
Eutrophication: Global Scenario and Local Threat to Dynamics of Aquatic Ecosystems

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Abstract

All self-regulated aquatic ecosystems maintain their structural and functional dynamics in equilibrium. Most natural oligotrophic surface water bodies maintain production: respiration ratio closer to 1 irrespective of geographical variations. The prevailing environmental gradients govern seasonal, structural and functional dynamics of aquatic ecosystem. During the past century, major socio-economic changes resulted into adverse alteration in both terrestrial and aquatic ecosystems. The terrestrial and aquatic ecosystems are not independent of each other. There is a delicate balance between the two. In the present work, changes in the delicate balance between seasonal, spatial, littoral dynamics and resulting bio-geo-chemical changes in the eutrophic water bodies have been highlighted. Seasonal environmental variables are the forcing factors behind cycling of materials in the water bodies which in turn result into structural and functional dynamics. Summer season triggers the release of orthophosphates bound in the sediments and advection brings the free nutrients to upper water surface and promotes phytoplankton abundance. The rain water input during monsoon may dilute or enrich the water bodies with nutrients subject to the quality of catchment areas. Upwelling and downwelling and surface run offs are among major drivers of the dynamics of water bodies. The hydrological characteristics of water bodies vary with the geographical location. Under extreme polluted conditions, seasonal heterogeneity in nutrient composition of water bodies may not remain maintained except on downstream scale. Phosphorus (P) in runoff from agriculture land accelerates eutrophication of lakes and streams. Seasonal variation of some selected macrophytes in a surface water body close to AMU campus has been studied. About 7.56 ha of catchment area of a nearby park forms a source of fertilizer "run off". Qualitative and quantitative seasonal estimates of density and productivity of two indicator species (*Lemna minor*, *Spirodela polyrrhiza*) and physicochemical properties indicated that the water body is under a fast rate of eutrophication process owing to chemical fertilizer inputs, variables of summer (high wind, high temperature, fast wind speed), winter (low temperature, reduced rain fall), and monsoon (excessive rainfall).

Keywords

Eutrophication · Fertilizers · Nitrogen · Phosphorus · Phytoremediation

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2.1 Introduction

Freshwater is an indispensable resource and essential for life. Freshwater constitutes only 2.5% of all freely available water on earth's surface, of which only 0.3% is readily accessible in lakes, reservoirs and rivers (Kalf 2001). Some major problems that humanity is facing in the twenty-first century are related to water quantity and/or water quality issues (UNESCO 2009). The anthropogenic activities result into large-scale contamination or pollution of water. The quality of surface water may degrade if quantities of suspended particles, organic and inorganic substances and microorganisms increase than their usual amounts and hence water becomes unfit for use. "Eutrophication" is the excessive enrichment of surface water with nutrients corresponded by high production of autotrophs, especially algae and cyanobacteria. The high productivity leads to high respiration rates, resulting in hypoxia or anoxia in poorly mixed waters. Low dissolved oxygen (DO) causes the loss of aquatic organism (Corell 1999). The undesirable overgrowth of phytoplankton and their subsequent death forms a greenish slime layer over the surface of water body, which restricts the light penetration (Khan and Ansari 2005, Ansari et al. 2011a, b and c). The death and decay of aquatic plants produce a foul smell and makes the water more turbid (Beeton 2002). Lake Taihu and Lake Baiyandian of China, several Danish lakes, Greek lakes, Lake Chapala of Mexico, Lake Yamoussoukro of West Africa, several water reservoirs and rivers in Asia, Europe, north and south America are highly eutrophic owing to nutrient loads from agriculture households (Jeppesen et al. 1999, Qin 1999, Jose et al. 2000, Raja 2000, Tripathi and Adhikari 1990, Nagy et al. 2002, Huang et al. 2003, Mama et al. 2003, Voutsas et al. 2004, Khan and Ansari 2005, Ansari et al. 2011a, b, c).

In past 30 years, seasonal variations in the characteristics of water bodies have been studied considering a wide range of water quality parameters. The DO in surface water layers and biomass of aquatic macrophytes of fresh water Surinsar Lake (Jammu, India) covaried seasonally (Sehgal and Jyoti 1987). The monsoon seasonality effectively regulated functions and processes of an artificial lentic ecosystem in Seoul (South Korea) and had important implications to eutrophication (An 2003, An et al. 2003). The algal and phytoplankton densities were found mainly related to seasonal water discharge in Rhine and Meuse rivers of Netherlands (Naim 1993, Ibelings et al. 1998). The seasonal variability in number and biomass of zooplanktons corresponded with O₂ availability in a polytrophic Mutek Lake, Poland (Widuto 1988). The seasonal water quality variation in northern coast of Karawang (West Jawa) was directly related with eutrophication. In wet season, excessive input of organic waste with high amount of dissolved inorganic nitrogen and phosphate from agriculture increased chlorophyll-a concentration (Sachoe-mar and Yanagi 1999). The nitrogen concentration in Yuqiao reservoir basin of China declined in the average flow season

near the source and increased in rainy season (Chen et al. 2002). The seasonal changes in summer increased orthophosphate content in Tokyo Bay (Japan) and reflected variations in biological activity (Miyata and Hattori 1986). In Austrian part of river Danube, the seasonal patterns of nutrients were minimum in summer and maximum in winter (Weilguni and Humpesch 1999). The long-term studies of nutrient pattern in Kentucky Lake (USA) revealed that the seasonal variations in nutritional discharge were more pronounced than the actual variation in the reservoir with regulated discharge. Greater variation in the nutrient concentrations were found on eastern forested side of Kentucky Lake (USA) than on agriculturally dominant embayment (Yurista et al. 2004).

Increasing inputs of inorganic fertilizers and pesticides and inefficient use of organic wastes in agriculture adversely affected the biophysical environment creating serious threats to human beings (Mukhopadhyay et al. 2005). Addition of agricultural nutrients (fertilizers) altered the nutrient cycles of watersheds of agro-ecosystems. Nutrients enter the watersheds via precipitation, fertilizers, nitrogen fixation, irrigation, and weathering. The nutrient losses are also derived from stream flow, subsurface flow, deep seepage, and loss of volatile gases as well as the harvest of plants and animal products (Kormondy 2003). Agriculture activities and livestock breeding are the two main nutrient sources responsible for the eutrophication, besides human-urban and industrial wastewater discharges (Sala and Mujeriego 2001).

Accelerated eutrophication of surface waters is often caused by high phosphorus losses from agricultural fields (Sharpley et al. 2001, Schroeder et al. 2004, Djodjic and Bergstrom 2005, Khan and Ansari 2005, Vadas et al. 2005, Ansari et al. 2011a, b and c). In India, the use of fertilizers (urea, phosphate and potash) has increased manifold in the past 40–50 years. A significant quantity of these nutrients reaches nearby water bodies through rain water, irrigation channels and seepage. Flood prone and rainfed water bodies around cultivated areas often show algal blooms. In the present study the seasonal variation in the population of *Lemna minor* and *Spirodella polyrrhiza* and water quality of the Lal Diggi pond, close to the Aligarh Muslim University campus has been studied at monthly interval with special reference to variations in local meteorological variables. The duckweeds are very sensitive to surrounding atmospheric factors. Their potential as indicators of water quality has been studied by several workers (Cheng et al. 2002, Khan and Ansari 2005, Ansari and Khan 2008, 2009, Ansari et al. 2011a, b and c).

2.2 Literature Review

The domestic waste (rich in phosphate and nitrate) when discharged in water bodies makes them highly productive or "eutrophic". Nutrient enrichment is the starting point of eutrophication in any water body and is followed by uncon-

trolled growth of primary producers which depletes oxygen owing to decomposition of algal organic matter. The phosphorous content of eutrophic lakes is between 30 and 100 $\mu\text{g/L}$ and above 100 $\mu\text{g/L}$ phosphorous content is typical of hypereutrophic lakes (Wetzel 2001).

Irradiance and water temperature in summer limited the growth of phytoplanktons in Dokoi Bay of Japan (Morishita et al. 2001). The Hiroshima Bay and Suo Nada of Seto Inland Japanese Sea had significant variation in microbial communities in spring and autumn and corresponded to seasonal changes in sediment parameters (Rajendran and Nagatomo 1999). Two seasonal peaks of the microzooplankton populations, one in the month between late spring and early summer and the other in the autumn season were recorded in highly eutrophic Tokyo Bay of Japan (Nomura et al. 1992). High primary production led to high concentration of particulate phosphorus in surface water of Tokyo Bay which later settled in deeper layers and released orthophosphate on decomposition. This orthophosphate was occasionally advected upwards by wind-induced water mixing and again promoted the phytoplankton growth in upper layers. Increased phosphorus in summer was attributable to increased input from river waters and release of orthophosphate from anoxic sediments (Miyata and Hattori 1986). The phytoplankton standing crop had a high correlation with nutrient loading in three experimental ponds in Japan. The relationship between total phosphorus and chlorophyll-a varied seasonally showing highest correlation in autumn (Aizak et al. 1986). The continuous input of nutrients from the rivers at their confluence with Kasumigaura Lake (Japan) increased algal primary productivity. The particulate matter varied seasonally and maintained higher concentration in Takahamairi Bay than in Tsuchiurairi Bay of the Lake (Ebise 1998).

During wet season, excessive input of organic waste in Karawang, West Jawa increased chlorophyll-a concentration (Sachomar and Yanagi 1999). The phytoplankton biomass and water quality were influenced by rainfall in Pyeongtaek Reservoir of South Korea (Shin 2003). In Austrian part of River Danube, the concentrations of some nutrients were minimum in summer and maximum in winter (Weilguni and Humpesch 1999). A succession of phytoplankton dominant turbid water from macrophyte dominant clear water state in eutrophic back water of river Denube was recorded between 1992 and 1994 (Kirschner et al. 1999).

In shallow eutrophic Doirani Lake (Denmark), small diatoms (r-species) dominant in the early stage, were replaced by *Microcystis*, *Anabaena* and *Ceratium* (s-species) in summer. Thermal fluctuation and small depth mixing increased sediment-water interaction and altered nutrient concentration (Temponeras et al. 2000). The hydrological conditions in hot season caused eutrophication leading to enhanced algal growth and reduced floral vitality in nutrient-rich degraded reef in France (Naim 1993). The algal growth, rainfall and winds led to nutrient fluctuations over space and

time in Messolonghi Lagoon of Greece (Frigos 1989). The wind in shallow lakes played a significant role in seasonal succession (Padisak 1980).

The long-term studies of nutrient patterns in Kentucky Lake (USA) revealed that the seasonal variations in nutrient discharge were more pronounced than the actual variation in the reservoir with regulated discharge. Greater variations in nutrient concentrations were found on eastern forested side of the reservoir than on the western agriculturally dominant embayment. The annual average of nutrient pattern did not change and eventually had no impact on the eutrophication potential during study period from 1989 to 1998 (Yurista et al. 2004).

2.3 Impact of Fertilizers

Phosphorus and nitrogen inputs owing to excessive use in agricultural practices, their cycling in the water bodies and seasonal variability (of temperature, water level, depth, irradiance and winds) are the main causes of eutrophication (Khan and Ansari 2005). The use of fertilizers in agriculture has increased several folds during the past 40 years in India (Anonymous 1998, 2002). Several brands of chemical fertilizers containing micro and macro nutrients are being excessively used in addition to compost for optimum crop productivity (Fixen and West 2002). The P-PO_4 concentration greater than $0.1 \mu\text{g L}^{-1}$ caused eutrophication in three Gorge Reservoirs of China. Nitrogen and phosphorus runoff from agricultural, municipal and industrial effluents increased nutrient input in water (Liu et al. 2004).

2.3.1 Impact of Nitrogen

Commercial nitrogen fertilizers (81.7 million MT) account for approximately half of all nitrogen (N) used in croplands on a global scale. Current N-efficiency and crop productivity are lower in several parts of Asia than in North America (Fixen and West 2002). The application of chemical fertilizer per unit area of farmland in Japan peaked in 1985 (Mishima 2001). Phosphorus and nitrogen in runoff from agricultural fields are key components of non-point source pollution of water bodies and can accelerate eutrophication of surface waters (Zheng et al. 2004). The main source of nitrogen in underground water of Europe is leaching from agricultural fields. High nitrogen inputs in the marine environment cause eutrophication and thus increase algal growth, change biological communities and deoxygenate water (Iverson et al. 1998). Nitrates from fertilizers account for nearly 50% of the surface water acidification in watershed. Non-point source pollution of surface water by nitrate from agricultural activities is a major environmental problem (Steinheimer et al. 1998). Biological transformations of N added to ponds

in the form of inorganic or organic fertilizers and formulated feeds were found to dominate the nitrogen biogeochemistry of aquaculture ponds. Nitrogen application in excess of pond assimilatory capacity deteriorates water quality (Hargreaves 1998).

2.3.2 Impact of Phosphorus

Phosphorus accelerates freshwater eutrophication and water quality impairment. Agriculture is regarded as an important source of P in environment. The loss of P in surface runoff and subsurface flow originates primarily from small areas around watershed, where high application of phosphorus fertilizer or manure coincide with high runoff or erosion potential (Sharpley et al. 2001, Carpenter et al. 1998). In water bodies phosphorus may be present in various forms. All forms of phosphorus are not readily available to plants. Total phosphorus is a measure of all forms of phosphorus (dissolved or suspended) found in any water sample. The soluble reactive phosphorus (SRP) is a measure of orthophosphate. The soluble inorganic phosphorus is directly taken up by plant cells and its concentration indicates the stage of eutrophy and oligotrophy (Hammer 1986). Accelerated eutrophication of surface waters is often caused by high phosphorus losses from agricultural fields (Schroeder et al. 2004, Djodjic and Bergstrom 2005, Vadas et al. 2005). In a German lowland eutrophic river, the clastic sediments acted as P sink in summer when SRP concentrations were relatively high. Organic river substrates serve as phosphorus source (Schulz and Herzog 2004). The application of phosphorus fertilizer and manure increased its transfer potential (Daniel et al. 1998, Zhang et al. 2004). Agriculture and urban activities are major sources of phosphorus and nitrogen to aquatic ecosystems. Nutrient enrichment seriously degrades aquatic ecosystems and impairs the use of water for drinking, industry, agriculture, recreation and other purposes.

The phosphate is relatively immobile element and may be carried to streams through soil erosion and storm runoffs from the excessively fertilized agricultural fields, nurseries, lawns and orchards. Certain synthetic chemicals such as pesticides, construction materials, flame retardants and plasticizers are the other sources of phosphate discharges in freshwater systems (Sharpley 1999). The literature review revealed that surface water bodies around agriculture land, nurseries, cities and fertilizer units are prone to nutrient enrichment which promotes excessive algal blooms. Human interference in up welling and down welling and prevailing climatic factors govern seasonal variations in the population dynamics of the aquatic flora and eutrophy of surface water bodies. In the present study, a devastating effect of human interferences on the existence of a small microcosm of a few acres near AMU campus has been studied.

2.4 Material and Methods

2.4.1 Description of the Study Site

Lal Diggi pond is a small rainfed pond located very close on the south of the campus of Aligarh Muslim University, Aligarh, India. Until last two decades, the human settlement around the pond was sparse but now its eastern side is densely populated. The western and southern sides have about 80 and 60 ft wide roads, respectively. In past 20 years, the roads have been raised, which act as weirs and prevents the rain water from its northern, southern and western catchments to drain into the pond. It is a rainfed pond and its water recharging capacity has thus reduced substantially. In 2002, the margins of this pond were raised again and a bypass drain constructed around its coastal lines took the rain water of its catchments away from this pond. The water level consistently reduced during 2002 and 2003. On realizing this disastrous change, the pond finally dried by May 2004. The pond was later on refilled and a passage for rain water unloading was reconstructed in 2005. The devastating changes in the physico-chemical property of the pond and seasonal variations were studied as described in the following section.

2.5 Results

2.5.1 Monthly Qualitative Studies

April 2003 The water level in the pond at various places varied between 2 and 4 feet. About 7–8 m wide moist and marshy northern coastline was occupied by *Typha angustata*. Eastern marshy coastlines (18–20 ft wide) had relatively denser population of *Typha angustata*. A patch of *Paspalum paspaloides* occupied 12–15 m wide area of the water body in the southern margin. South-western side had a patch of *Typha angustata* and remaining western side of the pond was open. Thus, the existing water body was surrounded by *Typha angustata* from northern, eastern and south western sides and by *Paspalum paspaloides* from the southern side. The main water body on its eastern margin was covered with mature water hyacinth (*Eichhornia crassipes*) almost in drying stage. The open area of water body was covered with duck weeds on the western side and south western side. The duck weeds were in the mature stage and at places most of them dried and formed slime body. About 50–100 cm of water level was recorded at about 5 m inside of the western coast of this mesocosm.

May 2003 The duckweeds on the western side of the pond dried almost completely. The water level in this area of the pond was maintained between 50 and 100 cm. The water hyacinth on eastern side completely dried. The *Typha angustata*

and *Paspalum paspaloides* occupied larger area on its northern and southern margins (Plate 1). But their density reduced in the harvested areas on southern side. *T. angustata* and *P. paspaloides* are harvested at small scale by local farmers and used for making mats and cattle feed.

June 2003 The size of water body reduced in area. The water depth varied from 25 cm to a little over 60 cm. The duckweeds and water hyacinth disappeared. The patches of *Typha angustata* expanded from moist eastern coast to the centre of pond. The water depth reduced to 12–15 cm on northern coast. The density of *T. angustata* further reduced owing to intensive harvesting. The *T. angustata* on eastern side was in drying phase but relatively green on south western side. The water receded and left eastern and northern sides as exposed moist sediments. About 20–30 m of southern coastal side of water body further dried and turned to be a marshy area.

July 2003 The pond was recharged owing to downpour in its catchment. The water level increased up to 90–110 cm with lesser density of duckweeds. The *Spirodela polyrrhiza* was more abundant (+++) than *Lemna minor* (+). The *Typha angustata* started sprouting again. The dried margins along all its sides, recorded in preceding month became marshy again. The water body swelled by the end of July 2003. The water-filled area and depth of the pond increased. The duckweeds covered the water surface within and between the patches of *Typha angustata* in the centre, eastern, northern and south western sides of the pond.

August 2003 Most of the water surface was covered with duckweeds (*Lemna minor* and *Spirodela polyrrhiza*). The density of duckweeds increased in this month as compared to July 2003. The water level increased up to 90–150 cm. The density of *Lemna minor* (+++) and *Spirodela polyrrhiza* (++++) increased as compared to the last month. The water-filled area of the pond was almost one and a half times larger than in the July 2003. The density of the *T. angustata* on eastern and southern coasts increased. The central part of the pond was free from any floating, submerged or rooted submerged plants. In this month, some diatoms and blue-green algae (details not covered in this study) were also noted to be present on coastal sides.

September 2003 Water level and area of the water body continued to be very high. The water depth was 100–150 cm on southern and eastern coast of the pond. The density of *Lemna minor* and *Spirodela polyrrhiza* decreased as compared to the density recorded in August. For the first time, some small patches of *Wolffia arrhiza* were also noted on the shallow coastal sides of the pond. The blue-green algae and diatoms were present.

October 2003 The water level at some places receded. The area of water body reduced. The water depth receded up to 30–50 cm on eastern southern and western coasts. The total area and volume of the water body reduced as compared to September. The density of *Lemna minor* and *Spirodela polyrrhiza* reduced substantially and disappeared from a large portion of the water body. The duckweeds were limited in 4 m × 6 m size patches in open water area and between the patches of *Typha angustata* on the eastern and south western sides. Some small patches of *Wolffia arrhiza* were also present.

November 2003 Both the selected duckweeds (*Lemna minor* and *Spirodela polyrrhiza*) rebloomed on the margins of open water body. The central part of the water body was almost devoid of duckweeds. Sparse populations of *Wolffia arrhiza* in small patches of approximately 25 × 30 cm to 50 × 50 cm sizes were found on the shallow and marshy margins of pond. The presence of algae and diatoms caused greenish appearance of water on the north western and western coasts of the pond.

December 2003 The duckweeds disappeared leaving the water surface open. The *Typha angustata* bloomed on north eastern, eastern and south western sides of the pond. *Paspalum paspaloides* grew predominantly on southern side. The water in this month was more turbid and dirty owing to the decaying duckweeds. The area of water body reduced slightly.

January 2004 The duckweeds started reappearing with abundant *Spirodela polyrrhiza* (++) and sparse population of *Lemna minor*. Dense patches of *Paspalum paspaloides* were recorded. The water body size reduced further than in the month of November and December. The north western side of the pond turned marshy and at places, patches of sediments were exposed. The main water body was limited to central and western side of pond. Rare occurrence of *Eichhornia crassipes* was seen on the eastern and north eastern margins. The water was more turbid than in the preceding month.

February 2004 The population of duckweeds was dense owing to gregarious blooming. The water level and area reduced further. The water was turbid. The density of water hyacinth was relatively higher than in the month of January.

March 2004 The major part of the water body was covered with densely populated duckweeds (*Lemna minor* and *Spirodela polyrrhiza*). A dense semi-lunar stripe of water hyacinth was formed and floated along northern, eastern and southern coasts. The water hyacinths were in the stage of drying. The patches of mature duckweeds formed thick brownish

mat. The area and volume of water body reduced further and eventually, the duckweeds and water hyacinth formed a thick cover on almost entire water surface.

April 2004 The duckweeds and water hyacinth were relatively denser than in April 2003, but in drying stage. The size of the water body was far smaller and limited to central and western side of the pond. Owing to fast reduction in water level and almost no recharging with the rain water, a vast area of the pond had several smaller patches of *Typha angustata* even in the centre of the pond. The pond dried by the end of May 2004. Sedge grass showed slight browning as it started drying after the maturity. Considerable drying of duckweeds was recorded along its coast and in the central part of very small patch of water body. The water level of 30–60 cm hindered the movement of small boats. Larger area sediment was exposed at many places (Fig. 2.1)

The aquatic body turned into terrestrial body and by April 2005, some trees of *Acacia nilotica* and *Prosopis* species appeared on the eastern, and northern and in the centre of the dried pond. In the following monsoon (July 2005–August 2005), the district local authorities managed the refilling of the pond with fresh water and reduced the weirs around it. This unusual restoration management resulted into a better non-blooming and lesser eutrophic water body.

2.5.2 Quantitative Studies

The monthly data on seasonal variation in population dynamics of *Lemna minor* and *Spirodela polyrrhiza* in the rain-fed Lal Diggi pond is summarized in Table 1. Both the duckweeds had numerical dominance in the months of February and March. *Lemna* bloomed in the months of November and August. *Lemna* and *Spirodela* did not grow in summer (April to June) and December. The density of *Lemna minor* dropped down significantly to 1,182 individuals/m² and of *Spirodela polyrrhiza* to 2,358 individuals/m² area of the pond. The highest fresh weight of the selected macrophytes along with blue-green algae and other floating macrophytes (excluding water hyacinth) was recorded in the month of November 2003, March 2003, August 2003 and February 2004. The fresh biomass was minimum in the month of January (Table 2). *Spirodela* accumulated maximum dry matter in the month of February 2004 followed by March 2003, November 2003 and August 2003. *Lemna* accumulated maximum dry matter in the month of March 2004 followed by November, February and August of previous year (2003). The dry weight of *Spirodela* and *Lemna* was least in the month of January 2004 and September 2003, respectively. The net primary productivity (NPP) of both the duckweeds was high in the months of February 2004, August 2003 and November 2003 (Table 2.1).

Spirodela polyrrhiza 225.82 g m⁻²yr⁻¹ The data in Table 2 show monthly variations in the population of *Lemna minor*, *Spirodela polyrrhiza*, *Wolffia arrhiza* and chemical characteristics of water (pH, NPK, TDS, turbidity) of the selected mesocosm, average atmospheric temperature and precipitation (rainfall in mm). *Lemna minor* and *Spirodela polyrrhiza* bloomed between July 2003 and March 2004 (except in December 2003). The occurrence of duckweeds was recorded in April 2003. The pH, water turbidity, total dissolved salts (TDS) and NPK contents were high but dissolve oxygen was very low in summer (April 2003 to July 2003). The nutrient contents (NPK) increased as the volume of water reduced in summer. The pH and turbidity reduced as the water body swelled after 11.4 mm downpour in the month of July (Table 2.2).

Lemna minor and *Spirodela polyrrhiza* bloomed in July 2003. The population ratio of *Lemna*:*Spirodela* was approximately 18:6 (105:36 individuals of *Lemna* and *Spirodela* respectively). The density of both these duckweeds increased in the month of August 2003 (Table 2). In this month the pH, turbidity and nutrients of the water decreased owing to recharging with rain water (causing natural dilution) and binding of nutrient into blooming aquatic organism. In September 2003, the population of duckweeds decreased substantially and few small patches (1–2 ft²) of *Wolffia* appeared. The population of *Lemna*, *Spirodela* and *Wolffia* continued to bloom until November. In the entire study period, the *Lemna*:*Spirodela* ratio varied between 18:6 and 24:6. The water pH reduced in November. The duckweeds dried and disappeared in December 2003. *Lemna* and *Spirodela* reappeared and bloomed in the month of January 2004. The turbidity, NPK and pH increased from December 2003 onwards. The highest population ratio between *Lemna* and *Spirodela* was recorded in November 2003, February 2004 and July 2003. In the month of April 2004, the duckweeds and other floating macrophytes such as *Eichhornia crassipes* (not covered in the present study) died. The water level also decreased sharply. The major part of the pond on eastern, southern and northern sides dried up first and completely by the end of May 2004. The pond remained dry for several months and could be recharged after the hurdles (weirs) around the pond were partially removed to let the mesocosm receive the rain water from its catchments.

2.6 Discussion

In the beginning of summer (April 2003), the size and volume of the main water body of “Lal Diggi” reduced with dirty appearance of water and moist or marshy margin around the pond with dense population of *Typha angustata* and *Paspalum paspaloides*. The water body size further reduced in May 2003 (Table 1). Rainfall in these 2 months

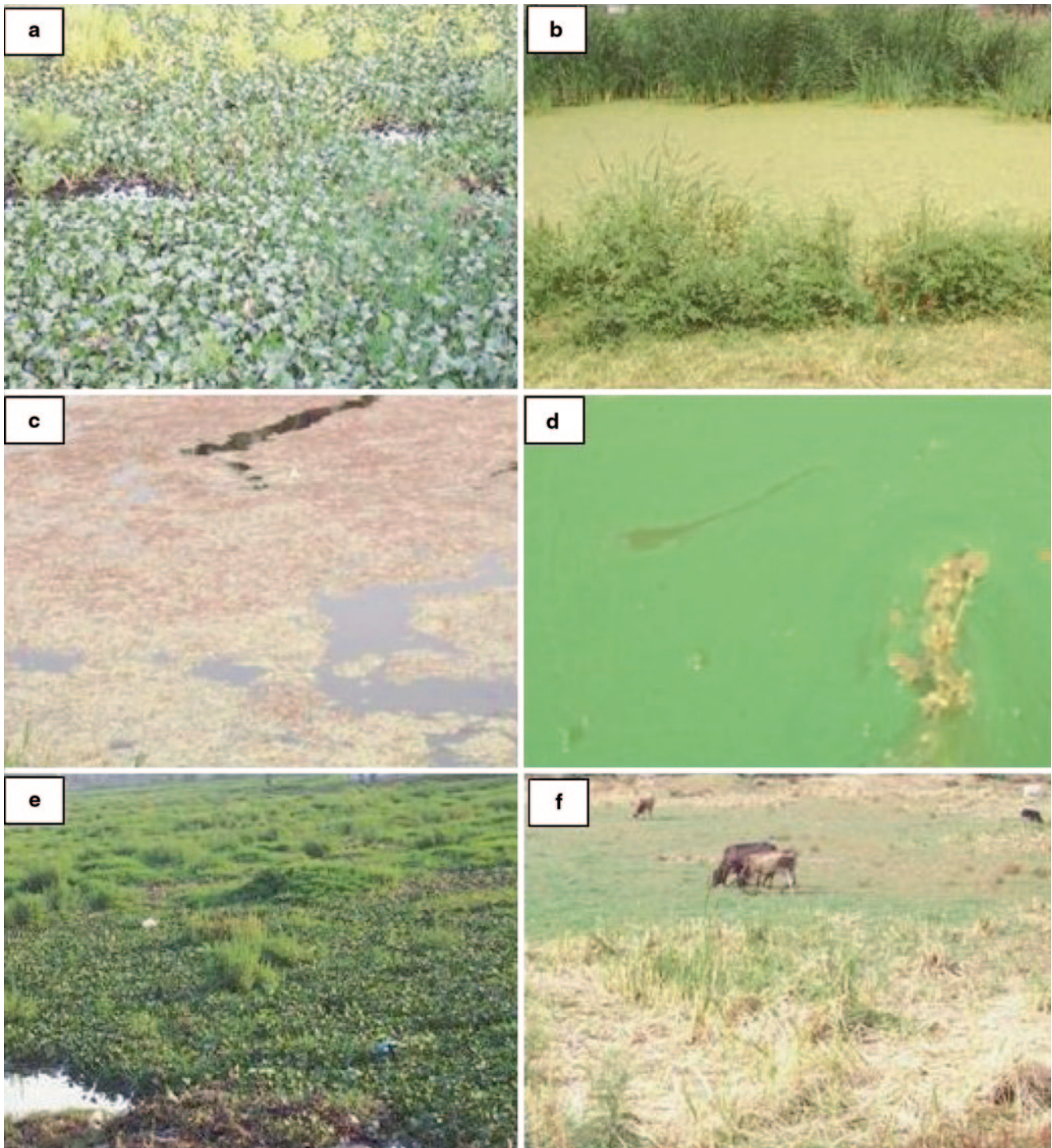


Fig. 2.1 Population of *Eichhornia crassipes* on eastern side of the pond (a), Blooming of duckweeds (*Lemna* and *Spirodela*) in the open part of western side (b), Duckweeds in the drying stage (c), Algal bloom in

small patches (d), *Eichhornia crassipes* and *Paspalum paspaloides* (e), Dried part of the pond in May 2004 (f)

was very low and average temperature and pH were very high (Table 2). The duckweeds in these two summer months did not survive. It is likely that reduction in area, depth and volume of water body in the summer may have increased turbidity and nutrient concentrations in the water body. The

nutrients bound in the plants were released after decay of duckweeds and advected to upper surface in summer. High pH, nutrient, turbidity and temperature were feasibly far above the optimum requirement of the duckweeds and may have increased their mortality. In microcosm experiments,

Table 2.1 Seasonal variations in the population dynamics and Net Primary Productivity (NPP) of selected floating macrophytes (duckweeds) in Lal Dikki pond near University campus

Month	Total fresh weight (g m ⁻²)	Plant	Population (×1,000 m ²)	Fresh weight (g m ⁻²)	Dry weight (g m ⁻²)	NPP (g m ⁻² d ⁻¹)
April 2003	–	–	–	–	–	–
May	–	–	–	–	–	–
June	–	–	–	–	–	–
July	448±24.1	L	9.47±0.08	116.48±4.11	12.79±0.05	+0.43
		S	3.25±0.05	135.29±1.55	17.23±0.08	+0.57
August	1,508±189.9	L	41.53±0.09	485.58±5.22	61.32±0.06	+1.57
		S	15.68±0.03	672.57±18.83	79.02±0.14	+1.99
September	1,108±188.7	L	8.35±0.02	95.29±9.9	11.68±0.03	-1.60
		S	8.71±0.03	385.58±15.98	42.77±0.10	-1.17
October	516±51.6	L	15.79±0.04	181.63±4.17	23.71±0.08	+0.40
		S	6.64±0.06	262.13±8.06	31.79±0.09	-0.37
November	1,732±159.8	L	63.84±0.06	730.90±48.49	84.18±0.08	+1.95
		S	15.83±0.02	710.12±74.32	81.16±0.05	+1.59
December	–	–	–	–	–	–
January 2004	300±40.9	L	1.18±0.02	136.20±4.20	1.44±0.04	+0.05
		S	2.36±0.05	100.80±1.04	12.24±0.09	+0.39
February	1,476±185.4	L	64.65±0.08	729.14±36.67	84.13±0.10	+2.67
		S	19.09±0.03	619.92±49.13	97.33±0.15	+2.74
March	1,680±106.0	L	65.62±0.09	735.84±45.12	97.88±.16	+0.49
		S	18.72±0.02	692.16±30.49	94.18±0.08	-0.11

Annual Production: *Lemna minor* 231.70 g m⁻² yr⁻¹

high NPK concentrations reduced the population growth of *Lemna minor* and *Spirodela polyrrhiza* (Hashmi 2006). The nutrient availability directly affects natality, mortality, density, growth pattern, life form, longevity and age structure of the plant population (Kormondy 2003).

The optimum concentrations of NPK usually influence natality, mortality, density and growth of plants. The concentration of the nutrients below and beyond the ecological amplitude may have influenced most or all these characteristics adversely. Laboratory experiments revealed that high NPK concentration induced early mortality and lower concentrations increased natality of *Lemna* and *Spirodela* (Hashmi 2006). Morishita et al. (2001) noted that high irradiance and water temperature in the month of summer hampered the growth and biomass of phytoplankton in Dokai Bay of Japan. In Tokyo bay (Japan), an oscillatory high and low particulate phosphorus and ortho-phosphorus was recorded. The wind speed in summer advected and mixed up the nutrients of sediments and upper and lower water layers which in turn altered the water quality parameters (Miyata and Hattori 1986). Alterations in water quality and related seasonal variability of phytoplankton and zooplankton have been noted in fresh and marine water ecosystem from various parts of Asia (Emir and Demirsoy 1996, Shin 2003). In a degraded reef, the hydrological condition in hot season caused eutrophication and reduced floral vitality (Naim 1993). Algal rain and wind caused nutrient fluctuation and thereby altered salinity, DO, nutrients and chlorophyll-a in the Messolonghi Lagoon of Greece (Friligos 1989). The harvesting of *Typha angustata*

as cattle feed transferred part of nutrients bound in organic form back to terrestrial environment. Consistent removal of aquatic plants from spring fed stream in Hiroshima (Japan) receiving sewage input paved the way for seasonal peaks in population of microzooplanktons in early summer (Nomura et al. 1992). In rainy season (July and August), the size of the selected rainfed water body swelled leading to the bloom of *Lemna minor* and *Spirodela polyrrhiza*. In September 2003, the density of duckweeds decreased marginally. There was adequate rainfall in September 2003. Seasonal monsoon rain modifies chemical and biological characteristics of an artificial lentic ecosystem. Monsoons regulate function and processes of water body and eutrophication (An et al. 2003). The pH, turbidity and biological characteristics of the present body may have changed in the month of September 2003 with consistent rainfall. The precipitation in the form of snow during December and March and anthropogenically increased water level in some lakes of Poland influenced water qualities (Gorniak and Piekarski 2002).

The atmospheric temperature in winter (October to December 2003) consistently decreased around the selected pond, but size of the water body did not reduce much. Some small patches of *Wolffia arrhiza* occurred from October to December 2003 on shallow margins of the pond which might have been introduced in the water body accidentally through predatory birds.

The death and decay of duckweeds and diatoms in December 2003 corresponded with the increase in the turbidity of pond water as was also noted in an eutrophic shallow lake

Table 2.2 Relative proportion of the occurrence of selected duckweeds, physico-chemical characteristics of water, atmospheric temperature, monthly precipitation and wind velocity in Lal Diggi pond

Month	L:S ratio** (Number)	<i>Wolffia</i> occurrence (Number)	pH	Turbidity	Dissolved oxy- gen (mg L ⁻¹)	Total dissolved salts (mg L ⁻¹)	Nitrate (mg L ⁻¹)	Phosphate (mg L ⁻¹)	Potassium (mg L ⁻¹)	Rainfall* (mm)	Average atmo- spheric* tempe- rature (°C)		Average wind velocity* (km h ⁻¹)
											Min.	Max.	
April 2003	-	-	7.7±0.3	25±2.6	3.60±0.21	2,290±512	0.8±0.3	3.9±0.16	23.7±1.9	3.2	20.6	36.6	7.920
May	-	-	8.1±0.4	24±3.3	3.30±0.18	2,361±407	11.2±0.6	3.8±0.17	24.6±2.8	2.0	25.3	40.0	8.237
June	-	-	8.1±0.4	25±4.4	3.60±0.17	2,416±506	11.3±0.7	3.6±0.16	24.3±3.1	10.0	25.8	38.1	8.870
July	105:36	0	7.6±0.34	20±2.7	4.60±0.18	1,933±461	11.3±0.3	3.5±0.21	20.3±1.3	11.4	2.64	36.9	7.286
August	138:52	-	7.1±0.39	18±2.1	5.60±0.27	1,763±498	9.8±0.6	2.8±0.13	19.6±1.8	277.2	25.0	32.2	6.494
September	37:39	20	7.3±0.3	17±2.2	5.58±0.31	1,952±524	9.3±0.3	2.4±0.12	23.1±1.8	117.9	23.7	34.1	6.178
October	153:64	43	7.3±0.2	19±2.5	5.11±0.22	2,061±318	9.8±0.2	3.6±0.11	24.6±2.6	95.0	18.6	30.3	4.910
November	184:45	47	6.8±0.3	20±3.8	4.80±0.18	1,822±276	9.8±0.3	3.1±0.14	23.3±2.1	-	11.5	27.9	4.594
December	-	-	6.9±0.6	21±4.0	3.30±0.21	1,890±386	9.8±0.6	3.2±0.13	20.6±3.2	-	8.0	17.2	4.752
January 2004	19:39	-	6.9±0.3	21±3.8	3.60±0.23	2,013±427	10.1±0.4	3.1±0.16	20.3±3.1	11.7	7.1	15.6	5.227
February	219:65	-	7.3±0.2	22±3.7	3.70±0.18	1,682±366	10.3±0.5	3.6±0.14	19.6±2.8	-	9.8	23.3	5.544
March	195:55	-	7.3±0.2	23±3.9	4.20±0.13	1,631±402	10.5±0.3	3.8±0.11	22.5±2.2	-	15.7	32.4	6.811
April	-	-	7.6±0.4	26±2.8	-	-	-	-	-	-	21.9	38.0	6.860

*Courtesy: Meteorological Survey of India, Govt. of India

**Median of the number of each species in 3 quadrats of 25 × 10 cm² approximately Within parenthesis numerical ratio of L:S each quadrat against a fixed number (6) of *Spirodela polyrrhiza* individuals

(Temponeras et al. 2000). Consistent and rapid reduction in size and depth of the pond was recorded from January 2004 to April 2004 which finally dried in May 2004. Despite sufficient precipitation in the month of January, the water body could not be charged with rain water from its catchments owing to anthropogenic reasons (development of weirs around the pond). Therefore, the size of this rainfed water body continued to decrease with rise in temperature and wind speed from January to April 2004. Consistent reduction in the size of water body, increase in temperature, wind speed, irradiance and failure in water recharging may have also increased turbidity, pH, nutrient and water temperature. These factors may not have been conducive for the growth of duckweeds in these months (January to April). Past studies have revealed that bio-physico-chemical factors and seasonal dynamics influenced the flora of water bodies (Wulff 1980, Friligos 1989, Christensen et al. 1990, Talling 1992, Koenig et al. 1995, Nogueira et al. 1997, Havens et al. 1999, Kirschner et al. 1999, Weilguni and Humpesch 1999, Temponeras et al. 2000, Dodds-Walter et al. 2002, Artioli et al. 2005, Khan and Ansari 2005, Ansari et al. 2011a, b and c). Therefore, anthropogenic alteration and climate influence the physico-chemical property of water and flora of the water body leading it to eutrophy.

2.7 Conclusion

The fresh water lakes and ponds in many Indian cities are source of fresh water for various purposes. The surface water bodies recharge the underground water resource. The nutrient enrichment of surface water bodies and formation of weirs inhibiting the water recharging may onset an early natural succession. The collection of rain water in such water bodies must be an essential part of city planning and water management.

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