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RESEARCH ARTICLE

Urban Metabolism of River Yamuna in the National Capital Territory of Delhi, India.

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Abstract

Rivers are important source of available fresh water for majority of the world's population. However the scale and demands of urban growth, especially in developing countries, is now posing the single largest threat to river sustainability across the world. Similarly, rapid pace of urban growth of National Capital Territory (NCT) of Delhi is having deleterious impacts on the water quality of River Yamuna flowing through it. Repeated action plans for reclaiming the riverine ecology of River Yamuna have failed and the river has been reduced to a drain in Delhi. The present research contribution makes an interdisciplinary attempt at studying the impacts of the NCT of Delhi on River Yamuna through an urban metabolism perspective. The paper explores water volume exchanges, water quality modifications and riverfront interactions of River Yamuna with the Delhi city-state. We conclude by highlighting that the NCT of Delhi has high consumption of River Yamuna's ecosystem services and this needs to be urgently optimized for ensuring sustainable urban development of Delhi.

Introduction:-

Cities have long had an organic connection with the rivers along which they are located. Urban rivers are usually the principal source of fresh water for the respective cities and also provide the pathway for disposal of waste water. Developing a comprehensive understanding of the relationship between the city and its adjoining river can go a long way in urban water management (Barles, 2007). India's National Capital Territory (NCT) of Delhi is located along River Yamuna which is also the principal source of fresh water for the Delhi city-state. Delhi is the world's second largest urban agglomeration with a population of over 25 million people (UN, 2014). The water demand of Delhi, and the resultant release of waste water by the city has had an adverse impact on River Yamuna (CPCB, 2006). The water demand of Delhi far exceeds the water extracted from River Yamuna (Singh, 2011). Simultaneously, the waste water treatment capacity of Delhi is much less than the total waste water generated by the Delhi Urban Agglomeration (GNCTD, 2015). As a result, River Yamuna has been transformed into a drain in the city of Delhi. The complexity of the problem can be understood by the fact that implementation of two river cleaning action plans in the last two decades and have not been able to yield any significant results.

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The decade long Yamuna Action Plan (YAP Phase I) launched in April 1993 was sanctioned at a cost of 6.8 billion rupees. It completed all 269 schemes envisaged under it (MoEF, 2011). The full Sewage Treatment Plant (STPs) capacity of 752.25 million liters per day (MLD), sanctioned under the Plan, was also achieved (MoEF, 2011). Sharma et al. (2003) compared water samples from River Yamuna in Delhi and upstream of Delhi after analysing them for microbial load. River Yamuna showed a 100- to 1000-fold increase in the microbial load as it traversed through Delhi during the completion year of YAP Phase 1 (Sharma et al., 2003).

Sanctioning of the second phase of the YAP further questions the success of the Plan. YAP Phase II was launched in April 2003 with an estimated cost of 6.2 billion rupees (MoEF, 2011). Despite such expensive measures (adding to over 13 billion rupees) the Central Pollution Control Board of India conceded to the apex court in the country that the polluted stretch of River Yamuna increased from 500 km to 600 km since the year 2010 (Ramchandran, 2012). 80% of the total waste water load and pollution in River Yamuna is contributed by Delhi (CPCB, 2006).

It can therefore be concluded that direct river restoration plans are proving insufficient for reclaiming River Yamuna and a more holistic and in-depth approach needs to be explored. In fact, direct river restoration plans have failed to restore the ecological and hydrological characteristics of rivers across many urban areas (May, 2006). At the same time, conceptual and empirical research focusing on trans-disciplinary aspects of urban riverfronts is lacking (Pickett et al., 2011). Consequently, there is a need to develop an interdisciplinary approach towards ensuring more effective urban river management. Such an approach will have to dwell on the concepts of urban metabolism (Wolman, 1965), its evolving nature (Kennedy et al., 2007), urban hydrology (Niemczynowicz, 1999) and the political ecology of urban waterfront transformation (Gregory, 2006; Bunce and Densfor, 2007).

The following research contribution is an attempt at revisiting the pollution crisis of River Yamuna from an urban metabolism perspective. Our focus is to study the interaction of the urban course of River Yamuna with Delhi and lay the foundation of developing alternative models for restoring the river.

Study Area:-

The present study is focused on the urban segment of River Yamuna along the National Capital Territory (NCT) of Delhi. The NCT of Delhi has a Census population of 16.7 million (Census of India, 2011) while the population of the larger Delhi urban agglomeration is 25 million (UN, 2014). River Yamuna enters NCT of Delhi at a point close to Palla village (28°50'N, 77°12'E) and leaves Delhi 4 km downstream of the Okhla barrage near village Jaitpur (28°31'N, 77°20'E) (Fig. 1). The 48 km 'urban stretch' of River Yamuna constitutes the 'Delhi segment' of the river. The first 22 km course of River Yamuna in Delhi is without any major diversions or drains falling into it. The remaining 26 km of River Yamuna has three barrages constructed on it. These are the Wazirabad barrage (28°42'N, 77°13'E), the ITO barrage (28°37'N 77°15'E) and the Okhla barrage (28°32′N, 77°18'E).

Three prominent drains flow into River Yamuna in the lower 26 km stretch of the river in Delhi (cf. CPCB, 2006). These are the Najafgarh drain, the Barapulla drain and the Shahdara drain (Fig. 1). Two water channels meet River Yamuna in this stretch and augment the water flow. These are the Western Yamuna Canal (meets indirectly via Najafgarh drain) and Hindon Cut (Fig. 1) which bring fresh water through a diversion in River Yamuna upstream of Delhi and the Upper Ganga Canal respectively.

Urban metabolism and River Yamuna:-

The 'urban metabolism' metaphor was first put forward by Wolman (1965) and is defined as the sum total of technical and socio-economic processes that occur in cities, resulting in growth, production of energy and elimination of waste (Kennedy et al., 2007). The impact of urban metabolism of NCT of Delhi on River Yamuna has been conceptualized and analysed in this research contribution.

The urban metabolism of River Yamuna by NCT of Delhi is found to take place at three distinct levels. The first level involves volume exchanges and flow rate regulations through barrages and canals. At the second level, the impact is reflected in water quality of the river during its course in Delhi. A third level, now gaining prominence, is the transformation of urban riverfront in the NCT. The three levels at which the urban metabolism of Delhi impacts River Yamuna have been entitled: 1) water volume exchange, 2) water quality modification and 3) urban floodplain transformation. These are discussed below.

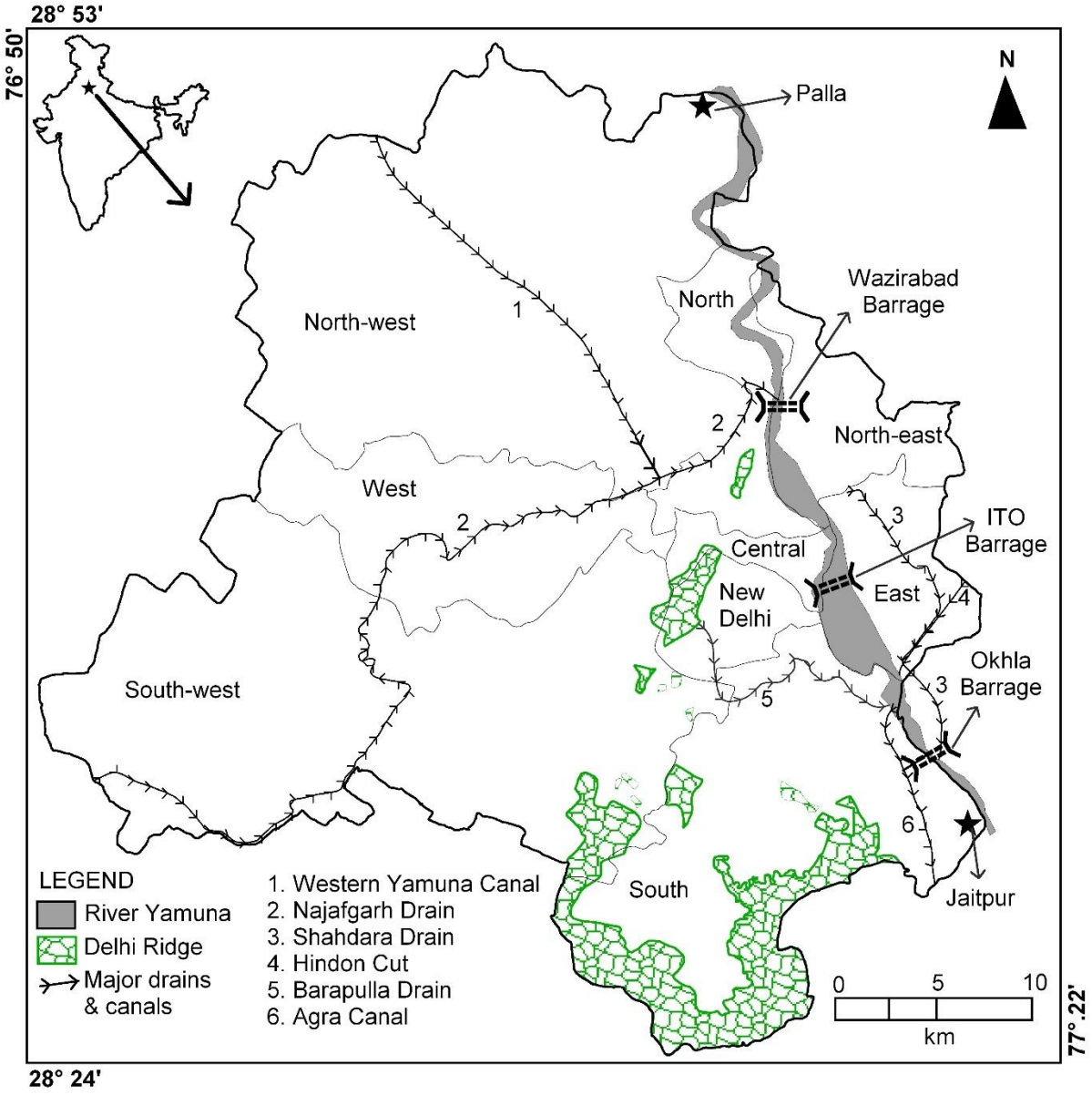

Figure. 1:- Map of National Capital Territory (NCT) of Delhi showing the major topographic features and the study area.

Water volume exchange:-

River Yamuna is the principal source of fresh water for NCT of Delhi. Delhi withdraws water from River Yamuna and also releases its waste water into the river. A detailed understanding of this water volume exchanges leads to alarming conclusions. River Yamuna enters NCT of Delhi near village Palla and flows undisturbed for approx. 22 km. This is the upper stretch of the river and there is no official water withdrawal from the river in this stretch.

The flow of River Yamuna is stopped at Wazirabad barrage, 22 km downstream of Palla. During peak summer season in Delhi there is very little, if any, water discharge from Wazirabad barrage (Manral et al, 2012). Water from the resultant 'Wazirabad pond' is diverted for treatment to the adjoining Haiderpur, Wazirabad and Chandrawal water treatment plants (WTPs). Water from Wazirabad pond and from other upstream sources is treated in these WTPs before supplying for meeting domestic and industrial water demand of Delhi. After fulfilling its utility value, the supplied water is released into the sewage network of Delhi as waste water. Over a dozen STPs have been set up across Delhi to treat this waste water.

The sewage system in Delhi is connected to the natural drainage system of the city and all the drains flow into River Yamuna. Consequently, River Yamuna receives treated, partially treated and untreated waste water from 22 prominent drains in Delhi downstream of the Wazirabad barrage. Among these, the Najafgarh drain is the largest and carries more than 60% of the total waste water flowing into River Yamuna. Interestingly, due to topography of Delhi, Najafgarh drain meets River Yamuna 0.5 km downstream of Wazirabad barrage and restores the flow of water in the river (Fig. 2).

The flow of River Yamuna is further regulated through ITO barrage and Okhla barrage. There are provisions of water withdrawal for requirement of powerhouse plants and agricultural activities taking place on river floodplain between Wazirabad and Okhla barrage. The Okhla barrage diverts water through the 'New Agra Canal' for meeting the water demand of downstream cities and towns. There is little water discharge from Okhla barrage and a part of its reservoir provides habitat to Okhla Bird Sanctuary. Water flow is restored in the river post Okhla barrage by the discharge of Shahdara drain.

Figure 2:- A satellite image showing the Wazirabad barrage and the 'confluence' of Najafgarh drain (entering from left of image) with River Yamuna. (Source: earth.google.com)

We therefore deduce that the 'environmental flow' of River Yamuna terminates at Wazirabad barrage. Further, despite stopping the entire flow of River Yamuna at the Wazirabad barrage, the city of Delhi is not able to meet its water demand. The water demand of the NCT of Delhi is about 1,100 million gallons per day (MGD) while the city administration is able to supply only 850 MGD (GNCTD, 2015; PIB, 2012). The resulting pressure on River Yamuna in its upper stretch in the city is therefore implicit. This raises serious questions about urban sustainability of the NCT of Delhi.

Water quality modification:-

The impaired water quality of River Yamuna in its lower stretch in Delhi does not require bio-physical analyses to be established. The foul smelling black water in this stretch of the river makes the impaired quality self-evident. Upadhyay et al. (2011) have pointed out three major reasons for poor water quality of River Yamuna in its lower stretch in Delhi: i) gap between sewage generation and treatment capacity; ii) improper allocation of sewage treatment plants (STPs); and iii) mixing of treated and raw sewage. The authors of this paper carried out a spatio-seasonal assessment of the physico-chemical characteristics of River Yamuna in Delhi. The results of this assessment are presented elsewhere (Singh, 2012).

The authors share the data of just one parameter (Dissolved Oxygen) here to present the scenario of water quality modification of River Yamuna in the NCT of Delhi. A total of eleven sites in River Yamuna were identified along its entire stretch in NCT of Delhi (Table 1). The site selection in River Yamuna had an internal bias and sites were selected based on location of barrages on the river and location of drains and canals meeting it (Fig. 3).

Three sites were selected upstream of Wazirabad barrage while eight sites were selected in the downstream. Of the latter, three sites each were selected between Wazirabad barrage and ITO barrage and between ITO barrage and Okhla barrage. The remaining two sites were selected downstream of Okhla barrage. One site in each of the three drains, viz. Supplementary drain, Barapulla drain and Shahdara drain was selected at a point 0.3 km before the respective drain meets the river.

The total length of the Najafgarh drain in Delhi is approx. 60 km because of which it has a larger basin area. Consequently, five equidistant sites were identified in the Najafgarh drain to develop a more detailed understanding of its pollution load. In addition to this, one site each in Western Yamuna Canal (0.3 km before it meets Najafgarh drain), Hindon Cut (0.3 km before it meets River Yamuna) and New Agra Canal (0.3 km downstream from Okhla barrage) was also selected (Fig. 3).

Sampling was done during two seasons: wet (Jul-Aug 2008) and dry (Dec-Jan, 2008-09) and samples were collected from perpendicular distance of 10 meters from each bank for each site at a depth of 20 cm. An integrated sample was prepared from these two samples at each sampling location. Similar strategy was followed for drains and other surface water channels except in case of Western Yamuna Canal and New Agra Canal. Water samples in these two canals were collected from a central point between the two banks. Water samples were tested for Dissolved Oxygen (D.O.) and temperature *in situ* using multi-parametric portable instrument (Cyber Scan Waterproof PD 650).

Table 1:- Location of sampling sites of the present study.

S.No.	Site ID	Description	Longitude (E)	Latitude (N)
1	**Y01**	River Yamuna at Palla	77° 12' 58"	28° 50' 36"
2	**Y02**	R. Yamuna close to Buradi	77° 12' 52"	28° 46' 22"
3	**Y03**	R. Yamuna Pre-Wazirabad	77° 14' 13"	28° 42' 45"
4	**Y04**	R. Yamuna Post-Wazirabad	77° 13' 57"	28° 42' 43"
5	**Y05**	R. Yamuna Post-Najafgarh Drain	77° 14' 2"	28° 42' 14"
6	**Y06**	R. Yamuna Pre-IP Barrage	77° 15' 39"	28° 37' 55"
7	**Y07**	R. Yamuna Post-IP Barrage	77° 15' 16"	28° 37' 38"
8	**Y08**	R. Yamuna Pre-Barapulla Drain	77° 16' 20"	28° 35' 22"
9	**Y09**	R. Yamuna Post-Barapulla Drain	77° 17' 44"	28° 34' 4"
10	**Y10**	R. Yamuna Post-Okhla Barrage	77° 18' 49"	28° 32' 40"
11	**Y11**	R. Yamuna Post-Shahdara Drain	77° 19' 13"	28° 32' 44"
12	**D1**	Najafgarh Drain at Dhansa	76° 52' 13"	28° 32' 7"
13	**D2**	Najafgarh Drain at Bagdosra	76° 59' 18"	28° 31' 33"
14	**D3**	Najafgarh Drain at Nangli	77° 1' 21"	28° 37' 24"
15	**D4**	Najafgarh Drain at Inderlok	77° 10' 31"	28° 40' 41"
16	**D5**	Supplementary Drain	77° 13' 24"	28° 43' 19"
17	**D6**	Najafgarh Drain at Wazirabad	77° 13' 41"	28° 42' 33"
18	**D7**	Barapulla Drain	77° 14' 57"	28° 35' 14"
19	**D8**	Shahdara Drain	77° 19' 18"	28° 33' 32"
20	**WYC**	Western Yamuna Canal	77° 9' 60"	28° 40' 52"
21	**HC**	Hindon Cut	77° 18' 7''	28° 35' 21"
22	**NAC**	New Agra Canal	77° 18' 44"	28° 32' 43"

The water quality criterion for rivers in India is based on 4-8 biological and physicochemical parameters (Table 2). Since D.O. is a limiting factor in the present datasets, analysis of D.O. in visibly polluted water of River Yamuna in

Delhi is adequate for criteria determination. D.O. is thus being used as the key parameter in understanding the impact of urban metabolism on water quality of River Yamuna.

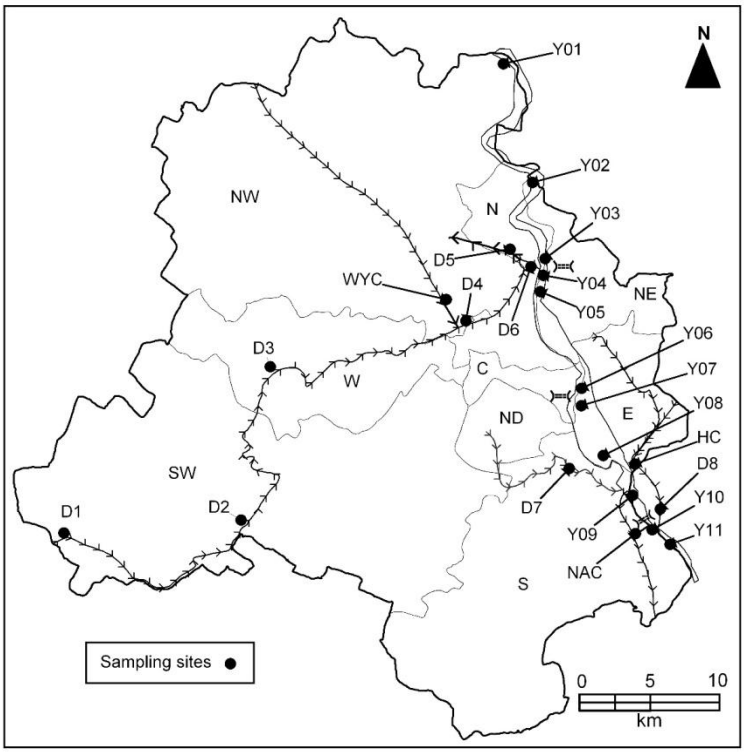

Figure 3:- Map of NCT of Delhi showing sampling sites of the present study.

Table 2:- Water quality criteria for designated best use of surface water in India (Source: CPCB, 2008).

Designated-Best-Use	**Class of Water**	**Criteria**
Drinking Water Source without conventional treatment but after disinfection	**A**	Total Coliforms Organism MPN/100ml shall be 50 or less pH between 6.5 and 8.5 **Dissolved Oxygen 6mg/l or more** Biochemical Oxygen Demand 5 days 20°C 2mg/l or less
Outdoor bathing (Organised)	**B**	Total Coliforms Organism MPN/100ml shall be 500 or less pH between 6.5 and 8.5 **Dissolved Oxygen 5mg/l or more** Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Drinking water source after conventional treatment and disinfection	**C**	Total Coliforms Organism MPN/100ml shall be 5000 or less pH between 6 to 9 **Dissolved Oxygen 4mg/l or more** Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Propagation of Wild life and Fisheries	**D**	pH between 6.5 to 8.5 **Dissolved Oxygen 4mg/l or more** Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	**E**	pH between 6.0 to 8.5 Electrical Conductivity at 25°C micro mhos/cm Max.2250 Sodium absorption Ratio Max. 26 Boron Max. 2mg/l
	Below-E	Not Meeting A, B, C, D & E Criteria

Analysis of Dissolved Oxygen (D.O.) concentration establishes the water quality in the upper stretch (upstream of Wazirabad barrage) to be closest to 'A' class (drinking water source after disinfection) and in the lower stretch (downstream of Wazirabad barrage) to be closest to 'E' or 'Below E' class (to be used only for irrigation, industrial cooling, and controlled waste disposal (Fig. 4). D.O. concentration in the Najafgarh drain reduces considerably in both wet and dry season as it nears River Yamuna. D.O concentration of at least 4.0 mg/l is considered essential for the survival of any kind of macroscopic aquatic life. Decreased D.O. levels is an indicative of excessive amount of biological oxygen demand and presence of pollution. No visible vegetation was observed in either the lower stretch of River Yamuna or the drains adjoining it during the field sampling. It can therefore be deduced that with respect to the A-E water quality categorization (Table 2), River Yamuna is completely consumed during its flow in Delhi during both the dry and wet seasons.

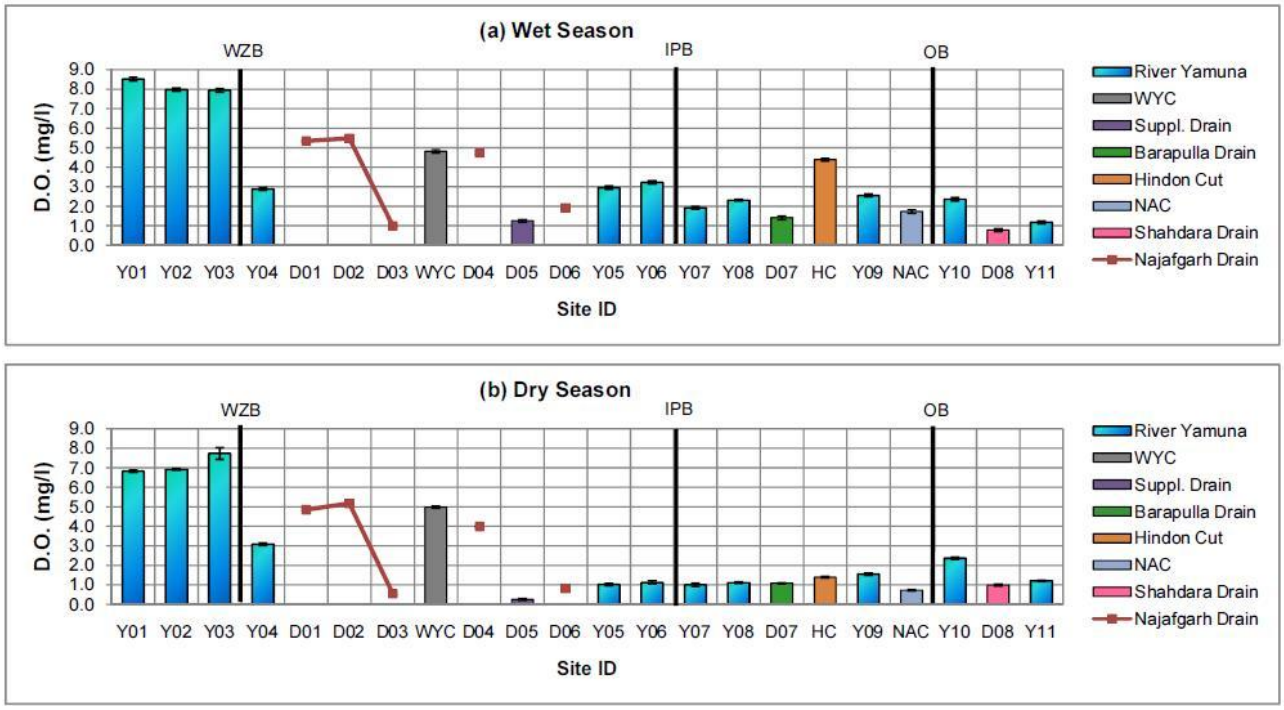

Figure 4:- Dissolved Oxygen concentration in River Yamuna and adjoining water channels during (a) wet season and (b) dry season (WZB – Wazirabad barrage; IPB – ITO barrage; OB – Okhla barrage).

Urban floodplain transformation:-

The urban floodplain of River Yamuna in the NCT of Delhi is highly competitive due to its real estate value. The floodplain in Delhi is delimited by surface and elevated roads running parallel to the river. A field survey with a GPS (Garmin eTrex) was carried out in the entire urban course of River Yamuna in Delhi during April 2011. Two field expeditions, one on left bank and the other on the right bank of River Yamuna were made to outline the expanse of the floodplain. The presence of any continuous concrete structure (road and building) was considered the limit of the floodplain. Farm land and temporary structures were included within the floodplain area.

The spatial data was validated with toposheets obtained from the Geological Survey of India using MapInfo v. 10. Data on modifications of land-use of floodplain area was also collected from land owning agencies in Delhi. The floodplain of River Yamuna in Delhi was subsequently outlined (Fig. 5). The course of River Yamuna was included in the floodplain area to facilitate better understanding of the impact of urban metabolism on River Yamuna.

The total area of urban floodplain of River Yamuna in Delhi is estimated to be 83 sq. km. Since some discontinuous structures have been ruled out in the calculation, the actual area figure may be less than this. While it is not the scope of this research contribution to carry out a temporal change analysis, this figure is in contrast to the previously reported 97 sq. km floodplain area in Delhi (NCRPB, 2009). The maximum width of the floodplain (perpendicular drawn from the course of the river on either side including the course of the river) upstream of Wazirabad barrage is 3.7 km while the minimum width of only 1 km was noted downstream of Wazirabad barrage.

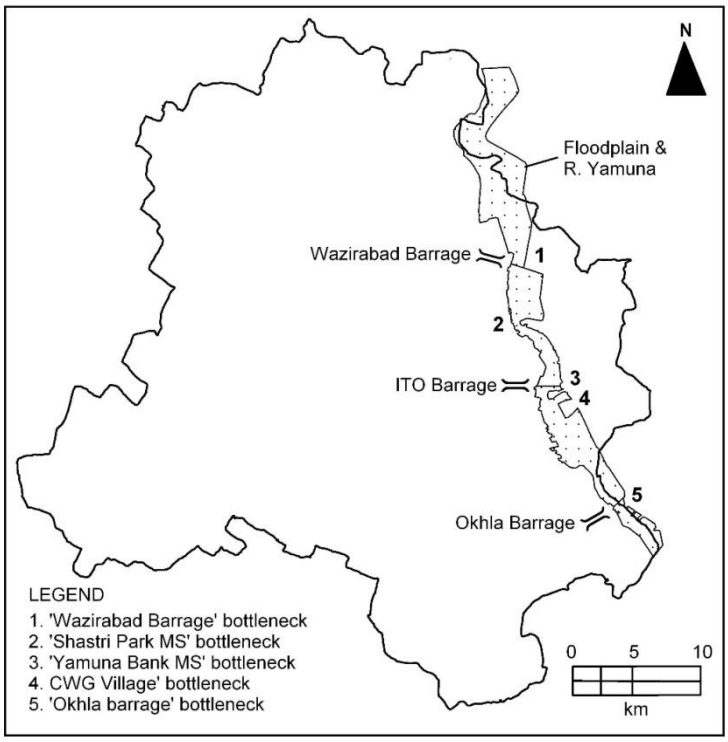

Figure 5:-Map showing geographic expanse of River Yamuna and its floodplain along with river bottlenecks in the NCT of Delhi

While River Yamuna has adequate floodplain area upstream of the Wazirabad barrage, it is severely bottlenecked at five locations downstream of Wazirabad barrage. These locations have been identified to be Wazirabad barrage, Shastri Park Metro station, Yamuna Bank Metro station, CWG Village and Okhla barrage (Fig. 5). The Wazirabad barrage and Okhla barrage bottlenecks do not pose significant threat since they are regulated through barrages. The width of the floodplain (including the course of the river) is reduced to less than 1 km at Shastri Park Metro Station (0.56 km) and Yamuna Bank Metro Station (0.57 km) bottlenecks. The presence of concretized urban infrastructure in the immediate vicinity of these two bottlenecks increases the vulnerability of NCT Delhi to flood hazard. The flood warning level of River Yamuna in Delhi is 204.0 m. while the flood danger level is 204.83 m. River Yamuna has crossed the warning level 14 times and the danger level 11 times in the 15 year time period between 1997 and 2011. Consequently, areas and buildings around these two bottlenecks need to be prepared for flood events. Urban infrastructures (like CWG village) immediately downstream of the Yamuna Bank Metro station bottleneck are also highly vulnerable to flooding events. The floodplain notes another emerging bottleneck of 0.5 km (perpendicular width) post the Okhla barrage. The urban floodplain transformation in Delhi is thus leading to a reduction in the active floodplain area of River Yamuna. The urban metabolism of Delhi has therefore not just consumed the entire flow of River Yamuna but also the active floodplain area around it.

Conclusion:-

The growth and development of the National Capital Territory (NCT) of Delhi is consuming River Yamuna at an alarming rate. There is 100% consumption of water flow and water quality of River Yamuna as it passes through the NCT of Delhi. The rapid and seemingly unplanned growth of the NCT of Delhi is now also consuming the floodplain of River Yamuna at a high rate. There is thus an urgent need for revisiting the vision and planning of the city-state of Delhi. Simultaneously, there is an urgent need to regulate population growth in Delhi and check the increasing water demand of the city. Provisions need to be made to ensure zero flow of untreated and partially treated waste water into River Yamuna. The latter is both urgent and important since the flow of River Yamuna downstream of Wazirabad barrage is maintained through the discharge of drains carrying waste water.

Urban floodplain transformation in Delhi is leading to a decrease in the total active floodplain area of River Yamuna. The primary role of a floodplain is to act as a buffer against flooding. The floodplain in Delhi also provides the regulating ecosystem service of recharging the ground water. The NCT of Delhi witnesses acute water

shortage most of the year and flood situation during monsoon. Decrease in the floodplain area and its constrictions along the course of the river have therefore increased the vulnerability of Delhi to water scarcity and flooding. Two Metro stations located on the floodplain and the residential colonies created in the Commonwealth Games Village in Delhi are found to be most prone to flooding. The floodplain in Delhi should not be exploited as real estate but instead must be developed as wetland reservoirs for storing surface and ground water and for flood prevention.

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