Chapter-IX
In recent age of science and technology the pollution problems are becoming more and more severe due to rapid and unplanned growth of industries. Varuna, an important tributary of Ganga in Varanasi receives effluents directly from many small scale industrial units. The important industries located during the study were battery industries, automobile servicing stations and printing & dyeing industries of Banarasi sarees. Their numerical strength was higher, sufficient enough to result in tremendous pollution. From literature survey it was noted that there is lack of information on the impact of such industries on the quality of river water, water sediments, plants and also in control and management of the river.

Therefore, present work was started to monitor the physico-chemical properties of river water and its sediment, to conduct the heavy metal analysis in water, to study macrophytic composition throughout the year, to develop pollution control technique to minimise the pollutants and suggest management practices for the river to reduce the pollution load.

Present investigation was carried out at Varanasi, the cultural capital of India and the oldest living city of the world. Site 1 was selected at Rameshwar in Jansa area which was free from any pollution source, site 2 was at Razabazar area which pour the effluents from battery industries, site 3 at Chaukaghat area, pour the effluents from automobile servicing station and site 4 at Kazzakpura area pouring the discharge from printing and dyeing industries. For water sampling five subsites were located at each site but for water sediment analysis three subsites were located.
Laboratory experiments for pollution control were conducted. Activated charcoal and ozone was used in chemical treatment, monoculture of *Eichhornia crassipes*, monoculture of *Hydrilla verticillata* and mixed culture of *Eichhornia crassipes* and *Hydrilla verticillata* was used as biological treatment.

For charcoal treatment 50 litre of water sample was maintained in a 100 litre of aquarium. 10 small packets of tissue paper containing 1 gm activated charcoal each were sanked with the help of weight. Initial reading of all the variables were recorded and the same was analysed 24 hourly for 5 days. Maximum pollutant removal was recorded on the fourth day. Thus, the value of variables on the 4th day is expressed in the record.

For ozone treatment two tire bubbling chamber of 12 litre capacity of glass was constructed, whose common surface consisted of profuse perforation. The chamber was filled with 10 litre of water sample collected from the polluted study sites. Inlet of the lower tire was connected to ozone generator. Ozonized gas was passed through the bubbler which comes above across the water in the form of minute bubbles. Change in the parameters was recorded hourly and the maximum pollution removal was found after 6 hours treatment, thus, only this value is expressed in the record.

For monoculture experiment *Eicchornia crassipes* and *Hydrilla verticillata* were cultured separately in 50 litre of water in aquarium of 100 litre capacity. For mixed culture both the above plants were cultured together. Maximum pollution removing capacity in most of the experiments were found on 16th day, thus, the record of that day is expressed.

Results obtained during present investigation revealed the following important facts:
METEOROLOGY

Monthly mean of minimum and maximum temperature was recorded during the study (April 2001 to March 2002). Lowest minimum temperature (10.03°C) was recorded during December 2001, but lowest maximum temperature (22.71°C) was recorded during January 2002 likewise highest minimum temperature (29.65°C) was recorded during June 2001 and highest maximum temperature (38.16°C) was found in April 2001.

During April 2001 to March 2002 highest monthly rainfall was recorded during July 2001 (380.5 mm) while minimum during November 2001 (0.6 mm). Winter season was dry with slight precipitation during summer, rainy season was wet with heavy rainfall.

Humidity varies widely in different season maximum being in the rainy and minimum in the summer season. The maximum average relative humidity during study period was in December, 2001 (92.54%) while the minimum was in April, 2001 (41.26%).

PROPERTIES OF RIVER WATER

The minimum temperature of water (20.75±0.243°C) was recorded during October 2001 at site 1 and the maximum temperature (34.35±0.190°C) during April 2001 at the site 4. Seasonally, temperature of water was found to be highest during summer followed by rainy season and it was minimum during winter at all the sites.

The minimum pH of water (7.61±0.05) was recorded during April 2001 at site 4 and the maximum pH (8.66±0.05) during November 2001 at the site 1. Seasonally, pH was found to be highest during rainy season followed by winter and summer season at all the sites.
Minimum acidity (0.21±0.052 mg/l CaCO₃) was recorded during April 2001 at site 1 and the maximum acidity (34.46±0.819 mg/l CaCO₃) during April 2001 at the site 4. Seasonally, acidity of the river water was found to be highest during summer season followed by rainy and winter season at most of the sites.

Minimum alkalinity (126.00±5.85 mg/l CaCO₃) was recorded during March 2002 at site 3 and the maximum alkalinity (461.66±3.14 mg/l CaCO₃) during November 2001 at the site 1. Seasonally, alkalinity of the river water was found to be highest during rainy season followed by winter and summer season at all the sites.

Minimum nitrate (0.023±0.005 mg/l) was recorded during May 2001 and January 2002 at site 1 and the maximum nitrate (0.968±0.028 mg/l) during April 2001 at the site 4. Seasonally, nitrate of the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Minimum phosphate content (0.015±0.002 mg/l) in water of river Varuna was recorded during August and September 2001 at site 1 and the maximum phosphate (1.565±0.028 mg/l) during April 2001 at the site 4. Seasonally, phosphate content in river water was found to be highest during summer season followed by rainy and winter season at all the sites.

Minimum chloride (12.66±1.63 mg/l) was recorded during July 2001 at site 1 and the maximum chloride (79.50±2.58 mg/l) during April 2001 at the site 4. Seasonally, chloride in the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Minimum DO (1.93±0.30 mg/l) was recorded during April 2001 at site 4 and the maximum DO (9.16±0.25 mg/l) during November 2001 at the site 1. Seasonally, DO in the river water was found to be highest during winter season followed by rainy and summer season at all the sites.
Minimum BOD (1.81±0.07 mg/l) was recorded during August 2001 at site 1 and the maximum BOD (84.16±3.40 mg/l) during April 2001 at the site 3. Seasonally, BOD of the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Minimum COD (5.10±0.23 mg/l) was recorded during June 2001 at site 1 and the maximum COD (136.66±5.46 mg/l) during April 2001 at the site 3. Seasonally, COD of the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Minimum total solids (193.50±1.41 mg/l) was recorded during October 2001 at site 1 and the maximum total solids (1128.50±10.80 mg/l) during May 2001 at the site 4. Seasonally, total solids in the river water was found to be highest during rainy season followed by summer and winter season at all the sites.

Minimum total hardness (38.83±2.31 mg/l CaCO₃) was recorded during August 2001 at site 1 and the maximum total hardness (963.83±5.56 mg/l CaCO₃) during April 2001 at the site 4. Seasonally, total hardness of the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Minimum electrical conductance (114.66±7.29 µmhos/cm) was recorded during July 2001 at site 1 and the maximum electrical conductance (857.50±9.13 µmhos/cm) during November 2001 at the site 4. Seasonally, electrical conductance of the river water was found to be highest during winter season followed by rainy and summer season at all the sites.

Minimum oil & grease (0.11±0.030 mg/l) was recorded during August 2001 at site 1 and the maximum oil & grease (6.09±0.09 mg/l) during March 2002 at the site 3. Seasonally, oil & grease of the river water was found to be highest during summer season followed by winter and rainy season at all the sites.
Cd was not found during June, July and August 2001 at site 1 and the maximum Cd (0.049 µg/l) during April 2001 and March 2002 at the site 4. Seasonally, Cd in the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Cu was not found during July and September 2001 in the river water at site 1 and the maximum Cu (0.496 µg/l) during May 2001 at the site 4. Seasonally, Cu in the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Cr was not found during August 2001 at site 1 and the maximum Cr (0.081 µg/l) during April 2001 at the site 4 in the river water. Seasonally, Cr was found to be highest during summer season followed by winter and rainy season at all the sites.

Ni was not found during August 2001 at site 1 and the maximum Ni (0.050 µg/l) during April 2001 at the site 4. Seasonally, Ni in the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Pb was minimum (0.001 µg/l) during July 2001 at site 1 and the maximum Pb (0.201 µg/l) during April 2001 at the site 2. Seasonally, Pb in the river water was found to be highest during summer season followed by winter and rainy season at all the sites.

Zn was minimum (0.042 µg/l) during September 2001 at site 1 and the maximum Zn (1.712 µg/l) during April 2001 at the site 2 in the river water. Seasonally, Zn in the river water was found to be highest during summer season followed by winter and rainy season at all the sites.
PROPERTIES OF WATER SEDIMENT OF THE RIVER

Colour of the water sediment was found light at the control site while dark at the polluted sites. The texture of water sediment at nearly all the sites was silty clay throughout the year but silty clay loam during rainy season.

The minimum pH of water sediments (6.8) was recorded during June and August 2001 at site 1 and maximum pH (9.0) during April 2001 at the site 4. Seasonally, pH was found to be highest during summer season. The value of pH was nearly uniform during rainy and winter season at site 1 and 2, however, it was higher at site 3 and 4 during rainy season as compared to winter.

Minimum potassium (0.440 μg/g) was recorded during April 2001 at site 4 and the maximum potassium value (0.926 μg/g) during August 2001 at the site 2. Seasonally, potassium of the water sediments of the river was found to be higher during rainy season followed by summer and winter season at most of the sites.

Minimum sodium (0.170 μg/g) was recorded during September 2001 at site 3 and the maximum sodium value (0.669 μg/g) during May 2001 at the site 2. Seasonally, sodium of the water sediments of the river was found to be higher during summer season followed by winter and rainy season at most of the sites.

Minimum calcium (1.764 μg/g) was recorded during August 2001 at site 1 and the maximum calcium value (7.022 μg/g) during April 2001 at the site 4. Seasonally, calcium of the water sediments of the river was found to be higher during summer season followed by winter and rainy season at most of the sites.

Minimum phosphorus content (0.053 mg/g) in water sediments of river Varuna was recorded during September 2001 at site 1 and the maximum phosphorus (0.119 mg/g) during May 2001 at the site 4. Seasonally, phosphorus content in water sediments of the river was found to be highest during summer season followed by winter and rainy season at all the sites.
Minimum total nitrogen (0.046 mg/g) was recorded during September and October 2001 at site 3 and the maximum total nitrogen (0.169 mg/g) during May 2001 at the site 1. Seasonally, total nitrogen in the water sediments of the river was found to be highest during summer season followed by winter and rainy season at all the sites.

Organic carbon was found to be minimum (0.411%) during August 2001 at site 2 and the maximum organic carbon (0.715%) during May 2001 at the site 3. Seasonally, organic carbon in the water sediments of the river was found to be highest during summer season followed by winter and rainy season at all the sites showing slight fluctuation.

MACROPHYTIC STUDY OF RIVER VARUNA

*Apomosoten natans* was found to be present at site 1 only. Likewise *Azolla pinnata* was present only at site 2 and *Potamogeton pectinatus* and *Wolffia* only at site 1. *Hydrilla verticillata* was present at site 1, 2 and 3 but was not found at site 4. *Ipomoea aquatica* was present only at site 3, however, it was not reported at site 1, 3 and 4. *Eichhonia crassipes* was present only at site 3 and 4, however, it was absent at site 1 and 2. Contrary to it *Salvenia natans* was present only at site 1 and 2 but not at site 3 and 4. *Salvenia molesta* was present at site 2, 3 and 4 but was not recorded at site 1. *Pistia stratiotes* were present only at site 1 and 2, however, it was not found at site 3 and 4. *Lemna minor* was not present at site 1 but it was recorded at site 2, 3 and 4.

By the study of similarity and dissimilarity index different habitat condition, quality and quantity of pollutants at the respective sites and response of the plants growing in the area can be interpreted. The same values with respect to the aquatic plants were calculated. The results indicate that maximum dissimilarity was found between site 1 and site 4 (0.9). Similarity index between site 1 and site 2 and also between site 3 and site 4 were highest and the value was 0.33. Likewise least value of similarity index (0.1) was recorded between site 1 and site 4.
Least density of plants was found during rainy season because all the plants were washed by rain water. At all the sites highest density of plants were recorded during winter followed by summer season. During summer decrease in their density started because by increase in temperature the rate of physiological reactions increases specially, respiration, therefore, decline in their population was recorded.

Frequency was also found to be higher during winter season because the river was nearly calm and the plants got proper time for growth and development. *Salvenia molesta* showed higher frequency during June 2001 at sites 2, 3 and 4.

The macrophytic composition of more polluted sites differ from the less polluted sites. For example *Eichhornia crassipes*, *Lemna minor* and *Salvenia molesta* were found only at the polluted sites, while *Potamogeton pectinatus*, *Pistia stratiotes* etc. were not found at the polluted sites. The plants preferring polluted area are pollution resistant, thus, they absorb the pollutants from the medium.

**RESULT OF WATER TREATMENT**

Charcoal treatment showed marked reduction in heavy metal, nitrate, phosphate, total hardness etc. in the water sample. But due to highly absorptive and porous nature reduction in DO was also recorded by charcoal treatment. Reduction in DO resulted in increase in BOD and COD. These three are very sensitive parameters for the water quality, thus, this was recorded as a prominent drawback of this treatment.

Marvelous response was recorded in the case of ozone treatment where 100% removal of chromium from polluted water was surprising. Most of the heavy metals were nearly washed along with reduction in acidity, nitrate, phosphate, BOD, COD and total hardness. Similar results were obtained in the
treatment of water samples of all the three sites. Ozone treatment showed significant increase in the value of DO and total solids.

In monoculture of *Eichhornia* considerable reduction in pollutants was recorded released specially in the case of nitrate, phosphate and some heavy metals like Cr, Ni, Pb and Zn in case of treatment of samples of all the sites. Slight increase in DO was recorded by this treatment. Monoculture of *Hydrilla* also showed marked reduction in pollution load specially in case of BOD, COD, total hardness, phosphate, nitrate, oil & grease, Ni, Pb and Zn. High increase in DO was also recorded in this treatment. Mixed culture of *Eichhornia* and *Hydrilla* showed brilliant response. In this treatment extensive reduction in nearly all the parameters were recorded. DO also increased many folds in this treatment.

**IMPORTANT FINDINGS**

- 5277 industrial units were located to be operating in Varanasi.
- The important small scale industries pouring directly into river Varuna were—
  - Battery and allied industries
  - Automobile servicing stations
  - Banarasi sarees printing and dyeing industries
- The number of battery and allied industries pouring directly in river Varuna were 596 in Razabazar area.
- The number of automobile servicing stations pouring directly in river Varuna was 117 in Chaukaghat area.
- The number of Banarasi sarees printing, dyeing and allied industries pouring directly in river Varuna were 164 in Kazzakpura area.
- Temperature of river water was found highest in Kazzakpura area.
- High pH, alkalinity and DO were found in the water at Rameshwar.
• High nitrate, phosphate, acidity, chloride, total solids, total hardness etc. in water was found in Kazzakpura area.

• BOD, COD and oil & grease were found highest in the river water at Chaukaghat area.

• High concentration of Cd, Cu, Cr and Ni in the river water was found in Kazzakpura area.

• Concentration of Cd, Pb and Zn was found high in Razabazar area.

• Considerable amount of Cu, Cr, Ni, Pb and Zn in the river water was found in Chaukaghat area.

• Colour of water sediment of river water is light in Rameshwar area.

• In polluted sites colour of water sediments appears dark.

• Concentration of K, Na, Cd, Zn and Pb in the water sediment of river water at Razabazar area was higher.

• Concentration of K, Na, P, Total nitrogen, organic carbon was higher in the water sediments of the river at Rameshwar.

• Water sediment of the river at Kazzakpura area shows high concentration of Ca, P, Cd, Cu, Ni, Cr, Pb and pH.

• Macrophytic investigation shows highest similarity index value between site 1 and 2 and also between site 3 and 4.

• Macroptically site 1 and site 4 show maximum dissimilarity index.

• River contains 6 aquatic macrophytes at Rameshwar and at Razabazar.

• 5 plants were present in the water at Chaukaghat while only 4 plants in Kazzakpura area.

• Out of the five treatments of river water, ozone treatment was found most effective in the control of water pollution.

• Charcoal treatment was also highly effective in the control of water pollution but it decreased the DO of water.
• Mixed culture of *Eichhornia crassipes* and *Hydrilla verticillata* was found to be the best and most feasible practice of water pollution control because it increased DO in addition to absorption of nutrients and heavy metals from the water body.

**Recommendations**

• The industrial units directly pouring their effluents into the river Varuna should discharge their effluents after treatment.

• Selected macrophytes must be cultivated in the river to check the pollution load of the river.

• Combination of *Eichhornia crassipes* and *Hydrilla verticillata* which gave brilliant performance in pollution abatement must be cultured in the river.

• Mix culture for river pollution control was also recommended because this process involves least input.

• Macrophytes harvested as a result of this treatment practice can be used for production of biogas, paper and also be used as fodder.

• Charcoal bags must be suspended in highly polluted area in the river for pollutant adsorption.