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Research Article

Yamuna Action Plan-III: Impact on Water Quality of River Yamuna, India

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Abstract: Water is indispensable to sustain life and livelihood, and rivers serve as major reservoirs of water in many parts of the world. River Yamuna is the major tributary of the River Ganges in India and is considered to be among the most polluted rivers of the world. The Yamuna Action Plan (YAP) is one of the largest river restoration projects in India and is initiated to clean the river. YAP is a bilateral arrangement between the governments of India and Japan, and consists of three Actions Plans-I, II and III. YAP-III is currently under execution with some of the major projects being the construction of the new Wastewater Treatment Plant (WWTP) at Okhla, rehabilitation and upgrading of WWTPs at Kondli and Rithala in the Delhi region. The impact of YAP-III with regard to these major projects on the reduction of the pollutant load reaching the river and cost-benefit has been evaluated in the current study. Findings from the study indicated that major projects such as construction of a new WWTP at Okhla (124 MGD) can effectively reduce the pollutant load by 283 kg/MGD of wastewater at a cost of Rs. 1161 crores while the rehabilitation project at Rithala (Phase I) can reduce the pollutant load by 92.5 kg/MGD wastewater at a cost of Rs. 300 crores. The present study indicates the need to evaluate projects in terms of cost-benefit analysis in addition to the economic and environmental evaluation for effective action. A holistic approach towards treatment of pollutant load in the river and prevention of further pollutants from reaching the river is required in addition to community awareness and participation for sustainable river water management.

***Keywords*:** River Yamuna, Yamuna Action Plan, pollutant load, Wastewater Treatment Plant

Nomenclature

ASP	Activated Sludge Process
BOD	Biological Oxygen Demand
CPCB	Central Pollution Control Board
DPCC	Delhi Pollution Control Committee
DJB	Delhi Jal Board
JICA	Japan International Cooperation Agency
MLD	Million Litres per Day
MGD	Million Gallons per Day

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TSS	Total Suspended Solids
WWTP	Waste Water Treatment Plant
YAP	Yamuna Action Plan

1. Introduction

Ancient civilizations have always developed along rivers and have supported different forms of life. However, the rapid industrial expansion and associated population growth in urban areas have a potential to impair the quality of water and associated ecosystem.[1] In developing countries, not all parts of the city are connected to sewer systems and untreated wastewater finds its way into lakes and rivers, which deteriorates the water quality.[2] Water quality monitoring and assessment is the first step towards understanding the nature of water pollution and devising mitigation strategies for pollution control.[3] As of 2018, the Central Pollution Control Board of India has identified more than 351 polluted stretches of rivers with a majority of them along urban settlements.[4]

The Yamuna is the largest tributary of River Ganges and originates from the Yamunotri Glacier with Himachal Pradesh, Uttar Pradesh, Haryana and Delhi being the riparian states.[5] The river caters to agricultural, industrial and domestic consumption and also functions as a dumping site for industrial effluents, agricultural run-off and domestic sewage discharge. Nearly 60 million people depend on the river to sustain their livelihoods.[3] Rapid urbanization and population growth in the major cities catered by River Yamuna have put tremendous pressure on the water supply and sanitation.[6] The population in Delhi for example has grown at an exponential rate increasing from 13.9 million in 2001 to 16.8 million in 2011,[7-8] which increases the domestic usage, agriculture and industrial usages and finally results in the deterioration of river water quality.[9] Along its course, water from the river is abstracted mainly for irrigation (nearly 95%), domestic purposes (4%) and the remained for industry.[10] The dilution capacity of the river gets reduced due to the significant water abstraction. The Yamuna is considered to be among the most polluted rivers of the world[11-12] with the cities of Delhi, Agra and Mathura being the chief polluters through either point or non-point sources.[13]

The Yamuna Action Plan (YAP) was put forth as one of the largest restoration projects in the country to clean the river. This Action Plan is a bilateral project between the governments of India and Japan with financial assistance provided by the Japan International Cooperation Agency (JICA). YAP has three Action Plans with YAP-III currently under execution[14] that analyzed the effectiveness of YAP-I and II. The results suggested that the projects have been unsuccessful in cleaning the river with respect to Biological Oxygen Demand, Dissolved Oxygen levels and coliform contamination.

There are huge investments made in numerous projects being executed as part of YAP-III, some of which are the rehabilitation of Wastewater Treatment Plants (WWTPs) at Kondli and Rithala and construction of new WWTPs at Okhla. To the best of our knowledge, there are currently no studies examining the effectiveness of YAP-III projects on cleaning of the River Yamuna. The objective of the present study is to analyze the impact of YAP-III and its effect in reducing the pollutant load in the River Yamuna with project cost and Biological Oxygen Demand (BOD) as factors.

2. Methodology

2.1 *Study area*

The present study covers a 22 km stretch of the Yamuna passing through the Delhi region, entering at the Wazirabad barrage. This stretch is considered to be the most polluted stretch of the entire river length.[3] Delhi is spread over 1484 sq km with an elevation of nearly 225 m above the mean sea level. The region is in the sub-tropical zone with mild winters alternating with extremely hot summers with average temperatures ranging between 40-45 °C in summers and 4-5 °C in winters.[15] The major projects of YAP-III along the Delhi stretch of the river namely (i) construction of new WWTP at Okhla; (ii) rehabilitation and upgrading of Rithala WWTP; (iii) rehabilitation and upgrading of Kondli WWTP in terms of water quality improvement and cost-benefit considerations in the present study.

2.2 *Analysis*

The three major projects under YAP-III above-mentioned were analyzed in terms of the total cost and the amount of BOD load removed per MGD (Million Gallons per Day) of wastewater treated in the WWTP. BOD gives the quantity of oxygen required for the complete oxidation and decomposition of organic matter present in water with the help of microbes.[16] The BOD load removed is calculated based on the initial design parameters of the WWTP and the new design parameters (BOD < 10 mg/l) for BOD in case of the WWTPs to be rehabilitated (Rithala and Kondli). In the case of the new WWTP at Okhla, the BOD load removed is calculated from the water quality parameters and the design parameters (BOD < 10 mg/l) of the WWTP.

3. Results and discussion

3.1 *Yamuna Action Plan-I and II*

The major components of YAP involved the construction of drain interceptors, pumping stations, and rehabilitation and construction of WWTP. The Plan identified 15 Class I cities for priority interventions to reduce the pollutant load.

3.1.1 *YAP-I*

YAP-I was initiated to improve the quality of water and to reduce the pollutant load reaching the Yamuna. The project focused on the reduction of discharge of raw sewage into the Yamuna from the cities and towns located along its banks.[17] Projects during this phase started in 1993 and continued until 2003. Under YAP-I, the emphasis was placed on cleaning the stretch in Delhi and surrounding towns in Haryana and Uttar Pradesh. A total of 21 cities were covered in this initial phase of YAP with the total cost (along with the cost of additional packages) being Rs. 682 crores.[11] Some of the major projects in YAP-I were: (1) Construction of 29 WWTPs, 58 pumping stations and 179 km of sewer lines; (2) Installation of non-sewerage facilities such as public toilet complexes, crematoria, riverfront development and plantation drives; (3) Construction of mini and micro WWTPs in community toilet complexes to reduce the pollutant load; (4) Public participation and awareness programs; (5) Supplementary work such as the lining of ponds, creation of sludge drying beds, rising mains and replacement of old pipes. Reports indicate that YAP-I did not address non-point sources of pollution nor consider population projection while designing the WWTPs. A total sewage treatment capacity of 753 MLD was constructed as part of YAP-I.[11]

3.1.2 *YAP-II*

YAP-II was initiated in 2004 and was scheduled to be completed by 2008. However, this phase was extended to 2013 with the total budget sanctioned, Rs. 624 crores.[11] YAP (II) was planned to maintain sewerage systems in the cities of Delhi and Agra as the most critical segment to reduce the pollution load in the Yamuna. In particular, several intercepting sewer lines were to be built along the banks of the river to trap untreated wastewater and divert it into treatment plants.[18] Some of the major initiatives undertaken under YAP-II in Delhi are: (1) Construction of 135 MLD Okhla WWTP; (2) Rehabilitation of 324 MLD Keshopur WWTP; (3) Rehabilitation of Ring Road Sewer; (4) Rehabilitation of Bela Road Sewer; (5) Laying of Wazirabad Road Sewer; (6) Public Outreach and demonstration projects. An additional sewage treatment capacity of 189 MLD was constructed as part of YAP-II covering Delhi, 6 towns in Haryana and 98 towns in Uttar Pradesh.[11]

More details on the impact of YAP-I[19] and II on the reduction of pollutant load on the Yamuna can be found.[17]

3.2 *Yamuna Action Plan-III*

YAP-III was launched in 2012 with the estimated cost for the Delhi stretch of projects being Rs. 1656 crores. A rapid deterioration of water quality of the river is observed as it enters the city of Delhi through the Wazirabad barrage due to wastewater discharge from 22 drains. River Yamuna can be segmented into five distinguished independent segments due to the characteristic hydrological and ecological conditions with the Delhi stretch being one of them.[18] The Delhi stretch of the Yamuna comprises 2% of the total length but contributes to more than 76% of the total pollutant

load carried by the river.[3, 19-21] A total of eight major sewerage infrastructure projects have been approved for Delhi to clean the 22-km stretch of Yamuna in Delhi under YAP-III in addition to other plantation drives, supplementary work and awareness programs. These projects are being implemented by the Delhi Jal Board (the nodal agency in charge of maintaining water supply and sanitation in most parts of the National Capital Territory of Delhi) in collaboration with Japan International Cooperation Assistance (JICA). Out of Rs. 1656 crores, Rs. 1407.59 Crores i.e. 85% is being funded by JICA through the Government of India and Rs. 248.41 Crores i.e. 15% will be funded by the Government of the National Capital Territory of Delhi. The Operation and Maintenance Cost of the projects is to be borne by the Delhi Jal Board (DJB).

3.2.1 *Major sewage infrastructure projects under YAP-III*

YAP-III is comprised of 9 packages of Rehabilitation and up-gradation of WWTPs in Rithala, Kondli and Okhla catchments including rehabilitation of trunk and peripheral sewer lines and rising mains in these catchments at critical stretches. Out of 9 Packages, 7 packages have already been awarded. Other packages in YAP-III involve plans to set up sewer systems in locations not connected to the current sewer network. Plans for the same are provided in the Sewerage Master Plan 2031.[8] The package also includes a public awareness component, involving the scope and content, education and public relations campaign.

3.2.1.1 *Construction of 124 MGD WWTP at Okhla*

This is an integrated project of treatment of wastewater and sludge management. Considering acute problems in sludge handling, its huge accumulation and disposal difficulties at various WWTPs, sludge management has also been included in the scope of the work. Briefly, the project included the construction of 564 MLD WWTP with effluent standards for Biological Oxygen Demand (BOD)-10 mg/l, Total Suspended Solids (TSS)-10 mg/l, or better and Power Generation on Design, Build and Operate (one-year Defect Liability Period plus 10 years Operation and Maintenance) basis and demolition of the existing Phase-I, II, III and IV WWTPs at Okhla under YAP-III (Package-O).

Construction of 564 MLD (124 MGD) WWTP at Okhla is one of the largest packages of YAP-III. There are four old existing STPs at Okhla, namely Phase I (136 MLD), Phase II (55 MLD), Phase III (205 MLD) and Phase IV (168 MLD). The existing Okhla Phase-I, II, III and IV STPs were constructed in 1937, 1982, 1991 and 1993 respectively with treated effluent parameters of BOD < 30 mg/l and TSS < 50 mg/l. The Phase-I plant of 136 MLD capacity was put out of operation in the year 2015. The digesters and Gas Holders of Phase-II, III and IV STPs are non-functional and the undigested sludge is dewatered on the Sludge Drying Beds. As the old plants have outlived their useful life, it was proposed to construct a new STP (Package O) of combined capacity of Phase I, II, III & IV (136 + 55 + 205 + 168) = 564 MLD using Activated Sludge Process (ASP) Technology.

The proposed WWTP is expected to meet stringent new discharge standards of BOD < 10 mg/l and TSS < 10 mg/l including removal of Biological Nutrients along with power generation and sludge management. It will have also the provision of Supervisory control and data acquisition (SCADA) and online monitoring of quality parameters of treated effluent. The project has been approved at a cost of Rs. 1161.18 Crores i.e. Rs. 942.18 Crores including the cost of sludge management for capital works and Rs. 219.00 Crores towards Operation and Maintenance.

3.2.1.2 *Rehabilitation and upgrading of Rithala WWTP*

The sewerage infrastructure projects at Rithala are being taken up in three packages (R1a, R1b, R2) under YAP-III. Work Packages R1a and R1b involve rehabilitation of Trunk, Peripheral Sewer and Rising Main at Rithala while R2 involves rehabilitation and upgrading of Phase I WWTP at Rithala.

Phase I of Rithala WWTP was constructed in 2001 and is based on ASP technology. The WWTP has a design capacity of 40 MGD and treated water from the WWTP is discharged into the Najafgarh drain via the Jahangirpuri drain and reaches the Yamuna. The initial design parameters of the WWTP were BOD < 30 mg/l and TSS < 50 mg/l. The rehabilitated and upgraded WWTP will meet the new stringent discharge standards of BOD < 10 mg/l and TSS < 10 mg/l. The initial date of completion of the project was expected at the end of 2021, however, the reality could be likely at the end of 2022.

3.2.1.3 *Rehabilitation and upgrading of Kondli WWTP*

The sewerage infrastructure projects at Kondli are being taken up in four packages (K1, K2, K3, K4) under YAP-III. Work Packages K1 and K2 involve rehabilitation of trunk sewers numbers 4 and 5 while K4 involves rehabilitation of rising mains. Work Package K3 involves rehabilitation and upgrading of Kondli WWTP (Phase I, II and III).

Kondli WWTP has 4 Phases-Phase I, II, III and IV of which Phase II was constructed in 1997 and Phase IV constructed in 2013. Phase I and III have been closed since 2013 and 2014 respectively while Phase II and IV are operational with a total design capacity of 70 MGD. Phase II is based on ASP technology and has the design parameters BOD < 30 mg/L and TSS < 50 mg/L. Treated water from the WWTP is currently discharged into the Shahdara drain. Phase II has 5 digestors of which only 3 are functional. Phase I, II and III with the design capacities of 10 MGD, 25 MGD and 10 MGD respectively are currently being rehabilitated and upgraded under YAP-III. The rehabilitated and upgraded WWTP will meet the new discharge standards of BOD < 10 mg/l and TSS < 10 mg/l. The initial date of completion of the project was February 2022, however, the likely date of completion is at the end of 2022.[15] The physical progress of the projects under YAP-III with their likely date of completion is shown in Table 1.

Table 1. Package wise details and timelines of YAP-III projects

Packages Name/Details of Project	Date of award	Contract Amount (INR (In crores))	Physical progress in (%) (as of Aug 2020)
Rithala WWTP related works			
R1a : Rithala-Rehabilitation of Trunk/ Peripheral Sewer	07.3.2018	30.71	61.75
R1b: Rithala-Rehabilitation/ Replacing of Rising Main	25.06.2018	37.58	64.75
R2 : Rithala-Rehabilitation & upgradation of Rithala (Ph-I) WWTP	01.06.2018	223.70 (296.13 including Operation and Maintenance)	27.25
Kondli WWTP related works			
K1 : Kondli-Rehabilitation of Trunk Sewer No.4	14.11.2017	55.41	74.40
K2 : Kondli-Rehabilitation of Trunk Sewer No.5	14.11.2017	74.35	90.46
K3 : Kondli-Rehabilitation & upgradation of phase I, II and III WWTPs	26.07.2018	314.71 (389.71 including Operation and Maintenance)	34.85
K4 : Kondli-Rehabilitation of Rising Main	02.07.2018	42.90	51.50
Okhla WWTP related works			
O : Okhla-Construction of 564 MLD (124MGD) New WWTP	04.06.2019	942.18 (1161.18 including Operation and Maintenance)	13.60

3.3 *Cost-benefit considerations and impact of YAP-III on the reduction of pollutant load*

An increase in population brings a corresponding increase in the BOD load if strategies are not in place to treat all the wastewater before it reaches the river. In case of cleaning of River Yamuna, execution of multiple projects are in parallel such as: (1) Rehabilitation of all WWTPs to discharge limits of BOD < 10 mg/L and TSS < 10 mg/L; (2) Increase in capacity utilization of WWTPs in all areas connected to the sewer network; (3) Automation of sewage pumping stations; (4) Reducing the flow of treated water into the river as a way to reduce the pollutant load reaching the water body. The completion of ongoing projects such as the Interceptor Sewer Project (ISP) can increase the capacity utilization of the WWTPs. The idea behind the ISP project involves using trunk sewers, which runs in parallel with

major drains, to intercept wastewater from smaller sewers. This will reduce the flow of untreated wastewater reaching River Yamuna through the major drains of Najafgarh, Shahdara and supplementary drains. Completion of this project is expected to divert nearly 250 MGD of wastewater to WWTPs of Nilothi, Kondli, Dwarka, Rithala, Yamuna Vihar and Coronation Park, thereby reducing the pollution load directly reaching River Yamuna.

Okhla WWTP with a capacity of 124 MGD being constructed at a cost of Rs.1161 crores can increase the treatment capacity by an additional 30 MGD and reduce the BOD load by 35 tonnes/day once being operational. Wastewater from the surrounding areas will be treated at the WWTP before getting released into Agra Canal. The average BOD load in Agra Canal as of 2019 was 33.5 tonnes/day. Rehabilitation of Rithala Phase I is being carried out at a cost of Rs. 300 crores. The plant is operating at design parameters of BOD < 30 mg/L and TSS < 50 mg/L and discharges into the Najafgarh drain. The Najafgarh drain currently has an average BOD load of 133.82 tonnes/day. Rehabilitation of the WWTP will remove an additional 3.7 tonnes/day of BOD (assuming BOD levels in raw wastewater to be 200 mg/L) reaching the drain and ultimately River Yamuna.

The upgrading and rehabilitation project at Kondli is being carried out at a cost of Rs. 389 crores. Phase II of the WWTP is operating at design parameters of BOD < 30 mg/L and TSS < 50 mg/L and the current project will enhance its design parameters to BOD < 10 mg/L and TSS < 10 mg/L. An additional 2.280 tonnes/day of BOD will be removed using Phase II of Kondli WWTP once operational. On the other hand, Phase I and III of Kondli are non-operational and rehabilitation of the WWTPs will treat raw wastewater and remove additional BOD loads of 8.664 tonnes/day each from both Phases. Treated water from Kondli WWTP is currently discharged into Shahdara drain which has an average BOD load of 61.44 tonnes/day as of 2019.

The comparsion between the expenditure and the BOD load that will be treated between the projects of Okhla and Rithala WWTPs reveals an interesting analysis. Construction of the new WWTP at Okhla at a cost of Rs. 1161 crores will reduce the BOD load by 283 kg/MGD of wastewater while rehabilitation of Phase I at Rithala at a cost of Rs. 300 crores will reduce the BOD load by 92.5 kg/MGD of wastewater. Increasing the cost by 4 times in Okhla has increased the BOD load removal by 3 times as compared to the rehabilitation project at Rithala. The total cost at Okhla involves demolition of Phases I-IV and construction of the new WWTP. In general, construction of a new WWTP removes more pollutant load from the wastewater than a project involving upgrading of the existing WWTP. Figure 1 shows the average BOD removal against investments made for the major YAP-III projects.

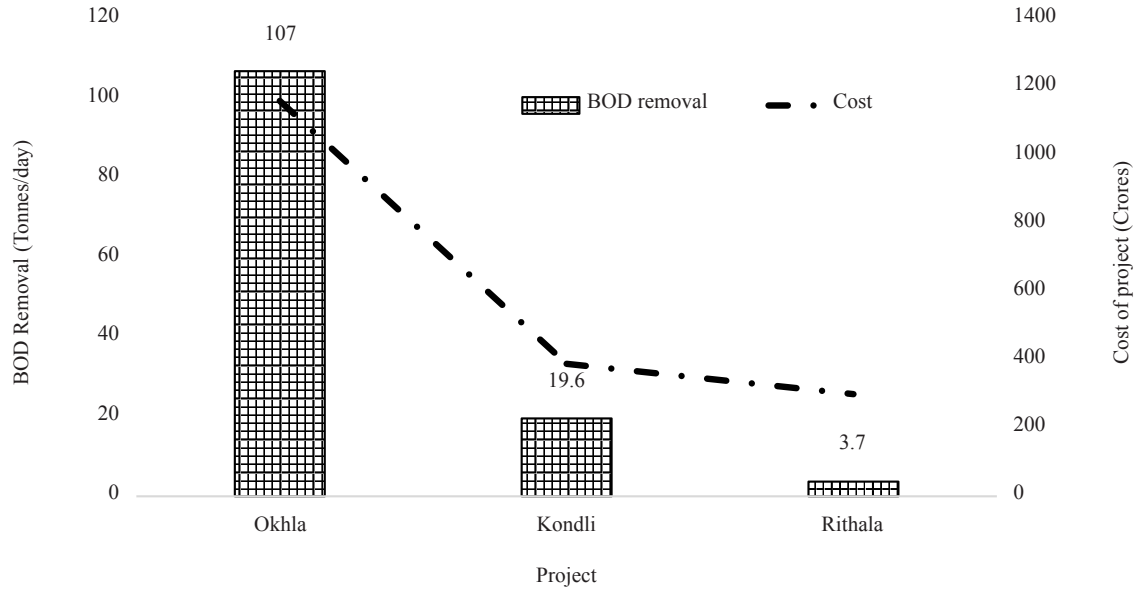

Figure 1. Cost comparison and BOD removal for projects under YAP-III

3.4 *Pollution in River Yamuna over the years*

The water quality of River Yamuna is monitored both by Central Pollution Control Board (CPCB) and Delhi Pollution Control Committee (DPCC).[22] Studies indicate that the pollutant load due to BOD in River Yamuna has been increasing despite the continuous efforts put into the Yamuna Action Plan Projects. Though there exist strong environmental regulations and legal provisions to control water pollution such as empowered under the Water (Prevention and Control of Pollution) Act, 1974, The Environment (Protection) Act, 1986 to mention a few, lack of strong enforcement in some cases has been linked to continued deterioration of water bodies.[16] Trends in organic contamination of the Delhi stretch of River Yamuna between 2007-2016 were studied, which indicated that BOD levels ranged from 1.3 to 61.8 mg/L. Figure 2 shows the change in average BOD load entering the river over the years and the results indicate that slight progress has been made from YAP-I until now.

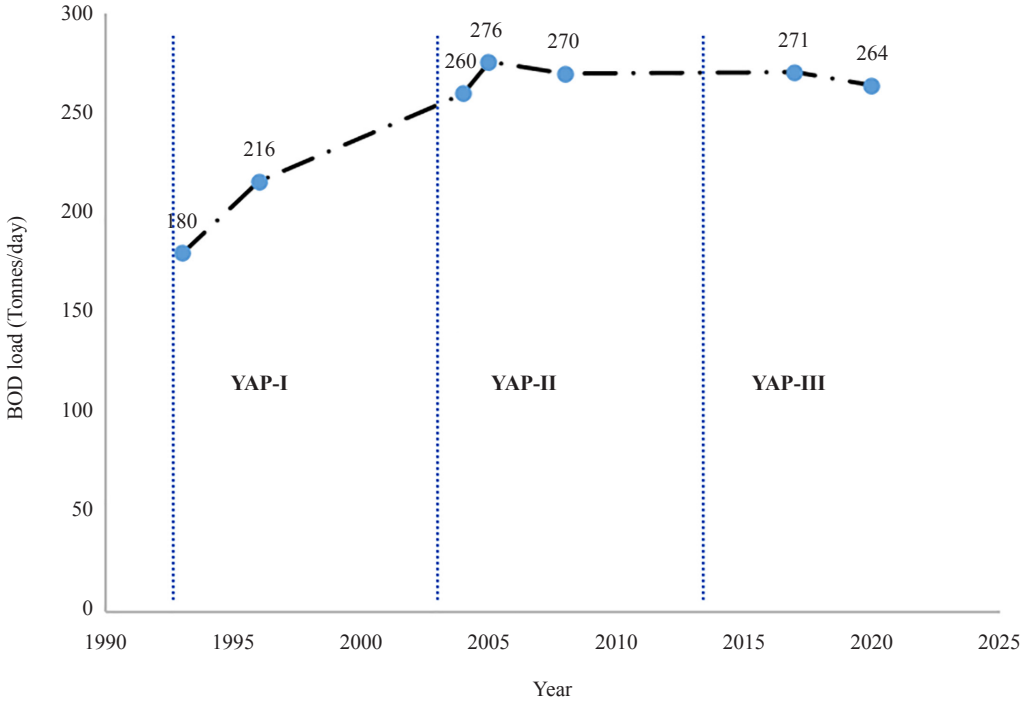

Figure 2. Pollutant load reaching River Yamuna between the YAP projects

Most of the untreated wastewater flows into sub drains and drains ultimately discharging into the river. A total of 22 drains discharge their waste into the River[23] mainly in the zones downstream from Wazirabad to Okhla. Among the major drains, Najafgarh is the main contributor to the total flow as well as pollutant load. The average BOD load carried by the Najafgarh drain was 68 tonnes/day in 2008[24] whereas it has increased to 134 tonnes/day in 2019. Figure 3 shows a comparison of the average BOD load carried by the major drains from 2017 to 2019. It is significant to be noted that even though there is only a marginal reduction in the BOD load from the drains from 2017 to 2019, a significant reduction in discharge has been observed between the years. The flow has reduced from 3450 MLD in 2017 to 3026 MLD in 2019.[25]

Some of the major activities in parallel that will ensure a significant reduction in the BOD load reaching the river are: (1) Completion of the Interceptor Sewer Project-Out of a total of 242 MGD to be trapped, 159 MGD has already been trapped. The remaining will be trapped by 2021;[22] (2) Completion of laying of sewer lines in unauthorized colonies-untreated sewage from non-sewered areas finds its way into the river through open stormwater drains.[21] From 2015 until the present, the sewer network has been extended from 255 to 384 unauthorized colonies, thus adding 129

colonies in sewerage network, covering a population of around 650,000. Further, work is in progress for laying sewer network in 432 Unauthorized colonies covering population of around 2,160,000. As of August 2020, there are a total of 1,799 unauthorized colonies,[22] out of which sewer lines have been laid in 620 unauthorized colonies; (3) Increase in capacity utilization of WWTPs-Out of 748 MGD sewage generated in Delhi, sewage treatment capacity infrastructure exists for 597 MGD, of which treatment is being done for 490 MGD wastewater;[25] (4) Rehabilitation of WWTPs; (5) Construction of decentralized WWTPs in locations wherever feasible.[16] Table 2 summarizes the timelines and investments of the YAP projects.

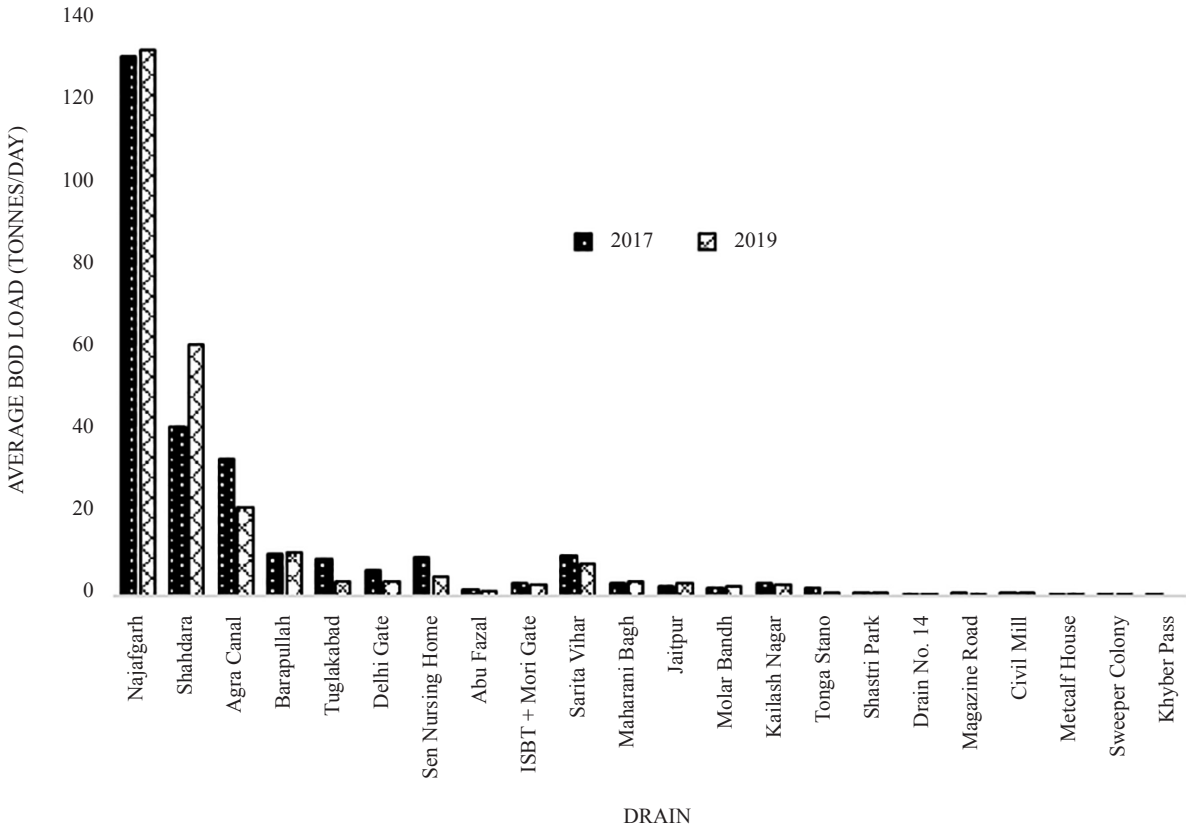

Figure 3. Wastewater Discharge into River Yamuna (2017-2019)

Table 2. Summary of Yamuna Action Plan timelines and investments

Description	YAP-I[23]	YAP-II[23]	YAP-III
Timeline	1993-2003	2003-2013	2012-till date
Total Cost (crore)	Rs. 682	Rs. 624	Rs. 1656
BOD load in Yamuna (tonnes/day)	260 (at end of YAP-I)	270 (in 2008)	264 (in 2019)
No. of schemes	269	32	8*
No. of towns/cities covered	15	2	1
States covered	Delhi, Uttar Pradesh, Haryana	Delhi, Uttar Pradesh	Delhi

*does not include schemes to promote plantation drives and awareness programs

4. Conclusion

The Yamuna Action Plan is a holistic approach formulated to mitigate water pollution from major urban areas into River Yamuna. The plan however is not targeted at other polluting activities such as industry, agriculture and livestock breeding. The YAP-III project focuses on the Delhi stretch of Yamuna to obtain quantifiable results in terms of the reduction in pollutant load reaching the river. The implementation of YAP-III is of importance both from the socio-economic and environmental points of view. Estimated yield from the project shall be in terms of: (1) The improved water quality and river ecology as well as reduction in pollutant load entering into River Yamuna in Delhi; (2) Construction of a new WWTP at Okhla with 124 MGD treatment capacity; (3) Upgrading and rehabilitation of Kondli and Rithala WWTP with a cumulative design capacity of 85 MGD; (4) Rehabilitation of sewers along Kondli catchment (15 km) and Rithala catchment (5 km); (5) Rehabilitation of along Kondli catchment (9.3 km) and Rithala catchment (12.4 km). Major projects such as the construction of a new WWTP at Okhla (124 MGD) can reduce the pollutant load by 283 kg/MGD of wastewater at a cost of Rs. 1161 crores while the rehabilitation project at Rithala (Phase I) can reduce the pollutant load by 92.5 kg/MGD wastewater at a cost of Rs. 300 crores. Therefore, projects should be evaluated in terms of cost-benefit analysis and, economic and environmental evaluation should be used as critical tools for effective action.

Conflict of interest statement

The authors declare no conflict of interest.

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