Variable flow regimes and their role in diversity of habitats and fish community structure in a tropical river

A Summary submitted to the
Babasaheb Bhimrao Ambedkar University, Lucknow
in fulfilment of Requirement for the Award of Degree of

Doctor of Philosophy

in Environmental Science

BY

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Enrolment No. 1124/15

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2023

The tropical rivers bring sufficient water for their healthy functioning and for catering to the needs of the instream and off-stream flora and fauna. However, the water abstracted for human needs leaves the river with less water in the main channel. Often, this water is not enough to sustain its longevity and endemic biodiversity. The longitudinal, lateral, and vertical connectivity over the temporal scale should be maintained in these running water bodies. However, sometimes one or two or sometimes all of the flow regime components are compromised due to excessive withdrawal of water for human needs. The demand for electricity is met by hydroelectricity which is generated by damming the river and storing its water in a reservoir. The rivers sometimes lose their longitudinal connectivity and become intermittent, exposing the bed which kills the flora and fauna thriving in it. Sometimes, intermittency leaves the entire river segment into small ponds isolating the native biodiversity in a few fragmented pockets. When the flow is re-established by the rainfall or releasing water from dams then these species are able to regain access to their habitats.

Water abstraction, diversion, and management schemes in order to store water for agricultural irrigation, hydroelectric energy production, industrial purposes, and various other commercial and domestic purposes have jeopardized aquatic ecosystems and aquatic organisms dwelling in these environments throughout the world. Yet, the impacts of these alterations on aquatic biodiversity in monsoon and glacial-dominated riverine ecosystems are not much known, particularly in India.

In this study, the variable flow regimes of the Ramganga River were identified and their role in habitat formation and fish diversity was investigated. Ramganga river is the first left-bank tributary of the Ganga River. While hydropower generation is thought to be vital to meet India's energy needs, traditional hydropower projects frequently compromise a river's intrinsic integrity, as demonstrated in the current study. There are a lot of water fragmentation, diversion, and abstraction structures on the Ramganga River. The Kalagarh Reservoir stores 2050 MCM of water at 75% dependability. A discharge of 226 cumecs is required for the production of 198 MW of hydroelectricity for the state of Uttarakhand, though when the water demand for irrigation increases to more than 30 cumecs, the water is released downstream. The water abstracted from the

Ramganga river at Afzalgarh is 73.3 MCM which is diverted through the Phika Feeder canal for irrigational purposes. About 1600 MCM of water is abstracted at the Hareoli Barrage and diverted through the 82 km long Ramganga Feeder into the Ganga River at Garmukhteshwar. Ramganga's water from the Kalagarh Dam contributes a lot to the farm economy in the basin and outside of it. However, there is insufficient water downstream of Hareoli Barrage from November to June deteriorating the river's health. Ramganga river also faces sewage and industrial pollution from Kashipur, Moradabad, and Bareilly districts. The over-exploitation of groundwater and wetland degradation in the basin leads to reduced recharge and base flows. Ramganga River contributes a significant amount of water to the Ganga River after merging with the Ganga main channel. Ramganga restores its health to a greater extent which is evident from the fact that Dabri is a favorable habitat for some of the native aquatic species of Ramganga. If adequate flows are maintained, the Ramganga River can transform into a breeding habitat for a variety of aquatic organisms during the deficient flow seasons.

Variable Flow Regimes of the Ramganga River Based on Long-term Flow Data at the Upper, Middle, and Lower Stretches

Riverine ecosystems can't survive with a fixed and pre-determined flow of water. Sometimes the rivers require high flows for the lateral connectivity of the river to the floodplains to provide nutrients to the floodplain communities of plants whereas sometimes it requires lean flows for longitudinal connectivity and to eradicate the invasive species from the main channel as only the endemic species can survive to the natural variable flows. A certain amount of fixed discharge should not be present throughout the year. Hence, variable flow regimes in the river stream must be maintained. It's essential to understand the importance of variable flow in the river stream based on different characteristics before recommending e-flows for the river stream. All the places or districts falling beside the river is important, however, we could not get the long-term flow data of all the districts. Therefore, it became imperative to identify such sites from which we can get daily water discharge and water level data. Although 4 sites were selected for water, fish, and sediment sampling, we could get daily discharge and water level data of only 3 sites or districts i.e., Katghar in Moradabad, Chaubari in Bareilly, and Dabri in Shahjahanpur, as the CWC GDSQ gauging sites are located at these places only.

Various hydrological indices of the Ramganga river like MAF, Low-flow-High flow range, HVI, Number of low-flow, high-flow, and intermediate-flow months, Baseflows, and BFI have been calculated based on long-term discharge data Moradabad, Bareilly, and Shahjahanpur districts. The MAF, Baseflows, and BFI are the highest at Dabri and lowest at Moradabad. However, the HVI is the highest in Moradabad signifying that the flows at this place are highly variable as this site is just downstream of the major obstructions like Hareoli Barrage. Again, while estimating the FDC across the sites, the Q25-Q100 values were highest at Dabri followed by Bareilly and Moradabad. At Q90, the discharge at Moradabad is 3.96 cumecs whereas at Bareilly it is 17.58 cumecs and at Dabri, it is 43.21 cumecs. The reason behind elevated levels of flow volume, baseflows, BFI, and FDCs at Dabri is that the number of drains and tributaries contributing to the main channel is higher at Dabri than at Moradabad or Bareilly. Moradabad is immediately below the major obstructions like Kalagarh Dam, Afzalgarh, and Hareoli barrages where most of the water has been abstracted leaving very low flow in the main channel. Katghar is the site in the plains where the number of tributaries contributing water to the main channel is high, however, their length is quite small (less than 50 Km) other than the Phika River (65.92 Km) and Khoh River (102.37 Km). This means that the amount of water brought by these tributaries and drains to the main channel is quite less at Katghar. As it moves further downstream from Moradabad the number of drains and tributaries like the Dhela River, Gangan River, Kosi River and Siddha Nadi join the main channel and amplify the volume of water in the Ramganga River, hence the discharge at Bareilly is greater than at Moradabad. The Ramganga River further receives water from the Nakatiya River, Aril River, and Baigul River, contributing a significant quantity of flow volumes to the Ramganga River at Dabri. Hence, the Q25-Q100 values of the Dabri site are higher than the other sites.

Baseflows or low flows form an important part of available waters, especially towards the lower reaches of the watershed as they are the flows sustaining over a prolonged period of time. The higher the BFI, the more contribution of baseflows to the river discharges is more and vice-versa. The BFI of all three sites i.e., Moradabad, Bareilly, and Dabri have been calculated using the local minimum, fixed interval, and sliding interval methods. The BFI calculated from the local minimum method gives the lowest baseflows and the sliding interval method gives the highest baseflows. The Baseflows

calculated through the sliding interval method, at Moradabad, Bareilly, and Dabri are 39.84, 180.81, and 241.60 cumecs whereas the BFI are 0.88, 0.94, and 0.96 respectively. The baseflow and BFI at Moradabad are less in comparison to Bareilly and Dabri. The GW aquifers contribute to the baseflows of the river. The GW levels at Moradabad lie between 5-8 mbgl to 8-12 mbgl, at Bareilly between 5-8 mbgl and 8-12 mbgl. The reduced GW level at Moradabad and Bareilly is due to the tremendous pressure on the GW aquifers for irrigational and industrial purposes. Nowadays, we cannot neglect the pressure created by submersibles in the domestic household. All these activities create a coupled pressure on the GW which in turn affects the baseflow contribution to the river in that particular region. The GW level at the Dabri site lies between 3-5 mbgl and 5-8 mbgl. Hence, the baseflow contribution to the river at Dabri is the highest i.e., 241.60 cumecs. The habitat-forming potential of the sites is reduced due to the lower water discharge and water level.

The cross-section analysis reveals that the upstream section in Moradabad is narrower and deeper in comparison to the downstream regions at Bareilly and Dabri cross-sections. The upstream region is narrow and deep because the water flows with a good velocity and cuts the valley interfluve region in Moradabad. As the river progresses further downstream at Chaubari, the channel becomes wider and wider and the depth decreases because of sediment deposition. As the river progresses towards Dabri, the velocity decreases and it starts depositing the sediment load brought by it in the floodplains, the channel width widens when the river is about to confluence with the main channel of the Ganga. These areas are good nursery grounds for the fishes as the sediments bring vital minerals and create good habitat grounds for fishes.

The hydrographs obtained by using the allocated E-flows through various hydrological methods suggest that the Tessman method gives the highest flows for each month followed by VMF, Tennant, Q90-Q50, and Smakhtin method. Among these, the Tessman method and VMF method recommend EF for three flow types whereas the other three recommend flows for only two flow types. During the monsoon season, when a flushing flow of 200% is required to flush away the impurities and pollutants in order to clean the river, these hydrological methods are recommending a very low amount of flow. During the lean flow season, when some amount of water is required to maintain the longitudinal connectivity and integrity of the river, at that time, flows as low as 1.54 cumecs have been suggested by the VMF method at the Moradabad site

during 2008. Tessman allocates 100% of MMF as LFR. This seems to be practically unfeasible as the water required for agricultural, industrial, and some other important activities could not be fulfilled. VMF method is fairly good considering the variability of flows across the year. However, it does not mimic the natural E-flow allocation. Both the Tessman and VMF methods consider the flow variability by dividing the year into 3 flow types i.e., low, intermediate, and high flows. However, all these methods fail to consider the natural flow variability also encompasses the overbank flows, flushing flows, and some moderate flow pulses which are required for maintaining the lateral connectivity to the floodplains, removing the pollutants from the channel, and maintaining a corridor between the floodplain and the main-channel. The hydrological methods fail to consider the inter-annual flow variability and dedicated uses while allocating the e-flows. The GEFC recommended EF in percentage based on MAR. The 'Natural' EMCs recommended elevated levels of flow in the river which is technically unfeasible as it doesn't consider the other water-utilizing activities like irrigation, domestic or industrial uses, or hydroelectric production, hence, 'Natural' EMCs were not considered for e-flows allocation. However, the 'Slightly Modified category' is considered as it recommends a decent level of flow despite water resource development and basin modifications at each site.

Habitat Types with Different Flow Regimes of the Ramganga River

The variable flows help in maintaining diverse habitat types required by organisms for their survival and growth. The flow and water level in the Ramganga River are comparatively better at Agwanpur than at Katghar. The left side of the river bank is low lying and the channel is unstable as the banks are muddy. The importance of this site lies in the fact that the river appears to be clean and it lies upstream of Katghar which is in Moradabad city where the river faces severe pollution from heterogenous pollution sources. The riffles were not found at this site, however, there were deep pools where adults of *Wallago attu, Xenentodon cancila, Heteropneutes fossilis, and Mystus bleekri* were found. This site doesn't have any connected backwaters or connected ditches. An extensive vegetated mid-channel bar and sidebars were visible at this site indicating that the depositional phase of the river has begun. The channel was wide having a vegetated bank, thus indicating the good health of the river at this site. Agwanpur area has extensive low-lying floodplain areas where vegetation like cucurbitaceous crops is sown which utilizes the vital nutrients brought by the river from the hills. During

monsoons, lateral connectivity is maintained as the river gets overbank flows and the banks are flooded majorly on the left side. An extensive floodplain having riparian vegetation is also found at this site thus indicating the floodplain and bank stability. As the banks are highly fertile, agriculture is practiced in this area.

Katghar stretch is dominated by elongated bars, including side and mid-channel bars. The channel beds are made up of fine to very fine sand, and the banks are made up of silt and clay. Both the bed and the bank material are made of fine-grained sediments. The cross-section analysis reveals that the landscape setting is valley interfluve of this region. The channel is straight with a very wide floodplain on the left bank. The wetted perimeter of the channel is very low. The instream habitat like deep pools and run is present at this stretch where species like *Cyprinus carpio*, *Punctius chola, Punctius sophore*, etc were found. However, the available volume of water is not good considering the habitat variability because the other habitat types like the backwaters, connected ditches, vegetated banks, etc. were not reported. Hence, this place does not have habitat heterogeneity. Though some good fish species are found in the pools, however, due to the detrimental activities on the river bank, and sand mining this site is not good for supporting a rich diversity.

The discharge volume as well as the velocity of water was quite good at Bareilly. The diverse instream natural habitats like pools, run, and riffles were found in abundance in the river. In addition, the backwaters, grassed banks, and shallow connected ditches were also present where rich fish diversity was found in these vital habitats. The floodplain is quite wide at Chaubari and a good amount of water discharge has created wonderful habitats for the fish species. The term ‘habitat heterogeneity’ is very well defined by Chaubari. Fish with less diversified diets predominate in riffles, whereas the increased variety of food items available in pools support communities composed of more generalist species. Lengthy sidebars, mid-channel bars, and point bars were the primary geomorphological structures found in this stretch. Due to the formation of sand bars in the middle of the channel near Chaubari, the river's main channel has been fragmented. The predominant substratum composition is one of clay and silt.

The water velocity and discharge over here are quite good, therefore, the habitat diversity is good at this place. The landscape of this region is valley interfluve but the channel is quite wide. Open rivers, vegetated banks, and backwaters are some of the

diverse habitats that support good ichthyofaunal diversity found in Dabri. The stretch, which is typically vegetated, has extensive sidebars comprised of sand and large mid-channel bars. The floodplain zones in the Dabri stretch are very vast having good vegetation.

The reproduction of many species depends on the seasonal inundation of floodplain habitats. Off-channel habitats like backwaters and shallow connected ditches serve as nursery and spawning sites for many fish species because they offer an active refuge from fast water velocity and are seasonally inundated. In times of flooding, off-channel habitats may offer refuge from the lower main channel temperatures. The river floodplains and off-channel habitats act as fish breeding sites. However, the constructions like dams, barrages, and weirs on big rivers for flood control, navigation, and energy generation have altered natural flow regimes. Kalagarh Dam, Afzalgarh and Hareoli barrages have caused habitat degradation and loss, altered habitat connectivity, and reduced reproductive success for many fishes. Ramganga River is a large river having its own distinct ecosystems that make up a diversity of habitats from various flow types like the flushing flows, and overbank flows establishing a lateral connection and helping in the formation of backwaters and ditches for sustaining its endemic diversity. This study of habitat identification will be useful for the Chaubari site in Bareilly as it can serve as baseline information after the new barrage that is under construction under the Badaun Irrigation Scheme has been built on the Ramganga River. This study will serve as a reference for pre-damming and post-damming studies in the future.

Sediment Profile of the Surface Bed Material at the Upper, Middle, and Lower Stretches Across the Channel and its Relation to Flow Events

On analyzing the 10-year annual variation of water discharge of Ramganga River at the sites of Bareilly and Dabri from 2008 to 2018, it is discerned that every year, Dabri's water discharge is higher than Bareilly's because Bareilly is located relatively upstream at an elevation of 268 amsl. The water discharge across all the months shows that during the monsoon months, the discharge is higher during the months of August and September. Ramganga River has 187.95 cumecs of annual water discharge at Bareilly, however, it has 252.50 cumecs of annual water discharge downstream at Dabri. This shift can be attributed to an increase in the tributaries of the Ramganga River up to

Dabri relative to Bareilly. Two tributaries, Baigul and Bhakra, enter the Ramganga River between the towns of Bareilly and Dabri, which causes a greater water flow downstream. The change in water discharge over the course of the year reveals that there is a consistent and significant water discharge during the non-monsoon months, but at a lesser rate than during the monsoon months. It is evident that Ramganga is a glacially fed perennial river that flows continuously throughout the year. Agriculture, inter-basin water transfer programs, and irrigation have become the most significant for seasonal variations in water discharge into the ocean. Being a perennial river, Ramganga's water flow is influenced by snowmelt and rainfall in the catchment area. As a result, the river's water flow and sediment discharge are influenced by the monsoon season. During the monsoon season, the river moves 70% of the annual sediment load.

The SEM-EDS study revealed that Oxygen, Silicon, Iron, and Aluminium were abundant (89.83%) in the sediments of Agwanpur whereas in the Katghar sediment, oxygen, silicon, aluminium, and iron were present. Though, Titanium was also present in the sediments of Katghar which reveals anthropogenic activities in and around this area as it comes from paint pigments as TiO_2 accounts for the largest use of the element. Oxygen, silicon, Potassium, aluminium, and iron were present in Bareilly samples. Whereas oxygen and silicon were abundant in the sediments of Dabri. SEM-EDS spectra revealed that all the sediment samples had aluminium and silicon though in varying quantities because the alumino-silicate mineral is a basic component of sediment.

The FTIR spectra gave bands between 400-4000 cm^{-1} and quartz is one of the non-clay minerals which is present in almost all the samples. The presence of quartz in the samples can be explained by Si-O asymmetrical bending vibrations, and Si-O symmetrical bending vibrations, at around 464-468 cm^{-1} and 690-696 cm^{-1} respectively. The minerals like quartz, orthoclase feldspar, calcite, kaolinite, haematite, smectite, cerussite, organic carbon, carbonates, and pyrophanite were identified with their respective wave numbers. These reveals that basic earth minerals are variably present in all the samples collected from all the four sites.

The obtained diffractogram through the XRD analysis shows more or less similar peaks of the minerals present in the sediment samples. The weathering of the mountainous rocks by the kinetic force of the gushing river brought the sediments to the plains areas

as sediment load. The underlying weathered rocks were the same, therefore, the mineral obtained are also the same. There are slight differences among the sites, however, no major variations were seen. The slight variation could be attributed to the fact that the big tributaries like Dhela, Gangan, Kosi, Aril, East Baigul coming from different places and geology bring their own sediment load. The peaks obtained in the diffractogram through XRD are sharp denoting its crystalline nature. The major minerals like quartz, kaolinite, and microcline feldspar are invariably present though in different amounts among all the sediment samples.

Physicochemical Characterization of the Water at the Upper, Middle, and Lower Stretches during Variable Flow Events that Influence the Fish Habitat

pH was high at Agwanpur, Katghar, and Dabri sites whereas it was always lower at Bareilly. The Katghar site reported the least DO concentration in all three samplings. This is because this site receives anthropogenic pollution from the point as well as non-point sources. Industrial, domestic, and municipal are the main reasons behind the low DO concentration at Katghar. Bareilly has an ample concentration of DO as it receives comparatively less pollution from the adjoining areas. Katghar has the highest concentration of most of the pollutants because it receives pollutants from heterogenous pollution sources. Dumping of solid as well as liquid wastes, burning and washing of electronic waste, sewage, as well as industrial discharge and washing as well as dyeing of clothes, are some of the reasons behind the elevated pollution levels in Katghar. The dendrogram of 2019 and 2020 list Agwanpur and Dabri in one cluster representing moderate pollution level and Bareilly in a different cluster however, closer to Agwanpur and Dabri indicating the water quality of these three sites have more or less the same water quality status. Katghar forms a different cluster indicating a distinct water quality status than the other three sites because of the heavy pollution received by this site. The dendrogram of 2021 represents cluster 1 with moderate pollution levels at Agwanpur and Bareilly, Cluster 2 having Dabri represents a comparatively higher pollution level than cluster 1 and Cluster 3 represents the highest polluted site i.e., Katghar. In the three dendrograms, it is seen that Katghar always stands out and forms a different cluster as the pollution at this place is concentrated as it receives domestic, industrial as well as municipal pollution from the adjoining areas and the slums located beside the river banks.

Karl Pearson's Correlation Matrix was used to measure the interrelation and degree of associations among the variables. The negative relation of pH with DO in 2019, 2020 and 2021 indicated that DO levels decrease due to increasing levels of pH, thus inhibiting aquatic life that keeps dissolved oxygen levels high. TDS and EC have a positive relationship because dissolved ionic species affect the conductance of electric current. Therefore, high EC concentration and high TDS are correlated. DO showed a strong negative correlation with BOD and COD which signifies that DO decreases with an increase in BOD and COD as DO has an inverse relation with both BOD and COD. SO4 and PO4 show positive relation with COD that indicates that the source of these parameters is the same as untreated domestic sewage, pisciculture effluents, and agricultural runoff were the main pollution sources for these parameters. Pb showed a positive correlation with Cd, Ni, Zn, Cu and Cr which may be caused by waste leachates from automotive batteries, electronics, tyres, petrochemicals and paints. Cd had a strong relationship with Pb, while Ni, Zn, Cu, and Cr are indicative of industrial effluents coming from the manufacturing of corrosion inhibitors and pigments, which may be detrimental to aquatic life. The high positive correlation coefficients among most of the metals imply that they have analogous input sources and geochemical features. The weighted arithmetic WQI method was used for WQI calculation of all the sites. 'Excellent' and 'Good' water quality is not reported at any location during any of the samplings. Katghar WQI fell into the 'Unfit for consumption' category during all the samplings. The WQI at Agwanpur fell under the 'Poor' category in two samplings and only once in the 'Very Poor' category.

Upstream of Kalagarh Dam, the Ramganga River is a vital natural water resource that the locals use for domestic water requirements, however, downstream of the dam, the communities refrain themselves from using its water due to water quality issues. There are an estimated 35,000 industries, along the Ramganga River and its major tributaries' banks. The majority of these units are situated in Uttar Pradesh (Moradabad, Rampur, and Bareilly), while the remaining are mostly located in the industrial hubs of Uttarakhand (Kashipur and Uddham Singh Nagar). Paper & pulp, metal products, sugar, and distilleries are the main polluting industries. The industries though don't divert the water of the Ramganga, but industrial activities across its stretch from downstream of Moradabad severely impact the health of the river as effluents (untreated or partially treated) are dumped into the river and its tributaries (Dehla, Gangan, Kosi

and Aril). The anthropogenic activities particularly sand-mining, washing and dyeing of clothes, dumping of solid and liquid wastes, and burning and washing of electronic waste are dominant over here including direct discharge of domestic, and industrial discharge in the main channel.

Macrophytes in the Riverine Environment and Their Role in Fish Habitat Formation vis-à-vis Flow Regimes

Aquatic macrophytes are used by freshwater fish for spawning, nesting, and nursery grounds as well as for protection from predators, a refuge from the elements, and a direct or indirect source of food in the form of periphyton and associated invertebrates. The presence of aquatic macrophytes may improve water quality because of their capacity to absorb excess amounts of nutrients, making them effective indicators of water quality. At Agwanpur (upstream), various species of free-floating macrophytes like *Azolla pinnata, Eichhornia crassipes, Pistia stratoides, Ceratophyllum demersum,* completely submerged species like *Vallisneria spiralis,* submerged macrophytes like *Aponogeton natans* and filamentous type green algae, are some of the species reported at this place. Katghar, however, has only the water hyacinth i.e., *Eichhornia crassipes,* and some filamentous green algae. This place receives domestic as well as municipal wastewater, hence the nutritional requirement of the algae is met giving rise to excessive algal growth. Bareilly had a good macrophytic diversity from free floating *Eichhornia crassipes* to submerged *Hydrilla verticillate*, *Vallisneria spiralis* and emergent macrophytes like *Typha angustata.* These macrophytes support good aquatic diversity especially the fishes as they come for refuge, habitat, and for spawning during the recruitment season. These offer stable habitats for laying eggs. Macrophytes are nutrient sources for fishes as their roots attached to soil and sediments may have some invertebrates as prey.

The species richness in the four sampling sites exhibited substantial discrepancy and maximum richness was documented in Bareilly with Cyprinidae being the dominant family during all the sampling. Ramganga at Bareilly has a wider stretch and a good volume of flow which creates ideal conditions for habitat formation and fish diversity. The tributaries like Siddha, Kichcha, and Sankha Nadi contribute enough water and amplify the volume as they meet the Ramganga River just upstream of Chaubari. A plethora of habitats are found in Bareilly from instream microhabitats like pools, riffles,

and glides to the adjacent habitats connected to the main channel like the backwaters, connected grassed ditches, shallow waters, etc. These make the suitable habitats required by the fish for spawning and refuge. Bareilly had the highest Simpson and Shannon diversity indices in 2019 and 2021 whereas in 2020, Dabri had the highest Shannon and Simpson Indices. However, Katghar had the lowest of the Simpson and Shannon indices during all three samplings because this site receives pollution from varied pollution sources. The human settlement at the bank of the Ramganga river discharges their domestic sewage into the river directly. The municipal drains as well as the industries also discharge their effluents into the river with less or without treatment. A good amount of flow and sediment load is present in the Bareilly and Dabri sites. Katghar faces sand mining issues around the year. Hence, the good-quality sediment brought by the main channel and tributaries which are considered ideal for habitat formation is mined. Hence, the bed sediments of the Katghar region are mostly clay and silt coming from the adjoining catchment areas. Also, the channel at Katghar is straight with less diverse habitats. The Channidae family was found in this area that requires benthopelagic habitats for their survival and Katghar is the ideal site for such fish species.

It is concluded from the above study that sites having good flow volume make excellent habitats for the fish population. Good flows bring sediment load which is also required for habitat formation. Ramganga has a good water discharge in Bareilly because the tributaries like Gangan, Siddha, Kichha, and Shankha and drains like Rajhera and Pla bring good volumes of water to the Ramganga main channel. The good discharge maintains the longitudinal connectivity during low flows and at times of flood, the lateral connectivity is also maintained through overbank banks. In this way, the backwaters and connected ditches get their water, and adult fishes migrate to those places for spawning. The Ramganga at Katghar requires adequate e-Flows due to the river's declining condition from the perspectives of water quantity and quality, so as to restore the river's health at this site.

There is a barrage under construction on the Ramganga main channel at Chaubari in Bareilly under the Badaun Irrigation Scheme which will further abstract 725 MCM of water from the river. After construction, this site will also become prone to post-damming flow alterations. Hence, this study will also serve as a baseline study for the habitat and ichthyofaunal diversity of the Ramganga River at Bareilly.