Comparative analysis of the trends in river water quality parameters: A Case study of the Yamuna River

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Abstract

This research paper explores the recent trends in critical water quality parameters of the Yamuna Riverwhich indicatesignificant deviationsin its different segments. The Delhi segment is the most polluted as the river gets severely affected by the impediments of industrialization, urbanization and agricultural advances. In view of the social, economic, religious and cultural significance of theYamuna Riverand progressive degradation of its water quality, numerous conservation campaigns and the major cleaning up projects like the Yamuna Action Plan (YAP) I, II and IIIwere undertaken for its restoration and conservation. Comparative analysis of the trends in river water quality parameters of the Yamuna River illustrate that despite of all the efforts the water quality in terms of DO and BOD is not fit for designated best uses in the Delhi and eutrophicated segments. The results necessitate innovative perspectives in the development of anupdated comprehensive conservation strategyfor the Yamuna River.The paper concludes with multidimensionalrecommendations for the improvement of water quality of the Yamuna River.

Keywords: *Yamuna River, water quality, trends, parameteranalysis, Dissolved Oxygen, BOD.*

1. Introduction

In the fast developing world with the escalating human population, increased industrialization, and urbanization coupled with ever increasing socioeconomic activities, the natural resources across the globe are subjected to tremendous stress resulting in their quantity decline and quality degradation (Nallathiga, R., 2011). Simultaneously, it has triggered a variety ofmammoth environmental issues such as the devastation of natural resources, ecological imbalance, climate change, bio-diversity depletion (Suthar, Nema, Chabukdhara, Gupta, 2009; Weiqi, Chen, Xuehua, Chen, 2008**)**. Water is one such natural resource which has been adversely affected as it is the primary source of various life sustaining activities on earth and has no known alternative (Kumar, Singh and Sharma, 2005).

In particular, the riverine water resources across the world have been subjected to increased stress. This is mainly due to the rapid population growths,land development activities, urbanization, industrialization, agricultural production and numerous other socioeconomic activities in and around the river basins. Additionally the rivers also play a vital role in maintaining soil fertility, wildlife conservation and development of forest resources (Kannel et al., 2007; Suthar et al., 2009). Since the prehistoric times till present-dayrivers and river basins have been utilized for drinking water source, irrigation, navigation, transportation, socioeconomic activities and human settlements as is evident from the fact that major ancient civilizations flourished alongside the rivers (Khaiwal et al., 1999) and even today river basins are thickly populated (Vega et al., 1998). Apart from this, rivers, since the early times have been a medium of cleaning and disposingwastes (Khaiwal et al.1999). Most of the rivers in the urban areas of the developing world are the end point of municipal and industrial effluents along with the agricultural runoffs (Phiri et al., 2005; Shrestha and Kazama, 2007).

Riverine water resources, in particular, have become vulnerable to quantity decline (with shrinking influent water) and quality degradation (with rising wastewater discharges) due to human activities. More so in a country like India, which has as many as fourteen rivers and several cities alongside them. Singh and Singh (2007) in their studies, concluded that indiscriminate industrialization and urbanization in our countryhave measurably influenced the quality of surface water resources.In India river water resources are under the risk of getting reduced to carriers of water of extremely poor quality in several stretches, particularly along the major cities wherein excessivevolumes of domestic and industrial wastewater enters them,(Nallathiga, R., (2011).

Due to increased anthropogenic inputs the rivers have come under increased stress, causing degradation of the water quality and the environment (Suthar et al., 2009; Maheshwari, Sharma and Sharma, 2011). The discharge of oxygen-demanding substances, suspended solids, and toxic and coloured wastes from agricultural, industrial and domestic units into the rivers, over pumping of aquifers and contamination due to substances promoting algal growth are adversely affecting the water quality of rivers (Suthar et al., 2009; Maheshwari et. al., 2011). Moreover, in our country the urban runoff and dumping of sewage in the catchment area of the rivers is also contributing to theirwater quality decline (CPCB 2008). Most of the 14 rivers in India are polluted to various levels (Kumar and Singh 2010) with major rivers like the Ganga and the Yamuna River being highly polluted among all (CPCB 2009).Emerging economies like India greatly rely on its rivers for a number of developmental activities, therefore,assessments of the effects of such activities on water quality are critical(Kaushik et al., 2009)

2. The Yamuna River: Location and tributaries

The Yamuna River is one of the primary rivers of Indiawith social, economic, religious and cultural significance. According to Hindu traditions, it is worshiped as a sacred river and a number of pilgrimage centers like the Yamunotri, Poanta-Sahab, Mathura, and Allahabad are situated along its banks (Upadhyay et al., 2010).Yamunotri glacier in the lower Himalayas (38° 59° 78° 27 ° E) at 6320 meters above sea level in the Uttrakhand state of India is the source of the Yamuna River (Khaiwal et.al.1999).

Length of the Yamuna Riverfrom its origin in the Yamunotri glacier up to its confluence with river Ganga at Allahabad in Uttar Pradesh is about 1376 Km (GNCT 2005).According to (Nema, A., 2007) in the Himalayan region it draws water from its four main tributaries namely Rishi Ganga, Hanuman Ganga, Tons and Giri and in the plains from Chambal, Hindon, Sindh, Betwa and Ken. It has a vast catchment area of about 366,220 sq.km (Khaiwal et al, 1993) which, according to (Nema, A., 2007) is spread over parts of Uttarakhand, Himachal Pradesh, Haryana, Uttar Pradesh, Rajasthan and Madhya Pradesh, and Delhi. The Table 1 below presents the major hydraulic structures on the Yamuna River.

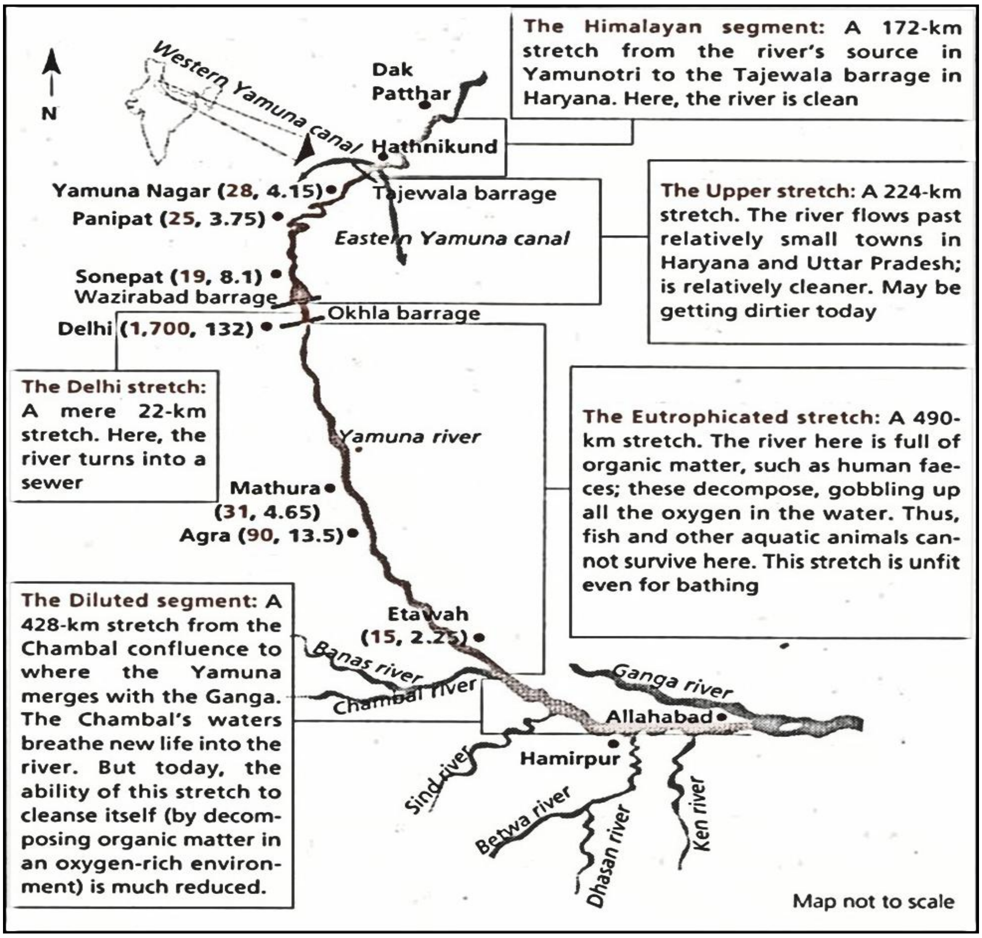
Table 1: Hydraulic structures on the Yamuna River

Section	State	Length (Km)	Tributaries/drains	Dam/Barrage	Canal
Hills (Yamunotri-Hathnikund Barrage)	Uttrakhand, UP and HP	172	Kamal, Giri, Tons, Asan	Dak Patthar Barrage, Asan Barrage	Dakpatthar Canal, Asan Canal
Upstream Delhi (Hathnikund Barrage – Wazirabad Barrage)	Haryana and UP	224	Som, Choti Yamuna drain no. 2 & 8	Hathnikund Barrage	Western and Eastern Yamuna canals
Delhi (Wazirabad Barrage– Yamuna Barrage – Okhla)	Delhi	22	22 drains, Hindon cut	Wazirabad and Yamuna Barrage	Agra canal
Downstream Delhi (Okhla Barrage confluence with Chambal)	UP and Haryana	490	Hindon, Bhuria Nala Mathura – Vrindavan drain, Agra Drain	Okhla Barrage	Agra Canal, Gurgaon Canal
Revived Yamuna(Confluence with Chambal. Confluence with Ganga)	UP	468	Chambal, Ken, Sindh, Betwa	-	-
Total		1376			

Source:Central Inland Fisheries Research Institute, 2014

Owing to its diverse hydrological, geological and ecological character, the Yamuna Riverhas been classified into five distinct segments (CPCB 2009). These segments are tabulated below in Table 2 and the same is being diagrammaticaly depicted in figure 1.

Figure 1: Diagrammatic presentation of the segments of the Yamuna River



Source: CPCB,2006-2007

Table 2: Major Water Quality Segments of the Yamuna River

No.	Segment	Reach	Length (Km)
1	The Himalayan Segment	From origin to Tajewala Barrage	172 km
2	The Upper Segment	From Tajewala Barragae to Wazirabad Barrage	224 km
3	The Delhi Segment	Wazirabad Barragae to Okhla Barrage	22km
4	The Eutrophicated Segment	Okhla Barrage to Chambal Confluence	490km
5	The Diluted Segment	Chambal Confluence to The GangaConfluence	468 km

Source:CPCB 2009

3. Usages of the Yamuna River Water

The Yamuna River sustains all forms of life along its banks and various social and commercial activitiesdepend on it (Upadhyay et al., 2010). Itis the major source of drinking water to millions of Indiansand hasmultiple other uses (Ali and Jain, 2001). The Yamuna Basin is of great economic significance due to its fertility and high productivity, particularly many parts of Uttar Pradesh and Haryana (Maheshwari et al., 2011).

Some well-designated uses of the water of the Yamuna River are as follows:

- Drinking water - Bathing water - Irrigation
- Livestock use - Industrial use - Navigation
- Aesthetics - Recreation and - Religious and Cultural

The availability water of the Yamuna River varies greatly with time and space with 80% of the water flowing in it in the Monsoon period (July, August and September) whereas whatever water is available in it in the non-monsoon period (October to June) is widely used for irrigation and drinking, leaving very little water in the river to flow (CPCB 2010). Along its course, the water of Yamuna River is abstracted for a variety of purposes such as about 94% for irrigation, 4% for domestic use, and 2% for the industries. The river water is extensively abstracted at Hathnikund / Tajewala and Okhla barrages.The annual abstraction at various locations is depicted inTable 3.

Table 3: Abstraction of water from the Yamuna River

Location	**State**	**Purpose**	**Water abstraction and state of**
Dak Patthar barrage	Uttarakhand	Powergeneration	Water diverted into canal
Asan barrage	Uttarakhand	Power generation	Water diverted into canal
Hathnikund barrage	UP/ Haryana	Irrigation and drinking water	20,000 MLD of Water abstracted anddiverted into Westerna and Eastern Yamuna canals. No waterflow downstream in dry season.
Wazirabad barrage	Delhi	Drinking water	1,100 MLD of water abstracted. No water flow downstream in dry season
ITO bridge	Delhi	Water supply to power plant	Water available mainly from drains
Okhla barrage	Delhi / UP	Water supply into Agra canal	5000 MLD of water abstracted between Wazirabad to Okhla. No waterflow downstream in dry season

Source: CPCB, 2000.

4.Pollution in the Yamuna River and its major Sources

The Yamuna River is one of the mostcontaminated rivers of India (CPCB 2010; Misra, A.K.,2010). Untreated or partially treated domestic sewage, industrial effluents and agricultural effluents are the major contributors of pollution in the river. The cities along side the Yamuna River release loads of contaminants in it.
Due to its religious, cultural, social and economic significance the Yamuna River flows in the hearts of many Indians, but unfortunately like many other riverine systems of the country, it too is affected by the setbacks of industrialization, urbanization and rapid agricultural developments (Maheshwari et al.,2011). In his study C.K. Jain (2004) reported that due to industrialisation in the towns along the Yamuna River basin, all the industrial effluent find its way into it. He also reported that the tributaries of the Yamuna River also transferred their pollution load into it.Water is consumed for different activities which generate a lot of wastewater causing deterioration of water quality of Yamuna River. Various point and non-point sources contribute to the contamination of the Yamuna River.

Point sources

Point sources are organized sources of pollution with measurable pollution load (CPCB 2008). These sources include surface drains carrying municipal sewage or industrial wastes; sewage pumping stations etc.

-*Domestic pollution*

Domestic pollution accounts for 85% of the pollution in the Yamuna River and is sourced to the major cities along the river (CPCB 2010). These cities include Delhi, Ghaziabad, Mathura-Vrindavan, Agra, Etawah, Panipat, Sonepat and Allahabad.The domestic waste majorly comprises of organic matter and microrganisms, salts, detergents, nutrients, oil and grease and others.

-*Industrial pollution*

A number of towns along the Yamuna River have numerous industries that discharge their waste water into the Yamuna. According to the CPCB (2009) report, “the industries include textile, chemical, pharmaceuticals, oil refineries, sugar, paper and pulp Leather, thermal power, fertilizers,food industries, etc. were set up in many cities in the Yamuna basin". Many of these have poor environment management systems anddischarge untreated or partially treated waste water containing toxic and organic effluents into the river, thus contributing to the degradation of water quality.

Non-point sources

Non-point sources are the numerous diffused and unspecified sources of pollution and are non-measurable as the amount of pollution generated by each source is less. These include the organic matter, residues of plants, topsoil, microbes, toxicants etc. (CPCB 2009).Such sources are influenced by the land-use patterns in the overall watershed and include sources from both, the natural processes and the anthropogenic inputs (Ritchie, Zimba and Everitt, 2003). The chief non-point pollution sources are:

- Agricultural runoffs
- Dumping of solid waste, dead bodies, animal carcasses etc.
- Immersion of idols made of Plaster of Paris, ashes and floral offerings
- Pollution due to in-stream use of water, such as bathing, washing, cattle wading and open defecation.

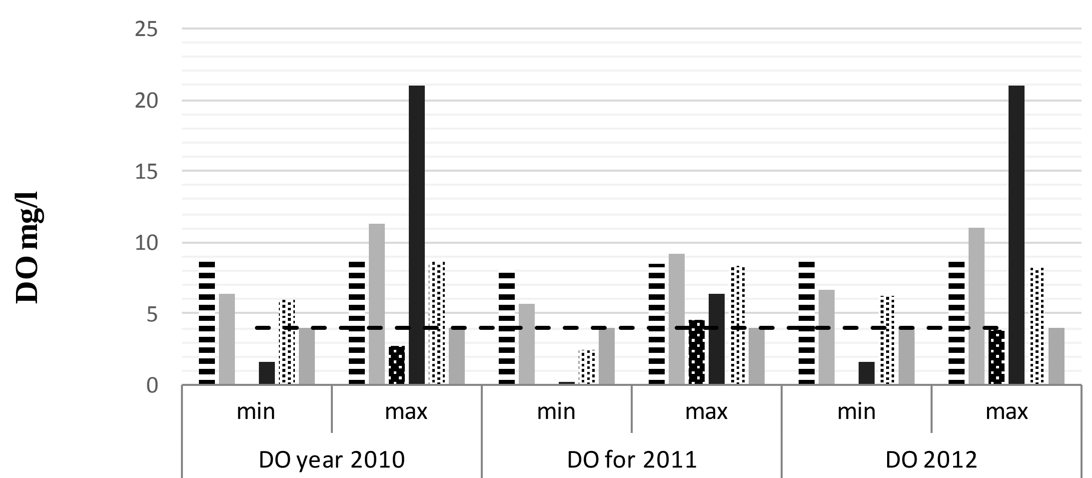
5. Segment wise trends in key parameters of the Yamuna River from 2010 to 2012

The Water quality of a river is assessed and categorized with reference to its designated uses, viz;
a) Raw water fit for drinking purposes,
b) Raw water fit for bathing purposes, and
c) Raw water fit for agricultural use.
The above stated categorization of water for its various uses is based on some basic parameters like the Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD),Fecal coliform and Total Coliform (TC) etc. The present paper assesses the trends in two critical parameters viz. Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) for the time period of 2010 to 2012 in the five segments of the Yamuna River.

5.1 Trends in Dissolved Oxygen (DO) of the Yamuna River (2010-2012)

All the aquatic organisms need sufficient amounts of dissolved oxygen for their survival. Production and consumption of oxygen happen in stream systems. The oxygen present in water can be dissolved from the atmosphere or is produced by photosynthesis by organisms like algae and other aquatic plants. In water, oxygen is consumed by animal respiration, decomposition and in-stream chemical reactions.

Figure 2: Trends in Dissolved Oxygen (DO) of the Yamuna River (2010-2012)



	DO year 2010 min	DO year 2010 max	DO for 2011 min	DO for 2011 max	DO 2012 min	DO 2012 max
Yamunotri	8.8	8.8	8.2	8.5	8.6	8.6
Sonepat Haryana	6.4	11.3	5.7	9.2	6.6	11
okhla bridge Delhi	0	2.7	0	4.5	0	3.9
d/s Agra	1.6	21.1	0.2	6.3	1.6	21.1
allahabad d/s balua ghat	6	8.7	2.4	8.4	6.3	8.2

Oxygen is measured in its dissolved form as dissolved oxygen (DO) and is an important indicator of the ability of the water body to support aquatic life. Thus D.O. reflects the physical and biological process prevailing in the water system; therefore, its measurement is of prime importance. Clean waters are normally saturated with dissolved oxygen, which can easily deplete by the discharge of oxygen demanding wastes. Major depletion in oxygen levels indicates heavy pollution by organic matter, the main sources of which are domestic sewage, agricultural run offs and food processing industries (Pande and Sharma, 1998).

DO is vital for the survival of aquatic organisms such as plants, micro-organisms, invertebrates and most importantly for fish which need to breathe just as we do. It is generally true that if the water quality is suitable to support fish life, then it will also meet the criteria for most, if not all the designated uses of water and indicate good ecological status. A decline in the DO level in water bodies not only affects some sensitive animals that may move away, weaken or even die, but according to (Pande and Sharma 1998) also reduces the self - purifying capacity of water. It also mobilizes the trace metals (Murphy 2007).

The concentration of dissolved oxygen (DO) in rivers varies seasonally and is "influenced by chemical, physical, and biochemical activities such as rate and period of photosynthesis, its consumption by aquatic organisms, water temperature and altitude" (CPCB, 2011). The above figure 2 shows the trends in the minimum and maximum values of dissolved oxygen in five stations distributed over the five different segments of the Yamuna River from 2010 to 2012.

Figure 2 clearly depicts that in the Himalayan segment the Yamuna River is healthy with good amounts of dissolved oxygen it in and meets the primary water quality criteria. However the river at Yamunotri does show a decreasing trend in the amount of DO from the year 2010 to 2012.In the Delhi segment the river water is deficient in dissolved oxygen, so much so that its concentration is nil (0 mg/l) at the Okhla bridge and falls far below the standard 4 mg/l level of DO as given by CPCB. This is mainly due to unprecedented discharge of domestic and municipal waste into the river that are then responsible for high oxygen demand. The river water in this segment does not meet the primary water quality criteria. Low values of DO here is a sign of the river being unhealthy with persisting septic and eutrophic conditions and having no capacity of self purification. However, the trends do show a minor increase in the DO here from the year 2010 to 2012 but still it is far below the desirable limit. In the eutrophicated and dilute segments the concentration of DO meet the standard limit, but show a decreasing trend in the DO levels from 2010 to 2012 indicating increasing pollution in the river in these segments.

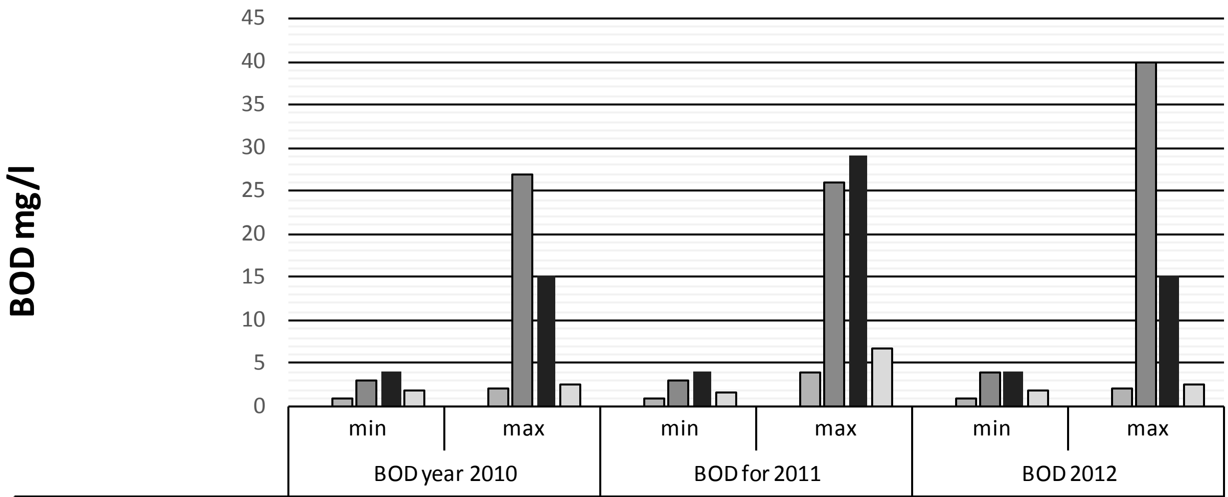
5.2 Trends in Biochemical Oxygen Demand(B.O.D.) of the Yamuna River from 2010 to 2012

Biochemical oxygen demand (B.O.D.) is an approximate measure of the oxygen consumed by the microorganisms in decomposing organic matter present in a water body under aerobic conditions. It also measures the chemical oxidation of inorganic matter.It is an empirical test, in which standardized laboratory procedures are used to estimate the relative oxygen requirements of wastewaters, effluents and polluted waters. The micro-organisms use the atmospheric oxygen dissolved in water for biochemical oxidation of organic matter, which is their source of carbon. As the concentration of DO in water is directly influenced by the BOD hence very high concentration of BOD or inversely very low concentration of DO has hazardous effects on the river's biodiversity and may lead to mass-death of aquatic organisms (Upadhyay et al., 2010). High BOD leads to rapid depletion of oxygen from the streams, consequently, less oxygen is available to higher forms of aquatic animals resulting in suffocation and death of aquatic organisms.

Figure 3 below represents the trends in the values of BOD of the Yamuna River from 2010 to 2012.In the Himalayan segment the observed value of BOD ranges between 0-3 mg/l and meets the desired standard. This is mainly due to the availability of adequate fresh water in the river and no significant discharge of waste water. In the upper segment the BOD ranges from 1- 4 mg/l and does not meet the desired limit at many stations. This is due to the industrial, human and animal inputs in this segment. In the Delhi segment it receives heavy loads of untreated or partially treated waste waters from the 22 drains in the National Capital Region and hence we observe a significant increase in the BOD level ranging between 3 to 40 mg/l.

The average BOD values do not meet the desired water quality criteria in this segment upto the confluence with the Chambal river. The water quality in the Delhi segment does not meet the bathing criteria Also the figure clearly shows an increasing trend in the BOD levels from 2010 to 2012 mainly due to increase in organic matter in the river.In the eutrophicated segment the BOD level exceeds the desirable limit. In the diluted segment, however the levels again tend to decrease to meet the desired criteria and this is due to the Chambal tributary of Yamuna that breathes new life into it.

Figure 3: Trends in Biological Oxygen Demand (BOD) of the Yamuna River(2010 to 2012)



	BOD year 2010 min	BOD year 2010 max	BOD for 2011 min	BOD for 2011 max	BOD 2012 min	BOD 2012 max
Yamunotri	0	0	0	0	0	0
Sonepat Haryana	1	2	1	4	1	2
okhla bridge Delhi	3	27	3	26	4	40
d/s Agra	4	15	4	29	4	15
allahabad d/s balua ghat	1.8	2.6	1.6	6.8	1.8	2.6

6. Conclusion and recommendations

As is evident from the above comparative analysis of water quality of the Yamuna River in terms of two critical parameters viz Dissolved Oxygen and Biological Oxygen Demand from 2010 to 2012 show variations from segment to segment and also year to year. Generally a healthy river should contain at least 5mg/l of Dissolved Oxygen (DO) and a maximum of 3mg/l of Biochemical Oxygen Demand (BOD) in its water. The Yamuna River in the Himalayan segment has good water quality with no discharge of sewage into it and shows good ecological health up to the upper segment, but gets polluted at the point when it enters Delhi (CPCB 2009;Upadhyay et al. 2010). It meets the primary water quality criteria and is suitable for its designated best uses.

Water of the Yamuna River, as it enters the Delhi Segment is of acceptable quality and is adequately suitable for sustaining the life forms, but after this point it gets polluted due to anthropogenic pressure and aggravating pollution load from the National Capital Region, thus becoming highly polluted downstream. Statistical data of (CPCB2010,2011 and 2012)clearly show that the stretch between Wazirabad and Okhla is the most heavily polluted. Here the river water is characterized by high amounts of organic and pathogenic contamination, turbid appearance, strong and unpleasant odor-thus indicating a depletion of oxygen, very high values of BOD and very low values of DO, which is even, zero in the Delhi segment thus reflecting high organic pollution and eutrophication in this segment (CPCB 2010; Malik et al., 2014). According to the CPCB reports (2010-2012) "here, the Dissolved Oxygen (DO) count is averaged at (1.85mg/l)and Biochemical Oxygen Demand (BOD) count is averaged at (17.1 mg/l), from 2010 to 2012 thus indicating considerable deterioration in water quality in the stretch due to discharge of sewage and industrial effluents and is far below the bathing standards". The water quality from the DO and BOD point of view is not fit for designated best uses in the Delhi segment.

In the eutrophicated segment the river undergoesa self-purification process as is indicated by the decreasing trend in the concentration of BOD averaged at 11.8 mg/L whencompared with the Delhi stretch for the same time period. While in the last, diluted segment the river water is relatively clean.Thus, it can be concluded that the water of the major part of the Yamuna River can hardly fulfil the designated uses.Inspite ofnumerous steps taken for the restoration of the water quality of Yamuna and investing crores of rupees on ambitious projects like YAP I, II and YAP III, which focused primarily on Delhi as it is the most critical segment the pollution level has not improved much specially in the most critical Delhi segment where the CPCB reports indicate reduction in the the pollution load but not in the pollution status of thr Yamuna River. Following are some effective ways to achieve restoration and conservation of the Yamuna:

Proper Sewage Management

- Sewage is one of the main sources of pollution in the Yamuna River and untreated or partially treated sewage effluents are still being discharged into the river. It calls for a total ban on such discharges and an effective legislation on it.

- The capacity of existing sewage treatment plants STPs should be increased and more sewage treatment plants of greater capacity should to be constructed.

- New technologies to reduce the BOD levels to below 10 mg/L should be implemented.

- The water authorities of Delhi are already in progress with an innovative master sewage plan 2031 for sewered and unsewered areas to effectively manage the wastewater system of the National Capital Territory.

EffectiveSolid Waste Management:

- Due to rapid urbanization along the Yamuna River a lot of solid waste is being generated everyday, adding to the pollution load on the river due to lack of proper solid waste management and disposal system. Most of the towns and cities need proper and adequate solid waste management systems and recycle and reuse units for effective waste management.

- New landfill sites are required for proper disposal of the ever increasing solid waste. These should be designed on the WHO standards.

- Since waste reduction and waste reuse and recycling are good methods of waste prevention as they not only eliminate the production of waste at its source of generation but also reduces the demand for waste treatment and disposal facilities. Keeping this in view, the public should be made aware and encouraged to use various ways of waste reduction in everyday life.

- Any developmental activity within the river zone should be restricted.

Community-based approach to address water related problems

Creating awareness among people about pollution in Yamuna River and its ill effects on the lives of people is very important. This can be done by the joint venture of public-private organizations.The role of local institutions such as the Panchayats should be increased. Active community participation is the need of the hour for monitoring, management and restoration of the Yamuna River.Involvement of public in program design helps ensure the smooth running of the programs (EPA, 1995).

Role of science and technology

New techniques should be used to develop suitable technologies to manage solid waste such as encouraging the emergence and development of industrial ecology where there is no such thing as waste but only resources. Where waste from one activity is input of raw materials for another activity. Such technologies will pave way for integrated waste management (IWM) which is best defined as a set of management alternatives, including reuse, source reduction, recycling, composting, landfill and incineration and pyrolysis a good and Eco friendly alternative to incineration for the thermal decomposition of solid wastes in an inert atmosphere

Improved agricultural practices

The unscientific use of chemical fertilizers, insecticides and pesticides in agriculture has significantly contributed to pollution in the Yamuna River. The agricultural practices need to be improved to minimize the effects of the chemicals. This can be done by some of the following ways:

- Employing organic or biological farming methods and prohibiting the use of pesticides, insecticides and fertilizers for agriculture in the river basin.

- Creating awareness among the farmers to avail facilities of programs like *Kisaan Call Centre* run by the ministry of agriculture for solving all their agriculture related queries including scientific guidance on the use of chemical fertilizers in cultivation, easily accessible through phones and mobiles;

- Emphasizing the use of bio-fertilizers which have least chemical constituents and

- Efforts should be made to reduce and prevent soil erosion in the river catchment area through vegetation cover. A suggested way is the development of Greenways along the drains. These severe for many other purposes, contributing to the conservation of the river.

Constructive Interactions

Interactions among consumers, policymakers, researchers, and industry representatives are needed to share their experiences and ideas about water quality management and propose sustainable and cost-effective solutions. There is also a need for continued interaction among scientists with different backgrounds, experiences, and knowledge bases to find solutions to the challenges of water availability, quality, and remediation and to explore ways for chemical, physical and biological solutions for dealing with water-related problems.

Lessons should be learnt from the success stories of the Rhine river (Europe), Thames river (England), Seine river (France) Missisippi river (USA), etc. for planning the cleanup action for the Yamuna River.

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