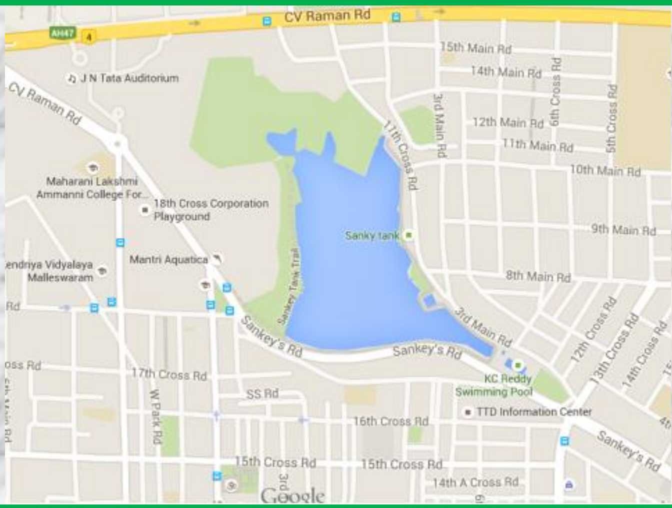
SANKEY LAKE: WAITING FOR AN IMMEDIATE SENSIBLE ACTION

PATHETIC STATUS OF WETLANDS IN BANGALORE: EPITOME OF INEFFICIENT AND UNCOORDINATED GOVERNANCE



Ramachandra T V	**Asulabha K S**	**Sincy V.**	**Vinay S**
Sudarshan P.Bhat		**Bharath H Aithal**	

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Energy & Wetlands Research Group [CES TE15]
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore - 560012, INDIA
Web: http://ces.iisc.ernet.in/energy/, http://ces.iisc.ernet.in/biodiversity
Email: cestvr@ces.iisc.ernet.in, energy@ces.iisc.ernet.in

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Sudarshan P.Bhat **Bharath H Aithal**

Energy & Wetlands Research Group,
Centre for Ecological Sciences,
Indian Institute of Science
Bangalore 560012, India

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Energy & Wetlands Research Group,
Centre for Ecological Sciences, TE 15
New Bioscience Building, Third Floor, E Wing
Indian Institute of Science
Bangalore 560012, India
http://ces.iisc.ernet.in/energy
http://ces.iisc.ernet.in/biodiversity

Email: cestvr@ces.iisc.ernet.in,
energy@ces.iisc.ernet.in
sahyadri@ces.iisc.ernet.in

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Note: Sections 2 and 3 pertains to Sankey Lake while Executive Summary and Section 1(Bangalore to Bengaluru) are applicable to all lake in Bengaluru

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Energy & Wetlands Research Group, Centre for Ecological Sciences,
TE 15, New Bioscience Building, Third Floor, E Wing,
Indian Institute of Science, Bangalore 560012, India
http://ces.iisc.ernet.in/energy
http://ces.iisc.ernet.in/biodiversity
E Mail: cestvr@ces.iisc.ernet.in; wetlands@ces.iisc.ernet.in

SANKEY LAKE: WAITING FOR AN IMMEDIATE SENSIBLE ACTION

(PROTECT BUFFER ZONE & LEAVE ONLY TREATED SEWAGE THROUGH CONSTRUCTED WETLANDS)

SANKEY LAKE: **Actions Required** –

- **Stop untreated sewage entry to the Lake;**
- **Leave only treated sewage through constructed wetlands and algae pond (as in Jakkur lake);**
- **No construction activities in the buffer zone of the lake (need to maintain ecological integrity, by protecting valley region (buffer region);**
- **Restrict organic debris dumping in the lake.**

Citizens of Bangalore allowed the development in the region with "**Utmost Good Faith**".

- ❖ Contaminated air, land and water are the penalty citizens have to pay for exercising tolerance with good faith.
- ❖ Growth in Bangalore has surpassed the threshold evident from stress on supportive capacity (insufficient water, clean air and water, inadequate electricity, traffic bottlenecks, etc.) and assimilative capacity (polluted water and sediments in water bodies, enhanced GHG – Greenhouse gases, etc.)
- ❖ There has been a 925% increase in built up area (concretisation, paved surfaces) in Bangalore from 1973 to 2013 with a sharp decline of 79% area in water bodies affecting the micro-climate, water availability, etc..
- ❖ Higher level of GHGs (Greenhouse gases) in the air environment, nutrient and heavy metal rich water bodies and land, highlight the penalty to be paid for allowing unplanned urbanisation.

Numerous para-state agencies with un-coordinated actions, inefficient regulatory agency and negligent industries have converted the garden city to unlivable city.

Solution is

"**Decongest and decontaminate Bangalore**"

so that at least next generation enjoys better environment in Bangalore

Need to ensure the ecosystem integrity to sustain goods and services for maintaining inter-generation equity.

Clean air, water and environment are the fundamental rights of citizens as per the Constitution of India (Article-21 of the *Indian Constitution*)

SANKEY LAKE: WAITING FOR AN IMMEDIATE SENSIBLE ACTION

PATHETIC STATUS OF WETLANDS IN BANGALORE: EPITOME OF INEFFICIENT AND UNCOORDINATED GOVERNANCE

Executive Summary:

Wetlands (and lakes) constitute the most productive ecosystems with a wide array of goods and services. These ecosystems serve as life support systems; serve as habitat for a variety of organisms including migratory birds for food and shelter. They aid in bioremediation and hence aptly known as 'kidneys of the landscape'. Major services include flood control, wastewater treatment, arresting sediment load, drinking water, protein production, and more importantly recharging of aquifers apart from aiding as sinks and climate stabilizers. The wetlands provide a low cost way to treat the community's wastewater, while simultaneously functioning as wild fauna sanctuary, with public access. These ecosystems are valuable for education and scientific endeavours due to rich biodiversity.

Bangalore city (Karnataka State, India) has been experiencing unprecedented urbanisation and sprawl due to concentrated developmental activities in recent times with impetus on industrialisation for the economic development of the region. This concentrated growth has resulted in the increase in population and consequent pressure on infrastructure, natural resources and ultimately giving rise to a plethora of serious challenges such as climate change, enhanced green-house gases emissions, lack of appropriate infrastructure, traffic congestion, and lack of basic amenities (electricity, water, and sanitation) in many localities, etc. Temporal data analysis reveals that that there has been a growth of 925% in urban areas of Bangalore across four decades (1973 to 2013). Sharp decline in natural resources – 78% decline in trees and 79% decline in water bodies highlight unplanned urbanisation process in the city. Urban heat island phenomenon is evident from large number of localities with higher local temperatures. The city once enjoyed salubrious climate (about 14-16 °C during peak summer – May month in early 18th century), now has been experiencing higher temperatures (34 to 37° C) with altered micro climate and frequent flooding during rainy days. The study reveals the pattern of growth in Bangalore and its implication on local climate (an increase of ~2 to 2.5 ºC during the last decade) and also on the natural resources, necessitating appropriate strategies for the sustainable management of natural resources (water bodies, tree cover, etc.). The frequent flooding (since 2000, even during normal rainfall) in Bangalore is a consequence of the increase in impervious area with the high-density urban development in the catchment and loss of wetlands and vegetation.

Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together (Ramachandra *et al*., 2012; Ramachandra and Kumar, 2008). The process of urbanisation contributed by infrastructure initiatives, consequent population growth and migration results in the growth of villages into towns, towns into cities and cities into metros. Urbanisation and urban sprawl have posed serious challenges to the decision makers in the city planning and management process involving plethora of issues like infrastructure development,

traffic congestion, and basic amenities (electricity, water, and sanitation), etc. (Kulkarni and Ramachandra, 2006). Apart from this, major implications of urbanisation are:

- **Loss of wetlands and green spaces:** Urbanisation (925% concretisation or paved surface increase) has telling influences on the natural resources such as decline in green spaces (78% decline in vegetation) including wetlands (79% decline) and / or depleting groundwater table. Quantification of number of trees in the region using remote sensing data with field census reveal 1.5 million trees and human population is 9.5 million, indicating one tree for seven persons in the city. This is insufficient even to sequester respiratory carbon (due to breathing which ranges from 540 -900 g per person per day).
- **Floods:** Conversion of wetlands to residential and commercial layouts has compounded the problem by removing the interconnectivities in an undulating terrain. Encroachment of natural drains, alteration of topography involving the construction of high-rise buildings, removal of vegetative cover, reclamation of wetlands are the prime reasons for frequent flooding even during normal rainfall post 2000.
- **Decline in groundwater table:** Studies reveal the removal of wetlands has led to the decline in water table. Water table has declined to 300 m from 28 m over a period of 20 years after the reclamation of lake with its catchment for commercial activities. In addition, groundwater table in intensely urbanized area such as Whitefield, etc. has now dropped to 400 to 500m.
- **Heat island:** Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decreases in vegetation and water pervious surfaces, which reduce surface temperature through evapotranspiration.
- **Increased carbon footprint**: Due to the adoption of inappropriate building architecture, the consumption of electricity has increased in certain corporation wards drastically. The building design conducive to tropical climate would have reduced the dependence on electricity. Adoption of building architecture unsuitable for Bangalore climate has contributed to higher electricity consumption and hence higher GHG (Greenhouse gases). Per capita electricity consumption in the zones dominated by high rise building with glass facades require 14000-17000 units (kWh) per year compared to the zones with eco-friendly buildings (1300-1500 units/person/year)Higher energy consumption, enhanced pollution levels due to the increase of private vehicles, traffic bottlenecks have contributed to carbon emissions significantly. Apart from these, mismanagement of solid and liquid wastes has aggravated the situation.

Unplanned urbanisation has drastically altered the drainage characteristics of natural catchments, or drainage areas, by increasing the volume and rate of surface runoff. Drainage systems are unable to cope with the increased volume of water, and are often blocked due to indiscriminate disposal of solid wastes. Encroachment of wetlands, floodplains, etc. obstructs flood-ways causing loss of natural flood storage.

THREATS FACED BY WETLANDS IN BANGALORE

The rapid development of urban sprawl has many potentially detrimental effects including the loss of valuable agricultural and eco-sensitive (e.g. wetlands, forests) lands, enhanced energy consumption and greenhouse gas emissions from increasing private vehicle use (Ramachandra and Shwetmala, 2009). Vegetation has decreased by 32% (during 1973 to 1992), 38% (1992 to 2002) and 63% (2002 to 2010).

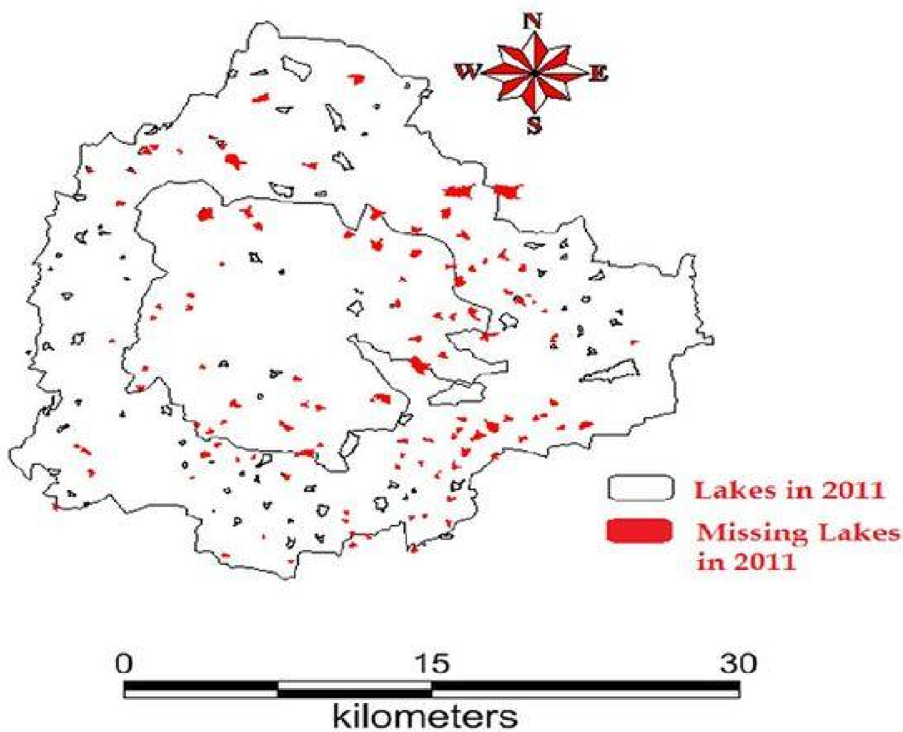


Figure 1: Lakes encroached by land mafia

Disappearance of water bodies or sharp decline in the number of water bodies in Bangalore is mainly due to intense urbanisation and urban sprawl. Many lakes (54%) were encroached for illegal buildings. Field survey of all lakes (in 2007) shows that nearly 66% of lakes are sewage fed, 14% surrounded by slums and 72% showed loss of catchment area. Also, lake catchments were used as dumping yards for either municipal solid waste or building debris (Ramachandra, 2009a; 2012a). The surrounding of these lakes have illegal constructions of buildings and most of the times, slum dwellers occupy the adjoining areas. At many sites, water is used for washing and household activities and even fishing was observed at one of these sites. Multi-storied buildings have come up on some lake beds that have totally intervene the natural catchment flow leading to sharp decline and deteriorating quality of water bodies. This is correlated with the increase in built up area from the concentrated growth model focusing on Bangalore, adopted by the state machinery, affecting severely open spaces and in particular water bodies. Some of the lakes have been restored by the city corporation and the concerned authorities in recent times. Threats faced by lakes and drainages of Bangalore:

1. Encroachment of lakebed, flood plains, and lake itself;
2. Encroachment of rajakaluves / storm water drains and loss of interconnectivity;
3. Lake reclamation for infrastructure activities;
4. Topography alterations in lake catchment;
5. Unauthorised dumping of municipal solid waste and building debris;
6. Sustained inflow of untreated or partially treated sewage and industrial effluents;
7. Removal of shoreline riparian vegetation;
8. Pollution due to enhanced vehicular traffic;
9. Too many para-state agencies and lack of co-ordination among them.
10. Different custodians for upstream and downstream lakes in the valley (Figure 2 and Table 1).

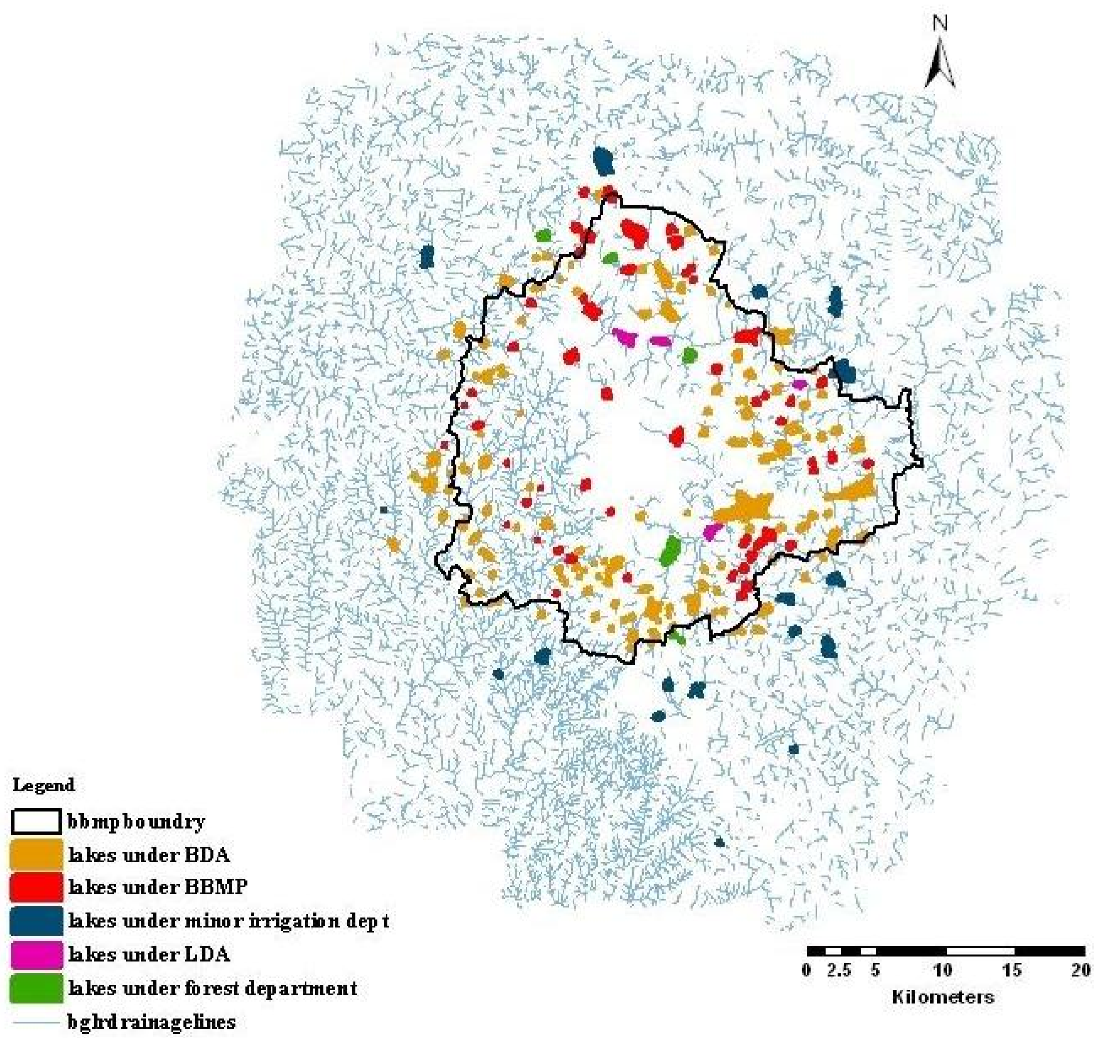


Figure 2: Spatial spread of lakes and custodians (too many – BBMP, BDA, LDA…. But too less effort to protect these lakes)

Table 1: Lakes with BBMP (A: Area in acres, G: Gunta, T: Total)

Sl.No	Name of the lake	Taluk	Hobli	Name of the village Survey No.	Extent (A-G) as per RTC
1	Agrahara Lake	B'lore North	Yelahanka	Agrahara -33	**15-34**
2	Allalasandra kere	B'lore North	Yalahanka	Allalsandra -15	**41-23**
3	Ambalipura Kelagina kere	B'lore East	Varthur	Ambalipura-40 & 41	3-0, 4-09 T-**7-09**
4	Amblipura Melinakere	B'lore East	Varthur	Ambalipura-36	**12-16**
5	Attur kere	B'lore North	Yalahanka	Attur kere-81 Ananthapura-92 Ramagondanahalli- 39 Kempanahalli-12	56-29 6-15 7-22 19-18 **T-90-04**
6	Avalahalli	B'lore North	Yalahanka	Avalahalli -10 & Singanayakanahalli 64	11-01 2-10 **T-13-11**
7	Bhimmana katte	B'lore South	Kengeri	Halagevaderahalli-138	1-23
8	Bayappanapalya Kunte (Munniyappana katte)	B'lore South	Uttarahalli	Vajarahalli -36	2-31
9	Challakere Lake	B'lore East	K.R. Puram	Challakere - 85	38-05
10	Chinnapanhalli kere	B'lore East	K.R. Puram	Chinnapanahalli 15 & 17	11-33 11-10
11	Chokkanahalli lake	B'lore North	Yelahanka	Chokkanahalli Sy-2	8-02
12	Dasarahalli kere (Chokkasandra)	B'lore North	Yeshwanthapura	Dasarahalli - 24 Chokkasandra - 5	3-29 24-04 **T-27-33**
13	Deepanjali kere	B'lore South	Kengeri	Devatige Ramanahalli-32	**7-22**
14	Devsandra kere	B'lore East	K.R. Puram	Devasandra 31	**16-08**
15	Doddabommasandra	B'lore North	Yelahanka	Dodda Bommasandra-56 Kodigehalli- 175 Thindlu - 53	39-10 49-21 35-28 **T-124-19**
16	Doddakanenahalli kere	B'lore East	Varthur	Doddakanenahalli - 109	**18-14**
17	Dore kere	B'lore South	Uttarahalli	Uttarahalli -22 Vasanthapura -06	19-11 '9-06 **T-28-17**
18	H Gollahalli Lake (Varahasandra Lake)	B'lore South	Kengeri	Kengeri Gollahalli-9 Varahasandra-9 Hemgepura-25	7-08 4-33 7-25 **T-19-26**
19	Halagevaderahalli Lake	B'lore South	Kengeri	Halagevaderahalli-1	**17-10**
20	Handrahalli	B'lore North	Yeshwanthapura	Handrahalli -8	**16-06**
21	Haraluru kere	B'lore East	Varthur	Haraluru-95	**34-70**
22	Herohalli	B'lore North	Yeshwanthapura	Herohalli-99	**34-33**
23	Harohalli lake	B'lore North	Yelahanka	Harohalli-91	**74-32**

24	Jogi kere	B'lore South	Uttarahalli	Mallasandra-30	**3-20**
25	J.P. Park (Mathikere)	B'lore North	Yeshwanthapura	Jalahalli-32 Mathikere-59 Thaniranahalli-01 Kasaba Yeshwanthpura-114	47-26 -- 20-39 -- **T-**
26	Kaikondanahalli kere	B'lore East	Varthuru	Kaikondanahalli -8 Kasavanahalli -70	18-18 30-05 **T-48-23**
27	Kalkere Agra kere	B'lore East	K.R. Puram & Bidarahalli	Kalkere-45 Kyalasanahalli-36 Beelisivale-101 & 106 Horamavu Agra-36	73-11 51-19 0-37 & 0-14 61-11 **T-187-12**
28	Kammagondanahalli	B'lore North	Yeshwanthapura	Kammagondanahalli-18 Shettyhalli-67 Myadarahalli (Medarahalli)-26	15-26 5-32 1-32 **T-23-10**
29	Kasavanhalli	B'lore East	Varthur	Kasavanahalli-50 Haralur-32	21-30 33-18 **T-56-08**
30	Kattiganahalli Kere-136	B'lore North	Jala	Kattiganahalli -136	**25-28**
31	Kattiganahalli Kere-31	B'lore North	Jala	Kattiganahalli -31	**20-10**
32	Kempambudhi Lake	B'lore North	B'lore	Kempambudhi-2	
33	Kodigehalli kere	B'lore North	Yeshwanthapura	Kodigehalli - 30	**9-25**
34	Kogilu Lake	B'lore North	Yelahanka Jala	Kogilu - 84 Kattigenahalli - 117	40-04 38-24 **T-78-28**
35	Koudenahalli kere	B'lore East	K.R. Puram	Koudenahalli -27	**55-05**
36	Kudlu Chikere	Anekal Taluk	Sarjapura	Koodlu-70	**13-05**
37	Kudlu doddakere	Anekal Talulk and B'lore South	Sarjapur & Begur	Koodlu-150 Parapanaagrahara-37	26-38 17-01 T-43-39
38	Kundalahalli Lake	B'lore East	K.R. Puram	Kundalahalli -05	30-20
39	Lingadiranahalli	B'lore North	Yeshwanthapura	Lingadiranahalli-2 & 4	5-32 4-08 **T-10-00**
40	Mahadevapura Lakde	B'lore East	K.R. Puram	Mahadevapura -7	26-23
41	Malgala kere	B'lore North	Yeshwanthapura	Malgala - 46	**6-26**
42	Munnekolalu kere	B'lore East	Varthur	Munnekolalu-25	**15-38**
43	Narasipura-20	B'lore North	Yelahanka	Narasipura-20	**15-30**
44	Narasipura-26	B'lore North	Yelahanka	Narasipura-26	**9-07**
45	Nayandanahalli kere	B'lore South	Kengeri	Nayadahalli -31	**15-18**
46	Parappana Agrahara	B'lore South	Beguru	Parappana Agrahara-23	**16-11**
47	Puttenahalli kere	B'lore South	Uttarahalli	Puttenahalli -42	**13-25**

48	Ramagondanahalli	B'lore North	Yelahanka	Ramagondanahalli-52	**36-26**
49	Sankey Tank	B'lore North	Vyalikaval	Vyalikaval - 21	35-00
50	Shilavantana kere	B'lore East	K.R. Puram	Whitefeild-41	19-32
51	Sigehalli	B'lore East	K.R Puram	Sigehalli-32	31-13
52	Singasandra Lake	B'lore South	Begur	Basapura-15 Singasandra -52	9-34 1-08 **T-11-02**
53	Sowl kere	B'lore East	Varthur	Bellandur-65 Doddakanelli-68 Kaigondanahalli-36	23-33 7-28 30-16 **T-61-37**
54	Thirumenahalli	B'lore North	Yelahanka	Thirumenahalli-63	7-10
55	Ulsoor	B'lore North	B'lore	Ulsoor	
56	Uttarahalli kere (Mogekere)	B'lore South	Uttarahalli	Uttarahalli -111	**15-16**
57	Veerasagara lake	B'lore North	Yelahanka	Veerasagara-26 Attur-25	'17-24 3-30 **T-21-14**
58	Vijanapura kere	B'lore East	K.R. Puram	Kowdenahalli -85 Krishnarajpura-97	11-28 2-07 **T-13-35**
59	Yediyur Lake	B'lore South	Utharahalli	Dasarahalli -01 Yediyur -59	No extent
60	Yelahanka kere (Kasaba Amanikere)	B'lore North	Yelahanka	Yelahanka-29 Kenchenahalli -15 Venkatala-39 Manchenahalli-19 Puttenahalli-49	53-36 30-23 199-31 7-34 18-04 **T-310-08**

Lakes with BDA

Sl. No.	**Name of the Lake**	**Taluk**	**Hobli**	**Name of the village Sy No.**	**Extent (A-G) as per RTC**
1	Abbigere kere	B'lore North	Yeshwanthpur	Abbigere-75 Singapura-95	26-06 21-7 **T-47-13**
2	Alahalli kere / Anjanapura	B'lore South	Uttarahalli	Allahalli -30 Gollahalli-3	15-35 5-30 **T-21-25**
3	Amruthalli kere	B'lore North	Yelahanka	Amruthalli-115	**24-36**
4	Annappahalli/ Yelachenahalli Lake	B'lore South	Uttarahalli	Yelachenahalli-06, Govinayakanahalli-14	4-39 1-33 **T-6-32**
5	Arakere	B'lore South	Beguru	Arakere-34	**37-21**
6	Avalahalli	B'lore North	Yelahanaka	Avalahalli-10 Shiganayakanahalli-64	11-01 2-10 **T-13-11**

7	B.Narayanapura	B'lore East	K.R. Puram	B.Narayanapura-109	15-06
8	Baiyappanahalli kere	B'lore East	K.R. Puram	Baiyappanahalli-61	8-09
9	Basapura Lake-2	B'lore South	Beguru	Basapura-66	10-29
10	Basavanapura Lake	B'lore South	Beguru	Basavanapura-14	**7-34**
11	Begur Lake	Bl'lore South	Begur	Begur-94	**137-24**
12	Bellahalli	B'lore North	Yelahanka	Bellahalli-68	**18-32**
13	Bellandur	B'lore East	Varthur	Yamaluru-62 Amanikere Bellandur Kahne-1 Ibbalur-12 Kempapura-6 Beluru-2	3-04 284-20 399-14 13-15 2-00 **T-700-13**
14	Beratena Agrahara Lake (Chowdeshwari Layout	B'lore South	Begur	Beratena Agrahara (Chowdeshwari)-18	**11-18**
15	Bhattralli kere	B'lore East	Bidarahalli	Bhattralli-2	**18-10**
16	Bheemanakuppe	B'lore South	Kengeri	Bheemanakuppe-180	75-15
17	Bhoganalli kere	B'lore East	Varthur	Bhoganalli-21	12-24
18	Byrasandra	B'lore South	Utharahalli	Byrasandra-56	15-11
19	Byrasandra kere (Chikkepet) (Melinakere)	B'lore East	K.R. Puram	Byrasandra-109	14-19
20	Chennasandra-2	B'lore East	K.R. Puram	Banasawadi-211	47-38
21	Chikka Banavara	B'lore North	Yeshwanthpur	Chikka Banavara-3, Somashettyhalli-73, Kere gullada halli-22 and Ganigarahalli-11,15	67-38 3-21 26-32 4-14 2-30 **T-105-15**
22	Chikka Bellandur kere	B'lore East	Varthur	Chikka Bellandur-9 Mullur -63	67-14 8-07 **T-75-21**
23	Chikkabasavanapura kere	B'lore East	K.R. Puram	Basavanapura-14	14-07
24	Chikkabasthi	B'lore South	Kengeri	Ramasandra-6	7-06
25	Chikkabettahalli	B'lore North	Yelahanka	Chikkabettahalli-52	1-32
26	Chick begur Lake	B'lore South	Begur	Begur-168, Singanadra-86	32-19 9-37 **T-42-16**
27	Chikkammanahalli Lake	B'lore South	Begur	Kammanahalli -22 Vamadevanahalli-	5-19
28	Chikkegowdana palya Lake	B'lore South	Kengeri	Hemmagepura-92	
29	Chunchanaghatta	B'lore South	Utharahalli	Chunchanaghatta-70, 70/2, 70/3	20-31 1-0 1-0 **T-22-31**

30	Chowdeshwari Layout Lake	B'lore South	Begur		
31	Devarakere Lake	B'lore South	Uttarahalli	Bikasipura-9	7-15
32	Doddabidarakallu	B'lore North	Yeshwanthpur	Doddabidarakallu-125 Nagasandra -06	23-21 16-36 **T-40-17**
33	Doddakallasandra	B'lore South	Uttarahalli	Doddakallasandra-27	**21-16**
34	Doddanakundi	B'lore East	K.R. Puram (village map) Varthur (In RTC-Bhoomi)	Doddanekundi -200 Kaggadasapura - 25 Vibhutipura -13	56-39 75-16 3-15 **T-135-30**
35	Dubasipalya Lake	B'lore South	Kengeri	Valagerehalli-43, 43/P1	23-35 1-0 **T-24-35**
36	Gangasetty kere (Diesel shed kere (Gangadhariahnakere) (Dyavasandrakunte kere)	B'lore East	K.R. Puram	KR Pura-58 Devasandra-46	18-32 2-35 **T-21-27**
37	Gandhinagara Lake	B'lore North			
38	Garudachar Palya Kere -1 (Achanakere)	B'lore East	K.R. Puram	Mahadevapura-31	**5-36**
39	Garudachar Palya Kere -2 (Goshala) Yekkalagatta kere	B'lore East	K.R. Puram	Mahadevapura-86	**5-14**
40	Garvebhavi Palya	B'lore South	Begur	Hongasandra -41	**18-04**
41	Gattigere palya Lake	B'lore South	Kengeri	Somapura-27/53	0-37
42	Gottigere Lake	B'lore South	Uttarahalli	Gottigere-71	**37-13**
43	Gowdana Palya Lake	B'lore South	Uttarahalli	Kadirenahalli-33	**9-30**
44	Gubbalala	B'lore South	Uttarahalli	Gubbalala-25 Vajarahalli-	**8-10**
45	Gunjur Kere (Carmelarm)	B'lore East	Varthur	Gunjur-95	**9-17**
46	Gunjur Mouji kere	B'lore East	Varthur	Gunjur-301, Kachamaranhalli-74	59-13 4-26 **T- 63-39**
47	Gunjur Palya kere	B'lore East	Varthur	Gunjur-83	**36-27**
48	Haralakunte Lake (Somasandrakere)	B'lore South	Begur	Haralakunte-51	**16-29**
49	Hoodi kere (GIDDANA KERE)	B'lore East	K.R. Puram	Hoodi-138	**28-31**
50	Hoodi kere -1	B'lore East	K.R. Puram	Hoodi-79	**15-10**
51	Horamavu Agara	B'lore East	K.R. Puram	Horamavu Agra-77	**51-34**
52	Horamavu kere	B'lore East	K.R. Puram	Horamavu-83	**37-14**
53	Hosakerehalli	B'lore South	Uttarahalli	Hosakerehalli-15	**59-26**
54	Hosakere	B'lore South			
55	Hulimavu	B'lore South	Beguru	Hulimavu-42 Kammanahalli -110	124-25 5-32 **130-17**
56	Ibbalur Lake	B'lore South	Beguru	Ibbalur-36	18-06

57	Jakkur & Sampigehalli	B'lore North	Yelahanka	Jakkur-15, 23 Yalahanka Amanikere-55 Sampigehalli-12 Agrahara-13	39-21,36-33 58-16 19-25 3-17 **T-157-32**
58	Jaraganahalli/Sarakki/Puttenahalli Lake	B'lore South	Uttarahalli	Jaraganahalli-7 Sarrakki-26 Puttenahalli - 5 Kothanuru-103 Chunchaghatta-28	38-14 38-0 6-10 11-21 13-07 **T-107-12**
59	Jimkenalli kere	B'lore East	Bidarahalli	Varanasi-47	**8-24**
60	Junnsandra kere	B'lore East	Varthur	Junnasandra-32	**24-33**
61	Kadirenapalya kere	B'lore East	KR Puram	Binnamangala-99	
62	K R Puram (BEML) Bendiganahalli kere	B'lore East	K.R. Puram	Benniganahalli-47 & 55	18-24, 27-14 **T- 45-39**
63	Kaggadasanapura	B'lore East	K.R. Puram (village map) Varthur (In RTC-Bhoomi)	Byrasandra -5 Kaggadasapura-141 Bendiganahalli - 24/3	14-24 32-16 3-26 **T-51-26**
64	Kalena Agrahara Lake	B'lore South	Begur	Kalena Agrahara-43	**7-30**
65	Kalkere Rampura kere	Anekal Taluk (B'lore East)	Jigani Bidarahalli	Kalkere-162 Rampura-22 Maragondanahalli-71 Huvineane-86	64-25 3-04 11-35 108-07 **T-187-31**
66	Kalyani / Kunte (Next to Sai Baba Temple)	B'lore South	Uttarahalli	Vasanthpura-21	**1-33**
67	Kannenahalli	B'lore North (Bng South)	Kengeri Yeshwanthpur		
68	Kelagina kere / Byrasandra	B'lore East	K.R. Puram	Byrasandra-112	**12-21**
69	Kembatha halli	B'lore South	Uttarahalli	Kembathahalli-3 Kathnuru-32/3	5-16 1-33 **T-7-20**
70	Kenchanapura	B'lore South	Kengeri	Kenchanapura-10	**17-20**
71	Kengeri Lake	B'lore South	Kengeri	Kengeri-15, Valagerehalli-85	27-03 5-13 **T-32-16**
72	Kommaghatta	B'lore South	Kengeri	Komaghatta-03 Ramasandra-46	9-04 28-01 **T-37-05**
73	Konankunte	B'lore South	Uttarahalli	Konanakunte - 2	**09-18**

74	Konasandra	Anekal Taluk	Jigani	Dyavasandra-9 Bommandahalli-18 Konasandra-17	21-13 7-39 3-20 **T-32-32**
75	Konnappana agrahara	B'lore South	Begur	Naganathpura (South)81	**5-17**
76	Kothnur	B'lore South	Utharahalli	Kothnur-54	**18-09**
77	Lakshmipura lake	B'lore North	Yeshwanthpur	Lakshmipura-25	**10-06**
78	Lingadheeranahalli	B'lore South	Kengeri	Lingadheeranahalli-13	**5-22**
79	Madavara	B'lore North	Dasanapura Yeshwanthpur	Madavara -48 Chikkabidarakallu-21 Tirumalapura-32 (from Yeshwanthpura hobli) Doddabidarakallu -98 (From Yeshwanthpura hobli	35-31 20-20 8-36 2-39 **T-68-06**
80	Mahadevapura (Bandemahadevpura kere)	B'lore East	K.R. Puram	Mahadevapura-187	**13-11**
81	Mallasandra Gudde lake	B'lore North	Dasanapura	Mallasandra-49, Mallasandra-50	11-28 5-23 **T-17-11**
82	Mallathahalli	B'lore North	Yeshwanthpur	Mallathahalli-101 Giddadakonenahalli-6	50-38 20-08 **T-71-06**
83	Manganahalli	B'lore North	Yeshwanthpur	Manganahalli - 43	**6-22**
84	Medi Agrahara	B'lore North	Yelahanka	Medi Agrahara-33	**13-15**
85	Meenakshi Kere	B'lore South	Begur	Kammanahalli (Meenakshi)-38	**18-37**
86	Mesthripalya Lake	B'lore South	Begur	Jakkasandra- 30	11-21
87	Nagarabhavi	B'lore North (Bng South)	Yeshwanthpur	Nagarabhavi-17	**17-39**
88	Nagareshwara-Nagenahalli Lake	B'lore East	K.R. Puram	Nagareshwara-Nagenahalli -10	11-08
89	Nellagaderanahalli	B'lore North	Yeshwanthpur	Nallagaderanahalli - 62	19-22
90	Nalluralli tank	B'lore East	K.R. Puram	Nalluralli-4 Pantandur Agrahara-85	20-34 27-05 **T-47-39**

91	Narasappanahalli	B'lore North	Yeshwanthpur	Karivabanahalli-40 Nelagadiranahalli - 90 Nelagadiranahalli -89 Doddabidarakallu - 24	27-13 19-05 5-26 1-20 **T-53-24**
92	Nyanappanahalli Lake	B'lore South	Begur	Begur-344	**6-07**
93	Panathur kere -38	B'lore East	Varthur	Panathur - 38	**27-17**
94	Panathur kere -48	B'lore East	Varthur	Panathur - 48	**6-30**
95	Pattandur Agrahara	B'lore East	K.R. Puram	Pattandur Agrahara-124	**16-35**
96	Pattandur Agrahara	B'lore East	K.R. Puram	Pattandur Agrahara-54	12-37
97	Pattanagere Kenchenhalli	B'lore South		Kenchenahalli-33 Pattanagere-43	3-39 0-31 **T-4-30**
98	Rachenahalli	B'lore North B'lore East	Yelahanka K.R Puram	Dasarahalli-61 (Bng East- KR Puram) Jakkur - 82 (Bng North-Yelahanka) Rachenahalli - 69 (Bng East-KR Puram)	73-23 39-07 18-16 **T-131-06**
99	Ramsandra (Hirekere)	B'lore South B'lore North	Kengeri Yeshwanthpur	Ramasandra-159 Kenchanpura-36/* Kenchenapura - 36/¥ÉÊQ Kannahalli-37 (Bng north-Yeshwanthpura)	66-20 56-05 5-0 12-29 **T-140-14**
100	Sadaramangala kere	B'lore East	K.R. Puram	Sadaramangala-61, Kodigehalli-8	51-04 1-17 **T-52-21**
101	Shivanahalli	B'lore North	Yelahanka	shivanahalli-48 Allalasandra-38, 48	14-30 3-22 0-27 **T-18-39**
102	Siddapura kere	B'lore East	Varthur	Siddapura -18	**27-38**
103	Singapura Kere	B'lore North	Yelahanka	Singapura-102	**66-18**
104	Singasandra	B'lore South	Beguru	Singasandra -99, 100	10-14 0-34 **T-11-08**
105	Sitaram Palya	B'lore East	K R Puram	Sonnenahalli (Seetharmapalya)-33	**23-37**
106	Sompura	B'lore South	Kengeri	Sompura - 11	17-38
107	Srigandadakaval (near Rajivgandhi nagar)	B'lore North	Yeshwanthpur	Srigandakavalu-15	**6-33**

108	Srinivasapura Kere	B'lore North	Yelahanaka	Srinivasapura-2	**3-14**
109	Subbarayanakere	B'lore South	Uttarahalli	Gottigere-12	**5-10**
110	Subedeharanakere	B'lore South	Begur	Begur-48	**6-05**
111	Subramanyapura Lake	B'lore South	Uttarahalli	Uttarahalli-64	**18-06**
112	Sulekere (Soolikere)	B'lore South	Kengeri	Maragondanahalli Krishnasagara	
113	Swarnakunte gudda kere	B'lore South	Begur	Chandrashekarpura-1	**09-05**
114	Talaghattapura (Gowdarakere)	B'lore South	Uttarahalli	Talaghattapura -73	**19-16**
115	Ullal	B'lore North	Yeshwanthpur	Ullal-93	**24-12**
116	Vaderahalli	B'lore North	Yelahanka	Vaderahalli-32	**9-34**
117	Varahasandra Lake	B'lore South	Kengeri	Hemigepura-4, Varahasandra-24	4-11 13-09 **T-17-20**
118	Varthur	B'lore East	Varthur	Varthur-319	**445-14**
119	Vasanthapura (Janardhanakere)	B'lore South	Utharahalli	Vasanthpura-28	**7-10**
120	Venkateshpura	B'lore North	Yelahanka	Ventateshpura-12 Sampigehalli-37	6-35 11-29 **T-18-24**
121	Vibhuthipura kere	B'lore East	Varthur	Vibhuthipura-175	**45-18**
122	Vishwa nidam lake	B'lore North	Yeshwanthpur	Herohalli-50	**4-30**
123	Yellenhalli Lake (Elenahalli)	B'lore South	Begur	Yellenhalli-55	**4-39**

Lakes under Lake Development Authority (LDA)

Sl.No	Name of the Lake	Taluk	Hobli	Name of the village Sy No.	Extent (A-G) as per RTC
1	Agaram Lake	B'lore South	Kengeri	Agara-11 Venkojiraokhane-11	5-39 136-30 **T-142-29**
2	Hebbal Lake	B'lore North	Kasaba	Hebbla-38 Kodigehalli-37	92-26 99-33 **T-192-19**
3	Nagavara Lake	B'lore North	Kasaba	Nagawara-58 Vishwanatanagenahalli - 12,13	56-17 12-35 6-01 **T-75-13**
4	Vengaiahnakere	B'lore East	K.R. Puram	Krishnarajapura-9 Sannathammanahalli-46	38-12 26-23 **T-64-35**

Lakes - Karnataka Forest Department

Sl.No	Name of the Lake	Taluk	Hobli	Name of the village Sy No.	Extent (A-G) as per RTC
1	Hennur (K.R.Puram Range)	B'lore North	Kasaba	Hennur - 53 Nagawara - 13	58-30 14-11 **T-73-01**

2	J.B.Kaval Tank (Bangalore Range)	B'lore North	Yelahanka	Jyarakabande Kavalu- P1-36	44-21 2-04
3	Madiwala (K.R.Puram Range)	B'lore South	Begur	Madivala- 7 Kodichikkanahalli-23 Belekannahalli-64 Rupena Agrahara-11	166-39 80-09 21-35 6-10 T-275-13
4	Mylsandra (Kaggalipura Range) Gumaiahanakere (Mylasandra 1) Mylasandra 2	B'lore South	Kengeri	Mylasandra-37 Kasaba Kengeri-58 Mylasandra - 27 Kasaba Kengeri-66	6-24 6-02 **T-12-26** 10-14 5-28 **T-16-02**
5	Puttenahalli (Yelahanka Range)	B'lore North	Yelahanka	Puttenehalli - 36 Attur - 49	29-14 7-26 **T-37-00**

Lakes - Minor Irrigation Department

Sl.No	Name of the Lake	Taluk	Hobli	Name of the village Sy No.	Extent (A-G) as per RTC
1	Agara kere	Bangalore South	Kengeri	Agara - 103 Agara -102 Agara - 104	13-11 0-08 0-06 **T-13-25**
2	Alluru kere	Bangalore North	Dasanapura	Aluru-132 Vaderahalli - 8 Mathahalli - 25 Narasipura - 41	39-38 27-23 5-32 1-21 **T-75-34**
3	Bhimanakuppe kere	Bangalore South	Kengeri	Bheemanakuppe-180	75-15
4	Bidara Amanikere	Anekal			
5	Bidarahalli kere	Bangalore East	Bidrahalli	Bidarahalli-8 Byappanahalli - 21	15-10 81-16 **T-96-26**
6	Chikkanahalli	Bangalore East			
7	Doddagubbi kere	Bangalore East	Bidarahalli	Doddagubbi-38 NadagowdaGollahalli-39 Chikkagubbi-9	105-18 16-37 1-32 **T-124-07**
8	Ghattahalli Bommankere	Anekal	Sarjapura	Gattahalli-62 Rayasandra - 33	51-17 21-22 **T-72-39**
9	Hoskuru kere (Huskur Lake)	Anekal	Sarjapura	Huskur - 163 Harohalli - 51 Avalahalli - 50	91-10 23-0 --- T-114-10
10	Hulimangala Doddakere	Anekal	Jigani	Hulimangala - 22	67-07

11	Kodatikere	Bangalore East	Varthru	Kodati-8 Solikunte - 52	40-32 37-09 T-78-01
12	Margondanahalli kere	Bangalore South	Kengeri	Margondanahalli -45	5-33
13	Rampura kere	Bangalore East			
14	Sakalavara Bujangadasana kere	Anekal	Jigani	Sakalavara - 93	23-34
15	Singanayakana halli kere	Bangalore North			
16	Singena Agrahara kere	Anekal	Sarjapura	Singena Agrahara-94 Narayanaghatta - 128 Gottammanahalli - 13	95-39 19-32 8-04 **T-123-35**
17	Vaderahalli kere	Bangalore South	Kengeri	B.M.Kaval P1 -136	21-07
18	Yellemallappa Shetty kere	Bangalore East	K.R. Puram	Avalahalli -57 Avalahalli -12 Heerandahalli - 95 Heerandahalli -96 Kurudu Sonnenahalli -2 Medahalli -63 Veerenahalli -29	13-26 17-26 170-16 33-24 31-2 91-35 132-06 **T-490-15**

Source: https://www.karnataka.gov.in/ldakarnataka/documents/Listof-210Lake-BDA,BBMP,LDA, KFD, MILIst.xlsx

The anthropogenic activities particularly, indiscriminate disposal of industrial effluents and sewage wastes, dumping of building debris have altered the physical, chemical as well as biological integrity of the ecosystem. This has resulted in the ecological degradation, which is evident from the current ecosystem valuation of wetlands. Global valuation of coastal wetland ecosystem shows a total of 14,785/ha US$ annual economic value. Valuation of relatively pristine wetland in Bangalore shows the value of Rs. 10,435/ha/day while the polluted wetland shows the value of Rs.20/ha/day (Ramachandra et al., 2005). In contrast to this, Varthur, a sewage fed wetland has a value of Rs.118.9/ha/day (Ramachandra et al., 2011). The pollutants and subsequent contamination of the wetland has telling effects such as disappearance of native species, dominance of invasive exotic species (such as African catfish, water hyacinth, etc.), in addition to profuse breeding of disease vectors and pathogens. Water quality analyses revealed of high phosphates (4.22-5.76 ppm) levels in addition to the enhanced BOD (119-140 ppm) and decreased DO (0-1.06 ppm). The amplified decline of ecosystem goods and services with degradation of water quality necessitates the implementation of sustainable management strategies to recover the lost wetland benefits.

Conservation and Management of Wetlands:

In recent years, there has been concern over the continuous degradation of wetlands due to unplanned developmental activities (Ramachandra, 2002)**.** Urban wetlands are seriously threatened by encroachment of drainage through landfilling, pollution (due to discharge of domestic and industrial effluents, solid wastes dumping), hydrological alterations (water withdrawal and inflow changes), and over-exploitation of their natural resources. This results in loss of biodiversity of the wetland and loss of goods and services provided by wetlands (Ramachandra, 2009). The mitigation of frequent floods and the associated loss of human life and properties entail the restoration of interconnectivity among wetlands, restoration of wetlands (removal of encroachments), conservation and sustainable management of wetlands (Ramachandra et al., 2012).

Despite good environmental legislations, loss of ecologically sensitive wetlands is due to the uncoordinated pattern of urban growth happening in Bangalore. Principal reason is lack of good governance and decentralized administration evident from lack of coordination among many Para-state agencies, which has led to unsustainable use of the land and other resources. Failure to deal with water as a finite resource is leading to the unnecessary destruction of lakes and marshes that provide us with water. This failure in turn is threatening all options for the survival and security of plants, animals, humans, etc. There is an urgent need for:

- **Restoring and conserving the actual source of water -** the water cycle and the natural ecosystems that support it - are the basis for sustainable water management
- **Reducing the environmental degradation that is preventing us from reaching goals** of good public health, food security, and better livelihoods world-wide
- **Improving the human quality of life** that can be achieved in ways while maintaining and enhancing environmental quality
- **Reducing greenhouse gases to avoid the deleterious effects of climate change** is an integral part of protecting freshwater resources and ecosystems.
- **Maintaining intergeneration Equity**

A comprehensive approach to water resource management is needed to address the myriad water quality problems that exist today from non-point and point sources as well as from catchment degradation. Watershed-based planning and resource management is a strategy for more effective protection and restoration of aquatic ecosystems and for protection of human health. The watershed approach emphasizes all aspects of water quality, including chemical water quality (e.g., toxins and conventional pollutants), physical water quality (e.g., temperature, flow, and circulation), habitat quality (e.g., stream channel morphology, substrate composition, riparian zone characteristics, catchment land cover), and biological health and biodiversity (e.g., species abundance, diversity, and range). The suggestions to implement in lakes in order to maintain its healthy ecosystem include:

❖ Good governance (too many para-state agencies and lack of co-ordination) - Single agency with the statutory and financial autonomy to be the custodian of natural resources (ownership, regular maintenance) and action against polluters (encroachers as well as those let untreated sewage and effluents, dumping of solid wastes).

❖ De-congest Bangalore: Growth in Bangalore has surpassed the threshold evident from stress on supportive capacity (insufficient water, clean air and water, electricity, traffic bottlenecks, etc.) and assimilative capacity (polluted water and sediments in water bodies, enhanced GHG – Greenhouse gases, etc.). No new projects shall be sanctioned and the emphasis would be on increasing green cover and restoration of lakes.

- Disband BDA – creation of Bangalore Development Agency has given impetus to inefficient governance evident from Bangalore, the garden city turning into 'dead city' during the functional life of BDA.
- Digitation of land records (especially common lands – lakes, open spaces, parks, etc.) and availability of this geo-referenced data with query option (Spatial Decision Support System) to public.
- Comprehensive development plan (CDP) for the city has to be developed through consultative process involving all stakeholders and should not be outsourced to outside agencies / consultants (from other countries).
- Removal of encroachment near to lakes after the survey based on reliable cadastral maps;
- Effective judicial system for speedy disposal of conflicts related to encroachment;
- Apply principles of 'polluter pays' principle to agencies responsible for contamination of Bangalore surface and ground water (Agency: BWSSB, industries);
- Action against regulatory agency (KSPCB) for dereliction of statutory duties and other responsibilities by allowing sustained contamination of water, land and air;
- Restriction of the entry of untreated sewage into lakes;
- To make land grabbing cognizable non-bailable offence;
- Letting off only treated sewage into the lake through constructed wetlands and shallow algae ponds (as in Jakkur lake);
- Regular removal of macrophytes in the lakes;
- Implementation of 'polluter pays' principle as per water act 1974;
- Plant native species of macrophytes in open spaces of lake catchment area;
- Stop solid wastes (municipal and demolition debris) dumping into lakes; treatment and management of solid waste shall be as per MSW Rules 2000, GoI.
- Ensure proper fencing of lakes
- Restrictions on the diversion of lake for any other purposes;
- Complete ban on construction activities in the valley zones;
- Monitoring of lakes through network of schools and colleges;
- Mandatory environment education at all levels (schools and colleges including professional courses).

Wetlands in Bangalore are to be restored considering:

Activities around lakes	**Norms to protect and conserve Wetlands**
Encroachment of lake bed and loss of interconnectivity among lakes	The Hon'ble Supreme Court in Civil appeal number 1132/2011 at SLP (C) 3109/2011 on January 28,2011 has expressed concern regarding encroachment of common property resources, more particularly lakes (and raja kaluves) and it has directed the state governments for removal of encroachments on all community lands.

	Eviction of encroachment: Need to be evicted as per Karnataka Public Premises (eviction of unauthorised occupants) 1974 and the Karnataka Land Revenue Act, 1964
Buildings in the buffer zone of lakes	In case of water bodies, a 30.0 m buffer of 'no development zone' is to be maintained around the lake (as per revenue records) • As per BDA, RMP 2015 (Regional Master Plan, 2015) • Section 17 of KTCP (Karnataka Town and Country Planning) Act, 1961 and sec 32 of BDA Act, 1976 • Wetlands (Conservation and Management) Rules 2010, Government of India; Wetlands Regulatory Framework, 2008.
Construction activities in the valley zone (SEZ by Karnataka Industrial Areas Development Board (KIADB)) **in the valley zone**	This is contrary to sustainable development as the natural resources (lake, wetlands) get affected, eventually leading to the degradation/extinction of lakes. This reflects the ignorance of the administrative machinery on the importance of ecosystems and the need to protect valley zones considering ecological function and these regions are 'NO DEVELOPMENT ZONES' as per CDP 2005, 2015
Alterations in topography	Flooding of regions would lead to loss of property and human life and, spread of diseases.
Increase in deforestation in catchment area	Removing vegetation in the catchment area increases soil erosion and which in turn increases siltation and decreases transpiration
Documentation of biodiversity	• The biodiversity of every water body should form part of the School, College, People's Biodiversity Registers (SBR, CBR, PBR). • The local Biodiversity Management Committees (BMC) should be given necessary financial support and scientific assistance in documentation of diversity. • The presence of endemic, rare, endangered or threatened species and economically important ones should be highlighted • A locally implementable conservation plan has to be prepared for such species
Implementation of sanitation facilities	• The lakes are polluted with sewage, coliform bacteria and various other pathogens • Preserving the purity of waters and safeguarding the biodiversity and productivity, dumping of waste has to be prohibited • All the settlements alongside the water body should be provided with sanitation facilities so as not to impinge in anyway the pristine quality of water

Violation of regulatory and prohibitory activities as per Wetlands (Conservation and Management) Rules, 2010; Regulatory wetland framework, 2008	Environment Impact Assessment (EIA) Notification, 2009. **Wetlands (Conservation and Management) rules 2010, Government of India; Regulatory wetland framework, 2008** **Regulated activity** • Withdrawal of water/impoundment/diversion/interruption of sources • Harvesting (including grazing) of living/non-living resources (may be permitted to the level that the basic nature and character of the biotic community is not adversely affected) • Treated effluent discharges – industrial/ domestic/agro-chemical. • Plying of motorized boats • Dredging (need for dredging may be considered, on merit on case to case basis, only in cases of wetlands impacted by siltation) • Constructions of permanent nature within 50 m of periphery except boat jetties • Activity that interferes with the normal run-off and related ecological processes – up to 200 m **Prohibited activity** i. Conversion of wetland to non-wetland use ii. Reclamation of wetlands iii. Solid waste dumping and discharge of untreated effluents
Damage of fencing, solid waste dumping and encroachment problems in Varthur lake series	High Court of Karnataka (WP No. 817/2008) had passed an order which include: • Protecting lakes across Karnataka, • Prohibits dumping of garbage and sewage in Lakes • Lake area to be surveyed and fenced and declare a no development zone around lakes • Encroachments to be removed • Forest department to plant trees in consultation with experts in lake surroundings and in the watershed region • Member Secretary of state legal services authority to monitor implementation of the above in coordination with Revenue and Forest Departments • Also setting up district lake protection committees
Polluter Pays principle	**National Environment Policy, 2006** The principal objectives of NEP includes : • Protection and conservation of critical ecological systems and resources, and invaluable natural and man-made heritage • Ensuring judicious use of environmental resources to meet the needs and aspirations of the present and future generations

	• It emphasizes the "Polluter Pays" principle, which states the polluter should, in principle, bear the cost of pollution, with due regard to the public interest
Prevention of pollution of lake	**National Water Policy, 2002** Water is a scarce and precious national resource and requires conservation and management. Watershed management through extensive soil conservation, catchment-area treatment, preservation of forests and increasing the forest cover and the construction of check-dams should be promoted. The water resources should be conserved by retention practices such as rain water harvesting and prevention of pollution.
Discharge of untreated sewage into lakes	**The Environment (Protection) Act, 1986** • Lays down standards for the quality of environment in its various aspects • Laying down standards for discharge of environmental pollutants from various sources and no persons shall discharge any pollutant in excess of such standards • Restriction of areas in which industries, operations or processes shall not be carried out or carried out subject to certain safeguards
The water pollution, prevention and its control measures were not looked upon	**Water (Prevention and Control of Pollution) Act, 1974** • It is based on the "Polluter pays" principle. The Pollution Control Boards performs the following functions : • Advice the government on any matter concerning the prevention and control of water pollution. • Encourage, conduct and participate in investigations and research relating to problems of water pollution and prevention, control or abatement of water pollution. • Inspects sewage and effluents as well as the efficiency of the sewage treatment plants. • Lay down or modifiy existing effluent standards for the sewage. • Lay down standards of treatment of effluent and sewage to be discharged into any particular stream. • Notify certain industries to stop, restrict or modify their procedures if the present procedure is deteriorating the water quality of streams.
Pathetic water scenario and insufficient drinking water in Bangalore	The depletion of ground water and drying up off lakes has affected the water availability to meet the current population. At the 4% population growth rate of Bangalore over the past 50 years, the current population of Bangalore is 8.5 million (2011). Water supply from Hesaraghatta has dried, Thippagondanahalli is

	drying up, the only reliable water supply to Bangalore is from Cauvery with a gross of 1,410 million liters a day (MLD). There is no way of increasing the drawal from Cauvery as the allocation by the Cauvery Water Disputes Tribunal for the entire urban and rural population in Cauvery Basin in Karnataka is only 8.75 TMC ft (one thousand million cubic – TMC ft equals 78 MLD), Bangalore city is already drawing more water-1,400 MLD equals 18 TMC—than the allocation for the entire rural and urban population in Cauvery basin

The restoration and conservation strategies has to be implemented for maintaining the ecological health of aquatic ecosystems, aquatic biodiversity in the region, inter-connectivity among lakes, preserve its physical integrity (shorelines, banks and bottom configurations) and water quality to support healthy riparian, aquatic and wetland ecosystems. The regular monitoring of waterbodies and public awareness will help in developing appropriate conservation and management strategies (Ramachandra, 2005).

Ecological and Environmental Implications:

- Land use change: Conversion of watershed area especially valley regions of the lake to paved surfaces would alter the hydrological regime.
- Loss of Drainage Network: Removal of drain (Rajakaluve) and reducing the width of the drain would flood the surrounding residential as the interconnectivities among lakes are lost and there are no mechanisms for the excessive storm water to drain and thus the water stagnates flooding in the surroundings.
- Alteration in landscape topography: This activity alters the integrity of the region affecting the lake catchment. This would also have serious implications on the storm water flow in the catchment.
- The dumping of construction waste along the lakebed and lake has altered the natural topography thus rendering the storm water runoff to take a new course that might get into the existing residential areas. Such alteration of topography would not be geologically stable apart from causing soil erosion and lead to siltation in the lake.
- *Loss of Shoreline:* The loss of shoreline along the lakebed results in the habitat destruction for most of the shoreline birds that wade in this region. Some of the shoreline wading birds like the Stilts, Sandpipers; etc will be devoid of their habitat forcing them to move out such disturbed habitats. It was also apparent from the field investigations that with the illogical land filling and dumping taking place in the Bellandur lakebed, the shoreline are gobbled up by these activities.
- *Loss of livelihood:* Local people are dependent on the wetlands for fodder, fish etc. estimate shows that wetlands provide goods and services worth Rs 10500 per hectare per day (Ramachandra et al., 2005). Contamination of lake brings down goods and services value to Rs 20 per hectare per day.

Decision makers need to learn from the similar historical blunder of plundering ecosystems as in the case of Black Swan event (http://blackswanevents.org/?page_id=26) of evacuating half of the city in 10 years due to water scarcity, contaminated water, etc. or abandoning of Fatehpur Sikhri and fading out of AdilShahi's Bijapur, or ecological disaster at *Easter Island or* Vijayanagara empire

It is the responsibility of Bangalore citizens (to ensure intergeneration equity, sustenance of natural resources and to prevent human-made disasters such as floods, etc.) to stall the irrational conversion of land in the name of development and restrict the decision makers taking the system (ecosystem including humans) for granted as in the case of wetlands by KIADB, BDA, BBMP and many such para-state agencies.

Recommendations for Conservation and Sustainable Management of Wetlands

1. **Carrying capacity studies for all macro cities:** Unplanned concentrated urbanisation in many cities has telling impacts on local ecology and biodiversity, evident from decline of water bodies, vegetation, enhanced pollution levels (land, water and air), traffic bottlenecks, lack of appropriate infrastructure, etc. There is a need to adopt holistic approaches in regional planning considering all components (ecology, economic, social aspects). In this regard, we recommend carrying capacity studies before implementing any major projects in rapidly urbanizing macro cities such as Greater Bangalore, etc. Focus should be on
   - Good governance (too many para-state agencies and lack of co-ordination) - Single agency with the statutory and financial autonomy to be the custodian of natural resources (ownership, regular maintenance) and action against polluters (encroachers as well as those let untreated sewage and effluents, dumping of solid wastes).
   - De-congest Bangalore: **Growth in Bangalore has surpassed the threshold evident from stress on supportive capacity** (insufficient water, clean air and water, electricity, traffic bottlenecks, etc.) **and assimilative capacity** (polluted water and sediments in water bodies, enhanced GHG – Greenhouse gases, etc.)
   - Disband BDA – creation of Bangalore Development Agency has given impetus to inefficient governance evident from Bangalore, the garden city turning into 'dead city' during the functional life of BDA.
   - Digitation of land records (especially common lands – lakes, open spaces, parks, etc.) and availability of this geo-referenced data with query option (Spatial Decision Support System) to public.

2. **Demarcation of the boundary of water bodies:**
   - The existing regulations pertaining to boundary demarcations within different states need to be reviewed according to updated norms and based on

geomorphology and other scientific aspects pertaining to individual water bodies.

- Maximum Water Level mark should form the boundary line of the water body.
- In addition, a specified width, based on historical records/ survey records etc. may be considered for marking a buffer zone around the water body. In case such records are not available, the buffer zones may be marked afresh considering the flood plain level and also maximum water levels.
- The width of the buffer zone should be set considering the geomorphology of the water body, the original legal boundaries, etc.
- The buffer zone should be treated as inviolable in the long term interests of the water body and its biodiversity.
- Declare and maintain floodplains and valley zones of lakes as no activity regions
- Remove all encroachments – free flood plains, valley zones, storm water drains, etc. of encroachments of any kind.
- Ban conversion of lake, lake bed for any other purposes.
- Urban wetlands, mostly lakes to be regulated from any type of encroachments.
- Regulate the activity which interferes with the normal run-off and related ecological processes – in the buffer zone (200 m from lake boundary / flood plains is to be considered as buffer zone)

3. **Mapping of water-bodies:** The mapping of water bodies should also include smaller wetlands, particularly streams, springs etc. The neglect of these hydrological systems could cause considerable impoverishment of water flow in the river systems as well as turn out to be threats to rare kinds of biodiversity. The waters of many of these streams are being diverted for private uses. This causes diminished water flow especially in the during the summer months. A judicious water sharing mechanism has to be worked out at the local level taking into account also the broader national interest as well as conservation of dependent biodiversity. The mapping of these smaller water-bodies, along with their catchments needs to be conducted involving also the local Biodiversity Management Committees. The jurisdictional agreements on the water usage and watershed protection need to be arrived at on a case to case basis involving all the stakeholders.
    - Spatial Extent of Water bodies,
    - Spatial extent of its catchment (watershed/basin),
    - Demarcate Flood plains,
    - Demarcate buffer zone – with a list of regulated activities,
    - Land cover in the catchment,
    - Ensure at least 33% of land cover is covered with natural vegetation (to ensure the lake perennial),
    - Identify the natural areas in the catchment,
    - Biodiversity inventory – capture entire food chain,

- The jurisdictional agreements on the water usage and watershed protection need to be arrived at on a case to case basis involving all the stakeholders,
- Develop a comprehensive database (spatial with attribute information) and available to public,
- Development of Spatial Decision Support System to aid decision makers,
- Identify and demarcate the region around the lake where all activities are to be prohibited (Flood plain)
- The biodiversity of every water body should form part of the Biodiversity Registers (BR),
- The local Biodiversity Management Committees (BMC) should be given necessary financial support and scientific assistance in documentation of diversity,
- The presence of endemic, rare, endangered or threatened species and economically important ones should be highlighted,
- A locally implementable conservation plan has to be prepared for such species.

4. **Holistic and Integrated Approaches – Conservation and Management:** Integration of the activities with the common jurisdiction boundaries of Government para-state Agencies for effective implementation of activities related to management, restoration, sustainable utilization and conservation. This necessitates:
    - Common Jurisdictional boundary for all para-state agencies
    - To minimise the confusion of ownership – assign the ownership of all natural resources (lakes, forests, etc.) to a single agency – **Lake Protection and Management Authority** (or Karnataka Forest Department). This agency shall be responsible for protection, development and sustainable management of water bodies).
    - Custodian (single para-state agency) shall manage natural resources - let that agency have autonomous status with all regulatory powers to protect, develop and manage water bodies.
    - All wetlands to be considered as common property resources and hence custodians should carefully deal with these ensuring security.
    - Management and maintenance of lakes to be decentralized involving stakeholders, local bodies, institutions and community participation without any commercialization or commoditization of lakes.
    - Integrated aquatic ecosystem management needs to be implemented to ensure sustainability, which requires proper study, sound understanding and effective management of water systems and their internal relations.
    - The aquatic systems should be managed as part of the broader environment and in relation to socio-economic demands and potentials, acknowledging the political and cultural context.
    - Wetlands lying within the protected area of National Parks and Wildlife Sanctuaries shall be regulated under the Wildlife Protection Act, 1972. Wetlands lying within the notified forest areas shall be regulated by the

Indian Forest Act, 1927 and the Forest Conservation Act, 1980; and the relevant provisions of the Environment (Protection) Act, 1986. The Wetlands outside protected or notified forest areas shall be regulated by the relevant provisions of the Environment (Protection) Act, 1986.

- Immediate implementation of the regulatory framework for conservation of wetlands.
- Socio-economic studies with land use planning in and around the lakes can help in providing ecological basis for improving the quality of lakes.
- Prohibit activities such as conversion of wetlands for non-wetland purposes, dumping of solid wastes, direct discharge of untreated sewage, hunting of wild fauna, reclamation of wetlands.
- Maintain Catchment Integrity to ensure lakes are perennial and maintain at least 33% land cover should be under natural Vegetation.
- Plant native species of vegetation in each lake catchment.
- Create new water bodies considering the topography of each locality.
- Establish laboratory facility to monitor physical, chemical and biological integrity of lakes.
- Maintain physical integrity - Free storm water drains of any encroachments. Establish interconnectivity among water bodies to minimise flooding in certain pockets. The process of urbanization and neglect caused disruption of linkages between water bodies such as ancient lake systems of many cities. Wherever such disruptions have taken place alternative arrangements should be provided to establish the lost linkages.
- Encroachment of lake beds by unauthorized /authorized agencies must be immediately stopped. Evict all unauthorized occupation in the lake beds as well as valley zones.
- Any clearances of riparian vegetation (along side lakes) and buffer zone vegetation (around lakes) have to be prohibited
- Penalise polluters dumping solid waste in the lake bed.
- Implement polluter pays principle for polluters letting liquid waste in to the lake either directly or through storm water drains.
- Lake privatized recently to be taken over and handed over to locals immediately thus restoring the traditional access to these lakes by the stakeholders.
- Restore surviving lakes in urban areas strengthening their catchment area and allowing sloping shorelines for fulfilling their ecological function.
- Alteration of topography in lake / river catchments should be banned.
- Appropriate cropping pattern, water harvesting, urban development, water usage, and waste generation data shall be utilized and projected for design period for arriving at preventive, curative and maintenance of aquatic ecosystem restoration action plan (AERAP).

- Desilting of lakes for removal of toxic sediment, to control nuisance macrophytes; further silting in the catchment should be checked by suitable afforestation of catchment areas and the provision of silt traps in the storm water drains.
- Maintaining the sediment regime under which the aquatic ecosystems evolve including maintenance, conservation of spatial and temporal connectivity within and between watersheds.
- Conversion of land around the lakes particularly in the valley zones and storm water drains for any kind of development must be totally banned.
- Flora in the catchment area should be preserved & additional afforestation programmes undertaken.
- Check the overgrowth of aquatic weeds like *Eichhornia, Azolla, Alternanthera* etc. through manual operations.
- Aquatic plants greatly aid in retarding the eutrophication of aquatic bodies; they are the sinks for nutrients & thereby play a significant role in absorption & release of heavy metals. They also serve as food and nesting material for many wetland birds. Therefore, knowledge of the ecological role of aquatic species is necessary for lake preservation.
- Adopt biomanipulation (Silver carp and Catla– surface phytoplankton feeders, Rohu – Column zooplankton feeder Gambusia and Guppies – larvivorous fishes for mosquito control), aeration, and shoreline restoration (with the native vegetation) in the management of lakes.
- Environmental awareness programmes can greatly help in the protection of the water bodies.

▪ Government Agencies, Academies, Institutions and NGO's must co-ordinate grass-root level implementation of policies and activities related to conservation of lakes and wetlands (both Inland and Coastal), their sustainable utilization, restoration and development including human health. There is also a need for management and conservation of aquatic biota including their health aspects. Traditional knowledge and practices have to be explored as remedial measures. Cost-intensive restoration measures should be the last resort after evaluating all the cost-effective measures of conservation and management of the wetlands.

▪ A Committee be constituted consisting of Experts, Representatives of Stakeholders (researchers, industrialists, agriculturists, fishermen, etc.) and Line Agencies, in addition to the existing Committee(s), if any, in order to evolve policies and strategies for reclamation, development, sustainable utilization and restoration of the wetlands and socio-economic development of the local people.

▪ At regional level, **Lake Protection and Management Authority (LPMA)** with autonomy, corpus funds from plan allocations of state and center and responsibility and accountability for avoiding excessive cost and time over runs.

LPMA shall have stakeholders-representatives from central and state and local body authorities, NGO's and eminent people and experts shall be constituted

- Generous funds shall be made available for such developmental works through the Committee, as mentioned above. Local stakeholders be suggested to generate modest funds for immediate developmental needs in the aquatic systems in their localities.
- Provisions should be made for adoption of lakes and wetlands by the NGO's and Self-help groups for their conservation, management, sustainable utilization and restoration.
- Aquatic ecosystem restoration works taken up by any agency, Govt. or NGO's should have 10% of restoration costs (per annum) spent or set off for creating awareness , research and monitoring compulsorily in future.
- Public education and outreach should be components of aquatic ecosystem restoration. Lake associations and citizen monitoring groups have proved helpful in educating the general public. Effort should be made to ensure that such groups have accurate information about the causes of lake degradation and various restoration methods.

5. **Documentation of biodiversity:** The biodiversity of every water body should form part of the School, College, People's Biodiversity Registers (SBR, CBR, PBR). The local Biodiversity Management Committees (BMC) should be given necessary financial support and scientific assistance in documentation of diversity. The presence of endemic, rare, endangered or threatened species and economically important ones should be highlighted. A locally implementable conservation plan has to be prepared for such species.
   - All kinds of introduction of Exotic species and Quarantine measures be done in consultation with the concerned Authorities and the data bank
   - There is an urgent need for creating a `Data Bank' through inventorisation and mapping of the aquatic biota.
   - Identify water bodies of biodiversity importance and declare them as wetland conservation reserves (WCR)

6. **Preparation of management plans for individual water bodies:** Most large water bodies have unique individual characteristics. Therefore it is necessary to prepare separate management plans for individual water bodies.
   - Greater role and participation of women in management and sustainable utilization of resources of aquatic ecosystems.
   - Impact of pesticide or fertilizers on wetlands in the catchment areas to be checked.
   - Regulate illegal sand and clay mining around the wetlands.

7. **Implementation of sanitation facilities:** It was noted with grave concern that the water bodies in most of India are badly polluted with sewage, coliform bacteria and various other pathogens. This involves:
    - Preserving the purity of waters and safeguarding the biodiversity and productivity, dumping of waste has to be prohibited;
    - In addition to this, all the settlements alongside the water body should be provided with sanitation facilities so as not to impinge in anyway the pristine quality of water.

8. **Management of polluted lakes:** This programme needs priority attention. This involves:
    - Implementation of bioremediation method for detoxification of polluted water bodies.
    - The highly and irremediably polluted water bodies to be restored on priority to prevent health hazards.
    - Based on the concept of **polluter pays**, a mechanism be evolved to set up efficient effluent treatment plants [ETP], individual or collective, to reduce the pollution load. Polluting industries be levied **Environmental Cess,** which can be utilised for conservation measures by the competent authorities. A `waste audit' must be made compulsory for all the industries and other agencies.

9. **Restoration of lakes:** The goals for restoration of aquatic ecosystems need to be realistic and should be based on the concept of expected conditions for individual eco-regions. Further development of project selection and evaluation technology based on eco-region definitions and description should be encouraged and supported by the national and state government agencies.
    - Ecosystem approach in aquatic ecosystem restoration endeavor considering catchment land use plan as of pre-project status and optimal land use plan shall first be prepared for short term (10 to 30 years) and long term (>30) periods keeping in view developmental pressure over time span.
    - Research and development is needed in several areas of applied limnology, and this programme should take an experimental approach which emphasizes manipulation of whole ecosystems.
    - Appropriate technologies for point and non-point sources of pollution and *in situ* measures for lake restoration shall be compatible to local ethos and site condition as well as objectives of Aquatic Ecosystem Restoration Action Plan (AERAP).
    - Traditional knowledge and practices have to be explored as remedial measures. Cost-intensive restoration measures should be the last resort after evaluating all the cost-effective measures of conservation and management of ecosystems.
    - Public needs to be better informed about the rational, goal and methods of ecosystem conservation and restoration. In addition, the need was realized for

scientist and researchers with the broad training needed for aquatic ecosystem restoration, management and conservation.

- Improved techniques for littoral zone and aquatic microphytes management need to be developed. Research should go beyond the removal of nuisance microphytes to address the restoration of native species that are essential for waterfowl and fish habitat.
- Basic research is necessary to improve the understanding of fundamental limnological processes in littoral zones and the interactions between littoral and pelagic zones of lakes.
- Bio manipulation (food web management) has great potential for low-cost and long-term management of lakes, and research in this emerging field must be stimulated.
- Innovative and low-cost approaches to contaminant clean up in lakes need to be developed.
- The relations between loadings of stress-causing substances and responses of lakes need to be understood more precisely. Research should be undertaken to improve predictions of trophic state and nutrient loading relationships.
- Improved assessment programmes are needed to determine the severity and extent of damage in lakes and wetlands and a change in status over time. Innovative basic research is required to improve the science of assessment and monitoring.
- There is a great need for cost effective, reliable indicators of ecosystems function, including those that would reflect long-term change and response to stress.
- Research on indicators should include traditional community and ecosystem measurements, paleoecological trend assessments and remote sensing.
- Effective assessment and monitoring programme would involve network of local schools, colleges and universities.

10. **Valuation of goods and services :** Goods and services provided by the individual water bodies and the respective species to be documented, evaluated through participatory approach and be made part of the Biodiversity Registers (PBR: People's Biodiversity Registers, SBR: School Biodiversity Registers). If in any case the traditional fishing rights of the local fishermen are adversely affected by lake conservation or by declaring it as a bird sanctuary, etc. they should be adequately compensated.
    - Ecological values of lands and water within the catchment / watershed shall be internalised into economic analysis and not taken for granted. Pressure groups shall play as watchdogs in preventing industrial and toxic and persistent pollutants by agencies and polluters.

11. **Regulation of boating:** Operation of motorized boats should not be permitted within lakes of less than 50 ha. In larger lakes the number of such boats should be limited to

restricted area and carrying capacity of the water body. In any case boating during the periods of breeding and congregations of birds should be banned.

12. **Protection of riparian and buffer zone vegetation:** Any clearances of riparian vegetation (along side rivers) and buffer zone vegetation (around lakes) have to be prohibited.
13. **Restoration of linkages between water bodies:** The process of urbanization and neglect caused disruption of linkages between water bodies such as ancient lake systems of many cities. Wherever such disruptions have taken place alternative arrangements should be provided to establish the lost linkages.
14. **Rainwater harvesting:** Intensive and comprehensive implementation of rain water harvesting techniques can reduce taxation of water bodies and also minimize electricity requirements. The country needs in principle a holistic rainwater harvesting policy aimed at directing water literally from “roof-tops to lakes” after catering to the domestic needs.
15. **Environment Education:** It was felt among the participants that public needs to be better informed about the rational, goal and methods of ecosystem conservation and restoration. In addition, the need was realized for scientist and researchers with the broad training needed for aquatic ecosystem restoration, management and conservation. Public education and outreach should include all components of ecosystem restoration. Lake associations and citizen monitoring groups have proved helpful in educating the general public. Effort should be made to ensure that such groups have accurate information about the causes of lake degradation and various restoration methods. Funding is needed for both undergraduate and graduate programmes in ecosystem conservation and restorations. Training programmes should cross traditional disciplinary boundaries such as those between basic and applied ecology: water quality management and fisheries or wildlife management: among lakes, streams, rivers, coastal and wetland ecology. In this regard the brainstorming session proposes:
    - Environmental education program should be more proactive, field oriented and experiential (with real time examples) for effective learning.
    - Environmental education should be made mandatory at all levels – schools, colleges, universities, professional courses, teachers and teacher educators at the teachers’ training institutes (C P Ed, B P Ed, B Ed, D Ed)
16. **Adopt Inter-disciplinary Approach:** Aquatic ecosystem conservation and management requires collaborated research involving natural, social, and inter-disciplinary study aimed at understanding various components, such as monitoring of water quality, socio-economic dependency, biodiversity and other activities, as an indispensable tool for formulating long term conservation strategies. This requires multidisciplinary-trained professionals who can spread the understanding of ecosystem’s importance at local schools, colleges, and research institutions by initiating educational programmes aimed at rising the levels of public awareness of aquatic ecosystems’ restoration, goals and methods. Actively participating schools and colleges in the vicinity of the water bodies may value the opportunity to provide hands-on environmental education, which could entail setting up of laboratory facilities at the

site. Regular monitoring of water bodies (with permanent laboratory facilities) would provide vital inputs for conservation and management.

Wetland Protection Laws and Government Initiatives

The primary responsibility for the management of these ecosystems is in the hands of the Ministry of Environment and Forests. Although some wetlands are protected after the formulation of the Wildlife Protection Act, the others are in grave danger of extinction. Effective coordination between the different ministries, energy, industry, fisheries revenue, agriculture, transport and water resources, is essential for the protection of these ecosystems. Thus, wetlands were not delineated under any specific administrative jurisdiction. Recently the Ministry of Environment and Forests of the Government of India issued Notification 2010 Regulatory Framework for Wetlands Conservation (Wetland Conservation Rules). Wetlands in India are protected by an array of laws given below:

- The Indian Fisheries Act - 1857
- The Indian Forest Act - 1927
- Wildlife (Protection) Act - 1972
- Water (Prevention and Control of Pollution) Act - 1974
- Water (Prevention and Control of Pollution) Cess Act - 1977
- Forest (Conservation) Act - 1980
- The Environment (Protection) Act - 1986
- Wildlife (Protection) Amendment Act - 1991
- National Conservation Strategy and Policy Statement on Environment and Development – 1992
- Environment Impact Assessment Notification, 2009
- Wetlands Regulatory Framework, 2008
- Wetlands (Conservation and Management) Rules 2010, Government of India

In addition to the above laws, India is a signatory to the Ramsar Convention on Wetlands and the Convention of Biological Diversity. According to these formulations India is expected to conserve the ecological character of these ecosystems along with the biodiversity of the flora and fauna associated with these ecosystems. Despite these, there is no significant development towards sustaining these ecosystems due to the lack of awareness of the values of these ecosystems among the policymakers and implementation agencies. The effective management of these wetlands requires a thorough appraisal of the existing laws, institutions and practices. The involvement of various people from different sectors is essential in the sustainable management of these wetlands.

Apart from government regulation, development of better monitoring methods is needed to increase the knowledge of the physical and biological characteristics of each wetland resources, and to gain, from this knowledge, a better understanding of wetland dynamics and their controlling processes. Discussions based on accurate knowledge and increased awareness of wetland issues can then begin to develop management strategies (to protect, restore and/or mitigate) that account for the function and value of all wetland resources in the face of natural and socioeconomic factors, while continuing to satisfy critical resource needs of the human population.

The Legal framework for the conservation and management of Wetland Ecosystems is provided by the following National and International Legal instruments:

The Wildlife Protection Act, 1972: This act provides for the protection of wild animals, birds and plants. For the purpose of this act, the state government constitutes the Wildlife Advisory board, which performs the following functions: It advices the state government:

- In the selection of areas to be declared as Sanctuaries, National Parks and Closed Areas.
- In the formulation of policy of protection and conservation of wildlife and specified plants.
- In relation to the measures to be taken for harmonizing the needs of the tribals and forest dwellers with the protection and conservation of wildlife.

This Act imposes prohibition on hunting of wild animals, their young ones as well as their eggs except with prior permission of the Chief Wildlife Warden. This acts prohibits the picking, uprooting, destroying, damaging, possessing of any plant in a protected area, except with prior permission of the Chief Wildlife Warden. The State government may declare any area; which it considers to have adequate ecological, faunal, geomorphological, natural or zoological significance for the purpose of protecting, propagating or developing wildlife or its environment; to be included in a sanctuary or a National Park. No person shall, destroy, exploit or remove any wildlife from a National Park and Sanctuary or destroy or damage the habitat or deprive any wild animal or plant its habitat within such National Park and Sanctuary. The State government may also declare any area closed to hunting for a designated period of time if it feels the ecosystem of that area is disturbed by hunting.

Water (Prevention and Control of Pollution) Act, 1974: for the prevention and control of water pollution and the maintaining or restoring of wholesomeness of water. To carry out the purposes of this act, the Central and the State government constitutes the Central Pollution Control Board (CPCB) and State Pollution Control Board (SPCB) respectively. The main functions of the pollution control boards include:

- Advice the government on any matter concerning the prevention and control of water pollution.
- Encourage, conduct and participate in investigations and research relating to problems of water pollution and prevention, control or abatement of water pollution.
- Lay down or modify standards on various parameters for the release of effluents into streams.

- Collect and examine effluent samples as well as examine the various treatment procedures undertaken by the industries releasing the effluent.
- Examine the quality of streams.
- Notify certain industries to stop, restrict or modify their procedures if it feels that the present procedure is deteriorating the water quality of streams.
- Establish or recognize laboratories to perform its functions including the analysis of stream water quality and trade effluents.

Forest (Conservation) Act, 1980: Without the permission of the Central government, no State government or any other authority can:

- Declare that any reserved forest shall cease to be reserved.
- Issue permit for use of forest land for non-forest purpose.
- Assign any forest land or portion thereof by way of lease or otherwise to any private person, authority, corporation, agency or any other organization, not owned, managed or controlled by government.
- Clear off natural trees from a forest land for the purpose of reafforestation.

The Biological Diversity Act, 2002: India is a signatory to the United Nations Convention on Biological Resources, 1992 and in accordance with that convention, brought into force The Biological Diversity Act, 2002. This act prohibits biodiversity related activities as well as transfer of the results of research pertaining to biodiversity to certain persons. It also necessitates the approval of National Biodiversity Authority before applying for Intellectual Property Rights on products pertaining to biological diversity. This act emphasizes the establishment of National Biodiversity Authority to carry out various functions pertaining to the Act, viz guidelines for approving collection, research and patents pertaining to biological diversity. It also notifies the central government on threatened species. The central government to develop plans, programmes and strategies for the conservation, management and sustainable use of the biodiversity. Where the Central Government has reason to believe that any area rich in biological diversity, biological resources and their habitats is being threatened by overuse, abuse or neglect, it shall issue directives to the concerned State Government to take immediate ameliorative measures.

Convention on Wetlands of International Importance, especially as Waterfowl habitats, (Ramsar) 1971: To stem the progressive destruction of the wetlands, Ramsar convention was signed. Waterfowls are birds ecologically dependent on the wetlands. The various points agreed under Ramsar convention includes:

- Each contracting party should nominate at least one wetland having significant value in terms of ecology, botany, zoology, limnology or hydrology to be included in the List of Wetlands of International Importance (Ramsar sites) and precisely describe its boundaries.

- The contracting parties will have right to add further wetland sites to the list, expand the boundaries of the existing sites and also to delete or minimize the boundaries of the existing sites.
- Each contracting party shall strive for the conservation, management and restoration of the wetlands in the list.
- Establishment of nature reserves in the area of wetlands thereby protecting it as well as the biological diversity it supports.
- Restriction of boundaries or deletion of a wetland listed as Ramsar sites should be immediately compensated by the creation of additional nature reserves for the protection of waterfowls and other species habiting that wetland.

International convention for the protection of Birds, 1950: To abate the ever dwindling number of certain bird species (particularly the migratory ones) as well as the other birds, this convention was made. This is an amendment to the "International Convention for the Protection of Birds useful to Agriculture, 1902". The objectives of this convention include:

- Protection to all birds, their young ones and their eggs especially in their breeding season.
- Prohibit hunting, killing, mass capture or captivating birds, except those causing intense damage to crops or other components of the ecosystem, such so that the above said components is in the danger of extinction.
- Adopt measures to prohibit industries and other processes causing contamination of air and water that has adverse effects on the survival of birds.
- Adopt measures to prohibit the destruction of suitable breeding grounds and the bird habitat and also encourage the creation of suitable land and water habitat for the birds.

Bonn Convention on Conservation of Migratory Species, 1979: According to the Bonn Convention on Conservation of Migratory Species, the participating parties:

- Should promote, co-operate in and support research relating to migratory species.
- Shall endeavour to provide immediate protection for migratory species which are endangered.
- Shall strive to conserve and restore those habitats of the endangered species in an effort to eliminate the chances of extinction of that species.
- Shall prohibit or minimize those activities or obstacles that seriously impede or prevent the migration of the species.

Convention on Biological Diversity, 1992: The main objectives of this convention are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of benefits arising out of the utilization of genetic resources. In accordance with this convention, each contracting party shall –

- Identify places supporting immense biological diversity.

- Monitor through sampling or other means the components of biological diversity identified and strive for the conservation of those components requiring urgent attention.
- Develop new or adapt existing strategies, plans and programmes for the conservation and sustainable use of biological diversity.
- Identify activities which have or may have significant adverse impact on the sustainability of the biodiversity in an area.
- It prescribes conservation of biological diversity by either *In situ* conservation mechanisms or *Ex situ* conservation mechanisms or both.

In situ conservation: Each contracting parties shall declare a region harbouring immense biological diversity as a protected area and develop various plans and strategies for the establishment, conservation and management of these protected areas and also strive to conserve biodiversity beyond these protected areas.

- Promote environmentally sound and sustainable development in the areas adjacent to the protected areas so as to further enhance the development and protection of these protected areas.
- Promote the protection of ecosystems, prevent the introduction of alien species likely to have an adverse effect on the existing ecosystem and also rehabilitate & restore degraded ecosystems.
- Enforce legislative measures for the protection of threatened species and population.

Ex situ conservation : Each contracting party shall establish facilities for ex situ conservation and for research on plants, animals and micro-organisms, especially the threatened species, augment their number and take steps for their reintroduction in their own natural habitat.

Relative merits and scope of the respective Indian laws with respect to the wetlands protection and conservation is given in Table 2.

Table 2: Sections applicable to Wetlands in the various environmental laws

No.	Act	Relevant Sections
1	The Wildlife (Conservation) Act, 1972	Prohibits hunting of wild animals, their young ones as well as their eggs Prohibits the picking, uprooting, destroying, damaging, possessing of any plant in a protected area Can declare any area with high ecological significance as a national park, sanctuary or a closed area.
2	The Biological Diversity Act, 2002	Prior approval needed from National Biodiversity Authority for collection of biological materials occurring in India as well as for its commercial utilization.

		Panchayath to document biodiversity and maintain biodiversity registers
3	Forest (Conservation) Act, 1980	Without the permission of the Central government, no State government or any other authority can : • Declare that any reserved forest shall cease to be reserved. • Issue permit for use of forest land for non-forest purpose. • Assign any forest land by way of lease or otherwise to any private person, authority, corporation, agency or any other organization, not owned, managed or controlled by government. • Clear off natural trees from a forest land for the purpose of re-afforestation.
4	Water (Control and Prevention of Pollution) Act, 1974	It is based on the "Polluter pays" principle. The Pollution Control Boards performs the following functions : • Inspects sewage and effluents as well as the efficiency of the sewage treatment plants. • Lay down or modifies existing effluent standards for the sewage. • Lay down standards of treatment of effluent and sewage to be discharged into any particular stream. • Notify certain industries to stop, restrict or modify their procedures if the present procedure is deteriorating the water quality of streams.
5	Wetlands (Conservation and Management) Rules, 2010	Prohibited Activities • Conversion of wetland to non-wetland use • Reclamation of wetlands • Solid waste dumping and discharge of untreated effluents. Regulated activities • Withdrawal of water, diversion or interruption of sources • Treated effluent discharges – industrial/domestic/agro-chemical. • Plying of motorized boats

		• Dredging • Constructions of permanent nature within 50 m • Activity which interferes with the normal run-off and related ecological processes – up to 200 m
6	National Environment Policy, 2006	The principal objectives of NEP includes : • Protection and conservation of critical ecological systems and resources, and invaluable natural and man made heritage. • Ensuring judicious use of environmental resources to meet the needs and aspirations of the present and future generations. • It emphasizes the "Polluter Pays" principle, which states the polluter should, in principle, bear the cost of pollution, with due regard to the public interest.
8	The Environment (Protection) Act, 1986	Lays down standards for the quality of environment in its various aspects. Laying down standards for discharge of environmental pollutants from various sources and no persons shall discharge any pollutant in excess of such standards. Restrictions of areas in which industries, operations or processes shall not be carried out or carried out subject to certain safeguards.
9	National Water Policy, 2002	Water is a scarce and precious national resource and requires to be conserved and management. Watershed management through extensive soil conservation, catchment-area treatment, preservation of forests and increasing the forest cover and the construction of check-dams should be promoted. The water resources should be conserved by retention practices such as rain water harvesting and prevention of pollution.

1.0 Bangalore to Bengaluru (transition from green landscape to brown landscape)

Status	**Disappearing water-bodies and vegetation**
Cause:	**Unplanned urbanisation**
Recommendation	"**Decongest and decontaminate Bangalore**" so that at least next generation enjoys better environment in Bangalore Need to ensure the ecosystem integrity to sustain goods and services for maintaining inter-generation equity. **Carrying capacity studies for all macro cities:** Unplanned concentrated urbanisation in many cities has telling impacts on local ecology and biodiversity, evident from decline of water bodies, vegetation, enhanced pollution levels (land, water and air), traffic bottlenecks, lack of appropriate infrastructure, etc. There is a need to adopt holistic approaches in regional planning considering all components (ecology, economic, social aspects). In this regard, we recommend carrying capacity studies before implementing any major projects in rapidly urbanizing macro cities such as Greater Bangalore, etc.
Action Plan	• Good governance (too many para-state agencies and lack of co-ordination) - Single agency with the statutory and financial autonomy to be the custodian of natural resources (ownership, regular maintenance and action against polluters (encroachers as well as those let untreated sewage and effluents, dumping of solid wastes). • De-congest Bangalore: Growth in Bangalore has surpassed the threshold evident from stress on supportive capacity (insufficient water, clean air and water, electricity, traffic bottlenecks, etc.) and assimilative capacity (polluted water and sediments in water bodies, enhanced GHG – Greenhouse gases, etc.) • Disband BDA – creation of Bangalore Development Agency has given impetus to inefficient governance evident from Bangalore, the garden city turning into 'dead city' during the functional life of BDA. • Digitation of land records (especially common lands – lakes, open spaces, parks, etc.) and availability of this geo-referenced data with query option (Spatial Decision Support System) to public. • Threshold on high raise building in the region. Need to protect valley zones considering ecological function and these regions are 'NO DEVELOPMENT ZONES' as per CDP 2005, 2015 • Evict all encroachments from lake bed and raja kaluves • Re-establish interconnectivity among lakes • Rejuvination of lakes

1.0 Bangalore to Bengaluru (transition from green landscape to brown landscape)

Bangalore (77°37’19.54’’ E and 12°59’09.76’’ N), is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka. With an area of 741 sq. km., Bangalore's city administrative jurisdiction was widened in 2006 (Greater Bangalore) by merging the existing area of Bangalore city spatial limits with 8 neighbouring Urban Local Bodies (ULBs), and 111 Villages of Bangalore Urban District (Ramachandra and Kumar, 2008; Ramachandra et al., 2012). Thus, Bangalore has grown spatially more than ten times since 1949 (69 square kilometres) and is a part of both the Bangalore urban and rural districts (figure 1.1). The mean annual total rainfall is about 880 mm with about 60 rainy days a year over the last ten years. The summer temperature ranges from 18° C – 38° C, while the winter temperature ranges from 12° C – 25° C. Bangalore is located at an altitude of 920 meters above mean sea level, delineating three watersheds, viz. Hebbal, Koramangala-Challaghatta and Vrishabhavathi watersheds (Figure 1.2). The undulating terrain in the region has facilitated creation of a large number of tanks providing for the traditional uses of irrigation, drinking, fishing, and washing. Bangalore had the distinction of having hundreds of water bodies through the centuries. Even in early second half of 20th century, in 1961, the number of lakes and tanks in the city stood at 262 (and spatial extent of Bangalore was 112 sq. km). However, number of lakes and tanks in 1985 was 81 (and spatial extent of Bangalore was 161 sq. km). This forms important drainage courses for the interconnected lake system (Figure 1.2), which carries storm water beyond the city limits. Bangalore, being a part of peninsular India, had the tradition of harvesting water through surface water bodies to meet the domestic water requirements in a decentralised way. After independence, the source of water for domestic and industrial purpose in Bangalore is mainly from the Cauvery River and ground water. Untreated sewage is let into the storm water drains, which progressively converge at the water bodies. Now, Bangalore is the fifth largest metropolis in India currently with a population of about 8.72 million as per the latest population census. Spatial extent of the city has increased from 69 (1941) to 161 (1981), 226 (2001) and 745 (2011) sq.km. Due to the changes in the spatial extent of the city, the population density varies from 5956 (1941) to 18147 (1981), 25653 (1991), 25025 (2001) and 11704 (2011) persons per sq.km.

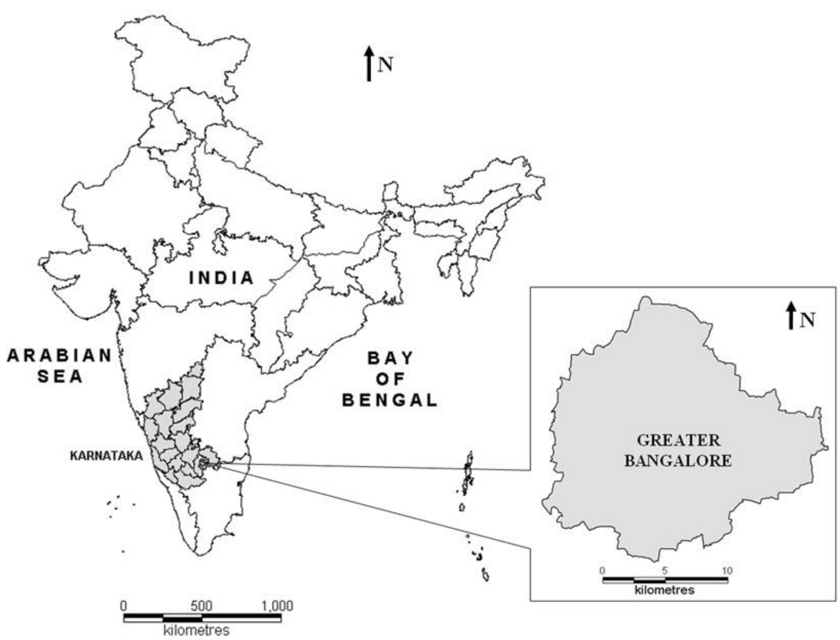
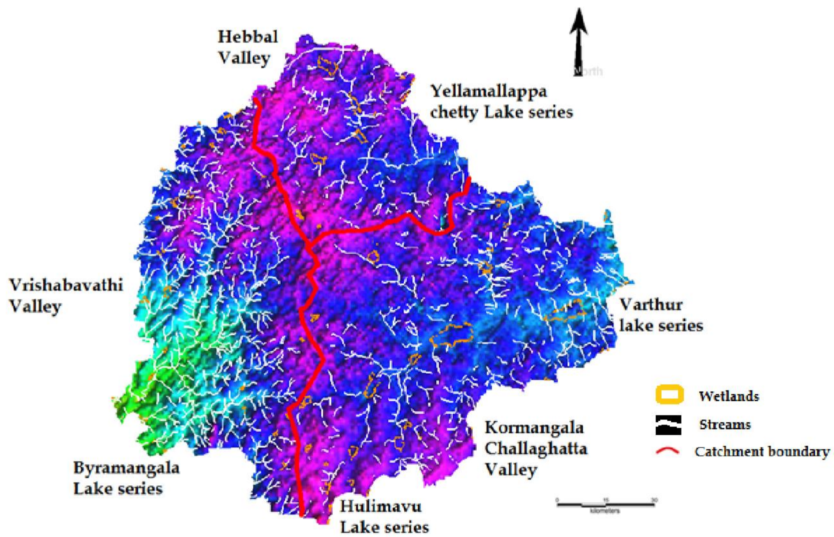


Figure 1.1: Study area –Bangalore



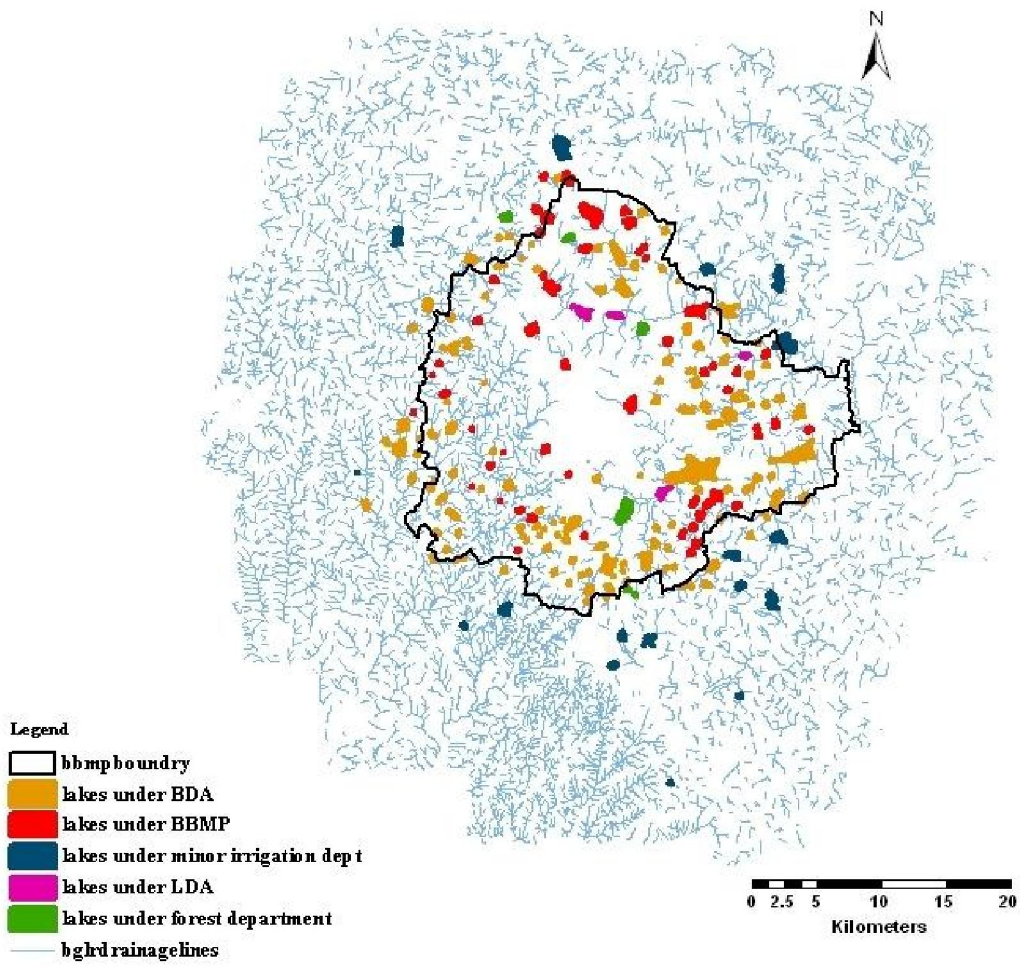


Figure 1.2: Watersheds (drainage with water bodies) of Bangalore

Land use analyses were carried out using supervised pattern classifier - Gaussian maximum likelihood classifier (GMLC) for Landsat and IRS data, and Bayesian Classifier (MODIS data). The method involved (Ramachandra *et al.*, 2012): i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS, vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, iv) supplementing this information with Google Earth (latest as well as archived data), v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

Land use analysis carried out using GRASS - Geographic Resources Analysis Support System (http://wgbis.ces.iisc.ernet.in/ grass) for the period 1973 to 2013 and details are in table 1.1 and urban dynamics is illustrated in Figure 1.3. There has been a 925% increase in built up area from 1973 to 2013 leading to a sharp decline of 79% area in water bodies in Bangalore mostly attributing to intense urbanisation process. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% (2006 to 2010). The rapid development of urban sprawl has many potentially detrimental effects including the loss of valuable agricultural and eco-sensitive (e.g. wetlands, forests) lands, enhanced energy consumption and greenhouse gas emissions from increasing private vehicle use (Ramachandra and Shwetmala, 2009). Vegetation has decreased by 32% (during 1973 to 1992), 38% (1992 to 2002) and 64% (2002 to 2013). Disappearance of water bodies or sharp decline in the number of water bodies in Bangalore is mainly due to intense urbanisation and urban sprawl. Many lakes (54%) were encroached for illegal buildings. Field survey of all lakes (in 2007) shows that nearly 66% of lakes are sewage fed, 14% surrounded by slums and 72% showed loss of catchment area. In addition, lake catchments were used as dumping yards for either municipal solid waste or building debris (Ramachandra, 2009a). The surrounding of these lakes have illegal constructions of buildings and most of the times, slum dwellers occupy the adjoining areas. At many sites, water is used for washing and household activities and even fishing was observed at one of these sites. Multi-storied buildings have come up on some lake beds that have totally intervene the natural catchment flow leading to sharp decline and deteriorating quality of water bodies. This is correlated with the increase in built up area from the concentrated growth model focusing on Bangalore, adopted by the state machinery, affecting severely open spaces and in particular water bodies. Some of the lakes have been restored by the city corporation and the concerned authorities in recent times.

Table 1.1: Land use changes in Bengaluru during 1973 to 2013

Class →	Urban		Vegetation		Water		Others	
Year ↓	Ha	%	Ha	%	Ha	%	Ha	%
1973	5448	7.97	46639	68.27	2324	3.40	13903	20.35
1992	18650	27.30	31579	46.22	1790	2.60	16303	23.86
1999	24163	35.37	31272	45.77	1542	2.26	11346	16.61
2002	25782	37.75	26453	38.72	1263	1.84	14825	21.69
2006	29535	43.23	19696	28.83	1073	1.57	18017	26.37
2010	37266	54.42	16031	23.41	617	0.90	14565	21.27
2013	50440	73.72	10050	14.69	445.95	0.65	7485	10.94

Urbanisation in Greater Bangalore

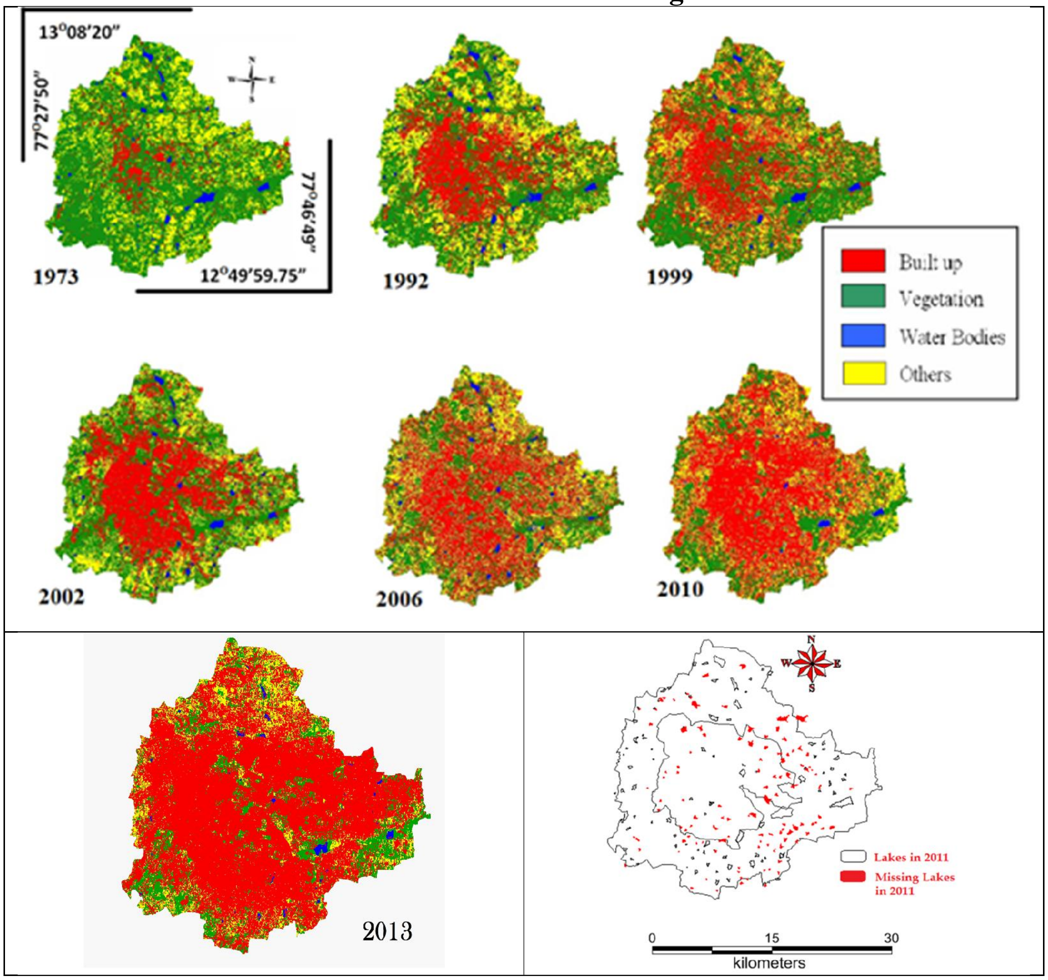


Figure 1.3: Land use dynamics since 1973

Increase in Built-up (concrete / paved surface): 925%

Loss of vegetation: 78%

Loss of water bodies: 79%

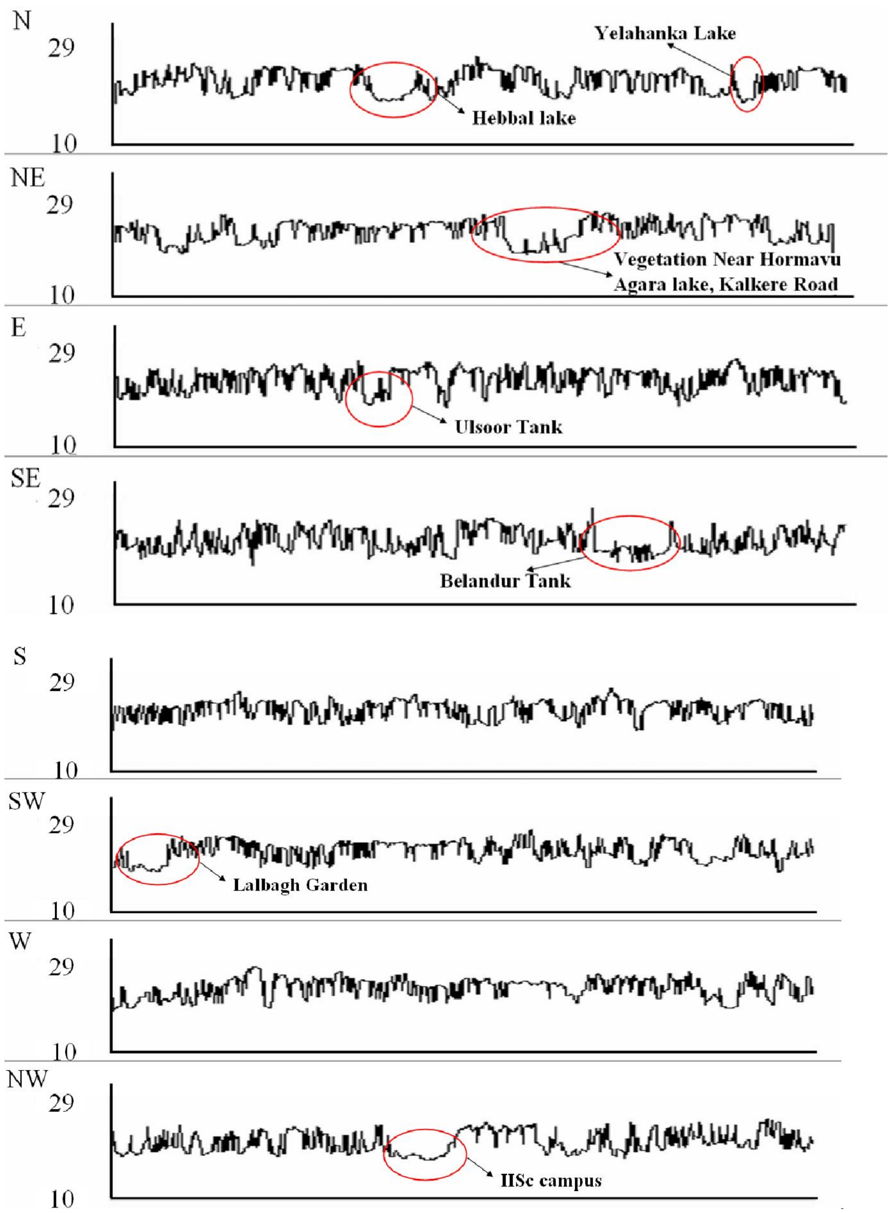


Figure 1.4: Temperature profile in various directions. X axis – Movement along the transacts from the city centre, Y-axis - Temperature (°C)

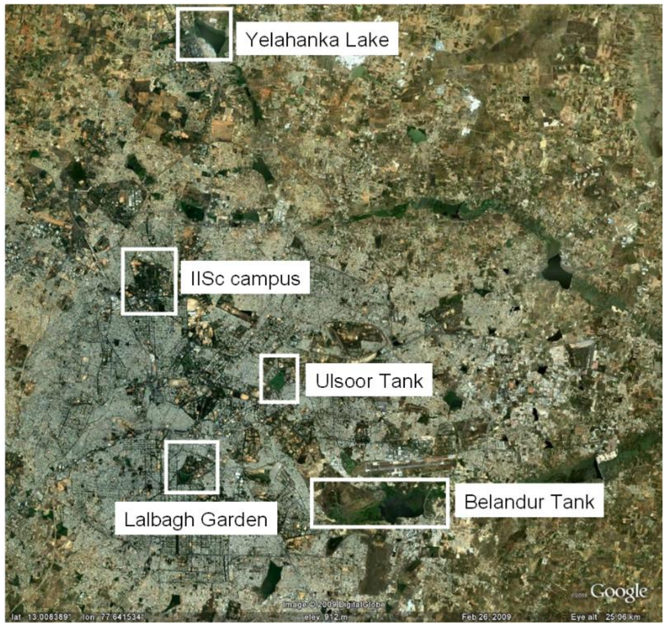


Figure 1.5: Google Earth image showing the low temperature areas [Source: http://earth.google.com/]

The temperature profile plot fell below the mean when a vegetation patch or water body was encountered on the transact beginning from the centre of the city and moving outwards eight directions along the transact as in figure 1.4 It is evident that major natural green area and water bodies act as microclimate moderators responsible for lower temperature (marked with rectangles in Figure 1.5). The spatial location of these green areas and water bodies are marked in figure 1.5.

Conclusion

Urbanisation and the consequent loss of lakes has led to decrease in catchment yield, water storage capacity, wetland area, number of migratory birds, flora and fauna diversity and ground water table. Temporal land use analysis reveal that there has been a 925% increase in built up area from 1973 to 2013 leading to a sharp decline of 79% area in water bodies in Bangalore mostly attributing to intense urbanisation process. The increase in urban built up area ranges from 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) to 126.19% (2006 to 2010). The gradient analysis showed that Bangalore grew radially from 1973 to 2010 indicating that the urbanization is intensifying from the city centre and has reached the periphery of the Bangalore. The temperature profile analysis by overlaying the LST on the land use reveal of higher temperatures in urban area while vegetation and water bodies aided in moderating temperature at local levels (evident from at least 2 to 2.5 °C lower temperature compared to urban pockets).

Frequent flooding in the city is a consequence of the drastic increase in impervious area (of 925% in 4 decades) and loss of wetlands (and interconnectivity of wetlands) with the high-density urban developments. The uncoordinated pattern of urban growth is attributed to a lack of good governance and decentralized administration, which was evident from the lack of coordination among many Para-state agencies. This has led to unsustainable use of the land and other resources. The mitigation of frequent floods and the associated loss of human life and properties entail the restoration of interconnectivity among wetlands, restoration of wetlands (removal of encroachments), conservation, and sustainable management of wetlands.

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2.0 FOUL ODOUR IN SANKEY LAKE: CAUSAL FACTORS AND REMEDIAL MEASURES

Status	Contaminated water, sediment and air
Cause	1. Sustained inflow of untreated or partially treated sewage; 2. Encroachment of lakebed, flood plains, and lake itself; 3. Loss in lake interconnectivity - Encroachment of rajakaluves / storm water drains and loss of interconnectivity; 4. Lake reclamation for infrastructure activities; 5. Topography alterations in lake catchment; 6. Removal of shoreline riparian vegetation; and unabated construction activities in the valley zone has threatened these urban wetlands. 7. Pollution due to enhanced vehicular traffic; 8. Too many para-state agencies and lack of co-ordination among them. 9. Too many para-state agencies and too less governance
Solution	• Good governance (too many para-state agencies and lack of co-ordination) • Single agency with the statutory and financial autonomy to be the custodian of natural resources (ownership, regular maintenance and action against polluters (encroachers as well as those contaminate through untreated sewage and effluents, dumping of solid wastes) • Digitation of land records (especially common lands – lakes, open spaces, parks, etc.) and availability of this geo-referenced data with query based information system to public. • Removal of encroachment near to lakes after the survey based on reliable cadastral maps; • Effective judicial system for speedy disposal of conflicts related to encroachment; • To make land grabbing cognizable non-bail offence; • Letting off only treated sewage into the lake (as in jakkur lake model); • Regular removal of macrophytes in the lakes; • Implementation of ‘polluter pays’ principle as per water act 1974; • Plant native species of macrophytes in open spaces of lake catchment area; • Aeration will help in maintaining high dissolved oxygen levels and likely reduction in toxic effect. • Stop solid wastes dumping into lakes; Ensure proper fencing of lakes; • Complete ban on construction activities in the valley zones. • Regular monitoring of the lake for assessing its water quality and for taking precautionary measures. • Avoid entry of sewage into the lake, which brings in excess nutrients that induces profuse algal growth. • Leave only treated sewage through construction wetlands and algal ponds (to remove nutrients)

	• Removal of sediments accumulated over a period, which is rich in the phosphorus (P), nitrogen (N) and carbon (C). • The harvesting and removal of cyanobacterial biomass during the early morning (when the algal scum is concentrated and at the top layer of water) through fine pore nets and pumping of the concentrated scums. • Introduction of Herbivorous fishes like silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*). • Avoid sewage entry, throwing of solid wastes to the lake and frequent fish feeding by the local people. • Ensure proper evaluation of inflow to the lake and proper maintenance of outflow. • Public awareness and public participation is necessary.
The restoration and conservation strategies has to be implemented for maintaining the ecological health of aquatic ecosystems, aquatic biodiversity in the region, inter-connectivity among lakes, preserve its physical integrity (shorelines, banks and bottom configurations) and water quality to support healthy riparian, aquatic and wetland ecosystems. The regular monitoring of water bodies and public awareness will help in developing appropriate conservation and management strategies.	

FOUL ODOUR IN SANKEY LAKE: CAUSAL FACTORS AND REMEDIAL MEASURES

Mitigation of deterioration of aquatic ecosystems integrity requires regular monitoring of the physico-chemical and biological characteristics of fresh water bodies, which helps in evolving appropriate management strategies. Physico-chemical parameters of Sankey lake in Bangalore District, Karnataka, India monitored since December, 2012. The various water quality parameters analyzed were water temperature, pH, electrical conductivity, total dissolved solids, dissolved oxygen, nitrate, orthophosphate, total alkalinity, calcium and magnesium hardness, total hardness, chloride, chemical oxygen demand, sodium and potassium. Algae being the primary producers play an important role in aquatic ecosystems and aid as indicators of water pollution. The distribution and diversity of algae in a water body are dependent on the its integrity based on physical and chemical factors. The entry of sewage into Sankey lake had raised its nutrient levels. Three algal species belonging to Cyanophyceae, Chlorophyceae and Bacillariophyceae were found in Sankey lake. Though Cyanophycean members dominated throughout the study period, Chlorophycean members represented the most diverse group. Excessive growth of toxin producing *Microcystis* sp. and *Planktothrix* sp. were evident, which had suppressed the growth of other algal groups. The algal species like *Microcystis* sp., *Planktothrix* sp., *Chlorella* sp., *Scenedesmus* sp., and *Nitzschia* sp. are indicators of organic pollution. In order to understand the factors affecting the massive growth of Cyanophyceae in Sankey lake. Multivariate statistical technique PCA and CCA , reveal that COD, DO, sodium and potassium influenced the growth of Cyanophyceae. The massive growth of Cyanophyceae inhibited the growth of other algal genera. In order to avoid this profuse algal growth and to ensure a healthy aquatic ecosystem, effective and most appropriate control measures have to be taken. The taste and odour problems and fish death in Sankey lake can be tackled only by adopting measures for the efficient removal of cyanobacteria from the lake.

Aeration of Sankey lake and letting only treated sewage would minimize the instances of cyanobacteria bloom.

Keywords: Physico-chemical parameters, *Microcystis*, PCA, CCA, control measures.

INTRODUCTION

Wetlands: Bangalore Scenario: Wetlands are diverse and highly productive ecosystems providing array of goods and services to millions of people, either directly or indirectly. Wetlands function as *ecotones, i.e.,* transitions between different habitats and have characteristics of both aquatic and terrestrial ecosystems, supporting diverse flora and fauna. Wetlands include habitats partially submerged by water like marshes, swamps, ponds, lakes, reservoirs etc. (Ramachandra, 2005). The differences in wetland characteristics may be due to regional and local variations in climate, soil type, topography, hydrology, water chemistry, vegetation and other factors. The depth and duration of inundation differs greatly among wetlands and varies yearly within a single wetland type (Ramachandra and Rajinikanth, 2005).

In case of Bangalore, wetlands occupy about 4.8% of the geographical area (640 sq km) which covers both urban and non-urban areas. Bangalore has no natural wetlands but possess many man-made wetlands that were built for various hydrological purposes as well as for irrigation in agricultural lands (Ramachandra, 2001). The anthropogenic activities to a large extent impairs ecosystem functioning by bringing about changes in the physical, chemical and biological entities of aquatic ecosystems, causing a decline or degradation of ecosystem services and also loss of economic value of wetlands (Ramachandra et al., 2011). The temporal analysis of wetlands indicated a sharp decline of 58% in Greater Bangalore due to intense urbanization which was evident from a 466% increase in the built-up area of Greater Bangalore from 1973 to 2007 (Ramachandra and Kumar, 2008). Recent studies reveal 925% increase in built-up with 79% decline in water bodies and 78% decline in vegetation. About 54% of lakes were unauthorized encroached for illegal buildings. According to the field surveys (held during July - August 2007), nearly 66 % of lakes were sewage fed, 14 % surrounded by slums and 72% of lakes showed loss of catchment area. The lake catchments had become dumping yards for either municipal solid waste or building debris (Ramachandra, 2010).

Need for conservation of Aquatic ecosystems: Wetlands (lakes) are very complex and dynamic ecosystems that interact with the environment and connected to the hydrological cycle through both the inflows and outflows from surface and underground layers, as well as via evaporation or precipitation fluxes. These interactions with the local environment also include chemical constituents and mineral phases, transported from the catchment area to the lake. Thus, the lake experiences either an outflow of water or accumulation in the lake sediments (Mook, 2001).

Lake ecosystems, being the most productive ecosystems in the biosphere play a significant role in the ecological sustainability of the region. These habitats are of great human importance as they provide the essential components for the sustenance of life on earth, such as water (agriculture, drinking, etc.), food (protein production, fodder, etc), biodiversity (diverse flora and fauna), energy (fuel wood, etc), recreation (tourism), transport, water purification, pollutant sink, flood control and climate stabilizers (Ramachandra et al., 2003). Lakes and tanks also acts as sediment traps and prevent clogging up of natural valleys and reduce erosion by regulating run off (Sivakumar and Karuppasamy, 2008). Biological (biomass, population numbers and growth) characteristics of lakes depend on their physical (intensity of light, temperature and water currents), chemical (composition of nutrients, major ions and contaminants) characteristics (Ramachandra and Ahalya, 2001). The environmental impacts on wetlands are loss of wetland area, changes to water regime, changes in water quality, overexploitation of wetland products and introduction of exotic or alien species. The variations in quality and quantity of water have contributed to a decline in the biological diversity of flora and fauna, migratory birds, and productivity of wetland ecosystems. The improper management of point sources of pollution (such as letting untreated sewage and effluents) has lead to problems of pollution, eutrophication, invasion of exotic species and toxic contamination by heavy metals, pesticides and organic compounds (Ramachandra, 2001). The pressure of population growth and the need to satisfy human demand for water, food and energy had resulted in intensive exploitation of wetland (Karthick and Ramachandra, 2006). In order to regain and protect the physical, chemical and biological integrity of wetland ecosystems, implementation of appropriate management and restoration mechanisms are necessary. The management of wetlands requires an intense and periodic wetland monitoring, increased interaction and co-operation among the various para-state agencies (Ramachandra, 2001; Ramachandra, 2009a). The key recommendations for the better conservation and sustainable management of urban wetlands are:

1) Mapping of water-bodies
2) Demarcation of the boundary of water bodies
3) Carrying capacity studies for all macro cities
4) Holistic and integrated approaches – conservation and management
5) Documentation of biodiversity
6) Preparation of management plans for individual water bodies
7) Implementation of sanitation facilities
8) Management of polluted lakes
9) Restoration of lakes
10) Valuation of goods and services
11) Regulation of boating
12) Protection of riparian and buffer zone vegetation
13) Restoration of linkages between water bodies
14) Rainwater harvesting
15) Protection of sacred grove-water body system

16) Environment Education
17) Adopt Inter-disciplinary Approach

Sankey Lake: A case study:

Sankey Lake is an artificial tank or lake, built by Col. Richard Hieram Sankey of the Madras Sappers Regiment in the western part of Bangalore city, Karnataka in the year 1882, to meet the water supply demands of Bangalore. It is located closely to the middle of the suburbs of Vyalikaval, Malleshwaram and Sadashivanagar. The lake covers a total area of about 42.76 acres of land and catchment area of 1.254 km (0.8 mile) with one island within its premise. At its widest, the lake has a width of 800 m (2,624.7 ft) and a maximum depth of 9.26 m (30.4 ft). The Sankey Lake was earlier known as Gandhadhakotikere since the Government Sandalwood Depot is located close to the lake (Ravikumar et al., 2013). Bangalore Water Supply and Sewerage Board (BWSSB) and Bruhut Bengaluru Mahanagara Palike (BBMP) had now changed Sankey Lake from a reservoir to a park. Sankey Lake also includes a park and a swimming pool toward its south, along with a Forest Department nursery in the northern direction and an exclusive tank for idol immersion during Ganesh Chaturthi festival (Ravikumar et al., 2013). The importance of Sankey Lake lies in maintaining the ground water level in its surrounding areas, that includes Malleswaram, Palace Orchards, Rajamahal Vilas, Vyalikaval, Palace Guttahalli and Yeshwanthpur. The study of morphology, hydrodynamics and sedimentation of the lake showed that the water percolating through the soil is not lost but helps in recharging the natural underground reservoir, which in turn, supplies water to the wells and bore wells in the nearby areas. This lake has great fish potential, supports human needs and contributes to climatic stability. It harbors a rich biodiversity that includes aquatic plants, birds, fishes, and microbes (Benjamin et al., 1996).

The Sankey Lake is a perfect example for a stagnant water bodywith more complex and fragile ecosystems compared to running water bodies as they lack self-cleaning ability (Patel and Patel, 2012). The contamination of water in Sankey Lake accounts to sewage inflow from seven points that are connected to storm water drains, choking of drains with sewage and garbage and also leakage of sewage pipes connected to the toilet at park area. These contaminants degrade the quality of water and in turn affect the aquatic life (Ravikumar et al., 2013). Water bodies get enriched with nutrients when, partially treated or untreated sewage enters the lakes, resulting in obnoxious algal blooms (Mahapatra et al., 2012). This brings about variations in different physico-chemical and biological characteristics of water bodies.

Nutrient enrichment affects water quality and phytoplankton growth: The water quality, especially the nutrients influence the abundance and diversity of phytoplankton. The physico-chemical characteristics play an important role in the assessment of water quality and trophic status of a water body. The phytoplankton survey also indicates the trophic status and the presence of organic matter in the ecosystem (Ramachandra and Solanki, 2007). Cyanobacterial dominance in lakes is an increasing problem that affects ecosystem integrity, recreation, human and animal health (Downing et al., 2001). Cyanobacteria, also known as blue-green algae includes single-celled algae that proliferate in water bodies such as ponds, lakes, reservoirs, and slow-moving streams when the water is warm and essential nutrients are available (Butler et al., 2009). A number of environmental factors influence the growth of cyanobacteria cells. These include quality and quantity of light, temperature, pH, nutrient conditions, such as nitrate and phosphate levels, dissolved oxygen, iron concentration and the salinity of the surrounding environment (Sember, 2002). The excessive growth/bloom formation of cyanobacteria persists in water bodies that contain adequate levels of essential inorganic nutrients such as nitrogen and phosphorus and increased levels of organic matter. Other important physical factors that determine the sensitivity of aquatic ecosystems to nutrient impacts are water residence time, temperature, mixing rates and turbidity (Sember, 2002).

Taste and odour problems in lakes: The primary sources of taste and odor problems in drinking water are algae and bacteria. Taste and odour (T&O) problems due to the release of several odorous compounds (above the threshold level) are frequently recorded during cyanobacterial bloom in natural waters. There are four basic taste types: sour, sweet, salty and bitter. The environmental factors such as nutrient concentrations, water clarity, water temperature and pH favor cyanobacterial blooms and thus, trigger T&O emissions. These odorous compounds can affect water supplies, decrease the aesthetic quality and consumer acceptability of drinking water, and increase the costs of water treatment. This necessitates the identification and quantification of these odorous compounds (Ma et al., 2013). The earthy and musty odours generated by Geosmin (trans-1, 10-dimethyl-trans-9-decalol) and MIB (2-methylisoborneol) are common odorous chemicals. Actinomycetes and cyanobacteria produce geosmin and MIB. Green algae blooms produce a grassy or fishy odor. Golden-brown algae (*Synura* sp.) can produce a cucumber, melon, or fishy odor. Biological activity in surface waters can produce 2,4-heptadienal and decadienal, which have a fishy, rancid odour. In addition, dissolved metals such as zinc, manganese, copper, and iron can produce a metallic taste. Other odorous sulfur compounds produced from blue-green algae blooms are methyl mercaptan, dimethyl sulfide, isobutyl mercaptan, and n-butyl mercaptan. Decaying vegetation (of algae, leaves, and aquatic weeds) is another source of odour in lakes. Bacterial activities in relation to mineral matter are the chief causes of tastes and odours. Iron bacteria are responsible for tastes and odours in groundwater as well as in water supplies. Sulfate-reducing bacteria are responsible for the production of odoriferous compounds, namely hydrogen sulfide (emits a rotten egg odour). Microcrustacea can produce intense fishy tastes and odours in small reservoirs. *Daphnia, Ceratium*, *Condonella* and *Anurea* when, in large numbers may impart a fishy odour to water (Lin, 1977). The odours produced by organic compounds from the wastes of industries, cities, and agricultural activities affects public water supplies, food chain, and causes off-flavours in fish flesh, and is toxic to fish and causes taste and odour problems (Lin, 1977). The decay of cyanobacterial blooms causes an anoxic water condition, increases nutrient loading and releases higher concentrations of volatile organic sulfur compounds such as DMTS (dimethyl trisulfide) and DMS (dimethyl sulfide) to the lake water. The concentration of taste and odour compounds in the water column changes with varied pH, DO, TN, TP, and NH_4^+-N. Thus, preventing anaerobic decomposition of cyanobacterial blooms is an important strategy against the recurrence of a malodor crisis in Lake Taihu (Ma et al., 2013).

Bloom formation and toxin production by algae: *Microcystis* sp.: *Microcystis* is a commonly found planktonic freshwater cyanobacterium that forms mass developments in surface waters used for recreation and as drinking water source (Ordorika et al., 2004). The growth of *Microcystis* produces bad-smelling and unsightly scum, preventing recreational use of water bodies, clogging irrigation pipe and hampering the treatment of water for drinking purposes (Yoshinaga et al., 2006). The colonies of *Microcystis* sp. are microscopic to macroscopic that are characterized by irregularly agglomerated spherical cells with colourless mucilage. The cell division occurs mainly in three different planes that are perpendicular to one another in successive generations. The daughter cells formed will be hemispherical, which later on grows into spherical form before the next cell division (Komarek and Komarkova, 2002; Visser et al., 2005). During the dominance of *Microcystis* sp., colonies appear largely within the epilimnetic and metalimnetic zones of water bodies (Reynolds and Rogers, 1976).

The *Microcystis* colonies are present in large numbers in the sediments during winter and spring. When *Microcystis* dies, the toxin microcystins releases into the water. Upon ingestion, fishes, birds and mammals actively absorb toxic microcystins. Microcystin primarily affects the liver, depending on the amount of toxin absorbed. The death of pets and livestock after drinking the water contaminated with microcystins was reported earlier, (Butler et al., 2009). Thus, the toxicity of *Microcystis* cells negatively affects phytoplankton, zooplankton and fish production either, directly or indirectly through the transfer or accumulation of toxins in the food web. *Microcystis* also affects aquatic community structure, mainly through impacts on feeding habits or food quality for zooplanktons and fishes. The profuse growth of cyanobacteria further affects total carbon production by causing a shift from large to small zooplankton species (Lehman et al., 2008).
The abundance of *Microcystis* sp in diverse water bodies attributes to: i) high nutrient loadings; ii) increased pH and decreased CO_2 conditions; iii) the interaction between light and stability of the water column; iv) tolerance of low O_2-concentrations and low redox potential affecting the availability of sulphur, iron and other metals; v) greater resistance to zooplankton grazing, either through size or toxicity; vi) a low N:P ratio; vii) superior competitiveness at high temperature; viii) ability to regulate buoyancy; ix) ability for phosphorus sequestration during sedimentary phase (Reynolds et al, 1981; Zohary and Breen, 1989; Dokulil and Teubner, 2000; Visser et al., 2005; Mc Carthy et al., 2009; Islam and Islam, 2012). In 1989, *Microcystis* sp. was dominant among algae in Sankey lake (Benjamin et al., 1996).

Fish death in lakes: Fish deaths in lakes occur due to variations in environmental and biological factors. The fish kill are common during a sudden change in temperature (thermal stress), oxygen depletions during summer and winter, vulnerable to diseases and parasite attacks and due to water pollution. In addition, fish deaths occur during prolonged cloudy weather, drought conditions, high ammonia concentrations and hydrogen sulphide, overcrowded fish population and excessive algae or other plant growth in lakes.

Fish death was reported in Ulsoor lake due to chemicals that flushed into the lake after cleaning of swimming pool, introduction of different varieties of fishes and due to phosphorus loading in the lake. The insufficient oxygen levels in water affects fish population as oxygen has a low solubility in water (0.5%) than in air (21%) and, diffusion of oxygen is slower in water than air. Fish death associated with stinking odour resembling rotten eggs, was characteristics of the presence of hydrogen sulphide (H_2S). H_2S (odour is perceptible in a dilution of 0.002 mg/l) is a colourless gas produced by respiration of certain bacteria and is highly toxic to most respiratory organisms with the ability to kill animals, plants and microorganisms in micromolar range by coming into contact with the respiratory enzyme, cytochrome *c* oxidase 7 (Maheshwari, 2005). The fish kill in Sankey lake (*Etroplus suratensis*, *Chanda ranga*, *Puntius* sp., *Nandus nandus* and *Amblypharyngodon mola*) during June – July, 1995 was due to sudden fall in DO levels in some locations (at sewage inlet) resulting in asphyxiation, not due to infection (Benjamin et al., 1996).

OBJECTIVE OF THE STUDY

- The primary goal of this study was to assess the physico-chemical characteristics of water in Sankey lake and identify the algal population present in the Lake.
- Understanding the prevailing taste and odour problems and fish death at Sankey lake.
- To understand the growth conditions of the abundant algae present and the various control measures taken so far to prevent cyanobacterial blooms.

MATERIALS AND METHODS

Study Area: Bangalore has three major watersheds, namely the Hebbal Valley, Vrishabhavathi Valley and the Koramangala and Challaghatta Valleys. There are two rainy periods in Bangalore i.e. from June to September (South-West Monsoon) and November to December (North-East Monsoon). The mean annual total rainfall in Bangalore is about 880 mm with about 60 rainy days a year over the last ten years. The summer temperature ranges from 18°C – 38°C, while the winter temperature ranges from 12°C – 25°C (Ramachandra et al., 2012). The Sankey Lake, situated in western part of Bangalore, Karnataka (India) is a man-made lake or tank. It lies in the Vrishabhavathi valley (Lat.:13° 00’24”-13° 00’41”N; Long.:77° 33’53”-77° 34’5”E (figure 2.1); altitude: 929.8 m MSL; maximum water spread area: 17.2 ha; maximum depth: 30.4 ft; average depth: 9 ft). It is a 500 year old, perennial water body and supports a significant biotic community (Benjamin et al., 1996).

Water Sample Collection: Water samples were collected from the three different sites in polypropylene bottles for a period of four months from December, 2012 to March, 2013 for the analysis of physico-chemical parameters and phytoplankton identification. The Site 1(S1; Inflow end), Site 2 (S2; rear end) and Site 3 (S3; opposite to raw sewage wet well) were the sampling locations chosen in the Sankey Lake and the sampling were done between 7:30 to 9:00 a.m. All samples were taken to the laboratory for further analysis.

Algal Identification and Enumeration: Phytoplankton samples collected from the surface water of Sankey lake at S1, S2 and S3 were identified (table 2.1) and counted microscopically. 100 ml of sample were collected from the selected locations. About, 15 ml of the sample was centrifuged at 3000 rpm at room temperature. From the concentrate, ~ 20 µl of the sample was transferred to glass slide, identified and counted under light microscope (Trivedy and Goel, 1986). The algal species were identified based on their key morphological features, according to Prescott (1954) and Desikachary (1959).

Table 2.1: Different sampling locations in Sankey lake

No.	Sites	Latitude	Longitude
1	S1	13°00'32" N	77° 34'31" E
2	S2	13° 00' 41" N	77°34' 29" E
3	S3	13° 00' 29" N	77° 34' 21" E

Analysis of Physico-chemical Parameters: The water quality parameters like water temperature, pH, electrical conductivity, total dissolved solids and dissolved oxygen (DO) were determined on site during sampling. Other parameters like total alkalinity, calcium and magnesium hardness, total hardness, chlorides, nitrate, orthophosphate, chemical oxygen demand (COD), sodium and potassium were analyzed using standard methods prescribed by Trivedi and Goel (1986), APHA (1998).

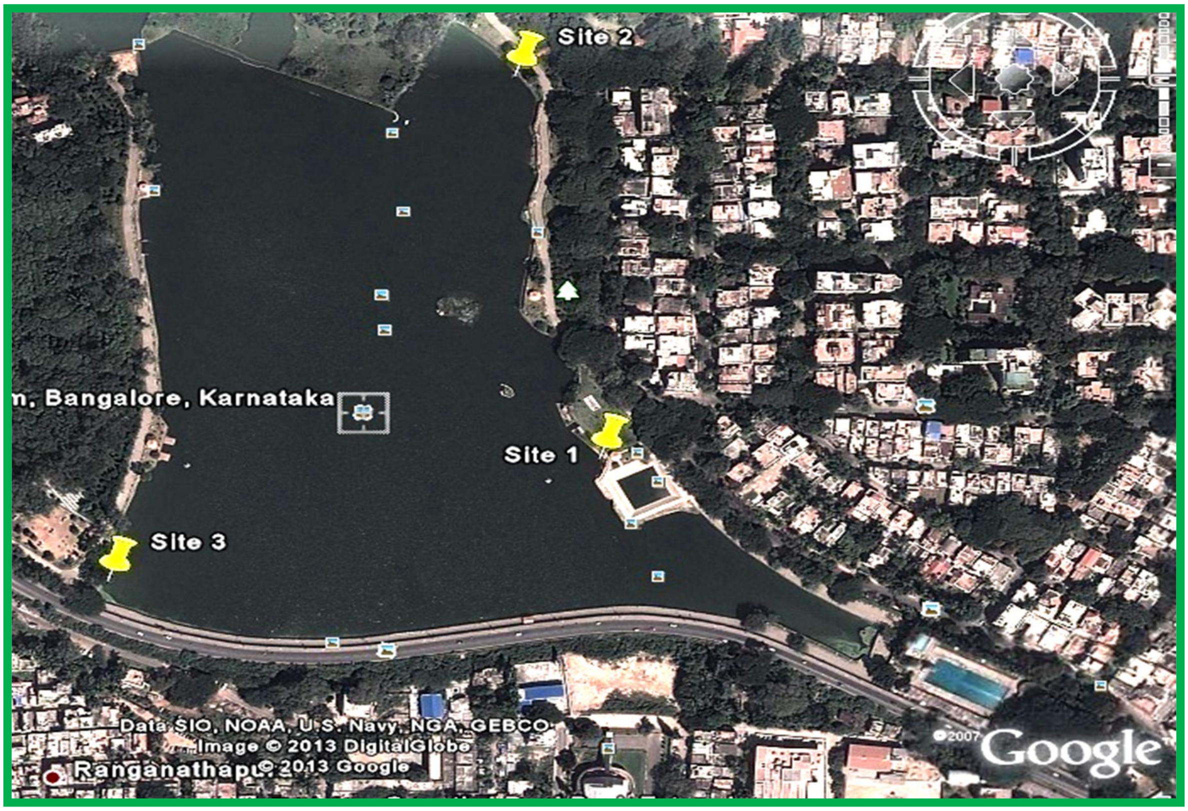
Statistical Analysis: The correlation coefficient was calculated to understand the relationship among different physico–chemical parameters. Correlation gives the mutual relationship between two variables. The correlation is said to be positive when increase in one parameter results in the increase of the other. The negative correlation occurs when the increase in one parameter causes the decrease in the value of the other. To find the relationship between two parameters x and y, the Karl Pearson's correlation coefficient, r is used and it is determined as follows

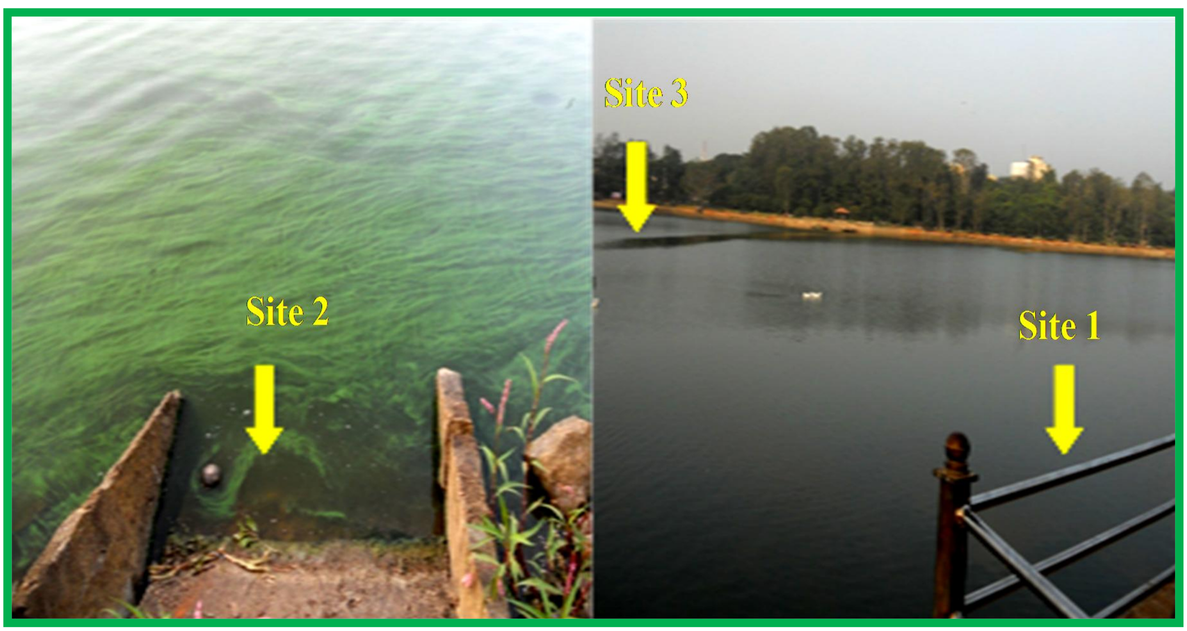
$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

where, n = number of data points ; x = values of x–variable; y = values of y–variable.

The water quality data sets were also subjected to multivariate techniques like principal component analysis (PCA) and canonical correspondence analysis (CCA). All the statistical computations were made using PAST3 software.

Figure 2.1: Sankey Lake, Bangalore, Karnataka, India





RESULTS AND DISCUSSION

Physico-chemical characteristics: The physico-chemical parameters play an important role in estimation of the constituents in water and the concentration of pollutants in water. Some parameters like temperature, dissolved oxygen, turbidity, hardness, alkalinity and nutrients (nitrogen and phosphorus) are the determinants of profuse growth of phytoplanktons. On contrary, parameters like biological oxygen demand and chemical oxygen demand indicates the pollution load in an aquatic ecosystem (Khanna et al., 2010). The interaction of both physical and chemical properties of water plays a significant role in composition, distribution and abundance of aquatic community. The water quality parameters of the three samples (S1, S2 and S3) collected from Sankey Lake have been presented and discussed with reference to their seasonal variations (figures 2.2 and 2.3).

Temperature: Temperature plays an important role in the wetland ecosystem, since it regulates the various physico-chemical as well as biological activities. The temperature of surface waters is influenced by climate, season, latitude, altitude, air circulation, cloud cover, flow, depth of water body and also the time of sampling, thereby, affecting various parameters like pH, alkalinity, dissolved oxygen, electrical conductivity etc. (Parashar et al., 2006; Savitha and Yamakanamardi, 2011). All these parameters in turn affect the various chemical and biological reactions such as solubility of oxygen, carbondioxide, carbonate – bicarbonate equilibrium, and increases the metabolic rate. The seasonal change in the productivity of a water body is related to the variation in temperature and photic conditions (Rani and Sivakumar, 2012). The water temperature did not vary much between sites during the four months study. It varied as 21.3˚C (January) – 26.2˚C (March) at S1; 21.23˚C (January) – 26.4˚C (March) at S2 and 21.8˚C (December) – 26.5˚C (March) at S3. The temperature increased towards the summer at all the three sites. The higher water temperature noted at all the sites during summer was due to reduction in the water level because of increased evaporation, high solar radiation and atmospheric temperature (Puri et al., 2010).

pH: pH indicates the measure of acidity or alkalinity of a solution and measures the concentration of hydrogen ions in water. The three main processes affecting the pH of aquatic ecosystems are photosynthesis, respiration and nitrogen assimilation. pH is also governed by the equilibrium between carbondioxide or bicarbonate or carbonate ions. It increases largely due to photosynthesis (uptake of carbondioxide) and lowers down during increased respiration (release of carbondioxide) (Ramachandra and Ahalya, 2001). The pH was alkaline throughout the study period. The pH varied from 9 (February) - 9.5 (January) at S1; 9 (March) - 9.8 (January) at S2 and 8.9 (March) - 10.3 (December) at S3. The highest pH (10.3 in December) was due to low water levels and increased photosynthetic activity. A decreased pH in March was due to decreased algal biomass and comparatively lesser rate of photosynthesis as evident during the study period. The desirable limit of pH recommended by Drinking Water Specification Indian Standard - IS 10500: 1991 is 6.5-8.5.

Electrical Conductivity (EC): EC is the measure of the ability of an aqueous solution to conduct an electric current. This ability depends upon the presence of ions, their total concentration, mobility and temperature. The greater the conductivity greater is the amount of ions such as calcium, magnesium, sodium, chloride, sulphates, bicarbonates and carbonates in water (Kumar and Oommen, 2011). High conductivity may arise through natural weathering of certain sedimentary rocks or may have an anthropogenic source, e.g. sewage effluent (Alobaidy et al., 2010). The electrical conductivity values at different sites were recorded as 446.67 (January) - 493 µS/cm (December) at S1, 447(January) - 504 µS/cm (December) at S2 and 420.33 (January) - 501 µS/cm (December) at S3. In the present study, the conductivity declined little bit in month of January and increased towards March, due to dilution of lake water with sewage water inflow in January and increased rate of evaporation during March.

Total dissolved solids (TDS): TDS is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The increase or decrease in TDS may be attributed to the concentration of principal constituents that are usually calcium, magnesium, sodium, and potassium cations and carbonate, bicarbonate, chloride, sulfate, and nitrate anions (Chandra et al., 2012). The TDS at S1 varied from 198.33 (January) - 220 mg/l (December). The values at S2 ranged between 197.67 (January) - 228 mg/l (December), while at S3 between 197 (January) - 224mg/l (December).

Dissolved oxygen (DO): Dissolved oxygen is another vital parameter regulating growth and survival of aquatic life. The dissolved oxygen content in water varies with temperature, turbulence, salinity, photosynthetic activity of aquatic plants and the atmospheric pressure. DO in water affects the oxidation – reduction state of many other chemical compounds such as nitrate and ammonia, sulphate and sulphite, and ferrous and ferric ions (Trivedy and Goel, 1986). The lower concentration of DO in water attributes to addition of effluents containing oxidizable organic matter and consequent biodegradation and decay of vegetation at higher temperature leading to consumption of oxygen from water (Thakor et al., 2011). It varied as 6.9 (February) - 14.92mg/l (January) at S1, 4.9 (December) - 17.25 mg/l (January) at S2 and 5.71 (February) - 18.78 mg/l (January) at S3. Low DO levels during summer may be due to higher temperature, affecting the solubility of oxygen in water (Verma and Singh, 2010); increased oxygen demands of fishes and increased bacterial decomposition of dead aquatic plants and algae (Gandhi, 2012). The variations in DO concentration in lake are directly relating with the abundance and diversity of prevailing phytoplankton (Verma et al., 2012).

Chemical oxygen demand (COD): Chemical Oxygen Demand (COD) measures the oxygen equivalent of the organic and inorganic matter in a water sample that is susceptible to oxidation. COD indicates the extent of pollution in water, determined by the various organic and inorganic materials like calcium, magnesium, potassium, sodium, and so forth (Ramachandra, 2001). The COD at S1 varied from 12 (March) – 360 mg/l (January). The COD values at S2 ranged between 16 (March) – 680 mg/l (January), while at S3 between 8.0 (March) – 440 mg/l (January). The higher values of COD in lakes create turbid conditions. Higher turbidity shows the presence of higher concentrations of organic and non-biodegradable components in the lake water that requires larger amounts of oxygen for the decomposition process (Sharma and Capoor, 2010).

Sodium and Potassium (Na and K): Sodium is ubiquitous in natural waters and in plant and animal matter. It is present in the ionic form, which is highly soluble in water. The concentration of sodium in surface waters (inclusive of the lakes having sewage inflow) is usually below 50 mg/l

(Ramachandra and Ahalya, 2001). The sodium values varied from 21.6 (January) -122.8 mg/l (March) at S1, 87.6 (February) -156.8 mg/l (March) at S2 and 98.8 (December) -144.8 mg/l (March) at S3. Potassium (in ionic form) is readily soluble in water and also incorporated into minerals and accumulated by aquatic biota in aquatic ecosystems. The concentration of potassium in surface waters is usually less than 10 mg/l (Ramachandra and Ahalya, 2001). The potassium values varied from 12.4 (February) -35.6 mg/l (January) at S1, 14.4 (February) -28.8 (January) mg/l at S2 and 12.4 (February) - 23.6 (January) mg/l at S3. The Sankey lake had high concentrations of sodium and potassium (above the permissible limits), which indicates sewage contamination.

Total Alkalinity (TA): Alkalinity is primarily a function of carbonates, bicarbonates and hydroxides content in water. Borates, phosphates, silicates and other bases also contribute towards alkalinity. It is the measure of capacity of water to neutralize a strong acid. A higher value of total alkalinity indicates the high trophic status of the lake. It is estimated that the high productive waters generally have total alkalinity above100 mg/l (Rao et al., 2010).The total alkalinity throughout the study period was observed as 130 (February) -160 mg/l (March) at S1, 136(February) -156 mg/l (December) at S2 and 140 (December) -174 mg/l (January) at S3. The high alkalinity attributes to the increased rate of organic decomposition during which, carbon dioxide releases and then reacts with water to form bicarbonates, thereby, increasing the total alkalinity of the aquatic body (Shinde et al., 2011).

Chloride: Chloride is one of the most important parameter in assessing the water quality**.** High chloride contents in freshwater is an indicator of high organic pollution (Savitha and Yamakanamardi, 2011). The salts of sodium, potassium and calcium contribute chlorides in water. The discharge of sewage wastes result in high chloride level in fresh water (Mohanta and Potra, 2000). The chloride concentration was observed as 60.35 (January) - 68.16 mg/l (March) at S1, 63.9 (January) - 70.29 mg/l (March) at S2 and 63.9 (December) - 70.29 mg/l (March) at S3. The chloride content in all the three sampling sites of the Sankey lake during the study period was within the permissible limit of 250 mg/1. Higher chloride content towards summer was due to the high atmospheric temperature and increased rate of evaporation.

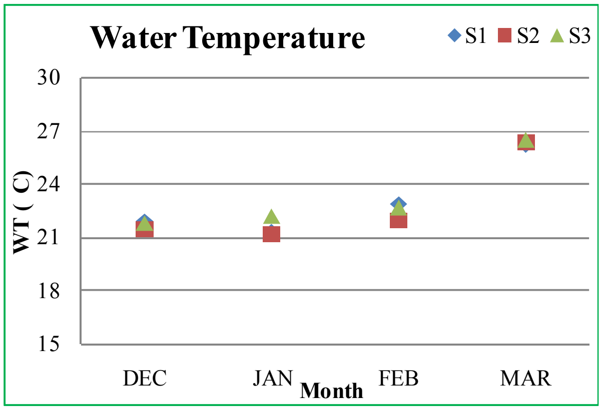
Total hardness (TH), Calcium hardness (CaH) and Magnesium hardness (MgH): Hardness is caused by the presence of calcium and magnesium ions (bivalent cations) in water. The polyvalent ions of some other metals like strontium, iron, aluminium, zinc and manganese, etc. contributes to hardness in fresh water ecosystems (Ramachandra and Solanki, 2007). The average total hardness in Sankey lake was observed as 91 (January) - 94 mg/l (December and March) at S1, 91 (January) - 106 mg/l (December) at S2 and 87 (December) - 98 mg/l at S3 (January). The addition of sewage might be the cause of increased levels of hardness (Mohanta and Potra, 2000). The increased photosynthetic activity, loss of CO_2 and precipitation of calcium carbonate increases the water temperature and contributes to the depletion of calcium (Chapman, 1992). The values of calcium hardness varied at all sites: 14.43 (March) - 24.85 mg/l (December) at S1, 13.63 (March)

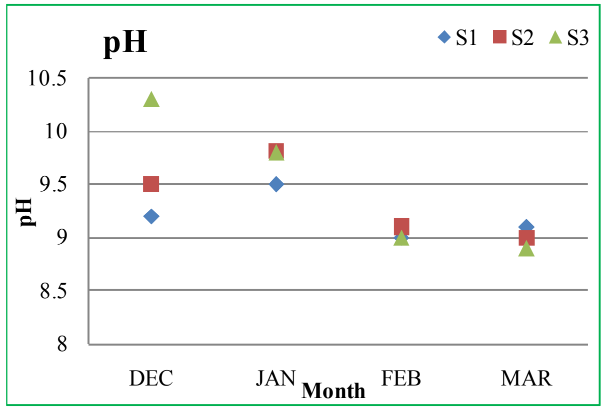
- 24.05 mg/l (December) at S2 and 12.83 (March) - 22.45 mg/l (December) at S3. Magnesium is essential for chlorophyll growth and acts as a limiting factor for the growth of phytoplankton. Therefore, depletion of magnesium reduces the number of phytoplankton population. The monthly value of magnesium hardness in Sankey lake was 16.8 (December) - 19.34 mg/l (March) at S1, 18.71 (January) - 19.91 mg/l (December) at S2 and 18.02 (March) - 20.02 mg/l (January) at S3.

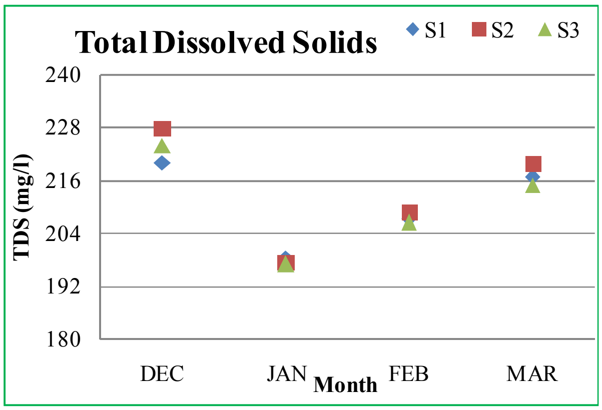
Nitrate: Nitrate is the most highly oxidized form of nitrogen compounds commonly present in water bodies. It is the product of aerobic decomposition of organic nitrogenous matter. The nitrate levels varied from 0.038 (March) - 0.399 mg/l (February) at S1, 0.036 (March) -0.553 mg/l (December) at S2 and 0.032 (March) -0.505 mg/l (January) at S3. The inflow of sewage to the Sankey lake increased the nitrate level and in turn had enhanced the productivity of the system. A drop in the nitrate levels was evident at all the sites in March, due to profuse growth of algae. The higher concentration of nitrate may be due to the higher phytoplanktonic production, decaying phytoplankton and concentration of nutrients because of the increased evaporation of lake water. The nitrogen levels (as nitrates) indicate the trophic status of the water bodies. Higher concentration of nitrates is an indicator of organic pollution and eutrophic conditions (Mahapatra et al., 2011; Rao et al., 2010).

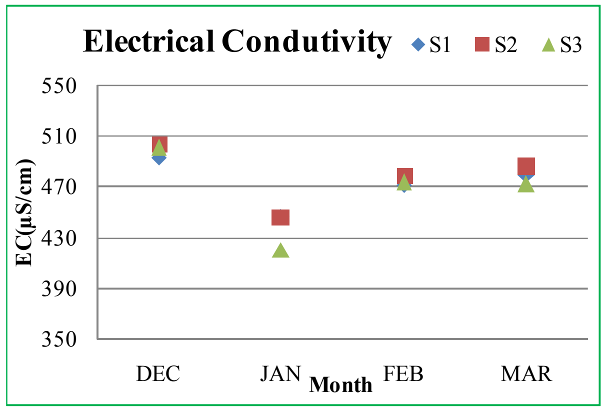
Ortho-phosphate (OP): Phosphorus controls algal growth and productivity as it acts as a limiting nutrient in aquatic ecosystems. Excess amounts of phosphorus along with nitrates and potassium in fresh water ecosystems leads to excessive algal growth (Ramana et al., 2008). Ortho-phosphate is the form of phosphorus that is readily soluble in water and directly utilized by aquatic biota for their growth and reproduction. The phosphate values varied from 0.028 (December) -0.087 mg/l (February) at S1, 0.025 (December) -0.082 mg/l (February, March) at S2 and 0.032 (February) - 0.12 mg/l (January) at S3. The decrease in phosphate content towards March is due to increased utilization of phosphate by the phytoplankton present in the lake. Table 2.2 lists surface water standards for various categories.

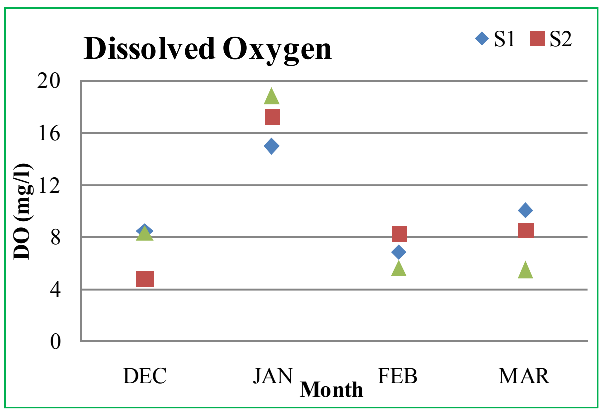
Figure 2.2: Physico-chemical parameters of Sankey lake at S1, S2 and S3 (December-March)

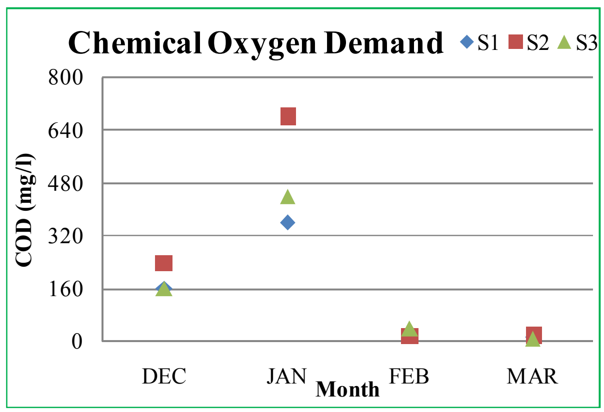

Water Temperature
S1 S2 S3
30
27
24
21
18
15
WT (C)
DEC JAN FEB MAR
Month

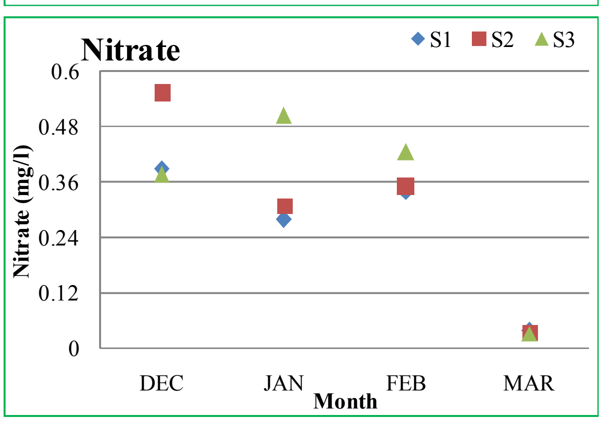

pH
S1 S2 S3
10.5
10
9.5
9
8.5
8
pH
DEC JAN FEB MAR
Month

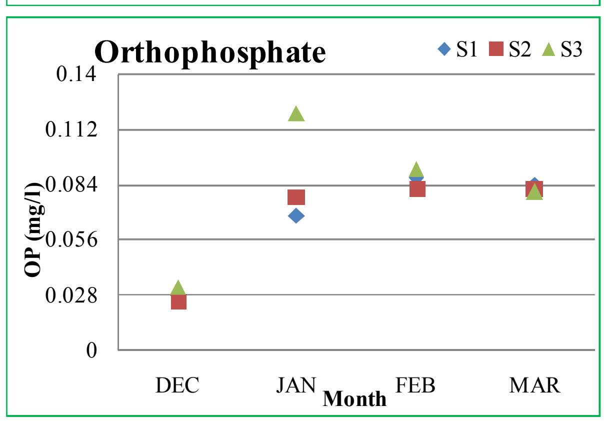

Total Dissolved Solids
S1 S2 S3
240
228
216
204
192
180
TDS (mg/l)
DEC JAN FEB MAR
Month

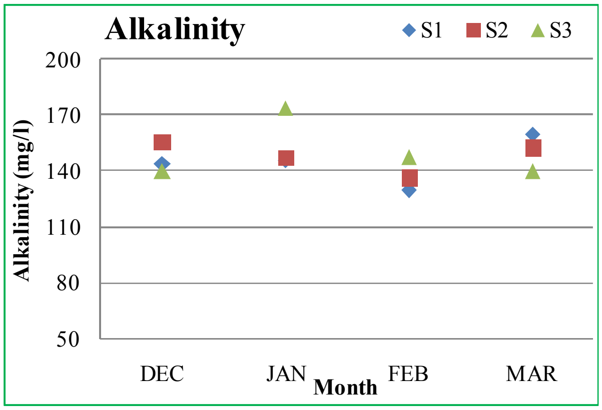

Electrical Condutivity
S1 S2 S3
550
510
470
430
390
350
EC(µS/cm)
DEC JAN FEB MAR
Month

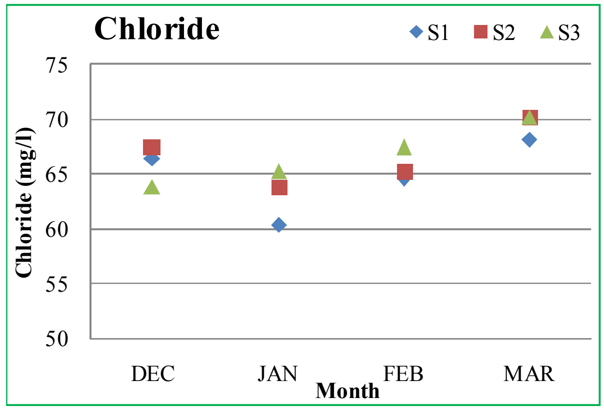

Dissolved Oxygen
S1 S2
20
16
12
8
4
0
DO (mg/l)
DEC JAN FEB MAR
Month

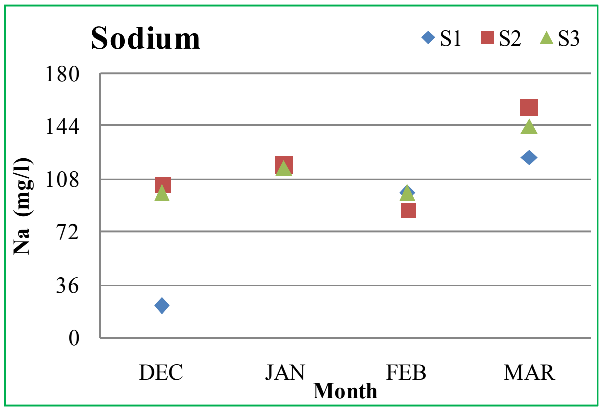

Chemical Oxygen Demand
S1 S2 S3
800
640
480
320
160
0
COD (mg/l)
DEC JAN FEB MAR
Month

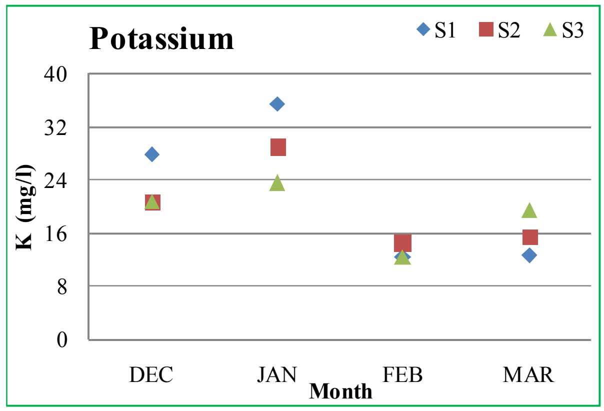

Nitrate
S1 S2 S3
0.6
0.48
0.36
0.24
0.12
0
Nitrate (mg/l)
DEC JAN FEB MAR
Month

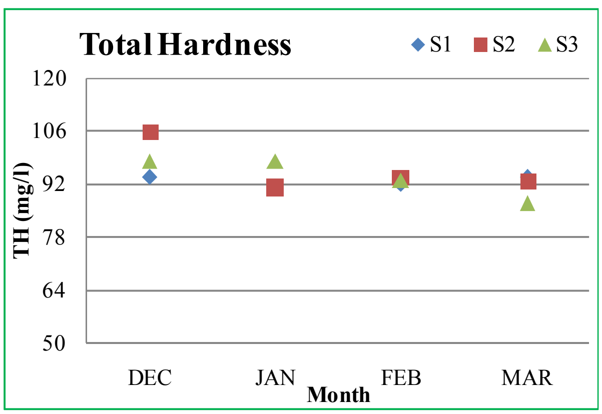

Orthophosphate
S1 S2 S3
0.14
0.112
0.084
0.056
0.028
0
OP (mg/l)
DEC JAN FEB MAR
Month

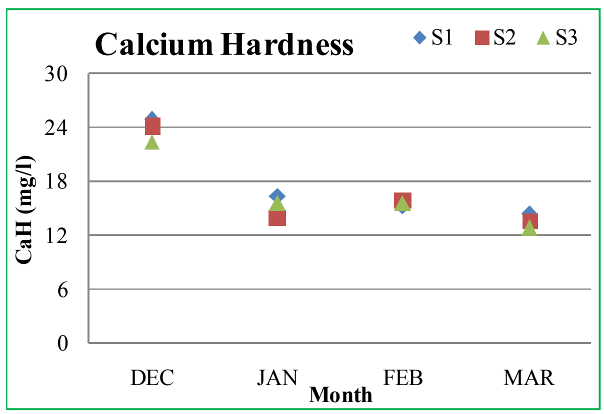

Alkalinity
S1
S2
S3
Alkalinity (mg/l)
200
170
140
110
80
50
DEC
JAN
FEB
MAR
Month


Chloride
S1
S2
S3
Chloride (mg/l)
75
70
65
60
55
50
DEC
JAN
FEB
MAR
Month


Sodium
S1
S2
S3
Na (mg/l)
180
144
108
72
36
0
DEC
JAN
FEB
MAR
Month


Potassium
S1
S2
S3
K (mg/l)
40
32
24
16
8
0
DEC
JAN
FEB
MAR
Month


Total Hardness
S1
S2
S3
TH (mg/l)
120
106
92
78
64
50
DEC
JAN
FEB
MAR
Month


Calcium Hardness
S1
S2
S3
CaH (mg/l)
30
24
18
12
6
0
DEC
JAN
FEB
MAR
Month

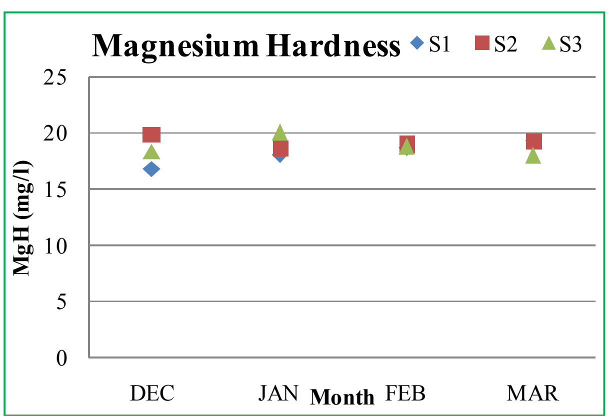

Magnesium Hardness
S1
S2
S3
MgH (mg/l)
25
20
15
10
5
0
DEC
JAN
FEB
MAR
Month

Table 2.2: Surface water quality standards (**IS: 2296**)

Sl No.	Parameter and Unit	Class A	Class B	Class C	Class D	Class E
		Drinking water without treatment but after disinfection	Water for outdoor bathing	Drinking water with conventional treatment followed by disinfection	Water for fish culture and wild life propagation	Water for Irrigation, industrial cooling and controlled waste disposal
1	pH (min : 6.5)	8.5	8.5	8.5	8.5	-
2	Conductivity (25°C) µS/cm	-	-	-	1000	2250
3	DO (mg/L)(minimum)	6	5	4	4	-
4	BOD (3d, 27°C) (mg/L)	2	3	3	-	-
5	Total Hardness (mg/L as $CaCO_3$)	300	-	-	-	-
6	Calcium (mg/L)	80.10	-	-	-	-
7	Magnesium (mg/L)	24.28	-	-	-	-
8	Chlorides (mg/L as Cl)	250	-	600	-	600
9	Nitrates (mg/L as NO_3)	20	-	50	-	-
10	Free NH_3 (mg/L as N)	-	-	-	1.2	-
11	Sodium Absorption Ratio	-	-	-	-	26

Correlation among different physico – chemical parameters: In order to understand the relationship among different physico–chemical parameters, correlation coefficient was calculated. The correlation coefficient showed that **at Site 1** (table 2.3), high positive correlation was found between water temperature and chloride; water temperature and MgH; pH and Na; EC and TDS; EC and chloride; EC and TH; TDS and TH; TDS and chloride; DO and COD; DO and K; COD and K; Na and MgH; Na and OP; chloride and TH; MgH and OP. High negative correlation was observed between water temperature and COD; water temperature and K; water temperature and nitrate; pH and EC; pH and TDS; pH and TH; pH and CaH; EC and DO; COD and chloride; Na and CaH; alkalinity and nitrate; CaH and MgH; CaH and OP; MgH and nitrate.

At Site 2 (table 2.4), high positive correlation was found between water temperature and chloride; water temperature and Na; pH and COD; pH and K; EC and TDS; EC and CaH; EC and TH; EC and MgH; TDS and chloride; TDS and TH; TDS and MgH; DO and COD; DO and K; COD and K; TH and CaH; TH and MgH; TH and nitrate; CaH and MgH; CaH and nitrate.

High negative correlation was observed between water temperature and pH; water temperature and nitrate; EC and DO; EC and COD; TDS and DO; DO and TH; DO and MgH; Na and nitrate; TH and OP; CaH and OP; MgH and OP; nitrate and OP.

At Site 3 (table 2.5), high positive correlation was found between water temperature and chloride; water temperature and Na; pH and TH; pH and CaH; EC and TDS; DO and COD; DO and K; DO and alkalinity; DO and MgH; COD and K; COD and alkalinity; COD and TH; COD and MgH; Na and chloride; alkalinity and MgH; alkalinity and OP; TH and CaH; TH and nitrate; MgH and nitrate; MgH and OP.

High negative correlation was observed between water temperature and pH; water temperature and TH; water temperature and CaH; water temperature and nitrate; pH and chloride; EC and DO; EC and COD; EC and alkalinity; EC and MgH; EC and OP; TDS and alkalinity; TDS and MgH; TDS and OP; Na and TH; Na and CaH; Na and nitrate; chloride and TH; chloride and CaH; chloride and nitrate; CaH and OP.

Algal Identification and Enumeration: The common algal species found in the Sankey Lake were Cyanophytes such as *Microcystis* sp., *Planktothrix* sp., *Merismopedia* sp.; Chlorophytes like *Scenedesmus* sp, *Ankistrodesmus* sp, *Chlorella* sp., *Cosmarium* sp, *Pediastrum* sp., *Tetraedron* sp., *Crucigenia* sp., *Monoraphidium* sp. and Bacillariophytes that includes both centric and pennate diatoms (*Nitzschia* sp., *Navicula* sp., *Cyclotella* sp.), listed in Table 2.6. The sampling site S2 harbored more algal species compared to the other two sites (S1and S3) as seen in figure 2.3.The site S2 supported more Cyanophyceae members with an average cell density of 37.15 x 10^6cell/l whereas S3 had more Chlorophyceae (average cell density of 25.3 x 10^6cell/l) and Bacillariophyceae (average cell density of 25.5 x 10^6cell/l) members. The algal species like *Microcystis* sp., *Planktothrix* sp.,*Chlorella* sp., *Scenedesmus* sp. and *Nitzschia* sp. are indicators of organic pollution thus, making water unfit for drinking and recreational purposes (Roselene and Paneerselvam, 2008). The presence of large population of algae in Sankey lake, especially in the month of January and March is due to an increase in photosynthetic activity, releasing a considerable amount of oxygen in water. The occurrence of bloom of *Microcystis* sp. indicates organic pollution. The factors affecting cyanobacterial bloom formation include light intensity and total sunlight duration, nutrient availability (especially phosphorus), water temperature, pH, water flow (whether water is calm or fast-flowing), an increase in precipitation events and water column stability (USEPA, 2012). Temperature also plays a major role in influencing the occurrence, periodicity and abundance of life (Sonawane, 2011).

Table 2.3. Correlation Coefficient among various physico-chemical parameters at sampling site 1 of Sankey lake

Parameters	WT^{0}C	pH	EC	TDS	DO	COD	Na	K	Alkalinity	Chloride	TH	Ca H	Mg H	Nitrate	OP
WT^{0}C	1														
pH	-0.006	1													
EC	0.355	-0.93	1												
TDS	0.485	-0.875	0.975	1											
DO	-0.276	0.621	-0.755	-0.627	1										
COD	-0.743	0.333	-0.634	-0.61	0.837	1									
Na	0.424	0.903	-0.69	-0.585	0.44	-0.02	1								
K	-0.772	0.085	-0.42	-0.405	0.726	0.968	-0.257	1							
Alkalinity	0.608	0.226	0.123	0.342	0.419	0.013	0.257	0.032	1						
Chloride	0.748	-0.662	0.886	0.931	-0.679	-0.824	-0.278	-0.687	0.381	1					
TH	0.578	-0.801	0.925	0.986	-0.522	-0.587	-0.479	-0.398	0.489	0.94	1				
Ca H	-0.505	-0.825	0.562	0.492	-0.193	0.246	-0.965	0.478	-0.115	0.144	0.411	1			
Mg H	0.747	0.627	-0.298	-0.202	0.032	-0.469	0.89	-0.657	0.291	0.163	-0.11	-0.951	1		
Nitrate	-0.876	0.12	0.038	-0.155	-0.221	0.339	-0.672	0.431	-0.809	-0.405	-0.301	0.634	-0.794	1	
OP	0.526	-0.307	-0.457	-0.419	0.012	-0.387	0.899	-0.607	-0.005	-0.058	-0.362	-0.982	0.949	-0.567	1

Table 2.4. Correlation Coefficient among various physico-chemical parameters at sampling site 2 of Sankey lake

Parameters	WT⁰C	pH	EC	TDS	DO	COD	Na	K	Alkalinity	Chloride	T H	Ca H	Mg H	Nitrate	OP
WT⁰C	1														
pH	-0.727	1													
EC	0.243	-0.506	1												
TDS	0.343	-0.416	0.965	1											
DO	-0.223	0.585	-0.987	-0.912	1										
COD	-0.58	0.958	-0.712	-0.601	0.787	1									
Na	0.845	-0.248	-0.031	0.181	0.122	-0.079	1								
K	-0.549	0.966	-0.637	-0.505	0.728	0.993	-0.026	1							
Alkalinity	0.216	0.292	0.35	0.573	-0.193	0.216	0.549	0.33	1						
Chloride	0.847	-0.658	0.68	0.784	-0.625	-0.663	0.696	-0.582	0.525	1					
T H	-0.29	0.106	0.799	0.795	-0.743	-0.171	-0.304	-0.087	0.523	0.262	1				
Ca H	-0.447	0.212	0.712	0.685	-0.666	-0.075	-0.445	-0.003	0.433	0.095	0.985	1			
Mg H	0.098	-0.144	0.909	0.957	-0.835	-0.371	0.05	-0.267	0.67	0.611	0.923	0.844	1		
Nitrate	-0.86	0.518	0.276	0.185	-0.272	0.263	-0.799	0.28	0.065	-0.463	0.732	0.838	0.414	1	
OP	0.39	-0.335	-0.644	-0.681	0.561	-0.07	0.268	-0.159	-0.631	-0.15	-0.969	-0.969	-0.862	-0.769	1

Table 2.5: Correlation Coefficient among various physico-chemical parameters at sampling site 3 of Sankey lake

Parameters	WT^{0}C	pH	EC	TDS	DO	COD	Na	K	Alkalinity	Chloride	TH	CaH	MgH	Nitrate	OP
WT^{0}C	1														
pH	-0.726	1													
EC	0.063	0.103	1												
TDS	0.157	0.261	0.93	1											
DO	-0.472	0.487	-0.819	-0.665	1										
COD	-0.571	0.597	-0.736	-0.585	0.99	1									
Na	0.911	-0.519	-0.244	-0.037	-0.082	-0.189	1								
K	-0.065	0.602	-0.401	-0.053	0.702	0.707	0.318	1							
Alkalinity	-0.409	0.192	-0.935	-0.888	0.931	0.892	-0.084	0.431	1						
Chloride	0.928	-0.93	-0.028	-0.063	-0.511	-0.624	0.771	-0.357	-0.317	1					
T H	-0.95	0.868	-0.175	-0.152	0.653	0.747	-0.749	0.374	0.507	-0.977	1				
Ca H	-0.719	0.87	0.53	0.556	0.036	0.173	-0.72	0.174	-0.213	-0.858	0.73	1			
Mg H	-0.565	0.275	-0.859	-0.856	0.912	0.893	-0.271	0.348	0.982	-0.446	0.626	-0.076	1		
Nitrate	-0.941	0.529	-0.353	-0.478	0.613	0.674	-0.815	0.028	0.646	-0.789	0.88	0.442	0.778	1	
OP	0.082	-0.44	-0.922	-0.971	0.555	0.451	0.255	0.034	0.797	0.288	-0.076	-0.735	0.727	0.256	1

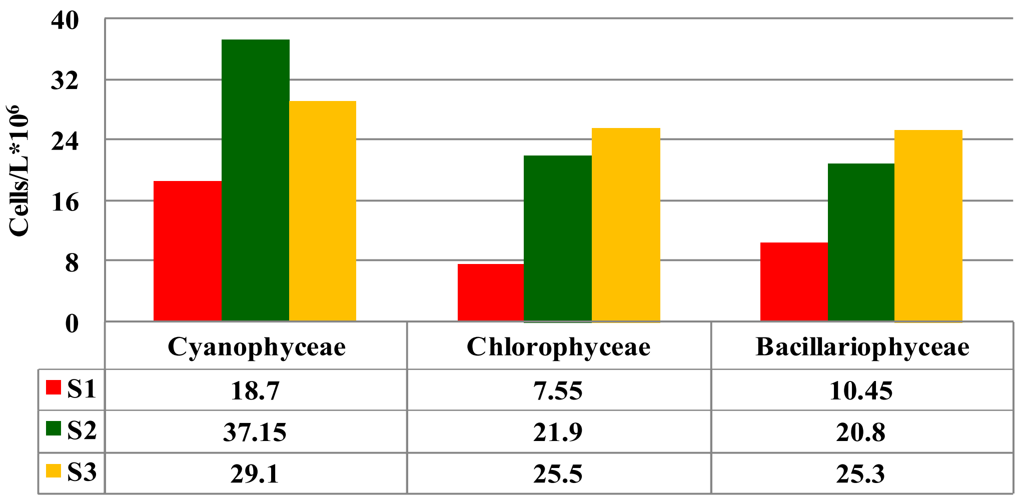
Aquatic organisms are affected by pH variations because most of the metabolic activities are pH dependent. Optimal pH range for sustainable aquatic life is pH 6.5 - 8.2. The main factors affecting pH are photosynthesis, respiration, temperature and entry of sewage (Verma et al., 2012). In the study conducted by Sincy et al. (2012), *Microcystis* grew well at temperature ranging between 21.9°C - 27.3°C and pH ranging from 7.9 - 9.68, which is in accordance with our study. The excessive growth of Cyanophycean members appeared in lakes when the phosphate and nitrate concentrations are present at moderate to high levels, especially during winter and summer months (Kumar and Oommen, 2011).The water bodies contaminated with sewage harbor more Cyanophycean members due to the presence of excessive amount of nutrients (N and P) in the system (Ansari et al., 2008). The high turbidity, pH, bicarbonate, orthophosphate, alkalinity and chloride may be responsible for the Cyanophyceae growth and bloom formation. The higher concentration of nitrate, calcium and phosphate in lakes are favorable for the growth of Chlorophytes (Tiwari and Chauhan, 2006). The concentration of nutrients present in water due to high evaporation rate towards and during summer promotes algal growth. The factors controlling distribution of Cyanophyceae are temperature, pH, alkalinity and phosphate whereas, the growth of Chlorophyceae and Diatoms are determined by high water temperature, phosphate, nitrate, low DO and CO_2, which is in accordance with the present study. *Microcystis* sp. was dominant among the Cyanophycean members throughout the study period (Figure 2.3) as its colonies were resistant to grazing population due to their toxin content as well as their large sized colonies. These algae, being excellent competitors of nutrients suppresses the growth of other algal groups in the lake. The *Microcystis* colonies can survive for longer periods and may accumulate at the lake bottom (over wintering). Even though certain amount of the *Microcystis* cells might die and decompose, most of them would still float upward back to the water from sediments to re-grow next year (Brunberg and Blomqvist, 2002; Feng et al., 2011). Thus, the biotic and abiotic factors either directly or indirectly influence the overall phytoplankton composition in water bodies.

Table 2.6: Different algal groups present at S1, S2 and S3 in Sankey lake

		S1				S2				S3			
		Dec	**Jan**	**Feb**	**Mar**	**Dec**	**Jan**	**Feb**	**Mar**	**Dec**	**Jan**	**Feb**	**Mar**
I	**Cyanophyceae**												
1	*Cylindriospermopsis* sp.	-	-	-	-	-	+	-	-	-	-	-	-
2	*Merismopedia* sp.	-	-	-	+	+	+	-	+	+	-	-	+
3	*Microcystis* sp.	+	+	+	+	+	+	+	+	+	+	+	+
4	*Planktothrix* sp.	+	-	+	+	+	+	+	+	+	-	+	+
II	**Chlorophyceae**												
1	*Ankistrodesmus* sp.	-	-	-	-	-	-	-	-	-	-	-	+
2	*Chlorella* sp.	+	-	+	-	+	-	+	-	+	-	+	-
3	*Closterium* sp.	+	-	+	+	+	-	+	+	+	-	+	+

4	*Cosmarium* sp.	+	-	+	+	+	-	+	+	+	-	+	+
5	*Crucigenia* sp.	+	-	-	-	+	-	-	-	+	-	-	-
6	*Monoraphidium* sp.	+	-	-	+	+	+	-	+	+	-	-	+
7	*Pediastrum* sp.	+	+	+	-	+	+	+	+	+	-	+	+
8	*Scenedesmus* sp.	+	+	+	+	+	+	+	+	+	-	+	+
9	*Tetraedron* sp.	+	-	+	+	+	-	+	+	+	-	+	+
III	**Bacillariophyceae**	+	+	+	+	+	+	+	+	+	-	+	+

Figure 2.3: Algal distribution at the three sites of Sankey Lake



In order to understand the factors affecting the massive growth of Cyanophyceae in Sankey lake, multivariate statistical technique such as PCA (Principal Component Analysis) and CCA (Canonical Correspondence Analysis) were used.

Principal Components Analysis (PCA) was performed on normalized data of lake water samples described by eighteen physical, chemical and biological parameters (18 variables). PCA is an established statistical technique that aims to transform the observed variables to a new set of variables (as Principal Components) which are uncorrelated and arranged in the decreasing order of importance that explain the actual variability and importance of the data and variables by simplifying the actual problem. Principal components (PCs) are derived from eigenvalue(s) that gives a measure of the significance of the factor/variable derived. Eigenvalues of 1.0 or greater are considered significant (Shrestha and Kazama, 2007). Table 2.7 represents the initial PCs and its eigenvalues and percent of variance contributed in each PC. When the eigenvalues are plotted against the corresponding PC, a screeplot is produced which shows the rate of change in the magnitude of the eigenvalues for the PC. The 'elbow' or the point at which the curve bends indicates the maximum number of PC to extract. Figure 2.4 shows the scree plot of the eigenvalues for each component.

Figure 2.4: Scree plot of the eigenvalues of principal components

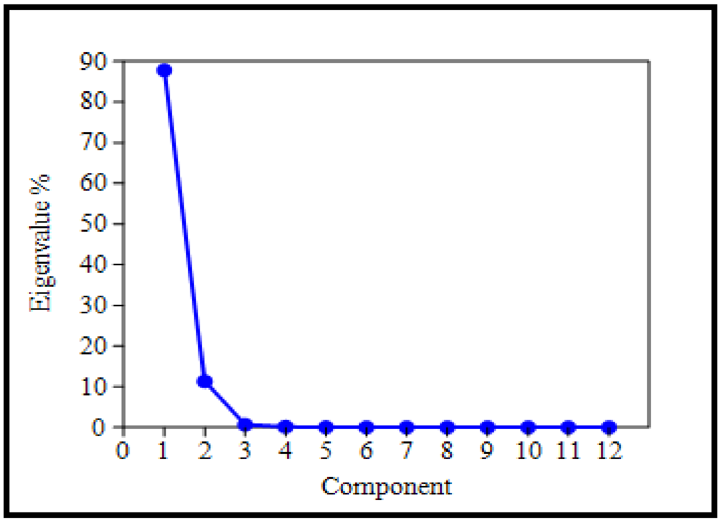


Table 2.7: Loadings and eigenvalues of water quality parameters on significant principal components for water samples collected from Sankey lake

	PC 1	PC 2
Water temperature (°C)	-0.494	-0.215
pH	-0.614	-0.172
EC (µS)	3.409	-0.785
TDS (mg/l)	1.141	-0.421
DO (mg/l)	-0.615	-0.101
COD (mg/l)	0.580	3.937
Sodium (mg/l)	0.224	-0.292
Potassium (mg/l)	-0.524	-0.059
Alkalinity (mg/l)	0.576	-0.158
Chloride (mg/l)	-0.122	-0.252
Total Hardness (mg/l)	0.120	-0.210
Ca Hardness (mg/l)	-0.545	-0.166
Mg Hardness (mg/l)	-0.533	-0.182
Nitrate (mg/l)	-0.692	-0.170
Phosphate (mg/l)	-0.694	-0.172
Cyanophyceae	-0.294	0.143
Chlorophyceae	-0.496	-0.335
Bacillariophyceae	-0.430	-0.390
Eigenvalue	10.54	1.36
% variance	87.79	11.32

PCA of the data sets yielded 2 PCs with eigenvalues >1 (Chatfield and Collins 1980; Mazlum et al., 1999), with eigenvalues of 10.54 and 1.36 and the % variance of 87.79% and 11.32% for PC1 and PC2 respectively and were considered to explain the variability in the data. Liu et al. (2003) classified the factor loadings as 'strong', 'moderate' and 'weak', corresponding to absolute loading values of >0.75, 0.75-0.50 and 0.50-0.30, respectively. PC1 has strong positive loading on EC and TDS and moderate positive loading on COD and alkalinity, whereas, moderate negative loadings on pH, DO, potassium, nitrate, phosphate, calcium hardness and magnesium hardness. PC2 has strong positive loadings on COD and strong negative loadings on EC. PC1 indicates the presence of both mineral and organic pollution. PC2 indicated that the components were related to organic pollutants from domestic wastewater (Figure 2.5).

Figure 2.5: Principal component analysis for physico-chemical and biological parameters

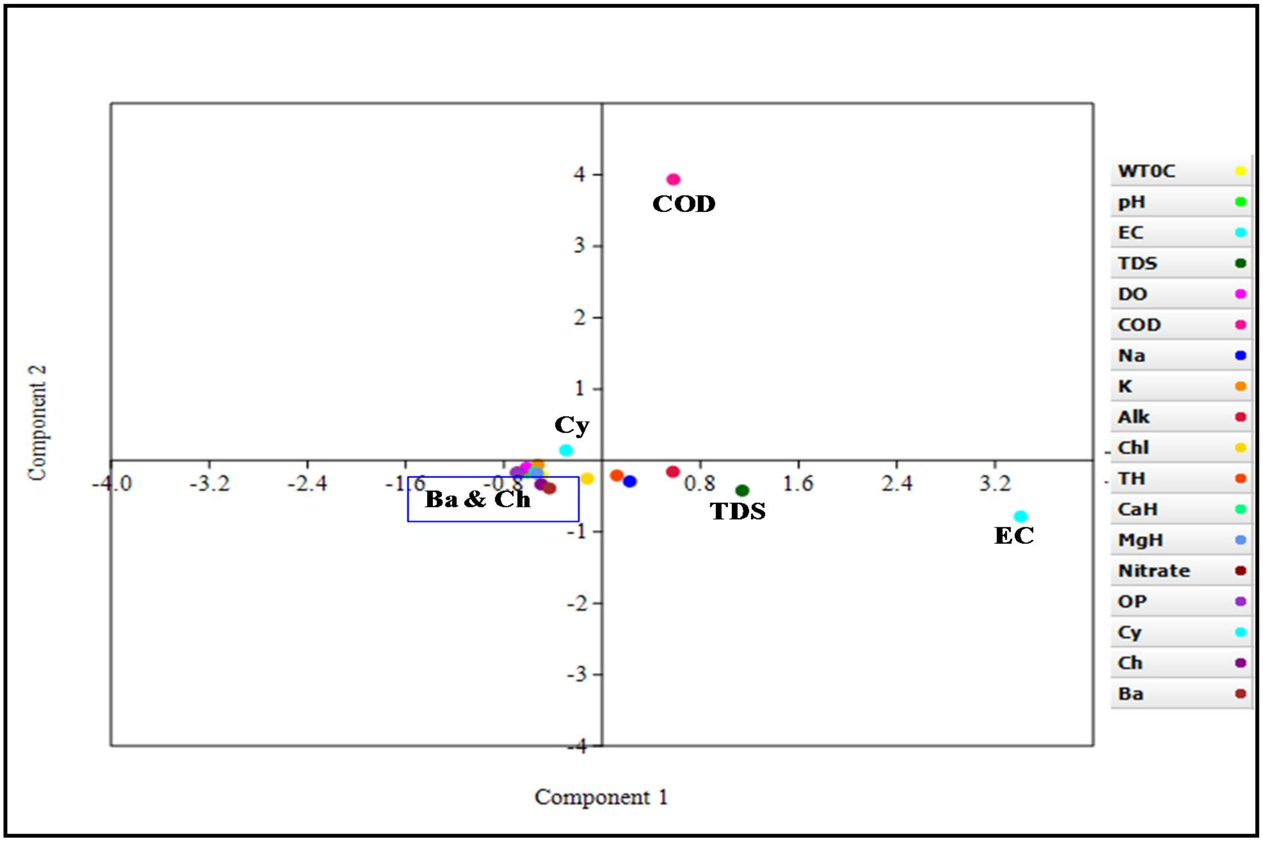
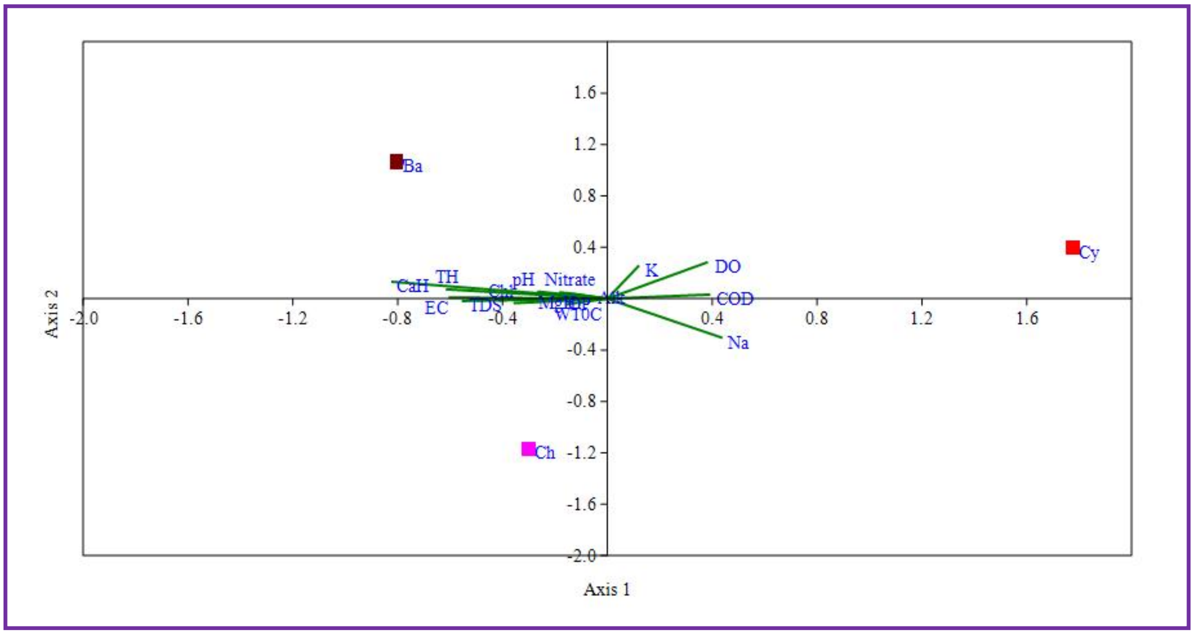


Figure 2.5 shows that EC, TDS and COD are the major components governing water quality and indicate the presence of organic matter in the lake water. The prolific growth of Cyanophyceae is independent of all the physico-chemical and biological parameters. The growth of Bacillariophyceae and Chlorophyceae are affected by other parameters like water temperature, pH, DO, potassium, chloride, nitrate, phosphate, calcium hardness and magnesium hardness.

Figure 2.6: Canonical correspondence analysis for the physico-chemical parameters and different algal species in Sankey lake



Canonical Correlation Analysis is chosen here as it allows us to calculate and to understand relationships by removing unnecessary statistics and computing lesser number of statistics while preserving the relationships among variables under consideration. Canonical Correspondence Analysis also known as canonical correlation analysis (CCA) or reciprocal averaging is a multivariate ordination technique that shows the chi-square distance widely used in environmental and ecological studies. CCA is an analysis of measuring the linear relationship between two multidimensional entities or variables. Basically, it determines two centers, one center for each multidimensional variable optimized based on correlating variable determining corresponding correlations, and dimensionality of the variables would be equal or smaller than the smallest dimensionality of the two variables. CCA is better than any other correlation analysis since these have no influence of description of variables. In the output graph (figure 2.6), the lengths and positions of the arrows provide information about the relationship between the original environmental variables and the derived axes. The arrows that are parallel to an axis indicate a correlation and the length of the arrow tells us about the strength of that correlation.

The environmental variables closely correlated to the first axis were EC, TDS, calcium hardness, total hardness, sodium and Cyanophyceae while, the variables strongly correlated to axis 2 were Bacillariophyceae and Chlorophyceae. COD, DO, sodium and potassium influences the growth of Cyanophyceae (figure 2.6). The massive growth of Cyanophyceae inhibited the growth of other algal genera. Bacillariophyceae and Chlorophyceae are influenced by other variables. Table 2.8 below shows the output of correspondence analysis with axis values in two dimension and eigenvalue representing each of the values.

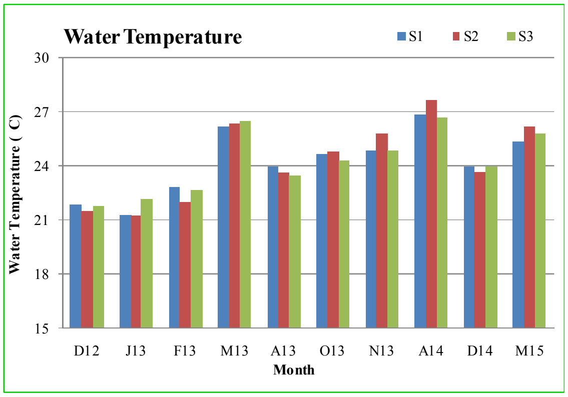
Table 2.8: Output of correspondence analysis

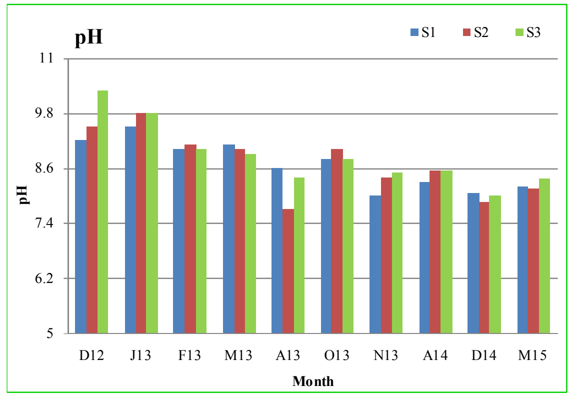
Parameters	Abbr	Axis1	Axis2
Water temperature	WT	-0.162	-0.045
pH	pH	-0.266	0.055
EC	EC	-0.606	0.01
TDS	TDS	-0.556	-0.018
DO	DO	0.383	0.285
COD	COD	0.393	0.032
Sodium	Na	0.439	-0.305
Potassium	K	0.121	0.259
Alkalinity	Alk	-0.065	0.006
Chloride	Chl	-0.358	-0.035
Total Hardness	TH	-0.616	0.073
Ca Hardness	CaH	-0.825	0.132
Mg Hardness	MgH	-0.27	0.048
Nitrate	Nitrate	-0.183	0.051
Ortho-Phosphate	OP	-0.157	0.046
Cyanophyceae	Cy	1.775	0.4
Chlorophyceae	Ch	-0.301	-1.164
Bacillariophyceae	Ba	-0.804	1.067
	Eigenvalue	0.176	0.014
	%	92.8	7.2

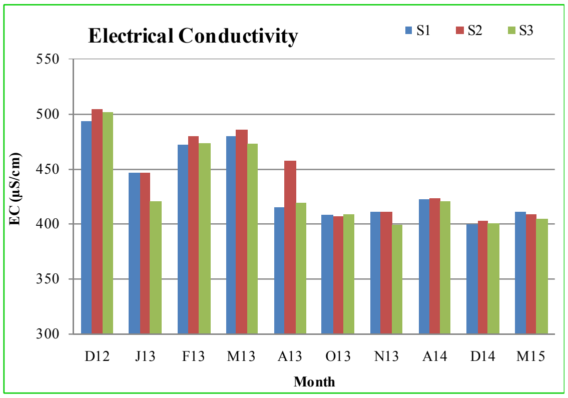
Note: Abbr - abbreviation

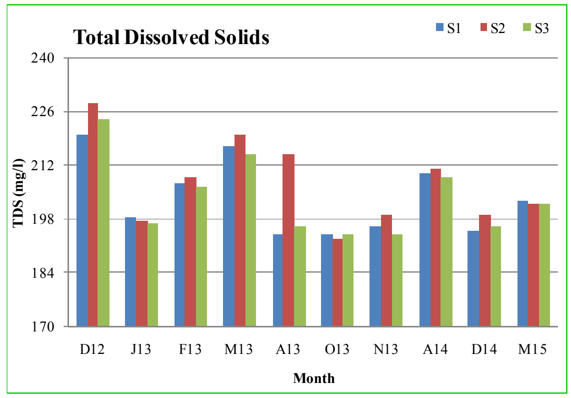
Figure 2.7 shows the physico-chemical characteristics of Sankey lake in the month of December, 2012 (D12); January, 2013 (J13); February, 2013 (F13); March, 2013 (M13); August, 2013 (A13); October, 2013 (O13); November, 2013 (N13); April, 2014 (A14); December, 2014 (D14) and March, 2015 (M15). During these periods, *Microcystis* sp. dominated during the study period except in December, 2014 and March, 2015, a time period. The introduction of aerators led to the prevalence of mixed algal groups indicating the functioning of Lake Ecosystem. The massive *Microcystis* growth during August - October, 2013 had reduced the levels of total dissolved solids, electrical conductivity, nitrate, sodium and potassium but gradually increased the pH, alkalinity, hardness and orthophosphate levels. The organic matter, carbonates, bicarbonates as well as ions play an important role in *Microcystis* growth. The values are in accordance with other studies as in table 2.10.

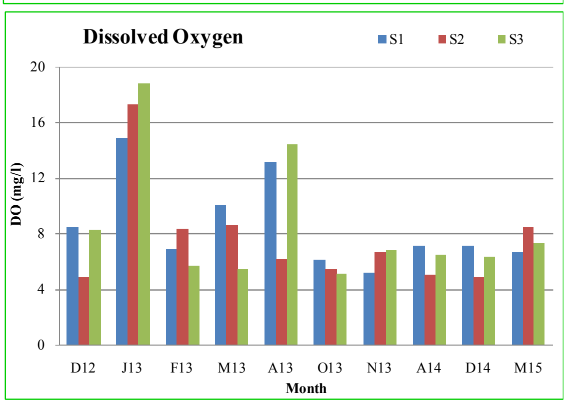
Figure 2.7: Physico-chemical characteristics of Sankey lake from December, 2012 – March, 2015.

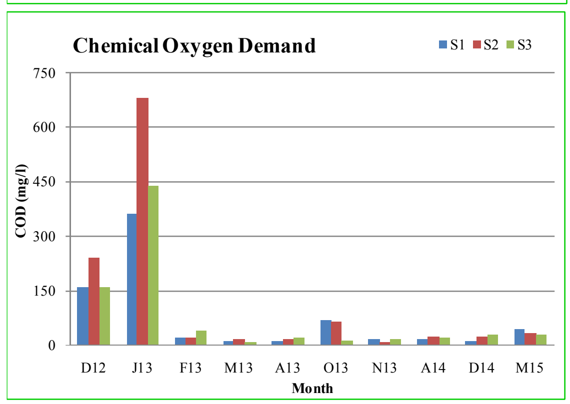

Water Temperature
S1 S2 S3
Water Temperature (C)
30
27
24
21
18
15
D12 J13 F13 M13 A13 O13 N13 A14 D14 M15
Month

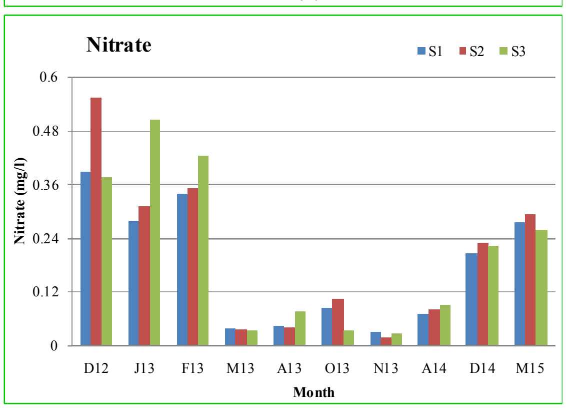

pH
S1 S2 S3
pH
11
9.8
8.6
7.4
6.2
5
D12 J13 F13 M13 A13 O13 N13 A14 D14 M15
Month

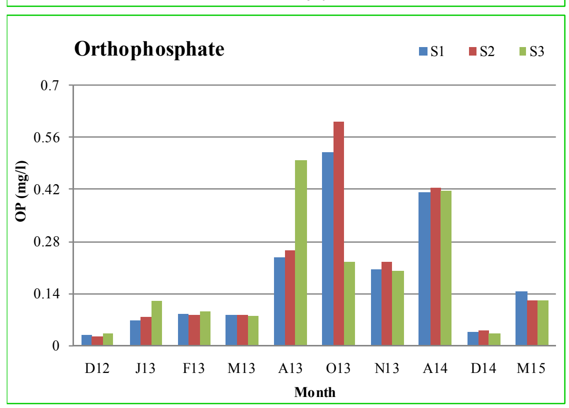

Electrical Conductivity
S1 S2 S3
EC (µS/cm)
550
500
450
400
350
300
D12 J13 F13 M13 A13 O13 N13 A14 D14 M15
Month


Total Dissolved Solids
S1 S2 S3
TDS (mg/l)
240
226
212
198
184
170
D12 J13 F13 M13 A13 O13 N13 A14 D14 M15
Month


Dissolved Oxygen
S1 S2 S3
DO (mg/l)
20
16
12
8
4
0
D12 J13 F13 M13 A13 O13 N13 A14 D14 M15
Month


Chemical Oxygen Demand
S1 S2 S3
COD (mg/l)
750
600
450
300
150
0
D12 J13 F13 M13 A13 O13 N13 A14 D14 M15
Month


Nitrate
S1 S2 S3
Nitrate (mg/l)
0.6
0.48
0.36
0.24
0.12
0
D12 J13 F13 M13 A13 O13 N13 A14 D14 M15
Month


Orthophosphate
S1 S2 S3
OP (mg/l)
0.7
0.56
0.42
0.28
0.14
0
D12 J13 F13 M13 A13 O13 N13 A14 D14 M15
Month

Variations in physico-chemical characteristics among different sites and different months of Sankey Lake: 2012 to 2015

The adverse ecological effects observed in Sankey lake were: (i) taste and odor problems, (ii) decreased water transparency, (iii) depletion of dissolved oxygen levels, (iv) massive growth of toxic phytoplankton species (Cyanobacteria), (v) increased incidences of fish kills and death of ducks, (vi) decrease in aquatic biodiversity, (vii) decrease in aesthetic value of the water body, etc.

During January, 2015, pH became slightly alkaline; total hardness, alkalinity, DO and nitrate levels gradually increased. In August, 2013 and March, 2015, fish death was reported in Sankey Lake due to toxic algal blooms as well as increased ammonia levels (8.74 mg/l) indicating higher organic load in the lake (Table 2.9). Ammonia enters the aquatic ecosystem via anthropogenic sources such as sewage entry, agricultural runoff, nitrogen fixation and the excretion of nitrogenous wastes from animals. The ammonia is released into lakes even during the breakdown of proteins in fish (USEPA, 2013). Fish digest the protein in their feed and excrete ammonia through their gills and in their feces. The amount of ammonia excreted by fish depends on the feeding rate and protein content in the feed. Ammonia also enters the lake through diffusion from the sediments. In the sediments at the lake bottom, the bacterial decomposition of organic matter such as uneaten feed, dead algae, aquatic plants and fecal solids excreted by fish, releases ammonia to the surface water (Hargreaves and Tucker, 2004). Excess ammonia (NH_4) levels accumulate in organisms and cause alteration of metabolic activities or increases in body pH harming the aquatic life. At extreme ammonia levels, fish may experience convulsions, coma, and death. A short-term exposure to toxic un-ionized ammonia at about 0.6 mg/l (ppm) is capable of killing fish over a few days. But, chronic exposure to toxic un-ionized ammonia as low as 0.06 mg/l (ppm) can cause gill and kidney damage, growth reduction, brain malfunctioning and reduction in the oxygen-carrying capacity of the fish (Durborow et al., 1997). Joung et al., (2011) reported the rapid growth rate of *Microcystis* sp. during summer due to the presence of increased TP and water temperature. The *Microcystis* sp. bloom occurred during August to September, 2006. Water temperature, NH_4-N:NO_X-N ratio, TN:TP ratios are the important factors determining the dominance of *Microcystis* sp. In Taihu lake, *Microcystis* sp. became dominant among all phytoplanktons as they are superior competitors at elevated temperatures. *Microcystis* sp. bloom (Figure 2.8) accompanied elevated suspended solid concentration (exceeding 10 mg/l) and pH (above 8.0) (Liu et al, 2011). The pH, dissolved oxygen and temperature at the sediment and water interface influences the P release from sediments to great extent. The soluble P present in the sediments is higher than that in the overlying water. The release rate of P increased with the increase of pH from 8 - 10. The P release also increased with increase in temperature. The TP concentration increases as DO concentration decreased. TP reached the maximum under anaerobic conditions (DO < 1 mg/l) with the increase of time and took longer time to reach the equilibrium (Li et al., 2013). Xie et al., (2003) found that *Microcystis* bloom resulted in high pH (due to increased rate of photosynthesis by algae) and induced P (phosphorus) pollution in lakes due to massive release of P from the sediments to the water column but decreased the concentration of nitrate nitrogen (NO_3-N) in an enclosure experiment conducted in the hyper-eutrophic subtropical lake, Donghu. Profuse growth and bloom of *Microcystis* occurred between August and September.

Table 2.9: Minimum and maximum values of physico-chemical parameters during the whole study period

Parameters	Min	Max
Water Temperature (°C)	21.23	27.7
pH	7.7	10.3
EC (µS)	399	504
TDS (mg/l)	193	228
DO (mg/l)	4.88	18.78
COD (mg/l)	8	680
Sodium (mg/l)	21.6	256.8
Potassium (mg/l)	7.2	41.2
Total Alkalinity (mg/l)	124	216
Chloride (mg/l)	55.38	70.29
Total Hardness (mg/l)	87	124
Calcium Hardness (mg/l)	12.83	33.67
Magnesium Hardness (mg/l)	16.8	23.9
Nitrate (mg/l)	0.019	0.553
Ortho-phosphate (mg/l)	0.025	0.601

Figure 2.8: *Microcystis* sp. in Sankey lake

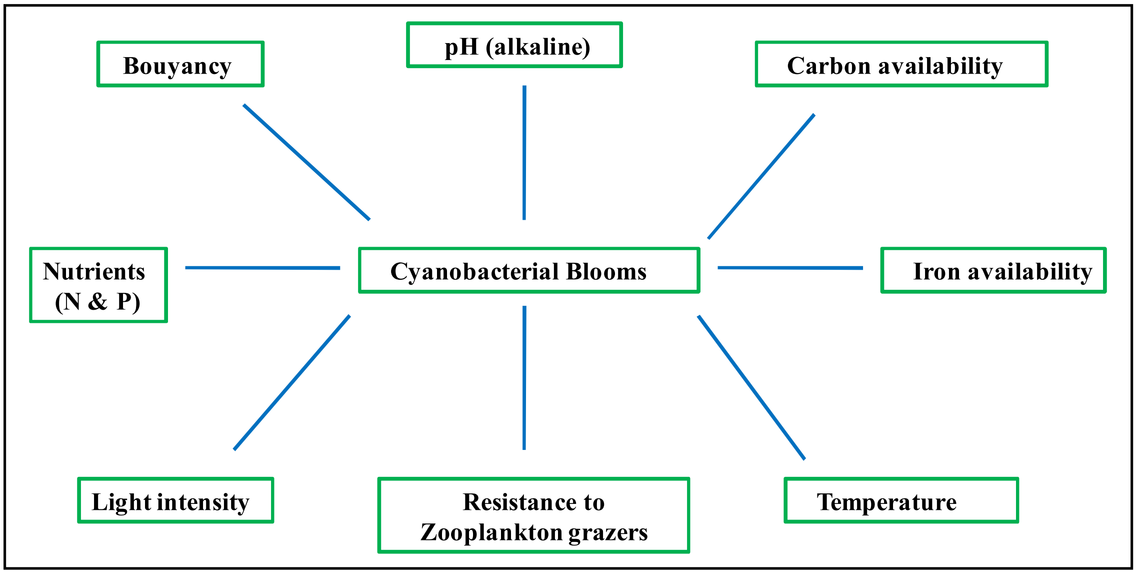
Table 2.10: Favourable conditions reported for *Microcystis* sp. bloom

Sl.No	Lakes	Place	WT °C	pH	Nitrate (mg/l)	Phosphate (mg/l)	COD (mg/l)	DO (mg/l)	Reference
1	Aras -dam reservoir	Iran	27	9.16	1	0.6	-	17.2	**Mohebbi et al, 2012**
2	Taihu	China	2.0- 32.3	7.0- 9.67	0.017 - 3.05	0.001- 0.039	-	-	**Chen et al , 2003**
3	Vellayani	India	25 - 34	8.3 - 9.5	0.06 - 1.3	0.01 - 0.04	-	6.4 - 10.2	**Aneesh and Manilal , 2013**
4	Kukkarahalli	India	-	9.41 - 9.5	2.66 -2.81	-	153.6 - 160	2.2 - 3.2	**Udayashankara et al., 2013**
6	Dabeerkulam Pond	India	-	7.3	9.9	5.5	-	0.8	**Muthukumar et al., 2007**
7	Unkal	India	24.9 - 27.5	-	3.0 - 11	0.006 - 0.08	17.5 - 24.3	6.1 - 7.0	**Ansari et al., 2008**
8	Ambazari	India	23.00–33.00	-	0.445–1.01	0.011–0.065	-	7.32–10.4	**Maske et al, 2010**
9	Phutala	India	22.00–31.00	-	0.286–0.979	0.011–0.066	-	5.93–10.46	**Maske et al, 2010**
10	Bathi tank	India	-	7.8-7.9	8.9-23	0.12-3.6	12.0 -18.0	2.9-5.3	**Suresh et al, 2011**
11	Udaisagar	India	20 - 29	-	0.50 - 0.80	0.56 - 0.90	-	5 - 6.5	**Vijayvergia, 2008**
12	Munshi Hussain Khan	India	21.8	7.2	7.114	5.64	178	8.8	**Napit, 2013**
13	Siddiqui Hussain Tank	India	22.1	6.9	5.563	8.42	188	8.4	**Napit, 2013**
14	California lakes	USA	21.4 - 25	9.24 - 10.0	0.01 - 0.33	0.06 - 0.18	-	7.8 - 16.3	**Backer et al., 2009**
15	Brno reservoir	Czech Republic	13.8 - 26.0	7.49 - 9.37	-	-	-	6.69 - 16.62	**Strakova et al., 2013**
16	Qinshan Lake	China	19.1	6.98	2.71	-	-	-	**Zhang et al., 2011**

Effects of persistence of Cyanobacteria in aquatic ecosystems:

1. Discoloration makes water unpleasant and water would be non-potable;
2. Oxygen depletion due to bloom respiration or decomposition;
3. Accumulation of toxins in aquatic organisms through food chains;
4. Poor light penetration to the depths (shading effects);
5. Mortality of aquatic organisms (fish, zoo planktons) due to toxin production;
6. Diversity of aquatic organisms decreases; Lowers algal and in particular native diversity;
7. Competes with other algae for nutrients and thrives well under adverse conditions;
8. Economic losses due to off- flavor in fishes caused by cyanobacteria

Figure 2.9: Factors favoring cyanobacterial growth



General cellular structure of Cyanobacteria (*Microcystis* sp.)

Cyanobacteria are the most primitive group of organisms on Earth and has a fossil record traced back to 3.5 billion years. They are also known as blue- green algae, blue- green bacteria or cyanophytes. They are gram negative bacteria that contain photosynthetic pigments like chlorophyll as in algae. The ability of cyanobacteria to perform oxygenic photosynthesis had gradually converted the primitive Earth's atmosphere from an anaerobic to an aerobic one and had paved way to the rapid evolution and dominance of aerobic organisms which represents the huge global biodiversity prevailing as now (Dietrich and Hoeger, 2005).

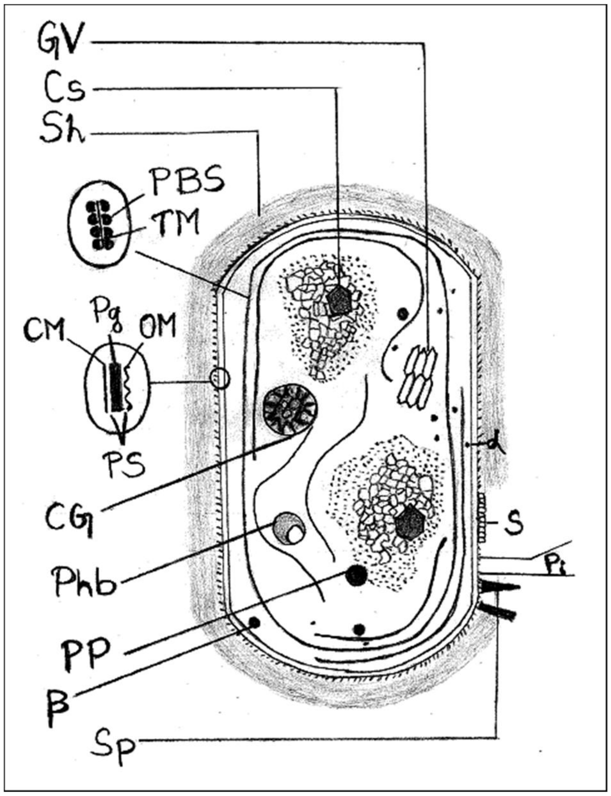
Cyanobacterial bloom (figure 2.9) occurs in fresh water bodies to oceans and produces a wide variety of toxins (cyanotoxins), broadly categorized into hepatotoxins, neurotoxins and cytotoxins. Microcystins are present in the genera *Microcystis*, *Planktothrix*, *Anabaena*, and *Nostoc*, whereas Nodularin is present only in *Nodularia* (Hitzfeld et al., 2000). These cyanobacterial blooms accompanies unappealing odours and a pungent taste due to the presence of the chemical geosmin (Sember, 2002).

Ultra structure of *Microcystis* cell

The protoplast of *Microcystis* cell is delimited by a tripartite plasmalemma outside which lie the cell wall made up of three uniform peptidoglycan layers and an outer proteinaceous S-layer. The S-layer constitutes about 10% of the total cyanobacterial protein and consists of crystalline arrays of protein or glycoprotein subunits forming oblique, square or hexagonal lattices on the cell surface. S-layers may serve as protective coats, molecular sieves and molecule and ion traps, cell adhesion and surface recognition structures and as frameworks that determine and maintains cellular shape and rigidity (Rachel et al., 1997).

The cyanobacterial cells (Figure 2.10) possess a number of cell inclusion bodies that may or may not have a limiting membrane but serve as energy reserves under certain culture conditions. These may include phycobilisomes, carboxysomes, glycogen granules, polyphosphate granules, poly-β –hydroxybutyrate granules, cyanophycin granules and gas vesicles.

Figure 2.10: General structure of Cyanobacterial cell



α glycogen α-granules, β high electron density lipid β-granules, CG cyanophycin granules, CM cytoplasmic membrane, Cs carboxysome, CW cell wall, GV gas vesicles, OM outer membrane, Pg peptidoglycan, PBS phycobilisome, Phb poly-β-hydroxybutyrate granules, Pi pili, PP polyphosphate granules, PS periplasmic space, R ribosomes, SS-layer, Sh sheath, Sp spines, T thylakoid(s), TM thylakoid membrane (Baulina, 2012).

Phycobilisomes: Cyanobacteria are aerobic phototrophic organisms that can perform photosynthesis as they possess Chlorophyll a and photosystem II. These photosynthetic pigments and electron transport chain components are situated in thylakoid membranes. Thylakoids in cyanobacteria are freely located in the cytoplasm arranged concentrically and equidistantly near to the cell periphery and are typically not stacked. Phycobilins are complex photoreceptor pigments seen attached to protein moieties by covalent bonds to the sulphur of cysteine residues forming phycobiliproteins. The light harvesting accessory pigments (phycobiliproteins) are located in phycobilisomes attached to the surface of thylakoids. Phycobilisomes pass the light energy to photosystem II for the splitting of water and generation of oxygen during photosynthesis.

There are four types of phycobiliproteins that renders colour to cyanobacterial cells namely, allophycocyanin (absorption maximum at 650 – 680 nm), phycocyanin (620 – 635 nm), phycoerythrocyanin (575 nm) and phycoerythrin (545 – 565 nm). Cyanobacteria can alter the constituents of phycobiliproteins and the size of light harvesting antennae in accordance to the quality and quantity of light and other environmental factors. This chromatic adaptation help them in efficient light absorption and enhanced photosynthetic rates (Sember, 2002).

Carboxysomes: Carboxysomes (or polyhedral bodies) appear as black polyhedral bodies about 200-300 nm in diameter. They are made up of CO2-fixing enzymes like ribulose - 1, 5 - bisphosphate carboxylase oxygenase (RUBPC'ase or RuBisCO) and carbonic anhydrase that plays an important role in photosynthesis. These are found in large numbers under low carbondioxide concentrations (Sember, 2002).

Glycogen granules: Under light microscope, glycogen granules (or polyglucose bodies or cyanophycean starch) appear as white, irregularly spherical forms with a dimension of 16 x 33 nm. They are the first visible product of photosynthesis in cyanobacteria. These are located between the thylakoids and are made up of polysaccharide containing only glucose molecules with α-1,4 linkages and α-1,6 linked branched oligosaccharide chains. The accumulation of glycogen in cyanobacterial cells occur during nutrient deficient or slow growth conditions or at stationary phase, mainly when a huge utilizable carbon source is present in the aquatic system (Sejnohova, 2008; Reynolds et al, 1981).

Polyphosphate granules (volutin granules or metachromatic granules): Polyphosphate granules were observed independently by Paul Ernst (1888) and Victor Babes (1889) in bacterial cells, that can be stained with methylene blue or toluidine blue. These granules are aggregates of high molecular weight linear phosphate molecules with a size ranging from 100-400 nm in diameter. They are rich sources of phosphate, which plays a major role in the phospholipid and nucleic acid synthesis and serve as an energy source for ATP synthesis. They are thought to contain metals, mainly potassium, calcium, magnesium and some heavy metals. The polyphosphate bodies are formed in the presence of excess phosphate in the growth media and are found to decrease in large numbers in phosphorus deficient cells (Shively, 2006).

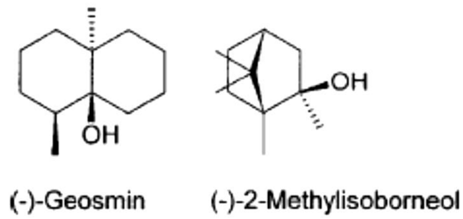
Poly-β –hydroxybutyrate granules (PHB): PHB is a lipid polymer that forms vesicles about 200 nm in diameter and has a limiting monolayer of 3 nm. These serve as storehouses of carbon and energy during nutrient stress conditions but in the presence of excess carbon source. The PHB helps *Microcystis* cells to survive during dark periods (Sejnohova, 2008).

Cyanophycin granules: These granules are high molecular weight with highly refractile bodies of diameter >1.0µm. Simon (1971) had isolated and tried to elucidate the chemical composition of cyanophycin granules. It is composed of co-polymers of aspartate and arginine (Shively, 2006). It serve as a store house of nitrogen and energy and accumulates in cells grown at low temperature, poor illumination intensities and also under phosphorus and sulfur deficient conditions, mainly in the late log phase of growth. They may also serve as a reserve carbon source under carbondioxide deficient conditions. Thus, the nutrient deprivation posed by cells is characterized by the accumulation of glycogen with decreased levels of structured granules and polyphosphate bodies.

Gas vesicles: They are minute, rigid and water proof hollow cylindrical structures with conical end caps. The wall of GVs are made up of proteins that are self-assembled to form firstly a biconical structure which enlarges to a critical diameter and then continues to grow by the extension of the cylindrical middle section. The GV in *Microcystis* sp. may reach to their maximum length of about 600 nm within 12 hours. The membrane of gas vesicles in *Microcystis* sp. are three layered, about 3 nm wide. In *Microcystis* sp., mainly two types of gas vesicle membrane protein are present – GvpA and GvpC. GvpA is the main hydrophobic small protein arranged in a linear crystalline array along ribs and forms the hollow shell of GV. GvpC is the large hydrophilic protein on the outer surface, which binds to GvpA and stabilizes the GV structure. The pores in the GV membrane are very small with a diameter of 0.36 nm. Thus, the surface of gas vesicles is freely permeable to gas molecules like H_2, N_2, O_2, CO_2, CO, CH_4 and Ar, due to which the internal gas composition will be equal to the external gas composition present in the surrounding media. A reduction in the GV volume occurs at low pressure, whereas GV collapses and cells loose their buoyancy at high-pressure conditions (Visser et al, 2005).

Geosmin and MIB: Blue-green algae and actinomycetes produce or secrete certain volatile metabolites like 2-methylisoborneol (2- MIB) with a molecular weight of 168 g/mol and geosmin (trans-1, 10-dimethyl-trans-9-decalol) with a molecular weight of 182 g/mol, that imparts an earthy or musty odour even at extremely low level (ng/l). They are relatively stable to chemical and biological degradation and persist as dissolved form in water for longer periods. Geosmin (Figure 2.11) is trapped inside cells and are released at high concentrations upon death of the bacteria whereas, MIB is produced during their life cycle. Both of these volatile metabolites are detectable by human olfaction at concentrations of 5 ng/l for 2-MIB and 30 ng/l for geosmin (Juttner and Watson, 2007; Mamba et al., 2007; Smith et al., 2008).

Figure 2.11: Structure of geosmin ($C_{12}H_{22}O$) and MIB ($C_{11}H_{20}O$)



Microcystins (MCYSTs): Cyanotoxins are produced in the actively growing cyanobacterial cells and are released into water bodies when the cells age and break down. They are readily soluble in water. The concentration of toxins will be higher in declining blooms (Chorus and Bartram, 1999). Microcystins (Figure 2.12) are potent hepato-toxins produced by many cyanobacterial genera like *Microcystis*, *Nostoc*, *Anabaena*, *Planktothrix*, *Hapalosiphon*, *Anabaenopsis*, *Aphanizomenon ovalisporum*. MCYSTs are cyclic heptapeptides with a molecular weight of 909 - 1067 Daltons. Microcystins are made up of five invariant amino acids that are not found in proteins and two variant amino acids found in proteins. MCYSTs have the general structure: cyclo (– D-Ala(1)–X(2)–D-MeAsp(3)– Z(4)– Adda(5)–D-Glu(6)–Mdha(7)), where, X and Z are variable L-amino acids, D-Ala and D- Glu are alanine and glutamic acid (in D - configuration) respectively. D-MeAsp is D-*erythro*-β-methyl-aspartic acid, Mdha is *N*-methyl-dehydroalanine and Adda is a novel amino acid (2*S,* 3*S,* 8*S,* 9*S*)-3-amino-9-methoxy - 2, 6, 8-trimethyl-10-phenyldeca-4, 6-dienoic acid. About 70 structural variants of MCYSTs are present. Microcystins are named by their two variant protein amino acids. For example, microcystin-LR (MC-LR) refers to microcystin containing the amino acids leucine (L) and arginine (R), MC-YR refers to tyrosine (Y) and arginine (R) and MC- RR indicates 2 arginine (R) amino acids. MC-LR is the most common and toxic microcystin than the other variants (Dietrich and Hoeger, 2005 and Hu et al., 2009; Butler et al, 2009).

Figure 2.12: General structure of microcystins

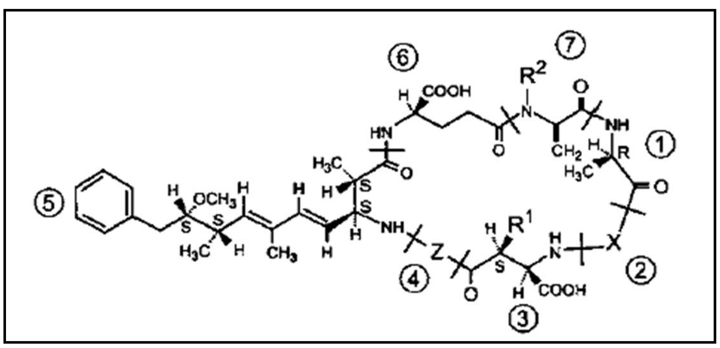
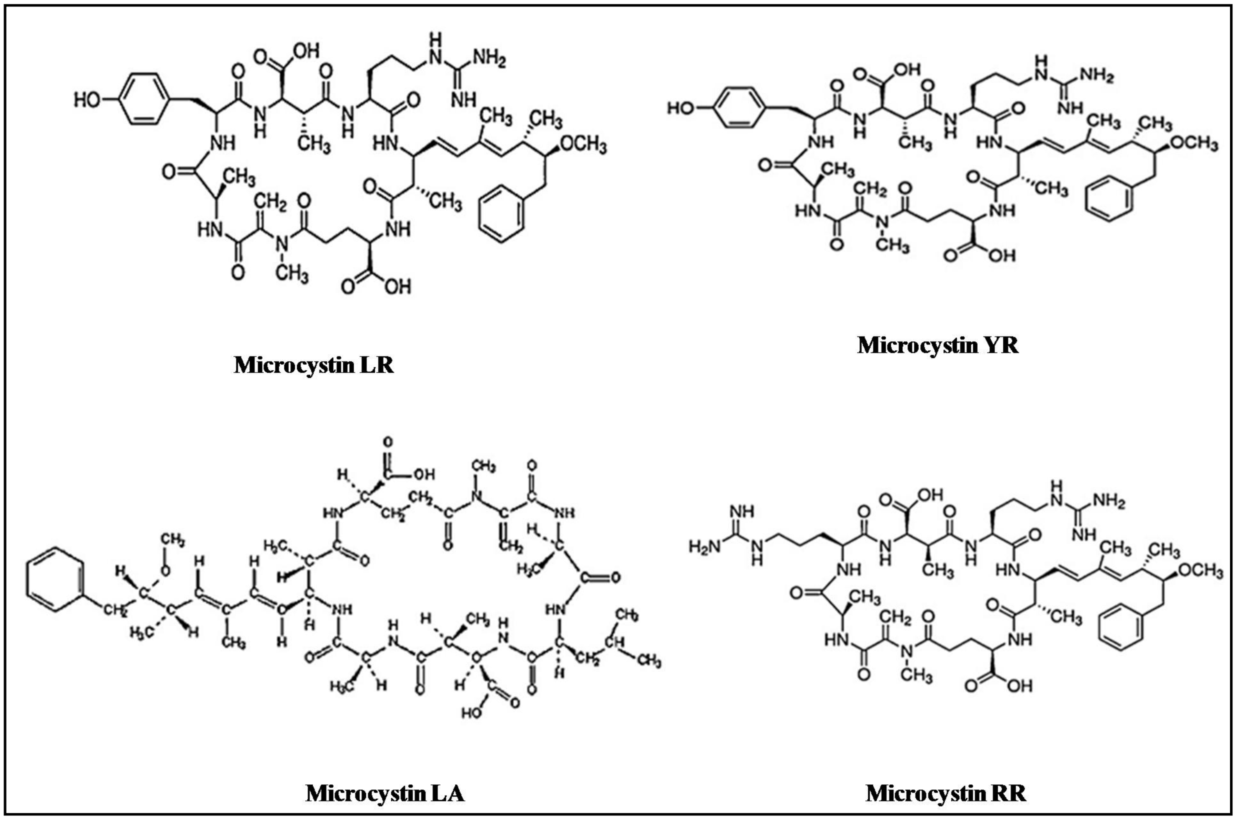


Table 2.11: Different types of Microcystins

Name	X-position Amino Acid	Z-position Amino Acid	Molecular Weight
Microcystin LA	Leucine (L)	Alanine (A)	910.06
Microcystin YR	Tyrosine (Y)	Arginine (R)	1045.19
Microcystin RR	Arginine (R)	Arginine (R)	1038.2
Microcystin LR	Leucine (L)	Arginine (R)	995.17

Figure 2.13: Chemical structure of different MCYNs (Babica, 2006; Tran et al., 2013)



Microcystins can persist for months or even years in natural waters without light. They are extremely stable in water and can tolerate periodic changes in water chemistry, including pH. They remain potent even after boiling. A decline in the microcystin concentration occurs under conditions such as dilution of water bodies, photolysis, biological degradation and decomposition triggered by altered temperature and pH. The variations in day length, temperature, wind mixing, rainfall, flushing and nutrient loading rates also affects phytoplankton distribution and species diversity, including bloom formation in water bodies. Ni et al., 2012 found that MCYST concentrations were positively correlated to water temperature, TP, Chl-a, cyanobacteria biovolume and *Microcystis* biovolume and negatively correlated to TN, TN/TP ratios, DO, and conductivity. Thus, the control of TP can mitigate cyanobacteria dominance and microcystin production in lakes during summer.

MCYSTs enter the human body through ingestion of food and water (plants, fish, shellfish etc.) and to a lesser extent, through inhalation and skin contact. The exposure to cyanotoxins can cause short-term health effects including nausea, vomiting, rashes, eye and ear irritation and fever. The inactivation of protein phosphatases disturbs the normal cell function and induces cell proliferation and cancer production. The death of animals occur due to severe liver damage as a result of cytoskeletal disorganization which includes cell blebbing, cellular disruption, DNA damage, lipid peroxidation, loss of membrane integrity, necrosis, apoptosis, intraheptic bleeding and hemorrhagic shock (Agrawal et al., 2006; Hu et al., 2009). The MC helps in defense mechanism against plankton grazers, ferrous iron (Fe^{2+}) chelation and allelopathic function related to cyanobacterial interactions with phytoplankton, zooplankton and bacteria in an aquatic ecosystem (Gagala, 2012).

Effects of Microcystin (MCYST) in living organisms: Microcystin (MCYST) enters into the tissues of fishes either actively during feeding or passively through the gills during breathing. MCYST released into the water bodies by cyanobacteria get accumulated in consumers at higher trophic levels of food chain. The consumption of these MCYST exposed or affected fishes may pose a great threat to human beings (Vasconcelos et al., 2013). Hepatocyte rounding, derangement of hepatic architecture and progressive necrosis of liver was observed due to microcystin concentration injected intra-peritoneally as well as in gavage trials conducted in rainbow trout or *Oncorhynchus mykiss* (Tencalla et al., 1994). The MCYST concentrations in water of lakes Doirani, Kastoria, Koronia, Pamvotis, Mikri Prespa Petron and Zazari were above the WHO guide level for drinking water. The results suggest that it is unsafe to consume *Carassius gibelio* harvested in lakes Koronia, Kastoria, Pamvotis, and Mikri Prespa due to the high concentration of accumulated MCYST in their tissues. Among all tissues of *C. gibelio*, liver and kidney had the highest average content of MCYST (124.4 ± 23.4 ng/g and 63.3 ± 12.2 ng/g, respectively), followed by brain, intestine and ovaries (43.8 ± 10.2 ng/g, 35.3 ± 15.7 ng/g and 9.27 ±5.2 ng/g, respectively). Muscle had the lowest values (7.1 ± 2.5 ng/g) (Papadimitriou et al., 2009).

Two *Microcystis* sp. i.e. *Microcystis aeruginosa* and *M. ichthyoblabe* dominated water bloom (total microcystins in the cyanobacterial biomass ranged from 1,187–1,211 µg/g dry weight which corresponded to 17.4–25.4 µg of total microcystin/l of water) resulted in significant microcystin accumulation in the hepatopancreas (350 ng/g fresh weight) whereas, its concentration in muscle were generally below the detection limit (2 ng/g fresh weight) of Nile tilapia (*Oreochromis niloticus*). The basic parameters of the dietetic quality (i.e. dry matter, ash, content of proteins and fats) were not significantly affected by the exposure to cyanobacteria (Palikova et al., 2011). The hatching rate of zebrafish embryos was strongly inhibited or decreased with high MCYST (200 µg/l) crude extracts. The mortality rate of the zebrafish larvae increased after 11 days of incubation even though, they were grown in non-toxic medium. Non-MCYST crude extract and 50 µg MCYST/l did not show any inhibitory effects on their hatching rate. The malformation of the fish embryos and larvae occurred during the experiments (Dao et al., 2013).

Microcystin accumulated in the fish, *Oreochromis niloticus* ranging from 16.01 - 37.09 ng/g in muscle and 228.2 - 804.0 µg/g in liver and exhibited potential mutagenic effects. Microcystin level in the fish was well above the WHO (0.04 mg/kg body weight/d) tolerable daily intake, indicating a serious risk to consumers (Vasconcelos et al., 2013; Pouria et al., 1998). Lake Karla supported cyanobacterial species such as *Anabaenopsis elenkinii, Sphaerospermopsis* and *Planktothrix agardhii*, which produces MCYST. MCYST were detected in the tissues of the species *Cyprinus carpio* in the following order: liver>kidney>brain>intestine>muscles, which suggest a high risk for fish consumption and the lake water is not apt for recreational activities (Papadimitriou et al., 2013). Toxin producing cyanobacterial blooms are an important water quality issue in zoos. The death of yellow-bellied slider (*Trachemys scripta scripta*), bighorn sheep (*Ovis canadensis*) and stillborn elephant (*Loxodonta africana*) calf had microcystin concentrations of 166 ng/g, 0.5 ng/g and <0.3 ng/g respectively, in the liver (Doster et al., 2014). A dog exposed to toxin producing *Microcystis* sp., developed lethargy and anorexia within hours of exposure and then showed symptoms like severe depression, vomiting, etc. (Rankin et al., 2013).

Figure 2.14: Death of fish (1) and duck (2) in the Sankey lake, August (2013)

In August (2013), large scale fish mortality occurred at Sankey lake (Figure 2.14). The different factors affecting fish death are oxygen depletion, toxic algal blooms and sudden changes in temperature, salinity and light availability. Certain infections by bacteria, fungi, virus and parasites also cause fish death. Fish death due to oxygen depletion occurs when the algae bloom die-off, lower photosynthetic activities and increased microbial respiration in lakes.

Metabolites of *Microcystis aeruginosa*: Cyanobacteria produce some secondary metabolites, which possess anti-viral as well as anti-bacterial activities. Nowotny et al., (1997) reported of the antiviral activity of *Microcystis aeruginosa* against influenza-A virus. About, 11µg dry extract/ml of crude aqueous extract of *Microcystis* accounted for about 50% inhibition of virus replication in MDCK cell. Ishida et al, (1997) isolated *Microcystis* sp. from Lake Kawaguchi and cultured under laboratory conditions and then isolated and structurally elucidated Kawaguchipeptin B

($C_{58}H_{76}N_{16}O_{18}$), colourless amorphous powder on the basis of 2D NMR data and chemical degradation. It was found that Kawaguchipeptin B exhibited antibacterial activity and thus, inhibited the growth of the Gram positive bacteria, *Staphylococcus aureus* at a concentration of 1 µg/ml (MIC).

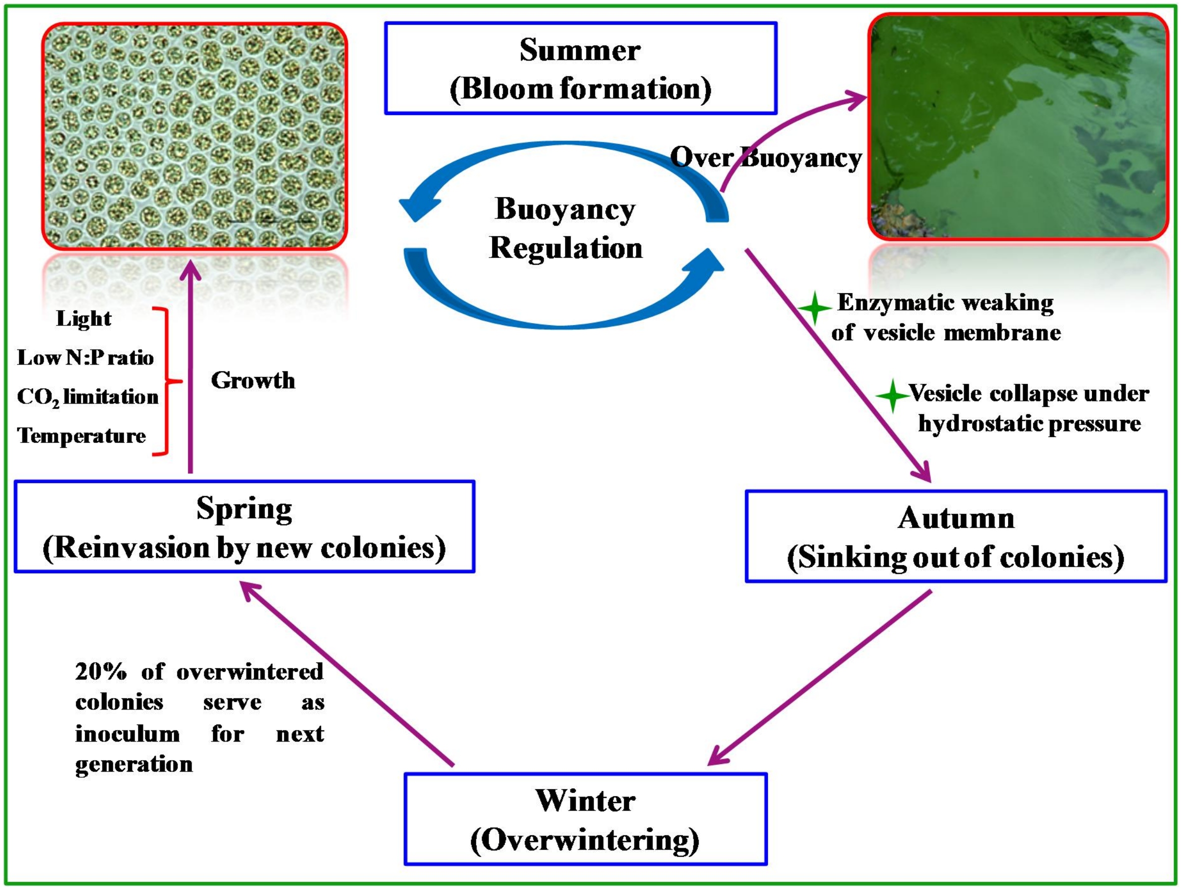
Zainuddin et al, 2002 evaluated the antiviral activity of aqueous and methanolic extracts of several genera of cyanobacteria like *Microcystis*, *Nodularia*, *Oscillatoria*, *Scytonema*, *Lyngbya* and *Calothrix* against influenza-A virus in Madin Darby canine kidney cells. The extracts were nontoxic to MDCK cells. The inhibitory concentration (IC_{50}) of antiviral activity ranged between 20 to 79µg/ml. The extract of *Microcystis* sp. was most effective. The methanolic extracts of *M. aeruginosa*, *M. ichthyoblabe* and *M. wesenbergii* showed notable antiviral activity against influenza-A virus with survival rate of cells of 73.0%, 45.9% and 55.4%, respectively. This effect was associated with protease inhibitory activity of approximately 90%, which could be the plausible reason for the reduction of viral replication.

Cyanopeptolin954 and Nostopeptin BN920 isolated from *Microcystis aeruginosa* inhibited the bovine chymotrypsin with an IC_{50} value of 44.5 and 31.2 nM respectively. These compounds also showed protease inhibitor activity (Von Elert et al., 2005). Kisugi and Okino, (2009) isolated four different micropeptins from *Microcystis aeruginosa* and elucidated their structure. Micropeptins C ($C_{53}H_{69}N_7O_{14}$), D ($C_{55}H_{73}N_7O_{14}$), E ($C_{50}H_{71}N_7O_{14}$), and F ($C_{52}H_{75}N_7O_{14}$) inhibited chymotrypsin with IC_{50}'s of 1.1, 1.2, 1.0 and 1.5µg/ml respectively. These peptides did not inhibit trypsin and thrombin at 20µg/ml. Yamaki et al., (2005) also structurally elucidated two new chymotrypsin inhibitors by the analyses of 1D and 2D NMR spectra, and chemical degradation methods, namely Micropeptins 88-N and 88-Y from *Microcystis aeruginosa*.

M. aeruginosa can produce a natural BHT (butylated hydroxytoluene) which exhibits the antioxidant activity. Synthetic antioxidants are added to food products to prevent lipid oxidation caused due to the presence of reactive oxygen species (ROS) such as superoxide anion, hydrogen peroxide and hydroxyl radicals. ROS decreases the nutritional value and appearance of food. The increased production of BHT was achieved in cultures grown under the highest irradiances (150 µmolphotons/m^2/s). The production of BHT in cells is light dependent and thus protects the cells from photooxidation (Babu, 2008). *M. aeruginosa* can degrade many organophosphorous and organochlorine insecticides present in the aquatic ecosystem (Vijayakumar, 2012).

Life cycle of *Microcystis aeruginosa:* The life cycle of *M. aeruginosa* includes four phases (figure 2.15): Overwintering (winter), Reinvasion (spring), Bloom formation (summer) and Sinking (autumn). These stages appear due to changes in the buoyancy of cells as well as marked seasonal variations. The cyanobacterial cells are denser than water (998 kg/m^3 at 20°C). The densities of major constituents like protein, carbohydrate and glycolipid of *M. aeruginosa* cells are 1330 kg/m^3, 1600 kg/$m^3$and 1050 kg/m^3 respectively, which makes cell denser than water. The cellular water content accounts to about 70 – 80% of wet mass of the cell. Therefore, in order to reduce the density of cells, they accumulate large amount of gas vesicles. The buoyancy of cells also depends on irradiance, accumulation of storage products (eg. polyphosphate bodies) and nutrient availability (Sember, 2002).

Figure 2.15: Life cycle of *M. aeruginosa* cell



When the *M. aeruginosa* cells become over buoyant due to low light intensities, about 10% of cell protein encodes for the production of gas vesicles. The accumulation of carbohydrates at reduced temperature conditions may be a cause for reduced rate of protein synthesis during the light period. The sedimentation of *Microcystis* sp. cells during autumn may be due to increased carbohydrate levels and decreased buoyancy at lower temperatures. Cyanobacterial cells with gas vacuoles become buoyant on exposure to low irradiances (at night) and then loose their buoyancy at high irradiances (daytime). Buoyancy of cells also increases at high nutrient (phosphorus or nitrogen) conditions and vice versa.

After the reinvasion of benthic colonies to the water column during spring, about 20% of overwintering benthic stock get entrapped in the lake sediments and thus serves as an inoculum for the next algal population that develops during summer (Sejnohova, 2008). The recruitment of colonies depend on several factors like number of cells that had overwintered to the lake bottom, resting period of colonies in the hypolimnion and the development of favorable environmental conditions for recruitment. The initiation of bloom formation in aquatic bodies occurs when favorable environmental conditions return like increasing light and temperature conditions, low N: P ratio, prevalence of anoxic environment and limitation of CO_2. As *M. aeruginosa* cells depend on endogenous respiration of stored carbohydrates, they are able to survive prolonged dark periods. The autumnal sedimentation also occurs due to the co-precipitation of buoyant cells with suspended particles like clay and iron compounds. A yellow colour precipitate is formed when reduced iron compounds that are soluble in anaerobic water of hypolimnion become oxidized upon aeration or mixing of water from epilimnion. This precipitate sticks to the cells of blue green algae and allows them to sink to the bottom (Reynolds et al, 1981; Sejnohova, 2008; Sember, 2002).

Measures to control cyanobacterial growth in lakes:

Chorus and Bartram (1999), Drabkova (2007) and Teichreb (2012) focused on the effectiveness, advantages and limitations of various management strategies to be adopted for the control of Cyanobacterial bloom in lakes, which includes both the watershed control and in-lake controls.

- **Arresting nutrient entry to the lake:** Watershed controls help to prevent the delivery of nutrients (mainly phosphorus and nitrogen) to a lake from non-point (runoff, etc.) and point sources (municipal wastewater). It includes implementing improved stormwater treatment, riparian restoration, development of wastewater lines and suitable tanks and adopting wetlands best management practices.

- **Improving aeration:** The physical control involves the physical modification of in-lake elements to remove accumulated nutrients or disturbing the conditions that are favourable for Cyanobacterial growth. These include strategies so as to achieve increased circulation (using air or water to prevent thermal stratification); dilution (reduces nutrient levels without altering the load) and flushing (to minimize response to pollutants and algal growth); dredging (removal of sediments by wet or dry excavation and its deposition in a containment area for dewatering); creating light limiting conditions in lakes by the use of light-limiting; water- soluble dyes and surface covers (opaque sheet material) and mechanical removal of blooms from water bodies by using booms, nets or other devices.

- **Chemical control** involves the application of certain chemicals to destroy algal cells and lower nutrient levels to prevent excessive algal growth. These include application of algaecides, aeration or oxygenation of the water column (to maintain oxic conditions and stratification), phosphorus inactivation (using the salts of aluminium, iron or calcium) and sediment oxidation (addition of oxidants, binders and pH adjusters so as to oxidize sediment, reduce phosphorus supply to algae, alters N:P ratio and decreases sediment oxygen demand). The algaecides mainly used includes liquid or granular formulations of copper in conjunction with chelators, polymers, surfactants or herbicides (cellular toxicant that disrupts photosynthesis, nitrogen metabolism and cellular membrane transport);

synthetic organic herbicides (disrupts cell metabolism and structural deterioration) and oxidants (attacks membranes and disrupts cell functions). Mostly, chemical controls are inapplicable to aquatic ecosystems harboring various fish communities.

- **The biological controls** comprises of modification of the biological components of an aquatic ecosystem to produce unfavourable conditions that will affect growth of the dominant and harmful algae and to achieve grazing control over algae. These may include enhanced grazing by stocking zooplankton species, introduction of bottom-feeding fish and inoculation of pathogens.

Xie and Liu, 2001 suggested the applicability of a new food-web manipulation for eliminating and controlling the unsightly and odorous cyanobacterial blooms in hypereutrophic lakes by increasing the filter-feeding silver and bighead carp through stocking. Both silver and bighead carp are filter-feeders that collect food by passing water through their filtering apparatus and feeds on phytoplankton, suspended detritus, and also zooplankton. This new integrated method is applicable to nutrient rich lakes where nutrient inputs cannot be reduced effectively and where zooplankton cannot control the massive phytoplankton production. In the hypereutrophic and subtropical lake, Donghu, *Microcystis* surface blooms did not occur even though abundant P and N were present in the lake which was due to the high grazing pressure by silver and bighead carp (Xie et al., 2003).

The control measures taken so far have their own advantages and disadvantages as well as varied in their own efficiencies. Visser et al., (2005) suggested three different ways to control the excessive growth of *Microcystis* sp. in different aquatic ecosystems. These include: **(a)** destroying or collapsing of the gas vesicles by using pressure devices like ultrasonic transducer, explosives and deep concentric pipes, so that the cells may sink to the aphotic zone where they will not be able to recover buoyancy and rejoin the population in the epilimnion; **(b)** artificial mixing of water reduces *Microcystis* biomass as it in turn, affects the cellular buoyancy. A shift in the cyanobacterial dominance to negatively buoyant green algae and diatoms was observed as the artificial mixing reduced their sedimentation losses and also lowered the pH thus increasing the carbondioxide (CO_2) levels; **(c)** reducing the phosphorus (P) loading in lakes.

Oberholster et al., (2004) suggested artificial water mixing of Sheldon lake using aerators placed at the bottom of the lake, so as to manipulate the physical environment, thus, making it less favourable for the cyanobacterial growth and more favourable for the growth of other algal species. A pilot study done by Magrann et al., (2012) achieved about 97% reduction in *Microcystis* cells, 72% reduction in chlorophyll-*a*, and 96% reduction in phosphate content in Mason lake water using the Blue Pro^{TM} water treatment facility. Daly et al., 2007 discouraged the use of chlorine as a pretreatment step to conventional water treatment as it causes cell lysis in *Microcystis* sp (by exposure to 7-29 mgmin/l chlorine) and releases the microcystin toxins. Chlorine degraded the microcystin toxin released from the cells but it depends on the pH conditions, exposure time and abundance of Cyanobacterial cells. Aluminum sulphate (at concentrations used in water treatment

practice) and mechanical stirring did not damage the cell integrity of cultured *M. aeruginosa* cells and additional release of microcystin was not evident. However, the water treatment through alum flocculation resulted in the efficient removal of *M. aeruginosa* cells without any release of toxin (Chow et al., 1999). Hoeger et al., (2002) concluded that the provision of safe drinking water from surface waters can only be ensured through regular monitoring of total organic carbon (TOC)/dissolved organic carbon (DOC), residual ozone concentration in conjunction with efficient filtration steps and determination of Cyanobacterial cell densities. TOC or DOC is one of the most important factors found to affect the ozonation capacity. They suggested water treatment with ozone concentrations of at least 1.5 mg/l to provide enough oxidation potential to destroy the toxin present in about 5 x 10^5*Microcystis aeruginosa* cells/ml [total organic carbon (TOC), 1.56 mg/l]. The presence of high TOC in water reduced the efficiency of oxidation and destruction of toxin. The ozonation of raw waters having high Cyanobacteria cell densities will result in cell lysis and liberation of intracellular toxins. Another method for the effective removal of cyanobacterial bloom is the use of H_2O_2 for the treatment of lake water. The H_2O_2 has algaecidal activity causing disaggregation of larger *Microcystis* colonies to smaller ones with the dissociation of PBS (phycobilisomes) from the thylakoid membrane in PSII core complexes. Thus, PSII gets irreversibly inactivated and the existing *Microcystis* population could not serve as an inoculum for the next bloom. After H_2O_2 treatment, further removal of H_2O_2-inactivated *Microcystis* colonies was through flocculation and sedimentation of the cells by the addition of lake sediment clay (2 g/l) and polymeric ferric sulfate (20 mg/l). This integrated method enhanced the DO levels in lake sediment (Wang et al., 2012).
Jurczak et al., (2005) estimated the efficiency of water treatment processes in the removal of microcystins. The continuous and stepwise water treatment processes like preoxidation, coagulation, sand filtration, ozonation and chlorination were done in the Sulejow-Lodz waterworks system, whereas, coagulation, sedimentation, sand filtration, ozonation and chlorination were done in the Tomaszow-Lodz waterworks system. These stepwise treatments were effective in the elimination of extracellular and cell-bound microcystins in both the water systems.

Nanotechnology can provide novel nanomaterials for treatment of surface water, groundwater, and wastewater contaminated by toxic metal ions, organic and inorganic solutes and microorganisms. These include production of nanomaterials for water filtration, remediation and disinfection. The nanomaterials developed for water remediation include Biopolymers, Carbon nanotubes, Iron nanoparticles, Zeolites etc. The microcystin variants are removed to above 90%, whereas, Geosmin and 2 methylisoborneol (MIB) are effectively removed about >75% by tight nanofiltration (NF) membranes (Jain, 2012).

Sui et al, 2014 synthesized the Ag_3PO_4 photocatalyst and checked the degradation capacity of Ag_3PO_4 for MC-LR under visible light. Ag_3PO_4 catalysts were found to exhibit the best photocatalytic performance for MC-LR degradation (99.98% within 5 hours) at pH of 5.01, Ag_3PO_4 concentration of 26.67 g/l and MC-LR concentration of 9.06 mg/l. They also proposed 3 main degradation pathways of microcystin, based on the molecular weight of the intermediates and the reaction mechanism: (1) hydroxylation on the aromatic ring of Adda, (2) hydroxylation on the diene bonds of Adda and (3) internal interactions on the cyclic structure of MC-LR.

Jiang et al., 2010, studied the *M. aeruginosa* removal efficiency of polyferric chloride (PFC), magnetic nanoparticles/PFC (MPFC) and magnetic Fe_3O_4 under different initial pH conditions and coagulant dosages. The removal mechanism of PFC and magnetite suspensions was through charge neutralization and adsorption, induced by electrostatic attraction respectively. In case of MPFC, the removal of *M. aeruginosa* occurs through the combined effect of PFC and magnetic nanoparticles. The magnetic nanoparticles in MPFC enhance the efficiency of coagulation by inducing the formation of large and magnetic flocs with fast settling velocity through adsorption. The added magnetic nanoparticles adsorbs and surrounds natural organic matter (NOM) and easily settles down and then nanoparticles and iron polymers together act on the *M. aeruginosa* cells and result in better removal efficiency.

The ability of bacteria in degradation and removal of microcystin has studied earlier. The ability of specific strains of probiotic bacteria to remove the cyanobacterial peptide toxin microcystin-LR from aqueous solutions was determined by Nybom et al., 2007. *Lactobacillus rhamnosus* strains GG and LC-705, *Bifidobacterium longum* 46, *Bifidobacterium lactis* 420 and *Bifidobacterium lactis* Bb12 has found to be most effective in toxin removal. *Bifidobacterium lactis* Bb12 showed the highest removal percentage of microcystin-LR i.e. 58.1%. The removal of microcystin-LR was dependent on both temperature and bacterial concentration.
Lee et al., 2006 assessed the degradation of microcystin by bacteria adsorbed on GAC (granular active carbon) filter from a water treatment system. About, 90% of toxin got degraded within 9-10 days and about 99% of toxin degraded within 18-21 days. This biological degradation along with the existing purification systems could increase the efficiency of water purification. A similar study carried out by Manage et al., (2009) to assess the degree of biodegradation of microcystin-LR by natural microbial populations isolated from Loch Rescobie, Forfar Loch and river Carron under aerobic conditions. About 3 strains from Forfar Loch, 4 strains from Loch Rescobie and 2 strains from river Carron showed strong MC-LR degradability when they were grown at three different concentrations of MC-LR (10 µg/ml, 1.0 µg/ml and 0.1 µg/ml) as sole carbon source.

All these control measures have disadvantages such as: **(a)** causes cell lysis resulting in the release of toxins into the water body; **(b)** they may be toxic to non-target species; **(c)** may disrupt ecological functions; **(d)** increases oxygen demand; **(e)** brings about fluctuations in the water chemistry during the treatment; **(f)** may be toxic to aquatic flora and fauna; **(g)** the excessive use of these chemicals in turn results in its accumulation in the tank or lake (Teichreb, 2012).

These reviewed control measures has both merit as well as demerits. Best options for Sankey lake are (i) letting only treated sewage to the lake, (ii) provision of wetlands and algal ponds to remove nutrients and (iii) improving aeration in the lake, (iv) removal of phosphates trapped in sediments through de-silting of the lake (wet dreadging). Excessive nutrient and organic inputs from anthropogenic activities into lakes and their watersheds lead to eutrophication, characterized by increase in phytoplankton biomass, nuisance algal blooms, loss of water clarity from increased primary production and loss of oxygen in bottom waters (Ramachandra, 2009b). The ability of microalgae in efficient removal of nutrients like nitrogen, phosphorus and toxic metals under controlled environmental conditions and from a wide variety of wastewaters is well known. The algae grown in wastewater are suitable for biodiesel production due to their higher growth rate, requiring lesser area for cultivation and higher content of essential fatty acids and biomass production efficiencies (Ramachandra et al., 2013).

Water hyacinth in aquatic ecosystems are found to be capable of removing high levels of BOD, suspended solids (SS), nitrogen and phosphorus. Duckweeds have the ability to remove the organic materials because of their ability to use simple organic compounds directly and form carbohydrates and various amino acids or proteins. Thus, the nutrient removal from water bodies in turn reduces the risk of harmful phytoplankton overgrowth (Abdel-Raouf et al., 2012).

Aeration introduces air into water, thus, increasing the oxygen content of lakes and reducing the carbon dioxide content. Aeration also removes hydrogen sulphide, methane and various volatile organic compounds responsible for bad taste and odour in lakes. The harmful algal blooms deplete nutrients and causes shading effects that allow poor light penetration in lakes or ponds, resulting in the death of other algal groups and other aquatic organisms, which later on sink to the bottom and promotes high bacterial growth and activity. When there is a lesser rate of photosynthetic (O_2 producing) activity and higher rate of microbial respiration (O_2 consuming) in lakes, oxygen depletion occurs. This oxygen deficiency can be tackled mainly through aeration in lake. Aeration improves the quality of water used for domestic and industrial purposes and decreases the treatment costs. Aeration also provides an aerobic environment for the degradation of organic matter by microorganisms and allows them to come in close contact with the organic matter. In order to meet the growing demands for water (domestic, irrigational and industrial purposes), the fresh water resources should be properly maintained, restored and conserved. Different laws indirectly protect wetlands in India:

i. The Indian Fisheries Act - 1857
ii. The Indian Forest Act - 1927
iii. Wildlife (Protection) Act - 1972
iv. Water (Prevention and Control of Pollution) Act - 1974
v. Territorial Water, Continental Shelf, Exclusive Economic Zone and other Marine Zones Act - 1976
vi. Water (Prevention and Control of Pollution) Act - 1977
vii. Maritime Zone of India (Regulation and fishing by foreign vessels) Act - 1980
viii. Forest (Conservation act) - 1980

ix. Environmental (Protection) Act - 1986
x. Coastal Zone Regulation Notification – 1991
xi. Wildlife (Protection) Amendment Act - 1991
xii. National Conservation Strategy and Policy Statement on Environment and Development – 1992
xiii. Wetlands Regulatory Framework 2008 (Wetland Conservation Rules)

In addition, India is a signatory to the Ramsar Convention on Wetlands and the Convention of Biological Diversity. This necessitates conservation of the ecological character of various aquatic ecosystems along with its associated varied biodiversity of flora and fauna (Ramachandra, 2009a).

Conclusion: The taste and odour problems due to massive cyanobacterial growth as well as fish death in Sankey Lake have affected its aesthetic value. The analysis of physicochemical characteristics and the phytoplankton communities present in Sankey lake revealed excessive nutrient entry due to sewage, thereby bringing about a change in its physico-chemical properties and promoting the growth of phytoplanktons. *Microcystis* sp. was present throughout the study period at all the three sites. The excessive growth of toxin producing cyanobacteria like *Microcystis* sp., *Planktothrix* sp. and *Merismopedia* sp. may produce harmful effects to all other aquatic plants and animals. The algal species like *Microcystis* sp., *Planktothrix* sp., *Chlorella* sp., *Scenedesmus* sp. and *Nitzschia* sp. are indicators of organic pollution. The sewage entry to the lake should be stopped as an immediate step to control the excessive growth of Cyanobacteria in Sankey Lake. The PCA results revealed that TDS, EC and COD are the major factors governing water quality and indicate the presence of organic matter in the lake water. The CCA results showed that COD, DO, sodium and potassium, mostly influence Cyanophyceae growth. The growth of Cyanophyceae inhibited the growth of other algal genera like Bacillariophyceae and Chlorophyceae. After the introduction of aerators, DO, total hardness, alkalinity and nitrate levels had increased gradually. The application of various control measures to the lakes depends on the area of the lake, the biotic components present including the fishes. Even though, many control measures for preventing Cyanobacterial growth was developed, its related problems in water bodies was not solved yet.

Recommendations

1. Regular monitoring of the lake for assessing its water quality and for taking precautionary measures.
2. Aeration will help in maintaining high dissolved oxygen levels and likely reduction in toxic effect.
3. Avoid entry of sewage into the lake, which brings in excess nutrients that induces profuse algal growth.
4. Leave only treated sewage through construction wetlands and algal ponds (to remove nutrients)

5. Removal of sediments accumulated over a period, which is rich in the phosphorus (P), nitrogen (N) and carbon (C).
6. The harvesting and removal of cyanobacterial biomass during the early morning (when the algal scum is concentrated and at the top layer of water) through fine pore nets and pumping of the concentrated scums.
7. Introduction of Herbivorous fishes like silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*).
8. Avoid sewage entry, throwing of solid wastes to the lake and frequent fish feeding by the local people.
9. Ensure proper evaluation of inflow to the lake and proper maintenance of outflow.
10. Public awareness and public participation is necessary.

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3.0 Landscape Dynamics: Violations and encroachments in Sankey Valley

Status	**Shrinking water body and loss of interconnectivities among lakes**
Cause:	**Encroachment of lake bed and raja kaluves (storm water drains)**
Norms	1. "Preservation of Lakes in the City of Bangalore" Report of the Committee constituted by the **Hon'ble High Court of Karnataka** to examine the ground realities and prepare an action plan for preservation of lakes in the City of Bangalore. (Hon'ble High Court of Karnataka's Order dated 26/11/2010 in WP NO.817/2008 & others), • Lake area should not be diverted for any other purpose as lakes have an increased and important role to play vis–a-vis lakes in rural areas, like **ground water recharge, climate moderation, act as lung spaces, water for various purposes, urban recreation** etc • Currently **30m** buffer space needs to be maintained as per the **BDA** from the legal lake boundary (wetland) free of any developmental activity. • **Lake preservation has to be integral to Layout Development by BDA** and Layout approvals by development and planning authorities like BIAPA, MICAPA, Nelamangala Planning Authority, Hosakote Planning Authority etc., as eventually these areas will be part of Bangalore city. • **BDA should not acquire lake area at the time of notifying the area for development** and allot sites in the lake area as was done in many a layout development previously. Instead they have to properly get all the **lakes, raja kaluves, drains surveyed and marked on the ground as per village records with boundary stones and make provisions for buffers** as laid out in their norms. • Lake preservation is not limited to lake area itself, but very much dependent on catchment area and the drains that bring rainwater in to the lake. **Raja kaluves, branch kaluves are to be surveyed and encroachment therein needs to be evicted**. • **Effective Lake area should not be reduced by converting lake area into parks, children play grounds, widened bunds** etc. The desilting has to be minimized to remove only

	sludge portion with minimum depth near foreshore reaching maximum depth at the bund. **2. Violation as per BDA, RMP 2015; Section 17 of KTCP Act** In case of water bodies, a 30.0 m buffer of 'no development zone' is to be maintained around the lake (as per revenue records) • **As per BDA, RMP 2015** • Section 17 of KTCP Act, 1961 and sec 32 of BDA Act, 1976 • Wetlands (Conservation and Management) Rules 2010, Government of India; Wetlands Regulatory Framework, 2008. **3. Construction activities in the valley zone:** This is contrary to sustainable development as the natural resources (lake, wetlands) get affected, eventually leading to the degradation/extinction of lakes. This reflects the ignorance of the administrative machinery on the importance of ecosystems and the need to protect valley zones considering ecological function and these regions are 'NO DEVELOPMENT ZONES' as per CDP 2005, 2015 **4. Violations of National Water Policy, 2002** Water is a scarce and precious national resource and requires conservation and management. Watershed management through extensive soil conservation, catchment-area treatment, preservation of forests and increasing the forest cover and the construction of check-dams should be promoted The water resources should be conserved by retention practices such as rain water harvesting and prevention of pollution **5. Wetlands (Conservation and Management) Rules 2010, Government of India; Wetlands Regulatory Framework, 2008.** **Prohibited Activities** • Conversion of wetland to non-wetland use. • Reclamation of wetlands • Solid waste dumping and discharge of untreated effluents. **Regulated activities** • Withdrawal of water/impoundment /diversion/interruption of sources • Harvesting (including grazing) of living/non-living resources (may be permitted to the level that the basic nature and character of the biotic community is not adversely affected.)

	• Treated effluent discharges – industrial / domestic/agro-chemical. • Plying of motorized boats • Dredging (need for dredging may be considered, on merit on case to case basis, only in cases of wetlands impacted by siltation) • **Constructions of permanent nature within 50 m of periphery except boat jetties.** • **Activity which interferes with the normal run-off and related ecological processes – upto 200 m** (Facilities required for temporary use such as pontoon bridges and approach roads, will be exempted) **6. Water (Prevention and Control of Pollution) Act, 1974** • It is based on the "Polluter pays" principle
Action Plan	• Good governance (too many para-state agencies and lack of co-ordination) - Single agency with the statutory and financial autonomy to be the custodian of natural resources (ownership, regular maintenance and action against polluters (encroachers as well as those let untreated sewage and effluents, dumping of solid wastes). • De-congest Bangalore: Growth in Bangalore has surpassed the threshold evident from stress on supportive capacity (insufficient water, clean air and water, electricity, traffic bottlenecks, etc.) and assimilative capacity (polluted water and sediments in water bodies, enhanced GHG – Greenhouse gases, etc.) • Disband BDA – creation of Bangalore Development Agency has given impetus to inefficient governance evident from Bangalore, the garden city turning into 'dead city' during the functional life of BDA. • Digitation of land records (especially common lands – lakes, open spaces, parks, etc.) and availability of this geo-referenced data with query option (Spatial Decision Support System) to public. • Threshold on high raise building in the region. Need to protect valley zones considering ecological function and these regions are 'NO DEVELOPMENT ZONES' as per CDP 2005, 2015 • Evict all encroachments from lake bed and raja kaluves • Reestablish interconnectivity among lakes • Restoration of lakes

Unplanned rapid urbanisation during post 2000 witnessed large scale conversion of watershed area of the lake to residential and commercial layouts. This has altered the hydrological regime and enhanced the silt movement in the catchment. Declining vegetation cover has lowered water yield in the catchment, affecting the groundwater recharge. Alterations in ecological integrity is evident from reduced water yield, flash floods, contaminated water, obnoxious odour, copious growth of invasive floating macrophytes, disappearance of native fish species, breeding ground for mosquito and other disease vectors, etc. A major portion of untreated city sewage (500+ million liters per day) is let into the lake, beyond the neutralizing ability of the lake, which has hampered the ecological functioning of the lake.

Ecological and Environmental Implications:

- Land use changes: Conversion of watershed area especially valley regions of the lake to paved surfaces would alter the hydrological regime.
- Loss of Drainage Network: *Removal of drain (Rajakaluve) and reducing the width of the drain would flood the surrounding residential as* the interconnectivities among lakes are lost and there are no mechanisms for the excessive storm water to drain and thus the water stagnates flooding in the surroundings.
- Alteration in landscape topography: This activity alters the integrity of the region affecting the lake catchment. This would also have serious implications on the storm water flow in the catchment. The dumping of construction waste along the lakebed and lake has altered the natural topography thus rendering the storm water runoff to take a new course that might get into the existing residential areas. Such alteration of topography would not be geologically stable apart from causing soil erosion and lead to siltation in the lake.
- *Loss of Shoreline:* The loss of shoreline along the lakebed results in the habitat destruction for most of the shoreline birds that wade in this region. Some of the shoreline wading birds like the Stilts, Sandpipers; etc will be devoid of their habitat forcing them to move out such disturbed habitats. It was also apparent from the field investigations that with the illogical land filling and dumping taking place in the Bellandur lakebed, the shoreline are gobbled up by these activities.
- *Loss of livelihood:* Local people are dependent on the wetlands for fodder, fish etc. estimate shows that wetlands provide goods and services worth Rs 10500 per hectare per day (Ramachandra et al., 2005). Contamination of lake brings down goods and services value to Rs 20 per hectare per day.

Sankey Lake: Sankey Lake is an artificial lake that was built by Col: Richard Hieram Sankey, in 1882 to meet the water supply demands of Bangalore to safeguard against water shortages experienced during great Famine in 1875 to 1877. The lake was also known as the Gandhadakoti kere, and was linked to Dharmambudi Lake and Millers tank in order to cater the water needs (Source: Figure 3.1)

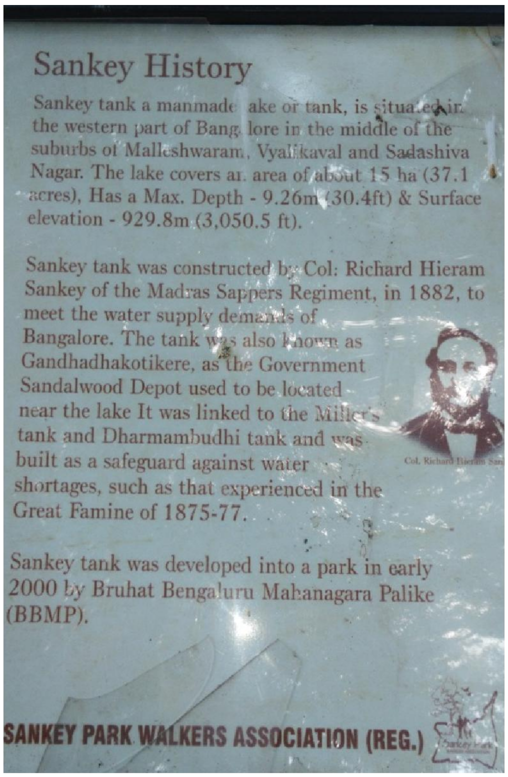


Figure 3.1: Brief description of Sankey lake.

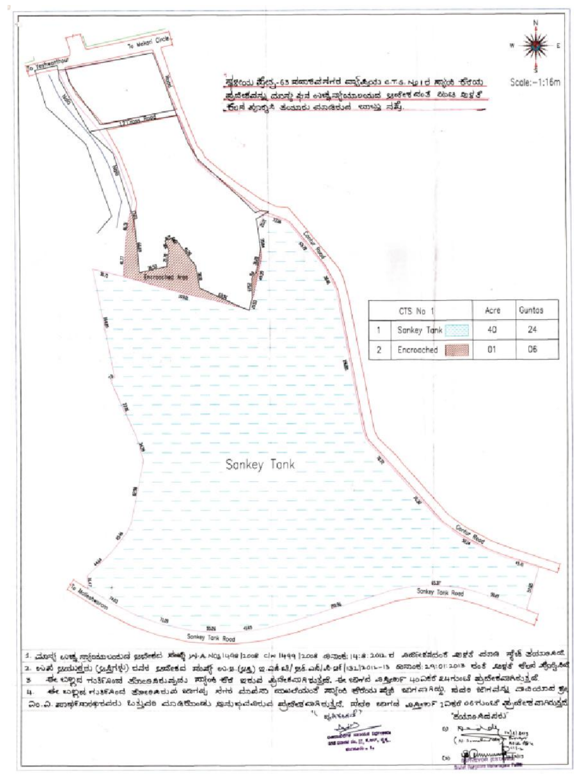


Figure 3.2: Cadastral map of Sankey lake As per BBMP records (http://bbmp.gov.in/certified-lakes)

Spatially, legal lake boundary (Figure 3.2) as per the BBMP records spreads for about 16.89 Hectares (41.75 acre), whereas considering the immediate water body (not considered in BBMP map), area was 17.2Hectares (42.76 acres). The tank has maximum depth of 9.26 m. Sankey tank spatially is located in the north western part of Bangalore (Figure 3.3) at an elevation of 929.8m above mean sea level.

Landscape Dynamics in and around Sankey Lake: Figure 3.4 temporally and spatially describes the land use dynamics within 30 m (BDA norms) buffer of Sankey Lake and upto 200 m (MoEF &Climate change). The development of the tank has been taken into account post 2004 where in a small tank was built within the lake in order to avoid pollution of the lake due to submerging idols, paved walk ways were built for the walkers, aerators were deployed etc.

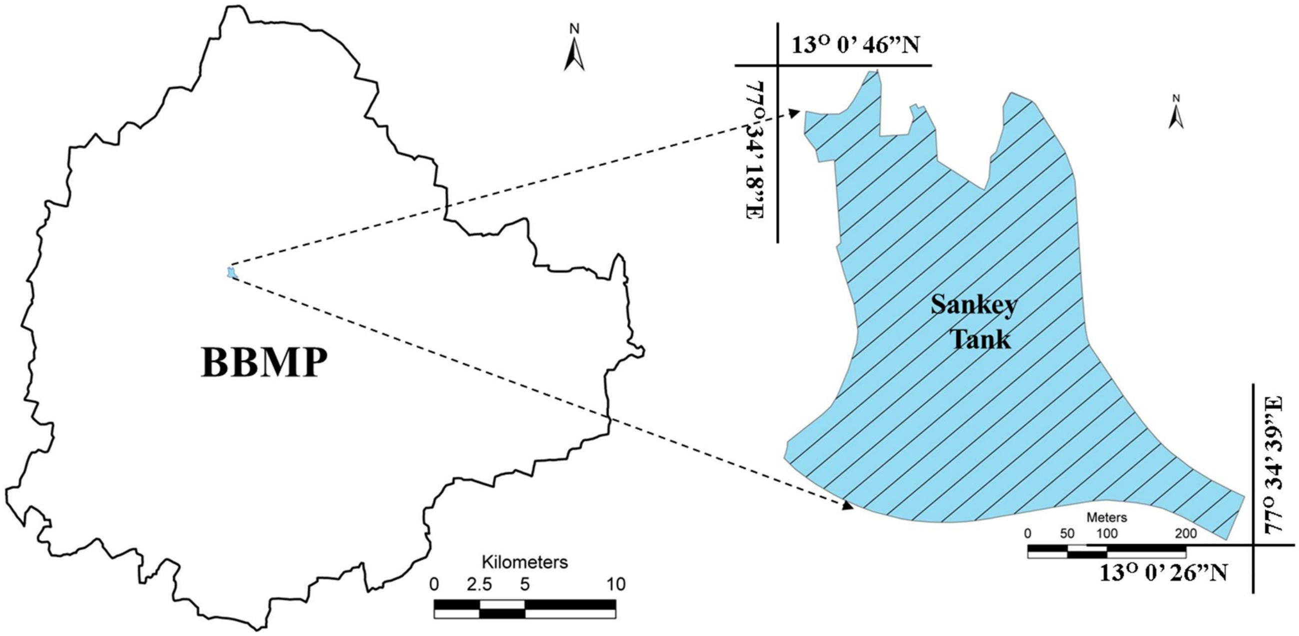


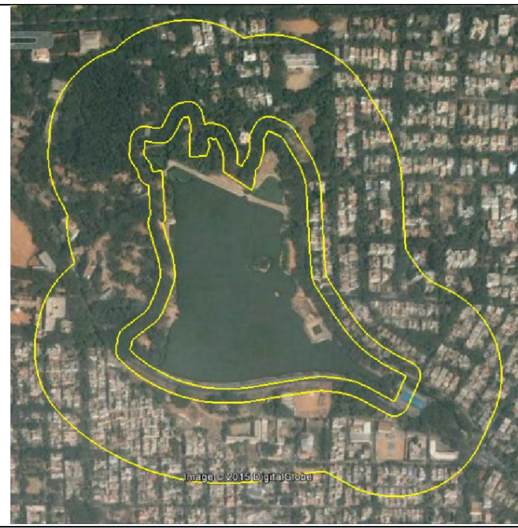
Figure 3.3: Sankey Lake

Within the study area (Figure 3.5) i.e., up to 200m buffer, Built-up area is about 36.88 Hectares (91.16 Acres), green cover and public utility (open areas, parks, swimming pool) accounts to an area of 17.95 Hectares (44.29 Acres).

Violation of bylaws in and around Sankey Lake: Sankey tank in its buffer zones is no different to other wetlands or lakes. The buffer zone have been found to violate the bylaws laid by both BDA (30 m) and MoEF (200 m), large residential construction activities have come up in the zones and still are being proposed to come up in the buffer zones. The proposed construction of residential complex will be in violation of norms. Figure 3.6 and Figure 3.7 depicts the violations that has occurred in the buffer zones. Within 30m buffer the existing built up area is about 2.7 Hectares (7.10 Acres), whereas with in the 200 m buffer zone, 36.88 Hectares (91.16 acres).

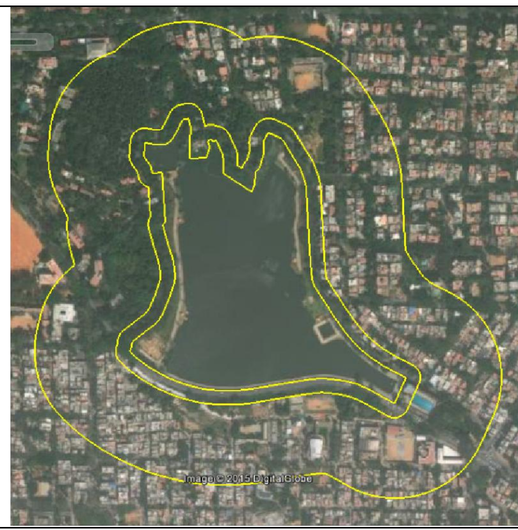
Figure 3.7 depicts the violation of the BDA and MoEF, GoI norms for protection of wetlands; the proposed apartment complex adjacent to the lake's legal boundary will adversely affect the ecological functioning of the lake apart from likely environmental consequences (associated with such massive construction of high raise building) on groundwater, surface water quality, aesthetics of the lake, hydrologic regime, etc.

2000



2004

2007



2010

2012

2014

Figure 3.4: Landscape dynamics around Sankey Lake

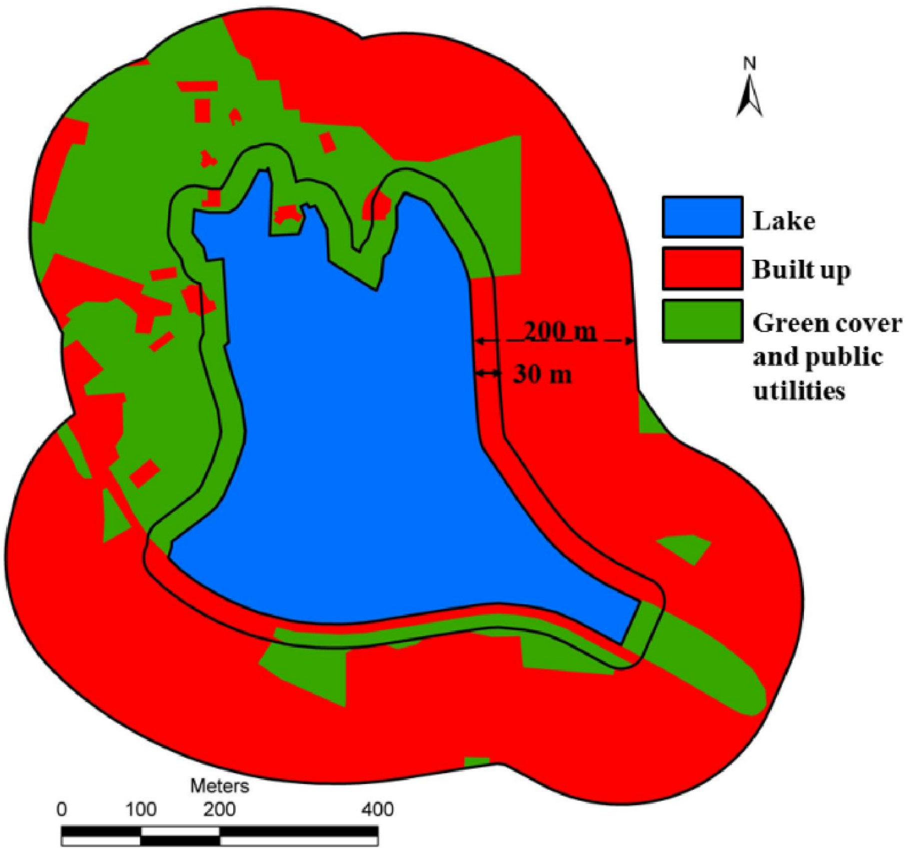
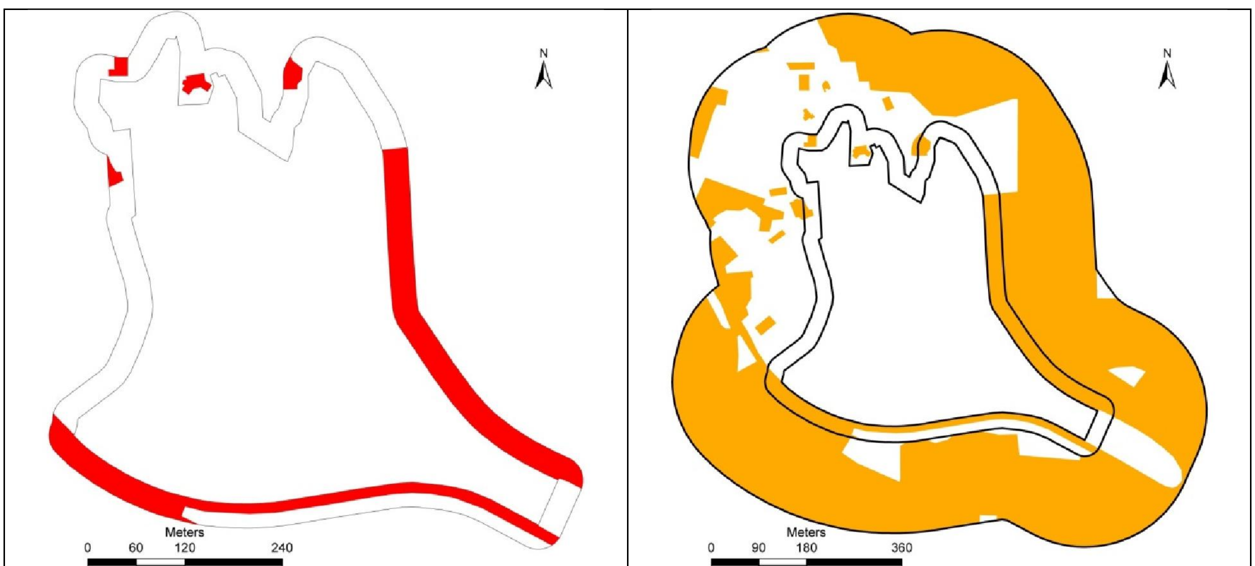


Figure 3.5: Land use around Sankey Lake



30m buffer zone	200m buffer zone

Figure 3.6: Violations of bylaws (built up area) around Sankey Lake

Figure 3.7: Violation of bylaws overlaid on Google earth

4.0 Ecological Impact Assessment of the Proposed Building Activities (Report prepared in 2004)

T. V Ramachandra — Ahalya N
Harish Bhat — Sudhira H. S
Karthick B. — T. V Jagadeeshan

Field Investigations: 20th August 2004, During 10 - 12:30 PM.

Lakes/Tanks are important components of the ecosystem with various beneficial functions. The various functions of lakes and wetlands include sustaining life processes, water storage for domestic, agricultural and industrial usage, protection from storms and floods, recharge of ground water, water purification, erosion control and stabilization of local climate. Thus they help to maintain the ecological balance of the region. Lakes/Tanks in Bangalore occupy about 4.8% of the city's geographical area (640 sq.km), which covers both urban and rural areas. All the lakes/tanks in Bangalore are man-made, which were built to serve the needs of irrigated agriculture and drinking water. One such tank/lake is Sankey, which is situated in the western part of the city between Malleswaram and Sadashivnagar. Col. Sankey built the tank/lake during 1882 to meet the drinking water demand of the nearby areas. The tank covers an area of 12.8 hectares and its catchment area is approximately 343 hectares (Figure 1 and 2). A public recreation park and corporation swimming pool is present at the southern part and a nursery at the northern side of the tank. The northern side has a good vegetation cover, which is one of the reasons for attracting large population of migratory birds to this wetland (Refer Annexure for Checklist of birds and plants).

Figure 1: Satellite imagery of Sankey tank and its catchment area (The marked area shows the proposed activities).

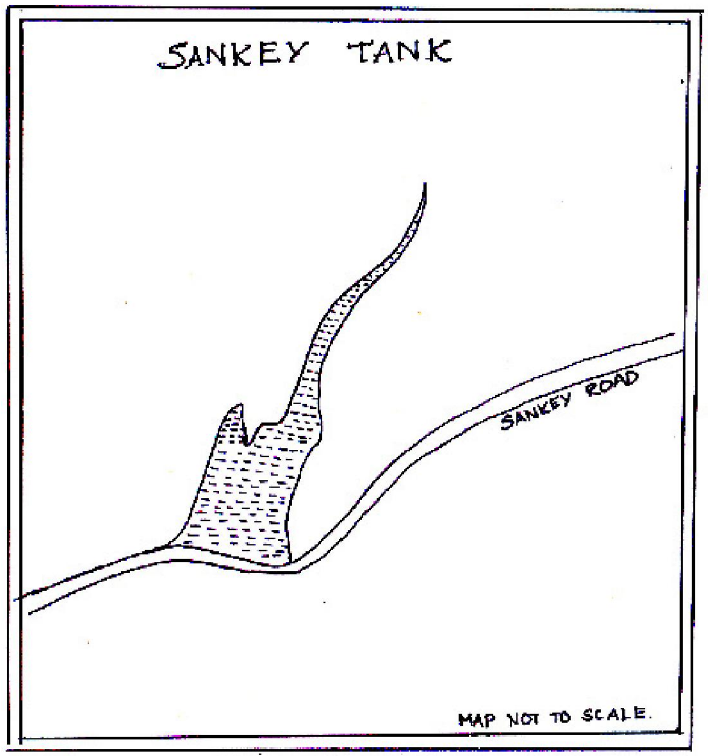


Figure 2: Water spread area of Sankey tank.

Proposed activities on the tank/lake bed: Construction of high-rise buildings in the immediate vicinity of the lake is being proposed. The construction activities would prove detrimental to the hydrological (water quality, amount of water flowing into the lake, quality of groundwater, etc) and ecological (planktons, birds, fish, etc) aspects of the Sankey tank. The impacts of the proposed construction activities are:

Impacts of proposed activities

1. **The construction activities would lead to alteration in the hydrologic regime, which would lead to decreased water yield.**
2. **The construction activities would result in cutting of trees, which would increase soil erosion. This in turn will increase the inflow of silt into the lake.**
3. **The inflow of silt will lead to sedimentation in the lake, ultimately decreasing the water storage capacity of the lake.**
4. **Sankey tank is rich in floral and faunal resources (Refer Annexure). The developmental activity will affect the faunal and floral composition of this wetland. The avifauna (birds) would be severely affected due to the construction of high rise buildings on the lake bed.**

5. **The proposed construction would increase the water demand and the demand for water would lead to high ground water tapping (would also reduce surface water in the lake).**
6. **Further investigations on the carrying capacities are needed especially for lakebed as the it is not conducive for the construction of high-rise buildings due to the underlying geology, topography and ecology.**
7. **The natural connectivity between lakes would be affected by the anthropogenic activities (subsurface, etc.) leading to a loss of interconnectivity (for example: drain from Rajajinagar connecting Sankey was encroached (by high raise building) leading to frequent flooding and water stagnation in the region, affecting the property and people's livelihood).**

Reduced water yield in the catchment as well as enhanced sediment yield (along with pollutants) would lead to reduced ecological functions of the lake. This would eventually leads to the disappearance of the lake. Thus to protect and conserve the lake, we need watershed-based approach for the sustainable management of the biotic and abiotic components of the ecosystem. Soil and water conservation is a very important aspect of watershed management. This would ensure in maintaining the hydrological balance in the ecosystem. The watershed - based management would ensure a vegetation cover, which will arrest the soil erosion. This will in turn enhance the water-holding capacity of the lake and ascertain the conservation of the biodiversity of the lake, namely its flora and fauna.

In the interest of the society and future generation, onus is on the proponent of these construction activities to hand over this land (acquired clandestinely) to the government of Karnataka to develop as children's park. This would also help in showcasing the commitment of citizens of Bangalore (in this case – proponent of massive construction activities in the lake bed) **towards maintaining inter and intra generation equity.**

Annexure:

Birds Sighted in and around Sankey Tank on 20th August 2004 during 10 - 12:30 PM.

1. House Crow
2. Jungle Crow
3. Common Myna
4. Small Green Barbet
5. Blue Rock Pigeon
6. Rose Ringed Parakeet
7. Pied Wagtail
8. Little Cormorant
9. Koel
10. Pariah Kite

Bird Checklist in Sankey catchment (R. J Ranjit Daniel, 1992)

1. Large Grey Babbler
2. White Headed Babbler
3. Crimson Breasted Barbet
4. Small Green Barbet
5. Blue-tailed Bee-eater
6. Small Green Bee-eater
7. Bluechat
8. Bluethroat
9. Red Vented Bulbul
10. Red Whiskered Bulbul
11. White Browed Bulbul
12. Pied Bushchat
13. Bushlark
14. Crested Honey Buzzard
15. Longlegged Buzzard
16. Goldfronted Chloropsis
17. Coot
18. Little Cormorant
19. Greater Coucal
20. House Crow
21. Jungle Crow
22. Common Hawk-Cuckoo
23. Indian Cuckoo
24. Pied Crested Cuckoo
25. Plaintive Cuckoo
26. Blackheaded Cuckoo-Shrike
27. Large Cuckoo-Shrike
28. Black Drongo
29. Grey Drongo
30. Haircrested Drongo
31. Whitebellied Drongo
32. Little Brown Dove
33. Red Turtle Dove
34. Rufous Turtle Dove

35. Spotted Dove
36. Booted Eagle
37. Crested Hawk-Eagle
38. Short-toed Eagle
39. Tawny Eagle
40. White-eyed Buzzard Eagle
41. Cattle Egret
42. Little Egret
43. Smaller Egret
44. Shaheen Falcon
45. Ashycrowned Finch-Lark
46. Tickell's Flower Pecker
47. Blacknaped Blue Flycatcher
48. Brown Flycatcher
49. Paradise Flycatcher
50. Redbreasted Flycatcher
51. Tickell's Blue Flycatcher
52. Verditer Flycatcher
53. Pale Harrier
54. Asiatic Sparrow Hawk
55. Grey Heron
56. Night Heron
57. Pond Heron
58. Hoopoe
59. Common Iora
60. Kestrel
61. Blackcapped Kingfisher
62. Pied Kingfisher
63. Small Blue Kingfisher
64. Whitebreasted Kingfisher
65. Blackwinged Kite
66. Brahminy Kite
67. Indian Kite
68. Indian Koel
69. Redwattled Lapwing
70. Yellowwattled Lapwing
71. Collared Sand Martin
72. Dusky Crag Martin
73. Redheaded Merlin
74. Small Minivet
75. Blackheaded Munia
76. Red Munia
77. Spotted Munia
78. Whitebacked Munia
79. Whitethroated Munia
80. Blackheaded Myna
81. Greyheaded Myna
82. Indian Myna
83. Jungle Myna
84. Little Nightjar

85. Golden Oriole
86. Barn Owl
87. Collared Scops Owl
88. Mottled Wood Owl
89. Spotted Owlet
90. Blossomheaded Parakeet
91. Roseringed Parakeet
92. Grey Partridge
93. Rosy Pastor
94. Grey Pelican
95. Blue Rock Pigeon
96. Indian Tree Pipit
97. Paddyfield Pipit
98. Indian Pitta
99. Yellowlegged Button Quail
100. Black Redstart
101. Indian Roller
102. Indian Robin
103. Magpie Robin
104. Common Sandpiper
105. Green Sandpiper
106. Shikra
107. Baybacked Shrike
108. Brown Shrike
109. Small Skylark
110. Common Snipe
111. Painted Snipe
112. House Sparrow
113. Blackwinged Stilt
114. Painted Stork
115. Maroonbreasted Sunbird
116. Purple Sunbird
117. Purple Rumped Sunbird
118. Common Swallow
119. Redrumped Swallow
120. Wiretailed Swallow
121. Alpine Swift
122. House Swift
123. Tailor Bird
124. Lesser Whistling Teal
125. Blue Headed Rock Thrush
126. Whitethroated Ground Thrush
127. Grey Tit
128. Tree Pie
129. Whitebacked Vulture
130. White Scavenger Vulture
131. Grey Wagtail
132. Large Pied Wagtail
133. White Wagtail
134. Yellow Wagtail

135. Ashy Wren Warbler
136. Blyth's Reed Warbler
137. Greenish Leaf Warbler
138. Large Crowned Leaf Warbler
139. Orphean Warbler
140. Plain Wren Warbler
141. Streaked Fantail Warbler
142. Tickell's Leaf Warbler
143. Whitebreasted Waterhen
144. Common Weaverbird
145. White-eye
146. Lesser Whitethroat
147. Woodcock
148. Indian Woodshrike

Plant species: (As seen from top of the adjacent building – Aranya Bhavan: Bird eye view)

1. Caryota urens
2. Ficus religiosa
3. Artocarpus heterophyllus
4. Santalum album
5. Brousonetia papyrifera
6. Pongamia glabra
7. Grewelia robusta
8. Spathodea campanulata
9. Causuarina equisetifolia
10. Cassia spectabilis
11. Eucalyptus sp.
12. Ricinus comunis
13. Polyathea longifolia
14. Mangifera indica
15. Peltophorum pterocarpum

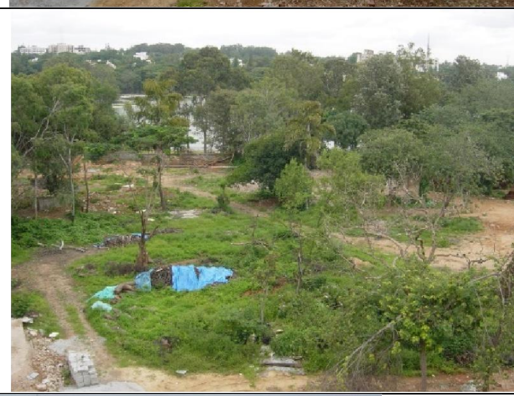
Reference:

Ramachandra T.V., Kiran, R., Ahalya N, 2002, Status, Conservation and Management of Wetlands, Allied Publishers Pvt Ltd, Bangalore.

Ranjit Daniels, R. J., 1992. Of Feathers and Colours: Birds of Urban South India. Indian Institute of Science, Bangalore, India.

Lakshman Rau, 1986, Report of the Expert Committee for Preservation, Restoration or otherwise of the existing tanks in Bangalore Meteropoliton Area.




Water percolation in this region happens due to green cover. But, removal of green cover with large scale buildings and paved surfaces, would reduce and affect the hydrologic regime of the lake. Lake is being used by all sections of the society – recreation (children and elders), education (science experiment), livelihood (fishing, etc.), etc. Need to protect the lake to maintain inter and intrageneration equity - **'hold the natural and cultural environment of the Earth in common both with other members of the present generation and with other generations, past, present and future'** (Weiss, 1990). It means that **we inherit the Earth from previous generations and have an obligation to pass it on in reasonable condition to future generations**.

Weiss, Edith Brown 1990, 'In fairness to future generations', *Environment*, vol. 32, no. 3, Apr., pp. 7-11, 30-1.

In the interest of the society and future generation, onus is on the proponent of these construction activities to hand over this land (acquired clandestinely) to the Government of Karnataka to develop as children's park. This would also help in showcasing the commitment of citizens and administrators of Bangalore towards maintaining inter and intra generation equity.

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Fish Mortality in Bangalore Lakes, India

Ranjeev Benjamin (1), B.K. Chakrapani (2), Kar Devashish (3), A.V. Nagarathna (4), and T.V. Ramachandra (5)

(1) University of Rochester, New York, USA.
(2) Zoology Department, Bangalore University, Bangalore, India.
(3) G.C. College, Assam University, Silchar, India.
(4) Biodiversity Unit, J. N. Centre for Advanced Scientific Research, Bangalore, India.
(5) Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India.

Abstract:
Large-scale episodal mortality among the freshwater fishes of certain lakes of Bangalore City, Karnataka State, India occurred in June 1995. We conducted an intensive study of the Sankey Lake which is situated in Sadashiva Nagar of Bangalore city where fish mortality occurred on quite a large scale during June - July 1995. These studies reveal that the fish-kill in Sankey Lake was due to a sudden and considerable fall in dissolved oxygen (DO) levels in some locations caused by sewage let into the lake resulting in asphyxiation. It was not due to any kind of infection because none of the fishes appeared to show any symptom of disease.

Introduction

Rivers, lakes and wells are important sources of water in a region. Water is an essential component of an eco-system. It sustains life on earth. A community depends on water for its domestic, agriculture and industrial needs. Availability of water has been a factor in the development of various civilisations near lakes and rivers. At a particular stage in development, tanks and wells are introduced to harvest rain and ground water. Wells and tanks are the sources of water in most places even today. Tanks harvest rainwater and store it, while wells tap water stored underground.

The total water spread in India is about 4.5 million hectares. Inland aquaculture resources cover about 3 million hectares. These include about 0.72 million hectares of natural lakes and 2.0 million hectares of constructed reservoirs. The state of Karnataka has about 2000 perennial and about 30,000 seasonal tanks with a total water spread area of 3,000,000 hectares. The average annual fish yield from these tanks is estimated to be about 350 kg fish per hectare per year.

In June 1995, there was a large-scale episodal mortality among the freshwater fishes of certain lakes of Bangalore city in Karnataka state, India.. We conducted an intensive study of the Sankey Lake, which is situated in Sadashiva Nagar of Bangalore city, where fish mortality occurred on quite a large scale during June-July 1995. This episode follows immediately after fish deaths in Lalbag Lake, which is located about 12 kilometers away.

Lakes and Bangalore City

Lakes and tanks are known to be the ecological barometers of the health of a city. They regulate the micro climate of any urban centre. Bangalore district has about 141 lakes. The government is spending millions for development of these lakes. Rapid urbanisation has lead to the loss of wetland habitat through encroachment, bad management, pollution from sewage, and waste and litter disposal activities. These factors have seriously affected the survival of tanks and lakes and have posed serious threat to the flora and fauna supported by them.

Sankey Lake is among the few lakes in the northern part of the city with continuous drains. It is also the main source of ground water to this part of Bangalore. It harbours a rich biodiversity which includes birds, fishes, aquatic plants and microbes. The presence of a biotically diverse and beautiful botanical garden and a forest nursery adjacent to the lake increases the ecological value. The Bangalore City Corporation is also developing a park at the north western end.

The 'Sankey Lake,' situated in the heart of Bangalore City (Lat.:13° 00'24" - 13° 00'41"N; Long.:77° 33'53" - 77° 34'5"E; altitude: 921 m MSL, maximum water spread area 12 ha, maximum depth 23 ft, average depth 9 ft), is a 500 year old, perennial water body and supports a significant biotic community. Since the beginning of 1982, drainage of industrial effluent and other domestic sewage into the lake has been stopped and the lake is expected to be free from noticeable pollution. Long-term studies on hydrology and microbial ecology, conducted during the last decade, have indicated that Sankey Lake has high potentiality for development of inland fisheries practices [1]. The average annual photosynthetic profile suggests the significance of the heterotrophic food chain in sustaining the higher trophic levels. With a mean fish production of 859 metric tonnes/year, the present fish production efficiency works out to 0.43 per cent. Since the lake is still mesotrophic and is amenable to management measures, a higher target fish production appears quite feasible [1, 2].

Sankey Lake was studied for its hydrobiological characteristics by many agencies like the Central Inland Fisheries Research Institute. the Central Institute of Freshwater Aquaculture, Bangalore University, University of Agricultural Sciences and the Indian Institute of Science from time to time but a comprehensive study was not carried out by these agencies covering all aspects of ecology [1,2,3,4]. This lake forms a nucleus for research investigations and an ideal breeding ground for commercially important fishes like Etroplus suratensis, Murrels (Channa marulius), Catfishes (Heteropneustes fossilis), small palaemonid prawns and the commercial variety, Macrobrachium malcolmsonii. This lake harbours Tilapia along with many other smaller fishes. In the past, the lake was stocked at times with small numbers of freshwater prawns (Macrobrachium malcolmsonii). The results were satisfactory, thus providing evidence of its potential for freshwater prawn culture as well.

Cage culture is the growing of fish in an enclosure of fish netting material, such as nylon, to monitor growth, productivity, and survival of different species like Catla, silver carp, common carp, Tilapia and Mrigal. In the first ever cage culture experiment (from fry to fingerlings stages) conducted in this lake for four months, common carp fry at a stocking density of 2.13 lakh/ha, showed a survival of 97.5% and 88.0% for silver carp. Cage culture (fingerlings to table size) of common carp, Catla has shown a production range of 92 to 225 t/ha with a survival rate from 80 to 100%. Experiments of cage culture with peninsular carps like Labeo fimbriatus, L. calbasu were also undertaken in this lake. Artificial breeding of the cage reared L. calbasu and common carp was also tried. A viable hybrid of common carp, calbasu, has been produced for the first time in this country from cage reared fishes of Sankey Lake [2].

Heavy washing of clothes by dhobis and continued entry of domestic sewage in some areas are posing pollution problems. Rapid growth of human population, proliferation of buildings, roads and vehicular traffic in Bangalore have taken a heavy toll of wetlands. Further, encroachment, disfiguring by brick/tile industries, waste disposal activities and bad management have threatened the very existence of many of the valuable and productive wetland habitats in the city, thereby posing serious threat to the flora and fauna supported by them. Although there is wide public concern about wise use of wetlands, lack of knowledge of the ecological conditions of these habitats has caused many losses. The loss of environmental benefits could be very crucial in a situation which the Bangalore city faces today [3,4,5]. Sankey Lake is the only wetland which has withstood the changes in the growth of Bangalore even though it is located in the heart of the city. As a result of human activity over the years, accumulations of silt and clay have led to changes in the pattern of sediment-water exchange. Dissolved oxygen is not a limiting factor and thus the water has promoted the growth of 21 species of phytoplankton. Although, the human activity has resulted in the enrichment of nutrients in the sediment, their level in water still remains low due to poor exchange of nutrients in the sediment [2].

Comparison of plankton species made from three different studies during 1981-84, 1982 and 1989 indicated that both the phyto and zoo plankton species richness has been increasing over the years [1,3,4]. In the 1989 survey, though Microcystis was observed to be dominant among the phytoplankton species, an increased number of Myxophyceae forms is considered ecologically significant. A total number of 27 phytoplankton and 28 zooplankton species have been recorded from this lake. The 1989 survey [4] covering 97 sites listed 58 plankton and 55 zooplankton species for the Bangalore area. This means that nearly half the plankton species richness of Bangalore is found in this lake which is right in the heart of urban Bangalore. From the point of view of the lake waters, the progression in plankton species richness from 1981 to 1989 probably indicates an improving situation [2].

Nevertheless, this ancient lake which reflects the cultural heritage of the city, has an annual average photosynthetic value ranging from 0.81-1.42% and has a mean fish production level of 36.57 gm-2 [1]. The important role of Sankey Lake needs to be highlighted, which has been maintaining the ground water level in the surrounding areas, that includes Malleswaram, Palace Orchards, Rajamahal Vilas, Vyalikaval, Palace Gutthalli and Yeshwantpur. Careful observation of the lake morphology, hydrodynamics and sedimentation, show that the water from Sankey Lake that seeps through the soil is not lost but recharges the natural underground reservoir which in turn supplies water to wells and bore wells in all the areas mentioned [1,2,3]. This lake has great fish potential, supports human environmental needs and contributes to climatic stability. Thus the multiple contribution of the Sankey Lake to the city's economy through ground water recharge and the ecological role of the tanks needs to be recognized.

Literature review

Water quality, habitat structure, flow regime, energy source and biotic interactions are the major environmental factors that determine water resource integrity [6]. The physical and chemical attributes of water are the critical components of a water resource. They include temperature, dissolved oxygen, pH, hardness, turbidity, concentration of soluble and insoluble organic and inorganic, alkalinity, nutrients, heavy metals, and an array of toxic substances which may have simple chemical properties or their dynamics may be complex and changing, depending upon other constituents in the geological strata, soils, and land use in the region [7]. The human effects on biological processes can result in mortality or may shift balance among species as a result of subtle effects, such as reduced reproductive rates or changing competitive ability.

Both fresh and salt water also form the habitats for innumerable organisms, such as seaweed, shellfish, crabs and other marine life that are components of human nutrition. In Europe and North America, impaired health and reproductive disorders were observed in aquatic animals and animal species that derive their sustenance from the water [8]. The causes were discovered to be contaminants in the water, such as organochlorines, e.g., DDT and other insecticides, and organic heavy metal compounds, e.g. methylmercury, which had been assimilated by the animals via their skin and respiratory systems or through food chains with associated concentration (biomagnification). Methylmercury compounds are considerably more toxic than elementary mercury and its inorganic salts. Human exposure to methylmercury comes exclusively from consumption of fish and fish products and prenatal life is more susceptible to brain damage than adults [9]. Nonetheless, these discoveries represented only the beginning; a large number of other contaminants were subsequently diagnosed and their dispersal paths identified.

In addition to restrictions in the utilization of water bodies as sources of drinking water, or other uses, contamination of fresh water and marine water can also have a multitude of indirect deleterious effects on human beings such as disruption of community and traditional activity, economic and nutritional hardships. It is therefore of overriding importance to find and improve means of monitoring and evaluating water quality and pollution levels in order to remedy and/or prevent harm to human beings and their environment.

Means of Detecting Water Pollution

Theoretically it would be impossible to keep all contaminants out of all water everywhere; even without human influences contamination of bodies of water has always occurred and will continue to occur. For example, we need only think of the compounds which can be formed in lakes under certain conditions, such as hydrogen sulphide (H2S), which causes most of the organisms within the affected zone to die off, or at the very least causing oxidophilic organisms to avoid such polluted aquatic environments. If there is excessive introduction of allochthonous organic matter and/or in-situ production of organic substances, hydrogen sulfide is formed, for instance on the bottom of lakes, when the oxygen content is no longer sufficient for mineralization of organic materials by aerobic processes. Studies of the earth's history have revealed that water pollution of this kind has often happened even without human beings playing a role, such as in situ bacterial conversion of inorganic mercury species to the methylmercury form [10-13]. The industrialized nations are also still burdened with problems of this sort as is illustrated by the example of the Rhine. The quality of the water flowing in the Rhine has improved since the report of the Council of Experts for Environmental Issues in the Federal Republic of Germany, but it is still far from satisfactory [14]. Heavy metal contamination of the river even now, seems to be increasing again after an earlier controlled downward trend. However, this fact does not relieve us of the dangers of water pollution and draws our attention to the means of detecting and avoiding such pollution [14-16]. This, of course, also necessitates the provision of training and technological know-how.

General review of assessment procedures

It would go beyond the scope of this paper to present here an exhaustive discussion of all possibilities which are available for the use of bioindicators and biomonitors in aquatic ecosystems. Therefore for classification of water pollution we review the following methods. To begin with, however, a brief review of the different types of evaluative procedures is in order. These are:

1. Physical and chemical water analysis;
2. Biological procedures based on the use of;
a) Bioindicators;
b) Biomonitoring;
3. Remote sensing

Physical and Chemical Water Analysis

With the aid of physical and chemical analysis techniques, it is possible to obtain information on the condition of water at the place and time at which the samples are taken. Depending on the quality of the investigatory methods used and the number of parameters studied, some useful data are yielded on the quality of the water at that point in time. How accurate and detailed the results must depend upon the purposes for which analyses are performed. In order to obtain more precise data, repeated analyses are necessary; these can even be aimed at identifying changes during the course of a single day [8]. A number of parameters are measured, including the presence of the amount of organic carbon, ammonium, nitrate, orthophosphate and oxygen, as well as the biochemical oxygen demand (BOD). By means of additional tests, it is also possible to obtain additional information on the concentration of toxic substances. As is to be expected, continuous taking of samples and performance of analyses are associated with high technical, financial and labour inputs. The costs incurred grow with the number of samples taken and the range of substances which are tested for. Even the industrialized countries can only afford to do this within certain limits. Nevertheless, within the scope of major technical projects, it would be useful to carry out similar sample-taking and analysis programs at various locations for monitoring purposes. This would have to be specifically decided upon with respect to each individual case [6,7,8,9].

When evaluating water pollution with the aid of bioindicators, an understanding of an organism's reaction to changes in its environment is essential. These reactions can take the form of growth and/or increased population density, modified activity, reduced growth, a decline in population, or even death. Depending on their degree of complexity, size, generation time and other factors, organisms and different species react at varying rates. Most bacteria adapt very quickly to environmental changes. Protozoa and algae take longer, and insects - many of which live for a year or longer as larvae in the same aquatic environment - require longer periods to react to changes in their surroundings. As a rule, organisms with longer generation times respond more quickly to negative changes -if they exceed the limits of what is tolerable - for example by migrating to zones with satisfactory living conditions or by dying. Depending upon the time which bioindicators or indicator organisms spend in a body of water, they are subjected to the prevailing environmental conditions and any changes that occur. Thus, members of a related group of organisms or a biological community integrate and reflect environmental conditions and possible changes over an extended period of time.

Consequently, critical evaluation of the species compositions of a biocoenosis can yield sufficient data on the situation of a body of water and the range of fluctuations in the environment over a lengthy period of time.

Remote Sensing

Aerial photography can yield qualitative and quantitative information on changes in environmental conditions. Remote sensing can be used to provide information on the environment at a wide range of scale. At local scales it can be used to study a small area in considerable spatial detail. Spatial resolution data sets provide valuable data on the environment especially in the context of changes. The studies of this type which have been performed on the expansion of dry regions (examples: Sahara, Sahel) are well known [17-24]. Changes in the condition of large bodies of water can be detected in the same way. Studies in South India [25] have shown that satellite remote sensing techniques can provide reliable and objective data on water quality, agriculture productivity and related water management aspects.

Methods

Water, fish and soil samples were collected from the Sankey Lake for six consecutive days at 12 various locations across the lake. Chemical analyses of soil, water and fish samples were carried out in various laboratories including the Zoology Department, Bangalore University, Regional Sophisticated Instrumentation Centre, North Eastern Hill University, Shillong (Meghalaya), G.C. College, Silchar (Assam) and Centre for Ecological Sciences, Indian Institute of Science, Bangalore.

Results and Discussion

This study revealed that large scale mortality has occurred among fish species like Eutroplus suratensis, Chanda ranga, Puntius sp., Nandus nandus and Amblypharyngodon mola. Investigations into the limnological parameters revealed not much deviation from the usual values for this region with water temperature 28°C, water transparency 31 cm, free carbon di-oxide (FCO2) generally absent, water ph 7.683 (avg: average) and 0.570 (Sd: standard deviation), water conductivity 0.397 (avg) and 0.07 (Sd) milli mhos/cm. However, dissolved oxygen (DO) was recorded, very low at 2.6 and an average of 3.025 (Sd:0.076) mg/lit during the period of fish-kill. Estimation of nitrite and nitrate revealed 0.229 (avg) and 0.054 (Sd) and 1.374 (avg) and 0.477 (Sd) mg/lit; Phosphorous was 7.055 (avg) and 2.925 (Sd) mg/lit.

Analysis of the bottom soil revealed medium acidic pH (5.90), normal conductivity (0.07 milli mhos/cm), low available phosphorus (3.068 kg/acre) and low available potassium (17.5 kg/acre). There had not been any prolific growth of aquatic macrophytes in the lake and plankton density was also usual during the period of fish mortality. Estimation of trace elements through atomic absorption spectrophotometry revealed a low quantity of lead and cadmium in both water and soil, mercury was not detected. The results of chemical analyses shows that, in water lead quantity was 0.47 ppm and cadmium 0.04 ppm and in soil lead content was 0.55 ppm and cadmium 0.05 ppm.

These studies reveal that the fish-kill in Sankey Lake was due to sudden and considerable fall in DO levels in some locations (due to sewage let into the lake) resulting in asphyxiation and was not due to any kind of infection because none of the fishes showed any symptom of disease. Steps are to be taken for the conservation of this biotope, which not only provides a recreational spot for the tourists, but has also been serving as one of the potential sites for stocking, hybridisation and cage culture of the Indian major carps.

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Mr.Ranjeev Benjamin <rb0056@uhura.cc.rochester.edu>, Chemical Engineering Department, University of Rochester, New York 14627, USA.

Dr. Chakrapani <energy@ces.iisc.ernet.in> Zoology Department, Bangalore University, Jnana Bharathi Campus, Bangalore 560 056, India.

Dr.Devashish Kar <dks@ces.iisc.ernet.in> Environmental Sciences, G.C. College, Assam University, Public School Road Silchar 5, Assam, India.

Ms. A.V. Nagarathna <avn@ces.iisc.ernet.in>, <avn@jncasr.ac.in> Biodiversity Unit, Jawaharlal Nehru Centre for Advanced Scientific Research, Jakkur Post Office, Jakkur, Bangalore 560 064, India.

Dr. T.V. Ramachandra <cestvr@ces.iisc.ernet.in>, <energy@ces.iisc.ernet.in> Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India.

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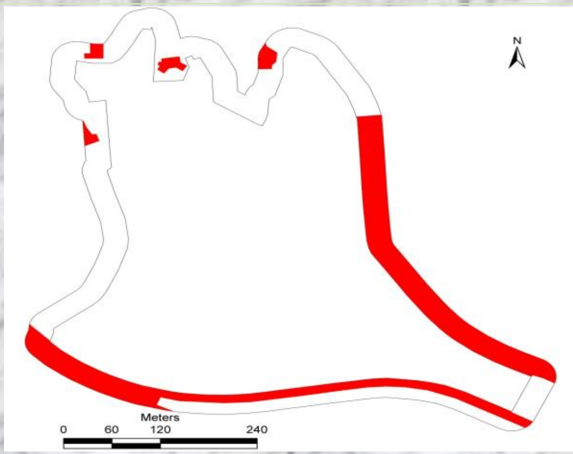

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