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RESEARCH ARTICLE

A COMPREHENSIVE WATER QUALITY REVIEW OF RIVER YAMUNA WITH SPECIAL REFERENCE TO WATER QUALITY INDEX IN THE HIMALAYAN REGION OF INDIA

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Abstract

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India with 4% of fresh water resources is facing a dual challenge of water scarcity and pollution. Several rivers in India originate from Himalayan systems and forms the basis of India's Economy. River contamination and diminishing water quality is reducing population's accessibility to clean and safe drinking Water. As one of the significant perennial tributaries of The Ganga Water systems, River Yamuna passes through the heartlands of thegreat North India Plains sustaining cities, feeding millions. Since Yamuna passes through major urban settlement it is heavily polluted with untreated industrial waste, sewage, domestic waste making its way into the river. The study presents a comprehensive reviewof the water quality assessmentsof theriver Yamuna with special reference to Water Quality Index based on severalhydrological parameters. Based on the levels of contamination the whole stretch of Yamuna from its source (at Uttarakhand) till its confluence with Ganga (at Allahabad) has been divided into 5 segments. While all the lower stretches depict "high" to "very high pollution" levels, the upper segment of the river in the Himalayas show "good water" quality. Water quality parameters of river Yamuna depict that BOD, DO and COD levels are not in range of permissible limits in Delhi segment but it falls under permissible limits range in Himalayan segment. Other than these parameters, ammonia, TKN and other organic and inorganic matters fall under the desired standards in Himalayan region of Yamuna.

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Introduction:-

Water is essential for life and clean water is fundamentalfor healthy life and wellbeing. Fresh water resources form the backbone of Indian Economy fulfilling its Agricultural, Industrial and domestic water demands. Though India has a vast network of Perineal River water systems, however it is degrading fast with staggering water demands and excessive pollution. India is facing a dual crisis of water scarcity as well as pollution. Rivers are being contaminated and polluted by numerous sources like discharge of industrial, agricultural and sewage wastes into the rivers which adversely affected the physicochemical quality of rivers[1].As one of the significant perennial tributary of The

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Ganga Water systems, riverYamuna passes through the heartlands of the North Indian Plains sustaining cities, feeding millions. It arises from an elevation of around 6320 meters above sea level at the Yamunotri glacier in Bandar Punch (38°59'N- 78°27'E) in the lower Himalayas in the Uttarakhand state of India and the catchment spreads across through 7 states –i.e., parts of Uttarakhand, Himachal Pradesh, Rajasthan, Haryana, Madhya Pradesh, Uttar Pradeshand flows through the capital Delhi. Betwa, Ken, Tons, Sindh and Chambal Rivers are the main tributaries of Yamuna and collectively contribute to 70.9% of the river's catchment area.

The Yamuna also holds sacred and holy significancein Indiaand several pilgrimage sites likeYamunotri in Uttarakhand, Paonta Sahib in Himachal Pradesh, Allahabad(Prayagraj), Mathura, Bateshwar, Vrindavan in Uttar Pradesh and are located at its banks. Along with this the river also passes through some big cities of North India like Agra, Mathura, Nioda, Prayagraj, including India's capital – Delhi. The river in its 1376 kms course is heavily polluted in several places and has altered the riverine ecosystem threatening biodiversity and aquatic life, along with human health. [1].Based on ecological and hydrological conditions, the river Yamuna has been categorized into 5 main segments viz. Himalayan, Upper, Delhi, Eutrophicated and Diluted segments **(Table 1 and Figure 1)** [2], [3].In 1993,Government of India launched the Yamuna Action Plan mostly funded by Government of Japan to revive the water quality status of the Yamuna[4]. The current study tries to contemplate various water quality assessment conducted for river Yamuna with special reference to water quality Index and discuss the hydrogeological and ecological characteristics of Yamuna River and its water quality index especially in its Himalayan segment and the potential impact such pollution levels can have on the human health and environment.

Study Area:-

The riverYammuna is the longest truibutary of Ganga and one of the most important artey of the Ganga River water system, draining the vast northern plains of India.It originates from Yammunotri Glacier at Height of 6387metres on the south western slopes of Banderpunch peaks of the Lower Himaylayas in Uttarakhand, and for 1356 kms before conflencing into river Ganga at Triveni Ghat, Allahabad (Prayagraj).The river flows southwards for about 200 kilometres (120 mi), through the Lower Himalayas and the Shivalik Hills Range. Morainic deposits are found along the steep Upper Yamuna, highlighted with geomorphic features such as interlocking spurs, steep rock benches, gorges and stream terraces. Large terraces formed over a long period of time can be seen in the lower course of the river, such as those near Naugoan. It has a drainage system of 366,223 square kilometres (141,399 sq mi), 40.2% of the entire Ganges Basin.An important part of its early catchment area, totalling 2,320 square kilometres (900 sq mi), lies in Himachal Pradesh. The Tons, Yamuna's largest tributary, drains a large portion of the upper catchment area and holds more water than the main stream and confuences with Yammuna at kalsi near, Daakpatthar. The Yamuna defines the state borders between Himachal Pradesh and Uttarakhand, and between Haryana, Delhi and Uttar Pradesh. When the Yamuna reaches the Indo-Gangetic plain, it runs almost parallel to the Ganges, the two rivers creating the Ganges-Yamuna Doab region. Spread across 69,000 square kilometres, one-third of the alluvial plain, the region is known for its agricultural output, particularly for the cultivation of basmati rice. [3]

The compendium of research works focusing on the Yammuna river water quality conditions has been prepared for the entire 1376km stretch of Yamuna from its origin at Yamunotri glacier in Uttarakhand (31.0140° N, 78.4600° E) to its confluence point in Allahabad(Prayagraj), Uttara Pradesh India (25.4210° N, 81.8902° E) and the entire riverstretch is divided into 5 segments based on pollution levels and general hydrological conditionsHighlighted in Figure – 1, Table -1)

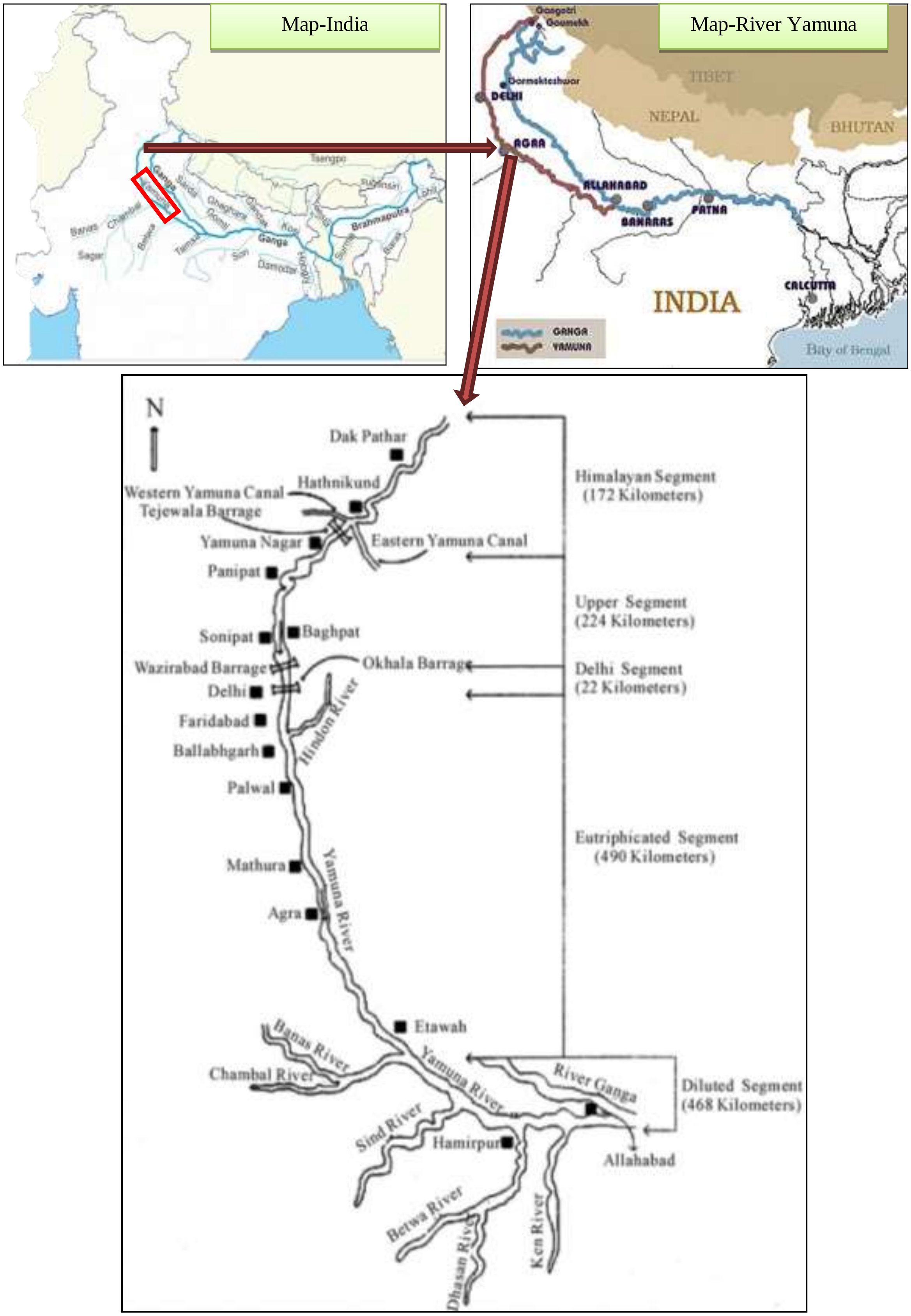

Figure1:- Study Area (River Yammuna, Longitudnal Stretch)

Water usage in different sectors:

The Water of River Yamuna is used in numerous ways throughout the northern Indian Plain region. About 94 percent water of river Yamuna is diverted for irrigation purpose via Gurgaon, Eastern Yamuna, Western Yamuna and Agra canal systems. The remaining 6 percent is diverted to meet the industrial and domestic water demands of the North Indian region primarily - Areas like Agra, Delhi, Allahabad (Prayagraj)and Mathura etc.**(Figure 2)**[6]

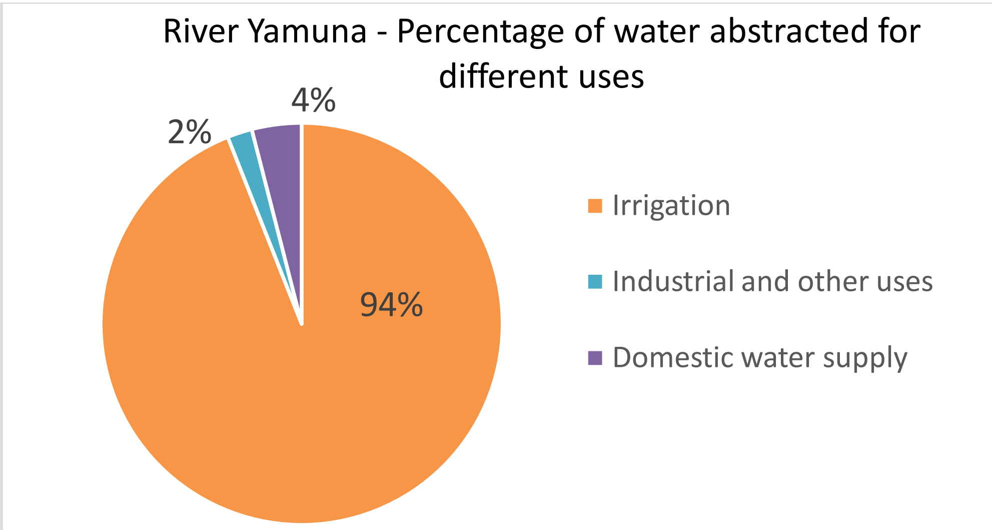

Figure 2:- Water percentage abstracted from Yamuna for different uses [7].

Water quality status of river Yamuna:

The Water quality of a river can be evaluated by analyzing its chemical, biological status. The healthy river should hold approximately 3mg/L of BOD and no less than 5mg/L of DO (important for aquatic life survival). The Fecal coliforms colony / FCC (represented diseases causing bacteria) should not be over 500/100ml of river water. Water qualities of Indian rivers have been categorized into 5 classes viz. class A, B, C, D and E **(Table 2)**. River Yamuna comes under class E[3], [8].

Table 1:- Water Quality Characteristics of 5 segments of river Yamuna [5].

S. No.	River segment	Segment description	Trophic index	Value	DO mg/l	BOD mg/l	pH	FC CFU/100ml
1	Himalayan segment	172 km from origin to Hathnikund barrage	Oligotrophic	Max	10.8	3	8.89	10200
				Min	7.2	1	6.83	70
				Avg	9.2	1	-	2448
2	Upper segment	224 km from Hathnikund barrage to Wazirabad barrage	Mesotrophic	Max	10.7	8	8.91	1390000
				Min	6.3	1	7.03	140
				Avg	8.1	3	-	16557
3	Delhi segment	22 km from Wazirabad barrage to Okhla barrage	Septic	Max	1.4	49	8.82	46000000
				Min	0	6	7.09	160000
				Avg	0.1	22.8	-	7267917
4	Eutrophicated segment	330 km Okhla barrage to Chambal confluence	Mesotrophic/Septic /Eutrophic	Max	19.5	40	9.04	47000000
				Min	0	3	7.24	1800
				Avg	7.4	12	-	1813017
5	Diluted segment	628 km Chambal confluence to Ganga confluence	Mesotrophic/Eutrophic	Min	5.7	2	7.40	1700

DO: Dissolved oxygen; BOD: Biochemical oxygen demand; FC: Fecal coliforms; CF**U:** Colony-Forming Unit.[5]**.**

Water quality of Yamuna River has been mainly affected by rapid industrialization, urbanization and agricultural intensification in the Yamuna basin.Dissolved oxygen (DO),Biological oxygen demand (BOD), Chemical oxygen demand (COD), pH, Total Kjeldahl nitrogen (TKN), ammonia are some water quality parameters of river Yamuna given by Central Pollution Control Board (CPCB)India. [7].

Table 2:- Five classes of Indian rivers (CPCB).

Class	Description
Class A	The water of river is suitable for drinking only after complete disinfection by adding bleaching powder or chlorine.
Class B	The water is only suitable for bathing.
Class C	Under this category, the water is suitable for drinking only after complete treatment of river water.
Class D	The water is suitable for aquatic life.
Class E	The water of river is mainly fit for irrigation, industrial purposes.

Source: (CPCB)

Dissolved Oxygen (DO)

DO level in the river water mainly rely on the temperature of river water, period and rate of photosynthesis etc. DO level in the river Yamuna from Yamunotri (Himalayas) to Palla (site between Sonipat and Nizamuddin bridge) is normal, but after Palla DO level reduce and after Wazirabad DO level reduce drastically. DO levels were observed to be zero at several places especially in the Delhi catchment area mainly due to confluence of Hindon and Shahdara drainsdirectly into the river releasing tons of waste and untreated water.**Figure 3** shows the annual DO values at various sites in river Yamuna[7], [9].

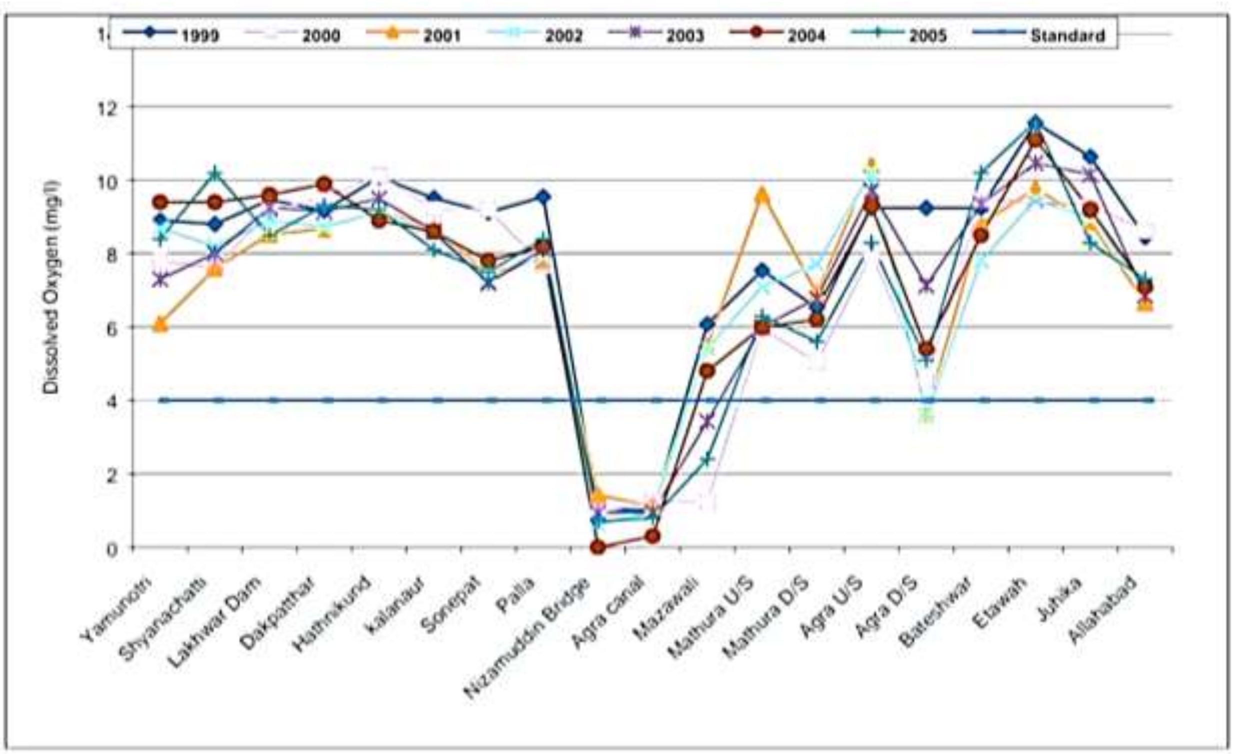

Figure 3:- Represents the annual Dissolved Oxygen values at various sites in river Yamuna.

Biological Oxygen Demand (BOD)

BOD estimates the amount of oxygen consumed by microorganisms in water to break down organic material polluted by industrial and sewage wastes. High level of BOD suggests that DO level is reducing and biodiversity and aquatic life of river is at risk. High level of nitrate and organic material in water causes high level of BOD and low level of DO [3], [10].

The BOD level in river Yamuna from Himalayas to Palla has been found between 1-3 mg/L. However, between Kalanaur to Palla the BOD level increases from 3-6 mg/L. Till Palla site river Yamuna is rich in aquatic life, but after the wastewater drains joins Yamuna constant reduction in aquatic biodiversity can be observed. The BOD level was observed between 3-51 mg/L from Nizamuddin bridge to Agra canal. The BOD level was also very high at Mazawali, Mathura, Etawah, Juhika and Agra. **Figure 4** shows the annual BOD values at various sites in river Yamuna [7], [11].

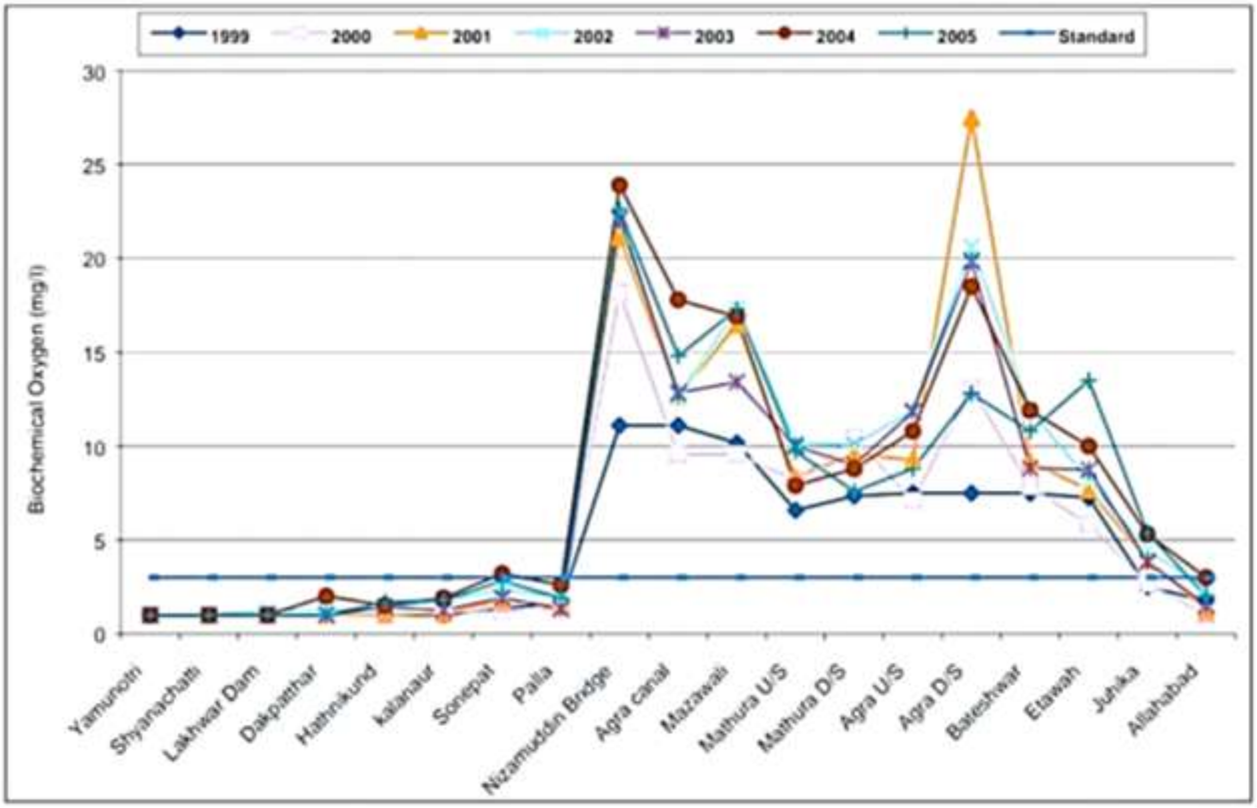

Figure 4:- Represents the annual Biological Oxygen Demand values at various sites in river Yamuna.

Chemical Oxygen Demand (COD)

The COD estimates the amount of inorganic and organic matter in water bodies[12]. From its origin (at Himalayas) to Palla, the COD level in Yamuna varied from 1-50 mg/L. After Palla, COD level increases drastically as it receives huge quantity of wastewaters from several drains in Delhi. From Wazirabad to Juhika, COD level reached beyond permissible levels i.e. 3-155 mg/L[7], [13].

pH

The pH in river Yamuna has been found in permissible limit. The pH level from Himalayas or Yamunotri to Bateshwar ranged from 6.11 – 9.39. The pH level has been found slightly low at Himalayan regions due to the presence of several Sulphur springs which joins the Yamuna River.Beyond Mathura (excluding Allahabad or now Prayagraj), the pH values at some sites were observed to be higher than the permissible limit or at higher value i.e. 9.0, and might be attributed to discharge of industrial effluents[7], [14].

Total Kjeldahl Nitrogen (TKN) and Ammonia

In clean segments of the Yamuna like Himalayan segment, the values of TKN and ammonia were low but at seriously polluted segments like from Wazirabad to Bateshwar, both TKN and ammonia values were alarmingly high. The values of TKN from Yamunotri to Nizamuddin bridge ranged from "belowthe detection limit" (BDL) to 46.20 mg/L. Similarly, ammonia values varied from BDL to 43.34 mg/L (Yamunotri to Nizamuddin bridge). Industrial effluents may be the reason for high concentration of TKN and ammonia at various sites in Yamuna river especially in the plain regions as compared to mountain segment.[7], [15].

Heavy metals and other parameters

Heavy metals like Chromium, Nickel, Zinc, Cadmium and Iron have been found at several sites viz. Palla, Nizamuddin bridge, Mathura and Agra downstream in river Yamuna. The maximum amount of Zinc and Iron was found 1.37 mg/L (at Palla) and 78.3 mg/L (at Nizamuddin bridge) in 2003 and 2001 respectively whereas the maximum value of Chromium was found 7.91 mg/L (at Agra downstream) in 2001. Other than heavy metals, pesticides like Dieldrin, Endosulfan, DDT, Benzene hexa chloride and Aldrin are also found at several sites in Yamuna. The maximum values of Dieldrin, Endosulfan and Aldrin were found 50.85 µg/L (in 2005), 4591.08 µg/L (in 2002) and 213.41 µg/L (in 2001) respectively at Mathura downstream and Nizamuddin bridge[2], [7], [16].

The contamination of the river system has greatly impacted the riverine biodiversity and aquatic life. A high number of fishes are reported dead every year in the river Yamuna between Delhi and Agra and reached a critical point where fishes are seldom found within this highly polluted segment of the river stretch.[17].Other water quality parameters in Yamuna Riverhave been shown in **Table 3** and **Table 4**.As per reports and observations, the Himalayan segment of Yamuna river is still better and not affected in terms of pollution[4].

Table 3:- Some water quality parameters values in river Yamuna [3].

S. No.	Parameter	Maximum			Minimum		
		Year	Value (mg/L)	Location	Year	Value (mg/L)	Location
1	Alkalinity	2004, 2005	425	Mazawali	2000	40	Hathnikund
2	Sodium	2004	406	Agra d/s (1/4)	2001, 2003, 2004	6	Hathnikund, Sonepat
3	Magnesium	2004	77	Agra canal (1/2)	2004	0.4	Sonepat
4	TDS	2000	1357	Etawah	2000	83	Hathnikund
5	Phosphate	2004	2.00	Mathura u/s	2005	0.02	Palla
6	Potassium	1999	48	Agra D/s	2000	1.0	Hathnikund
7	Calcium	2005	291	Agra d/s (1/2)	2001	7	Kalanapur
8	Chloride	2001	424	Agra d/s (1/2)	2005	2	Hathnikund, Sonepat, Kalanaur
9	Total hardness	2005	792	Agra u/s	2005	46	Hathnikund
10	Sulphate	1999	217	Nizamuddin bridge	2005	7	Etawah

Table 4:- River Yamuna water quality status [3].

Sewage Generated	Total Sewage	Treated Sewage	Comments
Daily Sewage Generated in Delhi	2871 million liters	1478 liters	Remaining sewage goes into the Yamuna through the 17 drain
Dissolved Oxygen	**Quantity**	**Normal Oxygen Level**	**Comments**
Dissolved Oxygen Level	0 mg/L	4 mg/L	The dissolved oxygen level is critically important for water plants and fish
BOD	**Quantity**	**Permissible Limits**	**Comments**
Biochemical Oxygen Demand (BOD)	15-30 mg/L	3 mg/L	
TDS	**Quantity**	**Permissible Limits**	**Comments**
Content of Suspended Solids in Yamuna	1000-10,000 mg/L	100 mg/L	
Coliform Level	**Quantity**	**Permissible Limits**	**Comments**
Coliform Level in Yamuna	11.8 Crore per 100 ml of water	5000 per 100 ml of water	Coliforms causes many serious diseases relating to the digestive system
Forest Cover	**Existing Forest Cover**	**Required Forest Cover**	**Comments**
Delhi's Forest Cover	10.2% of total area	33% of the total area	
Requirement of Drinking Water	**Total Requirement**	**Available Drinking Water**	**Comments**
Delhi's Drinking Water Requirement	1480 cusecs	1221 cusecs	

Water quality index (WQI)

In 1965, Horton categorized the water quality and Brown and his colleagues developed a general water quality index (WQI). Till 1970, at least 20 WQIs methods were used which were studied by Steinhart and Ott independently. Steinhart with his colleagues applied a novel environmental quality index to summarize all the technical details on the trends and status in Great Lake ecosystem. In Canada, WQI was introduced by CCME's water quality guidelines task group.WQI like Florida Stream Water Quality Index (FWQI), Canadian Water Quality Index (Canadian Council of Ministers of the Environment (CCME), The US National Sanitation Foundation Water Quality Index (NSFWQI), the Oregon Water Quality Index (OWQI) and British Columbia Water Quality Index (BCWQI) are repeatedly used across the globe. Canadian Council of Ministers of the Environment (CCME) certified the modified version of BCWQI into CCME WQI.

Bhargava developed WQI in India which gives an easy way to sum up complicated water quality data. This index provides water quality between 0 and 100, where 0 represents worst water quality and 100 represents excellent water quality**(Table 5)**. This water quality index comprises the impactof weight of every pollution related parameter in the sensitivity function values of several pollution related parameters to certain use**(Table 6)**[18], [19]**.**

Table 5:- Water quality legends[4].

S.No.	Value	Water Quality
1	0-25	Worst
2	25-50	Bad
3	50-70	Medium
4	70-90	Good
5	90-100	Best

Table 6:- Water quality parameters and their weights[4].

S.No.	Parameters	Weight
1	pH	0.11
2	Temperature change	0.1
3	Nitrate	0.1
4	Fecal Coliforms	0.16
5	Total solids	0.07
6	Turbidity	0.08
7	BOD	0.11
8	Dissolve oxygen	0.17
9	Total phosphate	0.1

WQI at Himalayan segment

The concentration of DO inHimalayan segment is 8.8 – 8.6 mg/L (2010-2012) and meets the desired standard.Likewise, the values of BOD and COD in this segment of Yamuna lies between 0 – 3 mg/L and 1 – 3 mg/L respectively and falls under permissible limits[7], [20]. This is primarily due to no discharge of industrial waste or polluted water into the river and less density of pollution in this segment of the river. Ammonia and TKN values are also very low in Himalaya region. Similarly, pH level has been also found in permissible limits[7].The water quality index of the Himalayan segment or in Himalayan region of Yamuna falls under "good water quality" valuewith no discharge of industrial waste into it. Presence of minimum amount of inorganic and organic matter in river Yamuna and absence of any main industrial hubsin Himalayan region are the main reasons of good WQI in Yamuna at Himalayan segment[21].The presence of clean fresh water in Himalayan segment of Yamuna allows high aquatic biodiversity in the region to thrive.

WQI at other segments

WQI falls under medium category in the upper segment of Yamuna but when it enters the Delhi segment it gets polluted as it receives large amount industrial and sewage wastewater. Okhla and Wazirabad are the heavily polluted sites of the Delhi segment. The water quality comes under "bad category" at this segment. In comparison with its previous segment, the BOD concentration has decreased in eutrophicated segment as at this stretch river go through self-purification process. At last segment i.e. diluted segment the river water is comparatively clear than Delhi and eutrophicated segments however still polluted as per permissible standards at various places.[20].

Conclusion and Recommendations:-

The river Yamuna being an important tributary of Ganga is significant artery of the large ganga river water system which serves millions of people in the subcontinent. However, the river while passing through major Urban settlement and industrial hubs becomes highly polluted at various places. Based on its levels of pollution the whole longitudinal stretch of the river Yamuna is divided into 5 five segments. The water of Yamuna is mainly used for irrigation followed by household water supply and other uses. The river water of Yamuna is not fit for drinking mainly in Delhi and eutrophicated segments as BOD, COD, DO levels are higher than the permissible limits in these segments. In Himalayan segment BOD, DO, COD levels, pH, ammonia, TKN and other organic and inorganic matters fall under permissible and desirable limits whereas in Delhi segment, water quality status is "bad". The heavily polluted segment of Yamuna River is primarily attributed to huge untreated discharge from industries, domestic wastewaters along with direct sewage discharges into the river. River Yamuna in the Himalayan region has "good water quality" due to absence of large Industrial centers, large settlements, and minimal amount of organic and inorganic matter is present. This segment therefore exhibits healthy hydro-ecological conditions.

Discharge of sewage effluents into the Yamuna or any other fresh water system is one of the major sources of pollution in India. So, there is urgent need for highly proactive policy initiatives to prohibit direct discharge of untreated industrial and sewage into the river systems. Industries must be standardized to have their own toxic water treatment plants with regular monitoring and control measures on the part of governments. Initiative calls for development of greener and efficient technological systems seeking long term environment development. Creation of new sewerage treatment plants and upgrading the efficiency of the older ones to maximize the capacity for sewage treatment is critical with minimum seepage into the river system. Industry and sewage wastes are associated with increasing BOD level of the river water so to minimize the value of BOD to less than 10 mg/L rigorous technological upgradation, adoption, implementation is required. Diversifying from usage of chemical pesticides, insecticides and fertilizers to better ecofriendly additives and upgrading diversifying agricultural systems is also crucial to sustain river water quality. Significant improvement measures from all fronts with conscious understanding of resource utilization and appreciation is the key in conserving our fresh water systems and river systems in particular.

Abbreviations:
1. BOD- Biological Oxygen Demand.
2. DO – Dissolved Oxygen
3. COD- Chemical Oxygen Demand.
4. TKN- Total Kjeldahl Nitrogen
5. WQI- Water Quality Index.
6. NSFWQI- National Sanitation Foundation Water Quality Index

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