in Powai lake compared to Vihar lake may

be attributed to the discharge of industrial and domestic sewage from the surrounding area and oxygen consumption due to high growth and activities of microorganisms (Paramita, 2012). Similar to the above observation, the impact of urbanization on Bellandur lake (Bangalore) also showed higher values of alkalinity and DO, and low levels of BOD and COD, which are indicators of the polluted nature of the lake (Chandrasekhar *et al.*, 2003).

Most fish species will survive in waters containing carbon dioxide upto 60 ppm (Hart, 1944). Absence and low values of free carbon dioxide recorded in pre-monsoon months may be attributed to high photosynthetic activity, may be correlated to a peak of phytoplankton and presence of appreciable quantity of carbonates in the water (Sahi and Sinha, 1968). High values were observed in the monsoon season, which is due to influx of rain water in the form of carbonic acid (Chakrabarty *et al.*, 1959) as well as decomposition of organic matter brought by catchment runoff inflow.

The total alkalinity maintains the buffering capacity of an aquatic ecosystem. The availability of carbon dioxide for primary production is related to alkalinity; water with total alkalinity levels of 20 to 150 ppm contains suitable quantity of carbon dioxide (Boyd, 1984). The total alkalinity in Powai lake was within this range (102 to 215 ppm) and indicates its productive nature. It was maximum in post-monsoon and minimum in monsoon period of the study. This matches with the observations made by Nair and Rajendran (2000). It revealed positive relation between pH and total hardness, is in conformity with the findings of Pahwa and Melhotra (1966).

Total alkalinity in Indian waters ranges between 40 and over 1000 ppm of CaCO_3 (Jhingran, 1982). Total alkalinity in Powai was found to be much higher than that in Vihar (around 50 ppm of CaCO_3). It is reported that alkaline pH is favourable for good plankton growth (Mahajan and Kanhere, 1995). In the present study also, high plankton density was observed in Powai lake (Fig. 10) where the alkalinity was comparatively higher. Khatavkar (1986), while studying two eutrophic polluted water bodies, observed alkalinity value above 150 ppm in two water bodies and reported that pollution of waters can increase the level of total alkalinity. While comparing with his report, it could be concluded that Powai lake is eutrophic in nature.

The hardness of water is mainly contributed by calcium and magnesium ions. According to Baeton, (1969); and Munawar (1970), high concentrations of calcium,

magnesium, sodium and potassium in water bodies are entirely due to pollution. Also, Boyd (1982) stated that total hardness values within the range of 20 to 300 ppm are good for fish culture. Pond waters having a total hardness of 15 ppm or above are satisfactory for growth of fish (Swingle 1967). The total hardness observed in this study indicates the productive nature of the lake (Fig. 11). Higher values of total hardness in the lake were observed in pre-monsoon and post-monsoon period is similar to the findings of Bade *et al.*, (2009). The relationship of water pH and total alkalinity with total hardness was positive for Powai.

Chloride content in the range of 31 to 50 ppm is considered suitable for freshwater fish culture (Saharan *et al.*, 2001). Chloride content of Powai lake during this study exceeded allowable limit for aquatic life in the month of May. Chloride content showed distinct temporal variation with its peak in May and November, followed by a fall in monsoon (Fig. 12). This is in accordance with findings of Bade *et al.*, (2009) and Paramita (2012).

Ellis *et al.*, (1946) stated that the quantity of ammonia in unmodified natural waters is very small, being less than 0.1 ppm. However, organically polluted waters have normally higher concentrations of ammonia which is a product of ammonification of organic matter (Rybak and Sikorska, 1976). The concentration of ammonia nitrogen in Powai lake is above the oligotrophic limit of 0.1 ppm indicating pollution in Powai lake (Fig. 13). Maximum values of ammonia were obtained in post-monsoon and low concentrations were observed in pre-monsoon months. Similar results were obtained by Joshi *et al.*, (1981). High concentration in post-monsoon period may be attributed to the catchment runoff in the monsoon season and accumulation of nitrogenous products. Similar observations were also made by Moss (1972), Agrawal *et al.*, (1976) and Jhingran (1991).

Nitrite nitrogen in a water body is produced due to decomposition of organic matter. The nitrite nitrogen concentration in present study showed irregular pattern of temporal variation in lake water.

Nitrate represents the end-product of oxidation of nitrogenous matter and its concentration may depend on the nitrification and de-nitrification activities of microorganisms. The nitrate-nitrogen plays a significant role in the productivity of a water body. It is one of the most important nutrient in an aquatic ecosystem and

generally, water bodies polluted by organic matter exhibit higher values of nitrate (Shanti *et al.*, 2002). In the present study, the concentration of nitrate-nitrogen was in Powai lake. High values of nitrate nitrogen in post-monsoon months may be as a result of catchment run-off from monsoon rains.

The seasonal variations of phosphate phosphorus in Powai lake ranged between 0.17 ppm to 5.0 ppm. The pattern of phosphate phosphorus fluctuation was in line with the rainfall distribution. Maximum phosphate phosphorus concentration was obtained in October corresponding to the decreasing volume of water in the lake. There was a subsequent decrease from pre-monsoon to monsoon as the rains established and progressed, possibly due to dilution effect (Fig. 14). There was continuous depletion of phosphate from June, this is in agreement with Owens and Wood (1968); and Paramita (2012), that 68% of phosphorus was from run-offs and only 28% from other sources. The phosphorus value range recorded in this study falls below the observed range of 3.80 to 6.30 ppm observed by Beadle (1981) in some African rivers and lakes. The phosphorus value recorded was 3.1 – 14.5 ppm in Praire lake (Hanson *et al.*, 1990) and 20 – 51 ppm in Delimi river (Anadu and Akpan 1986). The source of phosphorus can be from arable agriculture. It was also observed during the study period that the industries and hotel around the catchment discharge their waste into the lake. Some people were using the water for domestic use, washing of cloths, which could increase the phosphorus level of the water. The most important limiting factor in aquatic productivity is the phosphorus, and can be impoverished by being used up. Sandra (2000) observed that phosphorus is the most important and limiting substance controlling organic production.

Phosphorus is an important element for primary production and is one of the important limiting factors for plant growth especially in fresh waters (Thirumala *et al.*, 2006). Phytoplankton use phosphorus for their growth in phosphate form. Wetzel (1983) concluded that phosphorus is the most important limiting factor responsible for eutrophication of water all over the world. Comparatively lower levels of phosphorus are capable of causing eutrophication as indicated by Reid (1961). In the present study, the concentration of phosphate phosphorus may be responsible for eutrophication in the lake. Maximum values of phosphate phosphorus recorded can be correlated to the dip in phytoplankton density in monsoon when utilization by phytoplankton is low. Likewise, low values of phosphate phosphorus in pre-monsoon

justify the phytoplankton peak in the same period when the lower concentrations in water result from higher utilization of phosphorus in primary production by phytoplankton.

Total dissolved solids (TDS) are the amount of particles (lesser than 10^{-9} metre), that are dissolved in water. These were maximum during post-monsoon and minimum during monsoon (Fig. 15). This may be a result of mixing of nutrients during monsoon months. Post-monsoon to pre-monsoon showed high values of TDS since monsoon brings in lot of soluble nutrients and organic matter and soluble minerals from immersed idols near station E. Since suspended impurities brought in by water influx during monsoon take time to settle and allow particles lesser than 10^{-9} to dissolve, total suspended solids (TSS) were higher in monsoon.

The Biochemical Oxygen Demand (BOD) exhibited different trend to that of dissolved oxygen. The higher BOD recorded in station A (11.22 ppm) could probably be due to organic matter degradation, which utilized oxygen within the lake (Fig. 8). According to Umeham (1983), and Kolo and Yisa (2000), organic matter decomposition from increased human activities can increase the BOD variations. Moore and Moore (1976) reported that BOD is a fair measure of cleanliness of any water and classified values of less than 1.2 ppm as clean, while 4-6 ppm as fairly clean and 8-10 ppm as bad and polluted based on these values, Powai lake may be considered as polluted.

Higher values of BOD indicate a higher level of consumption of oxygen and a higher pollution load. The increased BOD load and decreased dissolved oxygen in Powai lake be attributed to the discharge of domestic sewage from the surrounding area and oxygen consumption due to high growth and activities of microorganisms. Similar to the above observation, the impact of urbanization on Bellandur lake (Bangalore) also showed higher values of alkalinity, BOD and COD, and low levels of DO, which are indicators of the polluted nature of the lake (Chandrasekhar *et al.*, 2003). This can also be substantiated with the result of the algal pollution indices used in the present study which reflected the higher organic pollution in Powai Lake.

Lowest and highest values of COD in this study reveal that Powai lake is in pattern of eutrophic and polluted water (Chandrasekhar *et al.*, 2003) and further confirms the fact that the lake is eutrophic and organically polluted (Fig. 16).

Specific conductivity is the total concentration of ionic substances in natural waters. The specific conductance of the Powai lake ranged from 142.33 to 602 $\mu\text{S}/\text{cm}$, which indicates eutrophic nature of the lake as also interpreted by Olson (1950) and Rawson (1960). High value recorded in monsoon may be due to dilution of water through catchment runoff and comparatively low values were observed in post-monsoon and pre-monsoon season (Fig. 17). This pattern was similar to specific conductance variations observed by Acharjee (1997) in *beels* of Assam. Low values were however observed in March and May 2011, which are again similar with the findings of Narain and Chauhan (2000) and Paka and Rao (1997). According to Jhingran 1990, freshwater bodies with conductivity more than 200 $\mu\text{S}/\text{cm}$ are highly productive. Similar to such reservoirs, Powai lake is also productive in nature. This explains that increase in conductivity every month and the highest during the rains, was a result of dissolved salt brought in by flood. According to Hutchinson (1975) lake water classification on conductivity, the Powai lake falls within the eutrophic range.

5.2 Productivity of Powai lake

Primary productivity is the rate of synthesis of organic carbon by primary producers. It depends on the efficiency of the primary producers to transform solar energy into biochemical food energy. In the present study, primary productivity is the phytoplanktonic productivity and production of organic carbon by macrophytes, since macrophyte infestation is very high in Powai lake. The total amount of oxygen produced during photosynthesis is directly proportional to gross primary production, since one molecule of oxygen is produced for each atom of carbon fixed (Adoni, 1985). The average gross primary productivity (GPP) estimated in the lake ranged from 131.94 to 346 $\text{mg C}/\text{m}^3/\text{hr}$ which is higher than 75 to 300 $\text{mg C}/\text{m}^3/\text{hr}$ in the same lake obtained by Paramita, (2012). Powai lake water revealed a high NPP in terms of wet weight up to 2289.99 $\text{mg}/\text{m}^3/\text{hr}$. The shallow depth and high water temperature increase primary productivity (Adoni, 1985). High gross primary productivity of Powai lake in early monsoon can be correlated to high water temperature and rich phytoplanktonic biomass. Low primary production in monsoon in the lake may be due to large influx of water, low water temperature and less planktonic biomass. The relation of biotic communities with primary productivity were studied under the present study showed positive correlation of gross primary

productivity with high biomass of phytoplankton, zooplankton and benthos in pre-monsoon months (January to May). NPP (wet weight) and tertiary productivity (TP) increased more than 100% compared to study of Paramita (2012) in the same lake. This indicated the strong role of plankton population and benthic communities in the production cycle of the lake.

5.3 Water quality index of Powai lake

Evaluation of overall water quality is not an easy task, particularly when different criteria for different uses are applied. Moreover, the classification of water quality follows various definitions with respect to the contents of different water quality parameters. Dozens of variables have been developed and are available to be used in management of governmental or environmental programs, but because of the high price for water analysis to attend these programs generally makes it difficult to use them. In this study, application of the water quality index approach to Powai lake has the objective of providing a simple and valid method for expressing the results of several parameters in order to more rapidly and conveniently assess the water quality for aquaculture. Combining different parameters into one single number leads to an easy interpretation of the index, thus providing an important tool for management purposes. The CCME WQI rank, defines Excellent water quality as (CCME WQI value 95-100), Good (CCME WQI value 80-94), Fair (CCME WQI value 65-79), Marginal (CCME WQI value 45-64), and Poor (CCME WQI value 0-44) respectively. The assigning of CCME WQI values to these categories is termed as “categorization” and represents a critical but somewhat subjective process. The classification is based on the best available information, expert judgment, and the general public’s expectations of water quality.

WQI_{obj} showed no significant difference ($P < 0.05$) among the sampling stations in general when the differences between station A, B, C, D and E were relatively in the same amplitude. WQI_{obj} was not support the results of analysis of variance simply because it was calculated using many variables to assess the overall water quality. This speculation was further supported by the findings of Ferreira *et al.*, (2011), who used same method in estimating water quality using the WQI of the Canadian Council of Ministers of the Environment

by including a large set of parameters and did not detect a significant difference between qualities of affected and unaffected sites from shrimp farms. However, there is a clearly need for the parameter selection and data reduction to clarify the aquacultural impacts, which is the main purpose for the present study.

Data selection and reduction by omitting the unnecessary variables such as depth can be an option to make WQI_{obj} simpler. In this study, eight parameters were used to calculate WQI_{min} considering that these variables have impacts on the water quality (Bergheim and Brinker, 2003; Sindilariu *et al.*, 2009a; Kocer *et al.*, 2013). The WQI_{min} in this way yielded high score (69.07) compared to the WQI_{obj} (63.80). However, WQI_{min} was not able to separate the reference station and the others to a large extent, though some significant difference for the different months was observed. One explanation of this can be that since both urban and domestic waste are also sources of the parameters included in the calculation of WQI_{min} in rivers, streams and lakes (Carpenter *et al.*, 1998; Mander *et al.*, 2000; Neal and Jarvie, 2005; Jarvie *et al.*, 2008; Moss 2008, and Sindilariu *et al.*, 2009b) it may not have clearly separated the affected sampling stations in the present study.

Instead of an arbitrary selection of the parameters in the calculation of WQI_{min} , it is assumed that statistical results would be more appropriate way to select the representatives of aquacultural impacts in the study area. The results suggested that water temperature, turbidity, and phosphorus along with COD were more associated with the monsoon as a result of the discharges into the lake. A calculation of WQI_{min} based on these eight parameters classified the water quality as “fair” water quality is usually protected but occasionally threatened or impaired; conditions sometimes deviate from desirable or natural (average values between 65 and 79 in annual period) whereas, other impacted points as “Marginal” (the index scores between 45 and 64). These results seemed to be more accurate in terms of characterizations for aquaculture potentials.

There was strong and significant relation between NH_4^+-N , NO_2^-N and NO_3^-N concentrations and the index scores (Fig. 13), indicating that they

make a remarkable contribution to WQI_{min} . Even though an interference of point or nonpoint sewage and domestic discharges may not be ruled out, WQI_{min} provided a more precise approach than WQI_{obj} and WQI_{min} in assessing the effects of effluents on the water quality in the lake. The better performance could be because TDS and TSS are the dominant fractions of TS (Fig. 15), in catchments under the effect of diffuse discharges from industrial as well as treated and untreated sewage wastes of urban community (Neal and Jarvie, 2005; Jarvie *et al.*, 2008). For a well thriving aquaculture, DO and BOD are critical to a certain degree (Sindilariu, 2007; Shamir *et al.*, 2015), are dominated by COD as well as ambient temperature and water temperature, (Fig. 5) respectively (Foy and Rosell, 1991; Roque d'Orbcastel *et al.*, 2008; Mehet and Huseyin, 2014). Chloride can be removed up to 90-95% through aeration and distillation, but the removal of hardness is highly difficult (Sindilariu, 2007; Sindilariu *et al.*, 2009b); thereby the ratio of alkalinity may increase (Dalsgaard and Pedersen, 2011).

The results suggest that Powai lake WQI_{obj} would be a useful approach for assessment of impacts on the receiving run-off, and NH_4^+ -N and NO_2 -N seem to be better indicators for aquacultural impacts as opposed to the suggestion of Simoes *et al.*, (2008), who noted that eutrophication could be the typical indicator. Therefore, as a next step in the parameter selection we calculated WQI_{min} based on transparency and turbidity. WQI_{min} produced highly similar scores for all sampling months and significant difference between these two affected productivity of the lake. However, WQI_{min} clearly separated the sampling months with respect to their water quality status, and rated monsoon and post-monsoon as “good” and “medium” classes, respectively for all conditions and annual period, which also revealed by Fabiano, *et al.*, (2008). An attempt at the index calculation (WQI_{NH_4} , WQI_{cond}) using only a single parameter (NH_4^+ -N or conductivity), which is actually an environmental quality standard (EQS), resulted in higher water quality classes of the sampling stations than WQI_{min} . Moreover, WQI_{NH_4} appeared to have a higher relation with WQI_{min} than WQI_{cond} . Although WQI_{NH_4} had a good association with WQI_{min} pre-monsoon, there was no reasonable relation for all the sampling months when compared with monsoon. This may suggest that the EQS of

$\text{NH}_4^+\text{-N}$ alone seemed to have been a good indicator for assessment of aquacultural impacts in Powai lake, but it was still insufficient for assessment of the entire water body probably due to interference of several other factors such as nitrification, dilution, diffused loads from domestic waste, eutrophication, etc.

5.4 Metals concentrations in fish, water and sediment of Powai lake

The calcium concentration recorded is higher than 0.9 ppm recorded in Arizona desert reservoir (Olsen and Sommerfield 1977), but it is lower compared to the permissible pollution limits of 0.10 ppm recommended by Dein Inger (1980). The significant increase in calcium concentration in all the stations may be linked to the activities occurring, such as excessive land runoff into the water and hence its affinity with calcium sulphate which is dissolved in the water body. It is also linked to the activities, such as human navigating activities and washing of fishing equipment directly into the water. On the contrary, the mean value of calcium was higher in the body tissue of *Clarias gariepinus*, than in *Catla catla* during monsoon and post-monsoon than pre-monsoon. In Powai lake like other lakes, the level of concentration in sediment is higher than water, and in water is higher than in fish. Wright *et al.*, (1985) reported that the concentration of iron, copper and magnesium were higher during the monsoon than in the post-monsoon and pre-monsoon.

The concentration of potassium, magnesium, sodium, silicon and manganese showed a little variation within the lake during this study. The highest concentration in various stations could be associated with domestic and industrial waste around the catchment. Odiete (1999) reported that domestic sewage and agricultural effluents have capacity to precipitate magnesium salts, which may exert a toxic effect on aquatic organisms. Other source may be as a result of localized inputs and sediments transport.

Okoye *et al.*, (1991) reported anthropogenic magnesium enrichment in the Lagos lagoon and implicated land-based urban and sediment transport, as well as individual sources and hence the level of magnesium in Powai lake is lower compared to the acceptable limits of <15 ppm by Dein Inger (1980). This shows that metals concentration in Powai lake is not high. The variation in the concentrations of heavy metals in the water may be mostly attributed to the discharge of dumped

waste, domestic activities, industrial as well as direct washing in of dry and wet particles by winds and floods.

All the metals determined were below the World Health Organization (WHO) safety standards, Food and Drugs Administration (FDA) and the United States Environment Protection Agency (USEPA) maxima (Stoeppler, 1999) except for silicon in sediment which is higher than the range recommended by WHO and other regulatory bodies. The level of zinc in sediment is however within the range recommended by USEPA (Stoeppler, 1999). Iron though high in sediment but is still safe because it has benefits to organism though in very high concentration leads to conjunctivitis, chroiditis and retinitis if it is in contact and remains in the tissue, but cadmium is a toxic metal and has no metabolic benefits to human and aquatic biota (USEPA, 1986). Therefore, Its presence in any compartment of the aquatic ecosystem indicates contamination, but is absent in Powai lake. The high level of calcium, magnesium, potassium and sodium in both the water and sediment samples was as a result of the runoffs during the monsoon couple with dumping of domestic and industrial wastes in the water body at different points along the length of the lake as they are known to contain heavy metals which include arsenic, cadmium, copper, iron, mercury, manganese, lead, nickel and zinc which will eventually end up in this aquatic ecosystem (Woodworth and Pascoe, 1982). Among all these metals determined, iron has the highest concentration in sediment and water. The absence of these metals analysed in the body parts of fish serves as an indicator that are safe for human consumption (Huckabee and Blaylock, 1972). Also the absence of most of the metals determined in the fish flesh is in agreement with the results of the report of the level of heavy metals in aquatic organism from different water bodies (Oluyemi *et al.*, 2008) which showed that aquatic animals, fish, bio-accumulate heavy metals in considerably good amount, and because these metals are not bio-degradable, the metal tend to stay in the fish tissues for a very long time which upon consumption of these fish, the heavy metals get transferred to man, leading to heavy metal poisoning in man especially if present in higher concentrations. In both species of the fish and water samples, chromium, cobalt, nickel, cadmium, arsenic, copper, manganese, silicon and zinc are absent (less than 0.01 ppm), while cadmium and arsenic are also absent in sediments.

The concentration of iron is consistent with the low solubility of iron in desert reservoirs as reported by Olsen and Sommerfield (1977). The presence of iron in

Powai lake may be due to direct or indirect discharges and land runoff into the lake. The concentration of iron was higher in late pre-monsoon season than in the monsoon season. Entry of the heavy metals into the lake especially during the rainy season may be through water influx and this trend to increase the concentration of the metal during the rain. In the case of iron it is in agreement with finding of Amuzu *et al.*, (1990) that heavy metals occur in low concentration in aquatic ecosystem. The values of iron for all the samples were lower than the values suggested by WHO for drinking water (Hart, 1993) classified as surface water with 1.9 ppm of iron as slightly polluted, 2.7 ppm as polluted and values above 2.7 ppm as heavily or polluted, on the basis of Harts classification, Powai lake can be classified as unpolluted.

5.5 Plankton communities in Powai lake

The taxonomic dominance of *Microcystaceae* as reported in this study has been observed in several other water bodies. This is regularly common in tropical and subtropical fresh water, whether in lakes, ponds, reservoirs, rivers or streams (Green, 1960; Jeje and Fernando, 1986; Cavlli *et al.*, 2001; Nogueira, 2001; Sampaio *et al.*, 2002 ; Neves *et al.*, 2003; Kudari *et al.*, 2005; Imoobe and Akoma, 2008, 2009; Armoro and Oganah, 2010). The species composition of plankton with dominance of *Microcystaceae* was also observed by Olaifa and Leilei (2007) in Ekole River and Paramita (2012) in the same Powai lake. Mathivanan *et al.*, (2007) also notice dominance of *Microcystaceae* in Cauvery river, with the predominance genus usually being *Microcystis aeruginosa*. In the present study a total of eleven (11) plankton species were identified belonging to nine (9) families. Ganapati and Pathak (1969) reported that under normal conditions, *Microcystis aeruginosa* occurred throughout the year with a bloom in summer, in enclosed water bodies. Sugunan (1995) also reported the overwhelming presence of *Microcystis aeruginosa* in Indian reservoirs. The dominance of *Microcystis* throughout the year in Powai lake was similar to the findings of Paramita (2012). An analysis of the family wise showed species depicted the relative quantitative sequence to be *Microcystaceae* > *Naviculaceae* > *Brachionidae* > *Moinidae* > *Volvocaceae* > *Acartiidae* > *Hydrodictyaceae* > *Bacillariaceae* > *Zygnemataceae*.

Abundance of plankton is influenced by the seasonal variations in water quality parameters of a water body. Plankton diversity has been studied in relation to

these parameters by Hedge (1985), Pollinger *et al.*, (1988), Kulshreshtha *et al.*, (1989) and Adholia (1991). Byars 1960; Hutchinson 1957 and Rao 1975, reported that temperature plays an important role in the periodicity of phytoplankton. In the present investigation (Fig. 18), peak population of phytoplankton recorded during the post-monsoon months (July to October). A direct relationship of phytoplankton was observed with specific conductivity of water and organic carbon of soil; and an inverse relationship for phytoplankton was observed with reactive phosphorus, nitrate nitrogen, which are supported by the works of Round (1957), Singh (1960), Vollenweider (1968), Lund (1965), and Das and Singh (1993). Phytoplankton is inversely related to phosphorus, less phosphorus in post-monsoon correlates with a peak in phytoplankton density. It is notable that increased deposition of organic wastes in station E due to immersion of idols, dry flowers and clay pots used in religious rituals during August to September. NH_4^+ -N, PO_4 -P, nitrate nitrogen and silica also registered higher values bringing in domestic wastes and leakage from sewerage lines has also contributed.

Pediastrum sp., *Volvox sp.* and *Eudorina sp.* were most commonly occurring green algae. From the study of phytoplankters, it can be concluded the total number of individuals (density) was quite high in Powai lake as compared to the number of species (diversity). This conforms to the report of Romo and Villena (2005), who stated that high nutrient levels and fish stocks decreased phytoplankton diversity and species richness, with a trend towards the establishment of an assemblage dominated mainly by cyanobacteria in a warm shallow lake. The lake has mostly pollution tolerant species giving an indication of the polluted nature of the lake. It is reported that the study of plankton serves as an index of water quality in respect of industrial pollution, municipal and domestic sewage pollution (Pati and Sahu, 1993; Acharjee *et al.*, 1995; Baruah *et al.*, 1997). Pollution load in Powai lake was confirmed by the presence of pollution indicator species as per Palmer (1969) comprising different groups like *Microcystis*, *Spirogyra*, *Navicula* and *Nitzschia* etc. in considerably higher numbers in Powai lake. The plankton biomass studies are also important for gaining insight into fish production (Lenz, 1973). Rich biomass of plankton indicates high fish production. Maximum phytoplankton biomass can be correlated to the influence of warm temperature of water and nutrient enrichment of the lake through surface runoff from monsoon rains which mature during post-

monsoon to increase primary productivity in pre-monsoon. The high phytoplankton biomass indicated good potential of the lake for fish production.

The population of the plankton within Powai lake is low compared with what was obtained in some southern Nigeria lakes, and this may be attributed to influences such as climate change, aridity, physical, chemical and biological factors within each station and may also be associated with tropic state as well as geographical factors observed by Arora and Narish (2003) in Yamuna River. Egborge (1981) recorded 78 species in Asejire Lake, Jeje and Fernando (1986) recorded 65 species in Adada, Bonny and Oguta lakes.

The average plankton species per station in Powai lake is higher in comparison with previous studies in northern Nigeria lakes. For example, Abdullahi (1982) observed 18 species from Tiga lake in Kano, Ovie (1993) recorded more than 12 species in Kainji lake, Nigeria. This is to a great extent notable given that the sampling assessed was from the arid lake with very low rainfall, as well as surface water sampled. A higher number would be expected if greater sampling frequency at a deeper depth was employed. Also low rain with reduced vegetation had a greater effect on the qualitative and quantitative level of plankton species.

The highest species recorded by Arora and Naresh (2003), and Egborge (1981) was associated with high vegetation which provides anchorage to the resting eggs and larva stage of zooplankton in those water bodies studied. Species abundance of plankton varies widely between stations in this study. It is difficult to make a clear conclusion on the causes of the species pattern but we can suggest that the depth significantly contribute, even though flow of water from the source through all other stations as well as homogeneity of the stations may be one of the factors to be considered.

Our result shows that the distribution of plankton varied among depths, some species recorded here are likely to be limited in their distributions by their tolerance to environmental conditions and their preferences for food quality and quantity. Not all the identified species were present in all the five stations and months. For instance, *Navicula* sp. was totally absent in station E, also in the month of January and February. *Nitzschia* sp. absent in February, while *Spirogyra* sp. absent in November, December, January and February, which agrees with the findings of Idowu *et al.*,

(2008) that for the determinant species (concentration), depth played a vital role. Idowu (2004), observed that majority of zooplankton were found to be sensitive to low, medium or high levels of illumination, and as transparency changes, their positions in the water column also changed.

In the previous investigation of Powai lake by Paramita (2012) a total of 25 species under 20 genera of plankton were recorded. Rawat (1991) also recorded 21 species of zooplankton from Tumaria reservoir of Uttarakhand. Dumount and Tundisi (1984); and Vijverberg *et al.*, (1987) reported that zooplankton species diversity (especially limnetic copepods and cladocerans) decrease progressively towards the equator. Fernando (1980) also reported that the number of species occurring in temperate regions of Britain and Canada were approximately 50% higher than in tropical Sri Lanka. Thus the plankton species spectrum of Powai lake matched with the species spectrum of tropical lakes. Plankton species diversity expressed as the number of species or combined abundance and number of species in Shannon-index was very low compared with what was obtained in Oguta lake. But it was higher in Powai lake compared with what was obtained in Tiga lake (Abdullahi 1982). Ovie (1993) also suggest that flow velocity may be particularly important as a determining factor of composition and diversity of plankton assemblage. Vertical migration with suspect to change in temperature can also be considered as limiting factor for zooplankton occurrence in Powai lake for the variation in their distribution in relation to depth and stations. More intensive study of the pelagic plankton in Indian lakes will lead to the documentations of other species and wider distribution many others than those that were recorded in the current study. This will lead to greater understanding of the factors that controls the distribution of these species.

5.6 Sediment parameters of Powai lake

The chemical characteristics of bottom sediment greatly influence the supply of nutrients through mineralization of decomposing organic debris, creating suitable conditions for the existence of aquatic life that play a vital role in the productivity of a lake ecosystem. The lake sediment and its catchment soil nutrients determine the nutrient status of the lake water. The run-off from the catchment and the fluvial inflow brings a lot of materials in suspended and dissolved forms to the lake. Most of these gradually settle down to its bottom and affect the sediment quality. Apart from this,

autochthonous organic matter generated by the aquatic organisms and the allochthonous organic substances brought in by surface run-off and riverine inflow or inflow from its feeding channels also influence the sediment quality.

The sediment texture in Powai lake was found to be clayey loam to silty-loam since the clay component was high throughout the year. According to Kaul and Handoo (1989), silty-loam sediment originates from the deposition of autochthonous and allochthonous particulate matter in the basin. It can be concluded that the sediment in Powai lake is the result of organic deposition. Jhingran (1988, 1991) has reported that the moderately alkaline nature of basin soil is good for aquatic productivity. Texture variation was negligible throughout the months and stations. The sediment pH, also indicates good aquatic productivity of the lake.

Sediments, in general, are rich in mineral nutrients. According to Kaul and Handoo (1989), the nutrient pools in different compartments of the lake indicate that about 96% of the total calcium capital and 99% of the phosphorus pool are locked up within the sediments; whereas, the remaining 4 and 1% of calcium and phosphorus, respectively, are distributed between macrophytic and water compartments. The higher concentrations of nutrients, particularly nitrogen and carbon, are naturally to be expected in polluted waters (Munawar 1970). The available nitrogen of the lake sediment (296.40 to 321.13 mg 100 g⁻¹ soil) is much higher than (200.6 to 310.2 mg 100 g⁻¹ soil) what obtained in the same lake by Paramita (2012), indicating eutrophic nature of the lake and its very high productivity (Jhingran, 1990). Moyle (1949) and Banerjea (1967) observed that soil with organic carbon content of 1.5 to 2.5% or above are productive. Total organic carbon (2.94 to 3.19%) and available phosphorus (7.11 to 7.70 mg 100g⁻¹) were quite high in Powai lake sediment indicating a substantial level of organic pollution.

5.7 GIS and remote sensing

Although GIS is useful as a freshwater spatial planning tool, the final suitability map is limited by some level of uncertainty in the application. However, the use of GIS tools is necessity for the implementation of the Inverse Distance Weigh (IDW) technique and for the integration of several data sets. At present there is no standardized set of criteria and suitability indicators for freshwater aquaculture, although there is a need for their establishment and implementation (Frankic and

Hershner, 2003; Kapetsky and Aguilar-Manjarrez, 2007). Nevertheless, it is expected that our integrative approach to freshwater aquaculture will be applicable in other coastal water bodies, although scaling functions should be adjusted to environmental (physical and biogeochemical) site-specific factors.

Microscopic analysis for species identification, density and biomass measurement remains the standard method for estimating the species-specific biomass of phytoplankton in natural samples (Hillebrand *et al.*, 1999; Harrison *et al.*, 2015). However, it requires a high level of expertise, it is time consuming and the accurate estimates of diversity patterns depend critically on the taxonomic skills of the operator and on the counting effort (Olli *et al.*, 2015). Moreover, plankton bloom may contain both phytoplankton and other algae as well as the presence of competitors, predators and parasites as factors influencing the population dynamics (Likens, 2010), thus making the species identification very challenging in particular from satellite-based technologies. Nevertheless, satellite data remain a valid tool to identify the extension and intensity of the bloom, helping environmental authorities and managers to set up the most suited control strategies.

In fact, as shown from our results, satellite data allow a synoptic view of the area of interest with high frequency of observation. In particular, in the case of algal bloom events, traditional limnologic *in situ* measurements, which are carried out more rarely, could miss rapid events lasting only for a few days, while satellite optical data could catch bloom phenomena, except in case of clouds. On the other hand, the influence of cloud cover when using satellite data could be significantly reduced by combining imagery acquired from several missions. In November, 2016 to October, 2017, over the region of Powai lake, a total of 18 acquisitions were available by Sentinel 2A. Out of them, about half (44%, that is 8 images) were cloud free. By focusing to a shorter period (November 2016 to October 2017), the percentage of cloud cover images were up to 56% (10 images).

The probability to find more cloud-free images is now enhanced with the availability of data collected by Sentinel 2B, which was launched by European Space Agency (ESA) in March 2017. Revisiting time of combined medium resolution optical sensors L2, Sentinel 2A in the study area is of 2–3 days. Moreover, for water quality monitoring, the operational availability of data acquired by Sentinel-3 (S3) OLCI (Ocean and Land Colour Instrument) is of key importance. This mission provides high frequency of observation (that is revisiting time over our study area of about 1–2

days) with a spatial resolution of about 300 m. Although spatial resolution is reduced compared to S2 and L8 optical sensors, these data represent a principal source for water quality studies and monitoring. In particular, S3-OLCI offers 21 spectral bands in the visible–near infrared regions of the electromagnetic spectrum to distinguish different types of phytoplankton, characterized by different pigments. L8 and S2 spectral bands alone do not allow the discrimination between phytoplankton bloom and other algae bloom in terms of secondary pigments. In fact, these multispectral sensors do not carry a spectral band sensitive for example, the presence of phycocyanin and phycoerythrin, like Sentinel-3-OLCI bands are. Again, a multi-source approach is the most suitable for operational and full monitoring of lake water quality such as using scattered plot (Fig. 48, 51, 54 and 57).

The use of satellite data for aquaculture planning has been emphasized by many studies (Aguilar-Manjarrez *et al.*, 2010; Kapetsky and Aguilar-Manjarrez, 2007; Longdill *et al.*, 2008; Pérez *et al.*, 2005; Radiarta *et al.*, 2008; Rajitha *et al.*, 2007). Remote sensing is an important and cost-effective approach for developing countries and data-poor regions. Improved methods for data access, particularly remotely sensed data, will contribute to the change of scattered data points into more meaningful information, especially in developing countries where there is a scarcity of *in situ* data measurements. In addition, it will promote a more informed decision-making process for freshwater and coastal aquaculture management; and the use of better data and more sophisticated virtual technology.

As reported by Callieri *et al.*, (2014), blooms of *D. lemmermannii* can be occasionally recorded even in deep subalpine lakes, as supported by nutrient pulses deriving from the mineralization of organic matter deposited along the lakeshore and released through runoff during rainfall events. Nutrients arriving from the lake catchment area can stimulate phytoplankton growth, especially in eutrophic lakes (Morabito *et al.*, 2012), and, combined with a seasonal increase in water temperature, it would facilitate *D. lemmermannii* proliferation (Olrik *et al.*, 2012; Salmaso *et al.*, 2015). Calm conditions are known to be advantageous for buoyant *Microcystis aeruginosa* which move toward the euphotic zone in response to reduced turbulent mixing (Johnk *et al.*, 2008; Zilius *et al.*, 2014).

The satellite-based approach has then to be always integrated to *in situ* observations. For instance, an obvious limiting factor in the use of satellite data in the study area is the impossibility of detecting and quantifying deep phytoplankton

blooms, due to cloudy condition around the lake (Salmaso 2005). In this case, the absorption and backscattering properties of phytoplankton cannot be detected due to lower penetration of light through the water column, since light is completely absorbed by the water column and the electromagnetic signal returning back to the satellite sensor is too weak to detect the presence of an algal bloom.

Chlorophyll concentration maps in (Fig. 38, 40, 42 and 44) show the bloom events detected in the December, 2016 to March, 2017 for Powai lake. In case of April, 2017 to October, 2017 imagery analysis did not reveal any significant result at that time and therefore left out from the analysis (Fig. 37). In Powai lake, chlorophyll concentration was higher during February (Fig. 42). The concentration values reach typical of eutrophic environments, and we considered these events as blooms, according to Reynolds and Walsby (1975). The blooms were mainly due to phytoplankton an usual condition in Powai lake, as this taxon commonly blooms in eutrophic water bodies (Mayer *et al.*, 1997; Zwart *et al.*, 2005); nonetheless, its characteristics are poorly investigated (Acinias *et al.*, 2009) even widely distributed as it occurs in diverse aquatic as well as in benthic environments (Castenholz *et al.*, 2001; Zwart *et al.*, 2005; Diez *et al.*, 2007).

5.7.1 Water Framework Directive (WFD) perspective

The Water Framework Directive (WFD, Ferreira *et al.*, 2007) aims to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. In practice, this means that State Members have to achieve good ecological status (the scale is High, Good, Moderate, Poor and Bad status) or good potential in terms of chemical and ecological parameters within time limits set in the directive. Chl-a concentration is one of the key parameters used in the status classification.

In Fig. 46, 49, 52 and 55, the histograms of the chl-a concentration distribution for each image related to the WFD scale status are shown. The results show the advantages to use synoptic view characterizing the whole water surface of the single lake. Results (Fig. 37) obtained from Powai lake for the images without the chlorophyll due to cloudy nature of the period, and are comparable to results obtained from MERIS time series analysis (GLaSS, 2015).

The multi-temporal analysis clearly showed the worsening of the quality of lakes, during the algal bloom event, and demonstrates the usefulness of high

frequency monitoring tools, allowing the detection of phytoplankton events, which could potentially affect the final classification of the ecological status.

The detection and the analysis of the characteristics and spatial and temporal trend of these rapid events were carried out through remote sensing techniques using TSM (Fig. 39, 41, 43 and 45), while traditional limnological measurements alone would not have been enough to completely describe and, in some cases, even to identify these blooms. For example, in lake Garda, the bloom was directly observed during radiometric field campaigns, but chl-a concentration measured in the same day in the Northern part of the lake would not allow identifying the bloom in the Southern area. Considering chlorophyll concentration in all the stations used for lake monitoring, values extracted by images in the lake showed that even if measures had been collected on these days in all stations, only some of them would have identified the huge variation in chl-a concentration (Fig. 46, 49, 52 and 55).

In order to complete the analysis, and to understand the whole environmental conditions in which these rapid events can occur, meteorological data potentially affecting algal growth, were necessary should be considered over the events time, and in this research TSM values was considered (Fig. 47, 50, 53, and 56).

Since the latest satellite sensors used (L8-OLI and S2A-MSI) have not primarily designed for observing the optical properties of water, this study shows that they have suitable characteristics to support environmental monitoring in tropical lakes. Moreover, the obtained results confirm the robustness of physic-based approach based on atmospheric correction and bio-optical modelling inversion, to retrieve chl-a concentration. The results show that combining remote sensing with *in situ* measurements can help to monitor phytoplankton blooms for the WFD in Powai lake. In this study, high spatial resolution products were useful to recognize spatial pattern of phytoplankton blooms, while combining products from the two different satellites (and in the future integrating their time series with Sentinel 2B and more frequent Sentinel-3 products) allowed assessing on time the occurrence of these events. If these medium spatial resolution multispectral sensors bring a great advantage for the analysis of trend at spatial scale, their integration with data acquired by sensors with daily overpass and improved spectral resolution, such as OLCI on Sentinel-3, could allow a continuous monitoring of water quality parameters and phytoplankton blooms for the entire tropical lake regions.

Finally, to use satellite data to obtain robust and reliable quantitative products of water quality parameters over lakes district (example Powai lake), a strict requirement is to have a robust atmospheric correction method, validated over lake with different trophic status. To this aim, we relied on *in situ* measurements of Sentinel 2A from photo-radiometers belonging to the United States Geological survey through Land Global Survey section network, which were exploited for correcting the imagery from the atmospheric effects. Nevertheless, further investigations are necessary to both increase the number of match-ups and to evaluate uncertainties due to radiometric measurements gathered in the field.

5.8 Conclusion

The physico-chemical of water and sediment parameters of Powai lake showed a considerable difference during different months and stations, during pre-monsoon, monsoon and post-monsoon months. A remarkable variation in the water quality parameters such as dissolved oxygen, alkalinity and hardness indicate that water quality parameters are influenced by a combination of anthropogenic and natural factors (rainfall, temperature, etc). The heavy metals showed their presence in lake water, however, the concentration always remained within permissible range. It is evident from this observation that the effluent discharged in lake does not carry heavy metal containing compounds and presently the metals do not pose a threat to the lake. Compared to water, higher concentrations of heavy metals in sediments suggest that the sediments are the major sink of the heavy metals in lake system. As evidenced from the tissue analysis of three species of fishes (*Oreochromis mossambicus*, *Catla catla* and *Clarias gariepinus*) no heavy metals accumulation was noticed. This observation indicates that there is no trophic transfer of heavy metals across the food chain in the lake ecosystem. The presence of plankton species, notwithstanding other limnological features strongly suggests that the water body is maintaining eutrophic status, where there is continuous eutrophication which is lethal to fish and other aquatic organism.

This study shows that information used in GIS and remote sensing have clearly identified the effluent areas in pre-monsoon, monsoon and post-monsoon for aquaculture as revealed by the scoring model as station D and E, may be due to discharge from Renaissance Hotel and anthropogenic activities. The application of GIS model in the study for established spatial models for identifying suitable areas for

aquaculture for cage and pen culture in Powai lake, such as station A, B and C. This research showed there is potential relationship between GIS, remote sensing and conventional methods data obtained for aquaculture. It provides data for aquaculture investment analysis to decrease the hazards caused by pollution, and it provides a model capable of application to wide field scenarios and suitable for freshwater lakes. This work illustrated that satellite image can play an important role for simple empirical algorithms, particularly for Powai Lake, where data is limited to multispectral sensors. This study clearly revealed WQI of Powai lake classified as 'Marginal' between November 2016 and October 2017, where the water quality is frequently threatened or impaired; conditions often depart from natural/normal or desirable levels, that's continuous deterioration of the lake.

Overall, the study provides baseline data about present status of water and sediment quality, and the level of heavy metals in fish fauna of the lake. The finding and observation of present study will facilitate future monitoring of the lake ecosystem and also in developing an appropriate strategy for the conservation of the lake.

6. SUMMARY

GIS have been used in site selection for aquaculture, or to contribute to the sustainability of aquaculture, and for managing the development of fisheries and aquaculture. GIS models have also been used to identify suitable sites for aquaculture and coastal planning, for shrimp site selection in coastal areas, and for cage aquaculture. GIS has also been used for planning and management of inland aquaculture modelling for carps and native species and catfish culture. GIS has also been applied to define suitable sites for valuable shellfish culture in several regions including oyster, scallops or to evaluate the impacts from environmental issues to aquaculture species and predicting production for cockle and mussels.

Remote sensing has long been recognised as having the potential to complement conventional approaches to lake monitoring. Many remote sensing investigations of lakes make use of sensors intended for ocean colour applications such as NASA Coastal Zone Color Scanner (CZCS) imagery and model simulations to show that green-to-red instate of blue-to-green ratios were necessary for the retrieval of chlorophyll-a in optically complex waters, particularly those with high phytoplankton biomass. Use of CZCS and NASA Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) data to obtain long time series of water clarity (Secchi depth). SeaWiFS data have also been used for chlorophyll-a retrieval for lakes, as well as dissolved organic carbon (DOC) and suspended matter retrieval for further use in spatiotemporal analysis. NASA Moderate Resolution Imaging Spectroradiometer (MODIS) data have been used over a number of lakes, particularly for the retrieval of chlorophyll-a, TSM, turbidity, Secchi depth and surface water temperature.

The aim of this study was to investigate and to understand the application of GIS and remote sensing in selected limnological aspects of Powai lake. Such a study on the water quality parameters, productivity, plankton and presence of heavy metals during pre-monsoon, monsoon and post-monsoon season is very important for proper understanding as well as management and accurate prediction of the seasonal changes that occur using GIS and remote sensing tools. Therefore, this study is conducted with following objectives. (i) To identify the effluent areas using GIS and remote sensing in Powai lake. (ii) To relate GIS and remote sensing data

with some physico-chemical and biological parameters of the lake. (iii) To assess the concentration of heavy metals in sediment, water and fish in the lake.

The physico-chemical parameters of Powai lake investigated include air temperature, water temperature, transparency, turbidity, depth, pH, dissolved oxygen, carbon dioxide, alkalinity, hardness, chloride, ammonia, nitrite, nitrate, phosphate, total solid, total dissolved solid, total suspended solid, biochemical oxygen demand, chemical oxygen demand and conductivity.

Air temperatures across the stations were relatively within closely related range of 23.33 to 27.33°C in station B and station A. The surface water temperature ranged between 23.75 and 32.92°C which shows a wide variation across the months of December and May. 16.96 to 42.36cm was recorded as the lowest and highest transparency values in the months of May and September. Turbidity of Powai lake ranged from 24.93 to 88.33 NTU during the months of September and May, while 2.83 to 6.90 m was the minimum and maximum depth observed during the months of May and July. The pH ranged between 7.12 and 7.50 in the months of November and September respectively. The DO ranged 3.46 and 13.81 mg⁻¹ as lowest and highest values during the months of May and September, carbon dioxide value was recorded the lowest value of 6.00 mg⁻¹ in station E, while the highest value of 8.03 mg⁻¹ was observed in station B for the month of February. For alkalinity, Station B recorded the lowest value of 123.33 mg⁻¹, while the highest value of 144.00 mg⁻¹ was recorded in station A for the month of November. The maximum water hardness value of 152.26 mg⁻¹ was recorded in the month of June and the minimum value of 20.93 mg⁻¹ was noticed in the month of December. The chloride ranged between 32.00 and 67.73 mg⁻¹ as lowest and highest values in the months of December and May. The ammonia ranged between 0.06 and 0.66 mg⁻¹ as lowest and highest values in the months of January and July. Nitrite ranged between 0.01 and 1.29 mg⁻¹ as lowest and highest values in the months of October and June. The nitrate ranged between 0.20 and 3.00 mg⁻¹ as lowest and highest value during the months of December and June.

The phosphate ranged between 0.17 and 5.00 mg⁻¹ as lowest and highest values respectively during the months of December, March and October. For TS, 150 to 260 mg⁻¹ was recorded in station E and A, as the lowest and highest values in the month of November. 10 and 40 mg⁻¹ was recorded in station D and B, as the lowest

and highest values in the month of November for TDS, while for TSS, 120 to 320 mg⁻¹ values of TDS was recorded in station E and D, as the lowest and highest values in the month of November. The BOD ranged between 2.29 and 9.02 mg⁻¹ as lowest and highest values in the months of January and September. The COD ranged between 12.80 and 123.46 mg⁻¹ as lowest and highest value in the months of January and April. The minimum value of 142.13 μ S/cm was recorded in the month of October and the maximum value of 602.73 μ S/cm was observed in the month of July.

The gross primary productivity value of 346.46 mg C/m⁻³/hr was recorded in the month of May and the minimum value of 142.36 mg C/m⁻³/hr was observed in the month of August. The minimum value of 131.94 mg C/m⁻³/hr was recorded in the month of August and the maximum value of 287.33 mg C/m⁻³/hr was observed in the month of January for net primary productivity, these are more than 100% increased compared to study of Paramita, (2012) in the same lake.

The WQI_{min} in the present investigation yielded high score (69.07) compared to the objective calculated as WQI_{obj} (63.80). However, WQI_{min} was not able to separate the reference station and the others to a large extent, though some significant difference for entire months was observed. A calculation of WQI_{min} based on these eight parameters classified the water quality as “fair” water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels (average scores between 65 and 79 in annual period) whereas, other impacted points as “Marginal” (the index scores between 45 and 64). These results are more accurate in terms of characterizations for aquaculture potentials.

All the metals determined were below the World Health Organization (WHO) safety standards, Food and Drugs Administration (FDA) and the United States Environment Protection Agency (USEPA) maxima, except for silicon in sediment which is higher than the range recommended by WHO and other regulatory bodies. The level of zinc in sediment is however within the range recommended by USEPA. Cadmium is a toxic metal and its presence in any compartment of the aquatic ecosystem indicates contamination, but is absent in Powai lake.

Plankton recorded during the present study belonged to nine families and eleven species. Phytoplankton comprised the greater proportion (95.09%) with six families and zooplankton were less dominant (4.91%) represented by three families.

The result showed dominance of blue-green algae *Microcystis aeruginosa* (family *Microcystaceae*) comprised a significant fraction (84.91%), of overall phytoplankton diversity. The pennate diatom *Navicula* sp. (8.16%) was second most prevalent specie (*Naviculaceae*). The prominent species of zooplankton in order of percentage were: *Moina brachiata* (1.66%) in family *Moinidae*, *Karatella chochlearis* (1.30%) and *Brachionus calyciflorus* (0.95%) in family *Brachionidae* (2.25%). *Acartia clausi* (0.95%) was the only specie in family *Acartiidae*. The phytoplankton with lower percentages of dominance were 0.59% (*Eudorina* sp.) and 0.37% (*Volvox* sp) belong to family *Volvocaceae* (0.96%). Others include *Pediastrum* sp. (0.56%) from family *Hydrodictyaceae*, *Nitzschia* sp. (0.41%) from family *Bacillariophyceae*, and *Spirogyra* sp. (0.09%) of family *Zygnemataceae*.

The monthly trend of Shannon-Weiner index for the Powai lake showed a temporal variation and month of March show the highest value for the index and the lowest value was recorded in February. The maximum number (3337551) of plankton species was recorded in October whereas the minimum (4204) was noticed in January. The concentration of phytoplankton was highest in March, followed by August, followed by same trend in July, September and October. The concentration exhibited lowest value in February. The species richness index ranged from 0.632 (October) to 1.095 (January). The equitability or evenness index was highest in March (0.327) and lowest (0.143) in December. Species heterogeneity was in descending order as February, December, January, November, April, May, July, June showing the same index.

The sediment samples showed relative significant variation in texture analysis of the catchment area, showing higher percentage of clay followed by silt and sand. Highest value of the lake sediment pH was recorded in the month of October (7.60) and lowest value in January (7.45). For available nitrogen, 321.13 (mg 100g⁻¹ sediment) was recorded as highest in the month of January and 296.40 (mg 100g⁻¹ sediment) was observed as lowest in the month of March. The minimum value of 7.11 (mg 100g⁻¹ sediment) was recorded in the month of March and the maximum value of 7.70 (mg 100g⁻¹ sediment) was observed in the month of July for available phosphorus. The maximum value of 3.19% was recorded in the month of January and the minimum value of 2.94% was seen in the month of March for organic matter,

while maximum value of 5.53% was recorded in the month of July and the minimum value of 5.07% was observed in the month of March for organic carbon.

The GIS scoring model revealed three classes such as most suitable, moderately suitable and not suitable on the basis of requirements for aquaculture using twenty one (21) parameters, and the interpretation suitability classes for each factor was classified on a scale from three (3) to one (1). The result reveals decrease in productivity which can be attributed to decrease in water level. However, station E remain the most suitable site, station B as not suitable and stations A, C and D are moderately suitable in post-monsoon.

Pre-monsoon data of Powai lake shows that water quality is moderately suitable in station B, C and E, with station A as the most suitable while station E as not suitable. There was increased in the productivity leading to high accumulation of nutrients causing eutrophication thereby reducing its productivity. During monsoon season, the water quality and the productivity improved covering the entire stations of the lake except station D, which may be due to runoff discharge into the lake from the metropolis. Station A, B and C are the most suitable while station E's greater radius was moderately suitable.

Out of the eighteen (18) downloaded remote sensing satellite image during present study (November, 2016 to October, 2017), two images each in the months of October, August, May, March, and February; one image each in September, July, June, April and January; three image in December; and no available was image in November. The downloaded images for the months of December, January, February and March were processed, while images for months of April, May, June, July, August, September, October and November were unable to show results after processing the data apparently due to cloudy nature and other factors.

The results of remote sensing showed that chlorophyll varied across the months and it ranged from 01.58 to 28.02 (mg m^{-3}) during the months of March to February. Other higher values were recorded in the months of December and January, while TSM varied across the months and it ranged from 2990 to 38410 mg m^{-3} in the months of March to January. The concentration values reach typical of eutrophic environments, and were considered these events as blooms.

Overall, the water quality variables were within the range in unpolluted water bodies, variations may be due to effect of human activities around the lake's catchment. WQI clearly separated the sampling months and stations with respect to their water quality status, and rated monsoon and post-monsoon as "good" and "medium"; and station A, B and C the most suitable areas for aquaculture like cage and pen culture in Powai lake. Pollution load in Powai lake was confirmed by the presence of pollution indicator species comprising different groups like *Microcystis*, *Spirogyra*, *Navicula*, and *Nitzschia* etc., in considerably higher numbers which indicate presence organic pollution, and this correlate with the GIS and remote sensing result of this finding that Powai lake is a eutrophic ecosystem. The findings of this study provide an evidence for the seasonal variations in plankton diversity and the dominance. The baseline information provided will facilitate further investigations and monitoring of the lake for better management and implementation of appropriate conservation measures. Finally, the conventional, GIS and remote sensing approach used in the present study revealed relatively similar results for water quality parameters, productivity and plankton concentration of Powai lake.

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