Decentralized vs. Centralized Water Pollution Cleanup in the Ganges in a Model with Three Cities[1]

by

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Abstract

We think of the cleanup of water pollution in the Ganges river in India as a local public good and ask whether this cleanup ought to be decentralized or centralized. We depart from the existing literature on this subject in two important ways. First, we allow the heterogeneous spillovers from cleaning up water pollution to be *positive* or *negative*. Second, we focus on water pollution cleanup in *three* cities---Kanpur, Prayagraj, Varanasi---through which the Ganges flows. Our model sheds light on two broad issues. First, we characterize efficient water pollution cleanup in the three cities, we describe how much water pollution is cleaned up under decentralization, we describe the set of cleanup amounts under decentralization, and we discuss why pollution cleanup under decentralization is unlikely to be efficient. Second, we focus on centralization. We derive the tax paid by the inhabitants of the three cities for pollution cleanup, the benefit to a city inhabitant from water pollution cleanup, how majority voting determines how much pollution is cleaned up when the spillovers from cleanup are uniform, and finally, we compare the amounts of pollution cleaned up with majority voting with the efficient pollution cleanup amounts.

Keywords: Centralization, Cost Sharing, Decentralization, Ganges River, Water Pollution

JEL Codes: Q53, O13

1. Setting the Scene

1.1. Preliminaries

Many of India's big cities are situated on the banks of well-known rivers. Examples include Kanpur, Prayagraj and Varanasi that are all located on the Ganges river, New Delhi, which is located on the Yamuna river, Ahmedabad, which is located on the Sabarmati river, and Kolkata which is located on the Hooghly river. In this regard, the work of Sanyal (2013) informs us that seven major rivers, along with their tributaries, make up the main system of rivers in India. Some salient rivers such as the Ganges and the Brahmaputra empty into the Bay of Bengal and others such as the Narmada and the Sabarmati empty into the Arabian Sea.

Although many of India's rivers in contemporary times are polluted, as pointed out by Sharma *et al*. (2022), when it comes to river water pollution, there is no question that the extremely polluted status of the Ganges, inarguably the most significant river in India, dominates public discussion about river water pollution.[4] This is because, consistent with the work of Black (2016), more than a billion gallons of waste are deposited into the Ganges every day. In addition, the problem of waste deposition into the Ganges arises at various points along the river.

Several previous studies including those by Black (2016), Jain and Singh (2020) and Batabyal *et al*. (2023a) inform us that as far as the flow of water and pollution in the Ganges are concerned, three problems deserve careful scrutiny. The first problem is water pollution from the tannery or leather producing industry, which is situated primarily in the city of Kanpur in the state of Uttar Pradesh (see Figure 1). The severity of the pollution problem caused by tanneries in Kanpur can be discerned by recognizing that in 2015, for instance, one-half of the 26 million liters

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See Markandya and Murty (2004) and Jani *et al*. (2018) for a more detailed validation of this claim.

Figure 1 about here

of tannery refuse was left untreated and a substantial portion of this refuse ended up in the Ganges.[5] The importance of the tannery industry in Kanpur explains why this city is frequently referred to as India's "leather city."[6] The second problem is waste deposited into the Ganges in the city of Varanasi, also in the state of Uttar Pradesh, which is, as shown in Figure 1, situated to the south-east of and about two hundred miles downstream from Kanpur. A lot of the pollution in Varanasi, inarguably the spiritual center of Hinduism, is the outcome of Hindu religious activities. In this regard, Dhillon (2014) notes that 32,000 bodies are cremated every year in Varanasi and that this practice results in 300 tons of ash and 200 tons of half-burnt human flesh being deposited into the Ganges.[7] The third problem is that the global warming phenomenon is diminishing water flows in the Ganges[8] and this factor has decreased the river's natural capacity to absorb pollutants that are deposited into it.

The subject of water pollution regulation[9] in the Ganges caused by tanneries in Kanpur has lately been studied from several vantage points by Batabyal (2023), Batabyal and Yoo (2022), and Batabyal *et al*. (2023b). Similarly, the topic of how pollution in the Ganges in Varanasi ought to be managed has been addressed by Batabyal and Beladi (2017, 2019, 2020) and Xing and Batabyal

5 Go to https://www.bqprime.com/business/why-kanpurs-tanneries-are-at-the-centre-of-a-fight-to-save-the-ganga for additional details on this point. Accessed on 2 October 2023.

6 Go to https://mahileather.com/blogs/news/the-world-s-most-famous-leather-markets for a more detailed discussion of this point. Accessed on 2 October 2023.

7 See Wohl (2010) for more details on how these damaging impacts exacerbate the Ganges water pollution problem.

8 Go to https://www.indiawaterportal.org/articles/impacts-water-infrastructure-and-climate-change-hydrology-upper-ganges-river-basin for more details and for a quantitative discussion of this point. Accessed on 2 October 2023.

9 For additional perspectives on this specific issue, see Kumar *et al*. (2022), Younas *et al.* (2022), and Kumar *et al.* (2023).

(2019). Batabyal *et al*. (2023b) have examined the effect that global warming has on the regulation of pollution caused by the activities of tanneries in Kanpur.[10]

In India, centralized planning has been the norm in water resources management for many decades. In the context of water pollution cleanup in the Ganges, "[e]fforts to clean the Ganges have, so far, fallen far short of their stated goals" (Das and Tamminga, 2012, p. 1649). Why? According to Das and Tamminga (2012, p. 1649), this saturnine situation is the outcome of water pollution cleanup in the Ganges being unduly *centralized* with pollution abatement programs "imposed from the top…" with little or no attempts being made to collaborate with local institutions.

1.2. Objectives

Given the above observations, Batabyal and Beladi (2023) and Batabyal and Yoo (2023) have recently demonstrated how *spillovers* from the cleanup of water pollution in the Ganges in the *two* cities of Kanpur and Varanasi determine whether this cleanup ought to be centralized or decentralized.

The purpose of our paper is to extend this line of inquiry in two important ways. First, in both Batabyal and Beladi (2023) and Batabyal and Yoo (2023), the number of cities studied that undertake Ganges water pollution cleanup is two, namely, Kanpur and Varanasi. Yet, we know from the work of Sharma *et al*. (2014), Shukla (2017), and Mani (2020) that the city of Prayagraj (formerly called Allahabad) which is situated in between Kanpur and Varanasi on the Ganges---

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In addition to the papers mentioned in this paragraph, the Ganges has been studied from multiple perspectives by a variety of authors. Specifically, Salman and Uprety (1999) have analyzed what they call water politics in the context of the Ganges. Bhaduri and Barbier (2008a, 2008b) have analyzed transboundary water sharing involving Ganges water. Islam and Gnauck (2009) have analyzed threats to mangrove wetland ecosystems in the Ganges basin. Kedzior (2017) has analyzed environmental awareness and participation in Ganges water quality policy in India, and Lee and Mitchell (2019) have analyzed water related conflicts with reference to the Ganges basin. More generally, sustainability considerations, broadly construed, in the context of rivers have been studied by Ferrer *et al.* (2022), Xu *et al.* (2022), and Anh *et al.* (2022).

see Figure 1---both causes and is impacted by upstream and downstream pollution in the Ganges. In addition, all three cities are situated in the state of Uttar Pradesh in India. Our first extension in this paper is to analyze whether Ganges water pollution cleanup ought to be decentralized or centralized in a model in which there are *three* cities, namely, Kanpur, Prayagraj, and Varanasi.

That said, the spillovers studied by Batabyal and Beladi (2023) and Batabyal and Yoo (2023) are implicitly assumed to be *positive*. However, in general, there is no reason to believe that these spillovers must necessarily be positive. For instance, if stringent cleanup in Kanpur causes some polluting tanneries to move either to Prayagraj or to Varanasi then there is a *negative* spillover from cleanup in Kanpur on inhabitants in either Prayagraj or Varanasi. Similarly, if there is strict cleanup of pollution in Varanasi then this may have a *negative* impact on Hindu religious tourists from either Kanpur or Prayagraj who intend to visit Varanasi for religious reasons but must now be careful about the extent to which their religious activities cause (hitherto unregulated or lightly regulated) local pollution. Therefore, this paper's second extension is to permit pollution cleanup related spillovers to be either positive or negative.

The remainder of this paper is organized as follows. Section 2 describes the theoretical framework in which there are three cities---Kanpur, Prayagraj, and Varanasi---through which the Ganges flows. The framework itself is adapted from Lockwood (2002). Section 3 first addresses the provision of water pollution cleanup and then analyzes the properties of the decision to clean up water pollution in a *decentralized* manner. Section 4 first deals with the provision of water pollution cleanup and then examines the attributes of decision-making when the decision to clean up pollution in Kanpur, Prayagraj, and Varanasi is made in a *centralized* manner with equal cost sharing by the three cities.[11] Section 5 concludes and then discusses four ways in which the research delineated in this paper might be extended.

2. The Theoretical Framework

Consider an aggregate economy in which there are three cities---Kanpur, Prayagraj, and Varanasi---denoted by $N = \{K, P, V\}$. The relevant pollution control authority (PCA) in each city must decide whether to provide water pollution cleanup. To simplify some of the subsequent mathematical analysis, we note that we are thinking of pollution cleanup in each city as a discrete, local public good that is either provided in the right amount or not. In this regard, it is worth emphasizing that as pointed out by Hindriks and Myles (2013, pp. 208-211), public goods that are provided in a particular geographic location are referred to as local public goods. What this means in our context is that in order to enjoy the benefit of a provided local public good (water pollution cleanup), an individual must be an inhabitant of this geographical location. In other words, to enjoy the benefit of pollution cleanup in, for instance, Kanpur, an individual must be an inhabitant of Kanpur.

In symbols, in each city $i \in N$, water pollution cleanup or w_i is either provided in the right amount or not. This means that $w_i = \{0, 1\}$. In words, if $w_i = 0$ (1) then the PCA in city i has decided to not provide (provide) water pollution cleanup. If a decision is made in city i to provide the right amount of water pollution cleanup ($w_i = 1$) then it costs this city $c_i > 0$ units of a private good that is available to the inhabitants of city i for consumption purposes. The benefit to an inhabitant of city i from the provision of water pollution cleanup is $b_i > 0$. As discussed in section

11 Decentralized provision means that each city *independently* determines whether to provide the efficient amount of pollution cleanup. In contrast, centralized provision means that a *central authority* in the aggregate economy of three cities---such as the Uttar Pradesh state government---determines whether the efficient amount of pollution cleanup will be provided in each of the three cities under consideration.

1.2, there is also a *spillover effect* from the provision of pollution cleanup w_i in city i to a resident of city $j \neq i$ which we denote by $s_{ij} \lesseqgtr 0$. This last inequality is meant to capture the idea that the spillover effect can in principle be either positive *or* negative. It would be positive if, for instance, the PCA in Kanpur (K) decides to provide pollution cleanup but the PCA in Prayagraj (P) does not, and yet, a Prayagraj inhabitant benefits from the cleaner water in the Ganges flowing to Prayagraj from Kanpur because Prayagraj is located downstream from Kanpur. In contrast, the spillover would be negative if, for example, the PCA in Prayagraj provides water pollution cleanup and, as a result, some polluting entities move from Prayagraj to Varanasi (V). Clearly, the "own" spillover effect or $s_{ii} = 0$.

The PCAs in the three cities in our aggregate economy can be ranked in terms of the cost efficiency with which they provide water pollution cleanup to their inhabitants. In this regard, we suppose that $c_K < c_P < c_V$. This ranking means that Kanpur is the *most* efficient provider of water pollution cleanup, Prayagraj occupies an intermediate position, and Varanasi is the *least* efficient provider of water pollution cleanup. Note that if $w_i = 0$ then clearly there is no benefit, cost, or spillover effect associated with this non-provision of water pollution cleanup decision by city i.

Let us define the *set* of pollution cleanup amounts that are provided by $W = \{i \in N / w_i = 1\}$. The consumption of the private good by an inhabitant of city i is denoted by $x_i > 0$. We suppose that an inhabitant of city i is endowed with one unit of the private good and that this inhabitant pays income tax denoted by $t_i > 0$. Clearly, this means that his consumption of the private good is given by $x_i = 1 - t_i$. Finally, the preferences of the inhabitants of city i are denoted by

$$u_i = \begin{cases} x_i + b_i + \sum_{\forall j \neq i} s_{ij} w_j, i \in W. \\ x_i + \sum_{\forall j \neq i} s_{ij} w_j,\ i \notin W. \end{cases} \quad (1)$$

The first (second) line on the right-hand-side (RHS) of equation (1) describes the utility obtained when water pollution cleanup is (is not) provided by city i. Our next task is to analyze the properties of the decision by the PCA in city i to provide water pollution cleanup to the inhabitants of this city in a decentralized manner.

3. Decentralized Provision

3.1. Efficient provision of pollution cleanup

We begin by describing the *efficient* provision of water pollution cleanup in the three cities under study. At the same time, we also look at whether pollution cleanup in the right amount is provided or not. To this end, let us denote the total welfare from the *provision* of water pollution cleanup in the right amount in cities 1 (Kanpur), 2 (Prayagraj), and 3 (Varanasi) by $W = \sum_{i=1}^{3} W_i$ where W_i is the welfare in city i. Using equation (1), it is straightforward to confirm that the total welfare W is given by

$$W = \{1 - c_1 w_1 + b_1 w_1 + s_{12} w_2 + s_{13} w_3\} + \{1 - c_2 w_2 + b_2 w_2 + s_{21} w_1 + s_{23} w_3\} + \\ \{1 - c_3 w_3 + b_3 w_3 + s_{31} w_3 + s_{32} w_2\}, \quad (2)$$

and it is understood that $w_i = \{0, 1\}$. The first, second, and third expressions in the curly brackets on the RHS of equation (2) denote the welfare in cities 1 (Kanpur), 2 (Prayagraj), and 3 (Varanasi), respectively.

To answer the question about whether water pollution cleanup in the right amount is or is not provided in each of the three cities under study, it will be helpful to rewrite the RHS of equation (2). This rewriting gives us

$$W = 1 + w_1\{b_1 - c_1 + s_{21} + s_{31}\} + 1 + w_2\{b_2 - c_2 + s_{12} + s_{32}\} +$$

$$1 + w_3\{b_3 - c_3 + s_{13} + s_{23}\}. \qquad (3)$$

Inspecting equation (3), it is clear that in any city i, water pollution cleanup will be provided by the responsible PCA ($w_i > 0$) as long as the condition $b_i - c_i + \sum_{\forall j \neq i} s_{ji} > 0$ holds. Otherwise, there will be *no* water pollution cleanup and, in symbols, this means that $w_i = 0$. Having described the efficient provision of water pollution cleanup in Kanpur, Prayagraj, and Varanasi, we now analyze the water pollution cleanup provision issue when this provision is undertaken in a decentralized manner.

3.2. Role of spillover effects

With decentralization, the decision to provide water pollution cleanup in the right amount by the PCA in city i is made in the city itself and, as a result, we can write city $i's$ budget constraint as

$$t_i = c_i w_i. \qquad (4)$$

Equation (4) tells us that in the ith city, the expenditure incurred in cleaning up water pollution (the RHS)) is equal to the receipt of revenue from the payment of income taxes by the city residents (the left-hand-side (LHS)).

The key point to recognize now is that water pollution cleanup in the right amount will be provided by the PCA in city i as long as this provision raises city welfare *without* accounting for any spillover impacts. From equation (2), we know that the utility obtained in city i when water pollution is cleaned up in this city is given by

$$u_i = 1 - c_i w_i + b_i w_i + \sum_{\forall j \neq i} s_{ij} w_j. \quad (5)$$

So, ignoring the spillover effects means that we set the last term on the RHS of equation (5) or $\sum_{\forall j \neq i} s_{ij} w_j = 0$.

Using this last result in equation (5), we deduce that water pollution in the Ganges will be cleaned up in the right amount in city i as long as the condition

$$b_i - c_i > 0 \quad (6)$$

holds. In words, with decentralized provision, water pollution cleanup will be made available in the right amount in any one of the three cities under consideration as long as the *city specific* benefit to inhabitants from such provision exceeds the *city specific* cost to these same inhabitants. Our final task in this third section is to first delineate the *set* of the right amounts of water pollution cleanup that are provided under decentralization and to then determine whether this decentralized provision of water pollution cleanup is efficient.

3.3. The provided set of pollution cleanup amounts

Let us denote the *set* of the right amounts of water pollution cleanup that are made available in each city by W^D and the *independent* provision decision in each city by w_i^D, where the superscript D denotes decentralization. Now, some thought ought to convince the reader that, mathematically, the set we are interested in can be expressed as $W^D = \{i \in N / w_i^D = 1\}$.

Whether the above described decentralized provision of water pollution cleanup amounts is or is not efficient will depend on the sign of the spillover term denoted by $\sum_{\forall j \neq i} s_{ji}$. As long as this spillover term is non-zero, that is, $\sum_{\forall j \neq i} s_{ji} \neq 0$, the decentralized provision of water pollution cleanup amounts will ignore this term and therefore the resulting provision of water pollution cleanup will be *inefficient*. In other words, the decentralized provision decision will be efficient only in the knife-edge case where the spillover term or $\sum_{\forall j \neq i} s_{ji} = 0$. We now proceed to analyze the properties of decision-making in our aggregate economy when the decision to provide water pollution cleanup in Kanpur, Prayagraj, and Varanasi is made in a *centralized* manner.

4. Centralized Provision

4.1. Tax paid by city inhabitants

With centralization, the decision to provide water pollution cleanup in the right amounts in the three cities in our aggregate economy is made *not* in the individual cities but, instead, by a *central authority* with jurisdiction over Kanpur, Prayagraj, and Varanasi. An example of such an authority would be the government of the state of Uttar Pradesh which is situated in the capital city of Lucknow. A second example would be the central government of India which is based in the capital city of New Delhi. The reader should understand that this central authority treats all three cities similarly and this means that there is *equal* cost sharing for water pollution cleanup by the three cities under consideration.

To reiterate, we denote the *set* of the right amounts of water pollution cleanup that are provided under centralization by W^C. In addition, the water pollution cleanup amount that is provided in city i under centralization is w_i^C. Then, mathematically, the set of interest to us in this section is given by $W^C = \{i \in N / w_i^C = 1\}$. We now want to derive an expression for the tax to be paid by any inhabitant of city $i, i = 1,2,3,$ to fund the expenditure incurred in providing the right water pollution cleanup amounts.

Using the logic of the budget constraint for city i described in equation (4), we infer that the tax payment to be made by any inhabitant of city i under centralization is given by $c_i w_i^C$. Also, because there is equal cost sharing by the three cities in our aggregate economy, an inhabitant of the ith city pays a tax given by

$$t_i = \frac{c_1 w_1^C + c_2 w_2^C + c_3 w_3^C}{3}. \tag{7}$$

Inspecting equation (7), we see that the tax payable by any inhabitant of city i or t_i is *increasing* in the three cost terms $(c_i' s)$. Put differently, the greater the cost---in terms of the private good---of providing water pollution cleanup in the three cities, the larger is the tax that the inhabitants in any one city have to pay to fund this cleanup provision decision. We now determine the benefit to any inhabitant of city i from the set of the right water pollution cleanup amounts that are provided under centralization.

4.2. Benefit received by city inhabitants

The benefit we seek is described by the utility function given in equation (1). Also, using the tax expression in equation (7), the consumption of the private good under centralization is $1 - t_i$. Therefore, putting these two pieces of information together, the complete expression for the benefit to any inhabitant of city i is

$$u_i = 1 - \frac{c_1 w_1^C + c_2 w_2^C + c_3 w_3^C}{3} + b_i w_i^C + \sum_{\forall j \neq i} s_{ij} w_j^C. \quad (8)$$

Observe from equation (8) that the water pollution cleanup provided in city i under centralization or w_i^C affects the benefit to an inhabitant of city i in *opposite* ways. First, it directly *increases* utility through the $b_i w_i^C$ term on the RHS. Second, it *decreases* utility by virtue of its appearance in the $c_i w_i^C$ term in the numerator of the ratio expression on the RHS that describes, in part, the tax under centralization. We now examine a noteworthy special case in which the spillover effects from the provision of water pollution cleanup in our aggregate economy are *uniform* and *positive*. In symbols, this means that $s_{ij} = s > 0, \forall i \neq j$.

4.3. Uniform spillover effects

To analyze this case in a meaningful manner, suppose that the water pollution cleanup provision decisions are made by *majority voting*. This means that any city that would like to see the right amount of water pollution cleaned up must secure the support of at least one other city. In this circumstance, what we would like to know is the following: What is the outcome of majority voting?

If the spillover effects are uniform and positive then the benefit expression given in equation (8) will need to be modified. This modification gives us

$$u_i = 1 - \frac{c_1 w_1 + c_2 w_2 + c_3 w_3}{3} + b_i w_i + \sum_{\forall j \neq i} s w_j. \quad (9)$$

Now, if the right amount of water pollution cleanup is to be provided in city i then, with majority voting, at least one other city must support this provision decision. This support will be forthcoming if and only if the spillover term *exceeds* the cost share. In other words, majority voting will lead to city i successfully providing the right amount of water pollution cleanup or, in symbols, $w_i > 0$, as long as the condition

$$s > \frac{c_i}{3} \quad (10)$$

holds.

Another way of conveying the outcome of majority voting is to say that this outcome is essentially ranked by the *cost*---in terms of the private good---of providing Ganges water pollution cleanup. Our final task in this paper is to compare the majority voting outcome with the efficient outcome.

4.4. Majority voting and efficiency

As in section 4.3, once again we suppose that the spillover effects from the provision of water pollution cleanup in the right amount in our aggregate economy are uniform and positive. Now, from our analysis in section 3, it is straightforward to verify that in the *efficient* equilibrium, water pollution cleanup will be provided in city i as long as the following two related inequalities

$$b_i - c_i + 2s > 0 \Rightarrow 2s > c_i - b_i. \tag{11}$$

hold.

In contrast, the inequality in (10) tells us that when there is centralized provision of water pollution cleanup with majority voting, this pollution cleanup will be made available in city i only when

$$3s > c_i. \tag{12}$$

Comparing the inequalities in (11) and (12), it is clear that the efficient and the majority voting outcomes will be identical if and only if the uniform spillover term *equals* the benefit term or when $s = b_i$. Some thought ought to convince the reader that this is the knife-edge case. Therefore, we conclude that, in general, the centralized provision of water pollution cleanup will be *inefficient* whenever $s \neq b_i$. Two other points in this comparative exercise are worth emphasizing. First, if $s > b_i$ then there will be instances in which water pollution cleanup is provided with majority voting in city i even though it is *inefficient* to do so. Second, if $s < b_i$ then we can have scenarios where it is *efficient* to provide water pollution cleanup in city i but majority voting will lead to this cleanup *not* being provided. This completes our analysis of decentralized versus centralized provision of water pollution cleanup in a model with the three cities of Kanpur, Prayagraj, and Varanasi.

5. Conclusions

Given the contemporary concern about the extremely polluted status of the Ganges river in India, we addressed the cleanup of water pollution in this river by analyzing a theoretical model with three cities. Our analysis shed light on three broad questions. First, we described the conditions under which water pollution cleanup in the three cities under study ought to be provided. Second, we discussed the attributes of a policy regime in which water pollution cleanup is made available in each of the three cities in a decentralized manner. Finally, and once again based on the supposition that inhabitants of the three cities under study are to be provided with water pollution cleanup, we shed light on the characteristics of a policy regime in which water pollution control is made available in a centralized manner with equal cost sharing by the three cities.

We now provide four examples of the ways in which the research delineated in this paper might be extended. First, it would be useful to analyze an intertemporal version of our model in which the pertinent PCA can *learn* about how effective the present provision of water pollution cleanup is in enhancing the *future* health of the Ganges river. Second, it would also be helpful to collect data and determine the strength and the direction of the spillover effects that we have discussed in our analysis. Third, one could construct an expanded model that includes privately provided water pollution cleanup to see how useful public-private initiatives that share personal or private data are in promoting the health of the Ganges. Finally, given differences across cities in preferences for clean water in the Ganges, one could analyze the residential location choice problem faced by citizens who must decide whether to stay in a city or to move to a more environmentally friendly city. Studies that analyze these aspects of the underlying problem about the provision and the impacts of water pollution cleanup will provide additional insights into the nexuses between water pollution cleanup efforts in the Ganges on the one hand and the maintenance of the health of this river on the other.

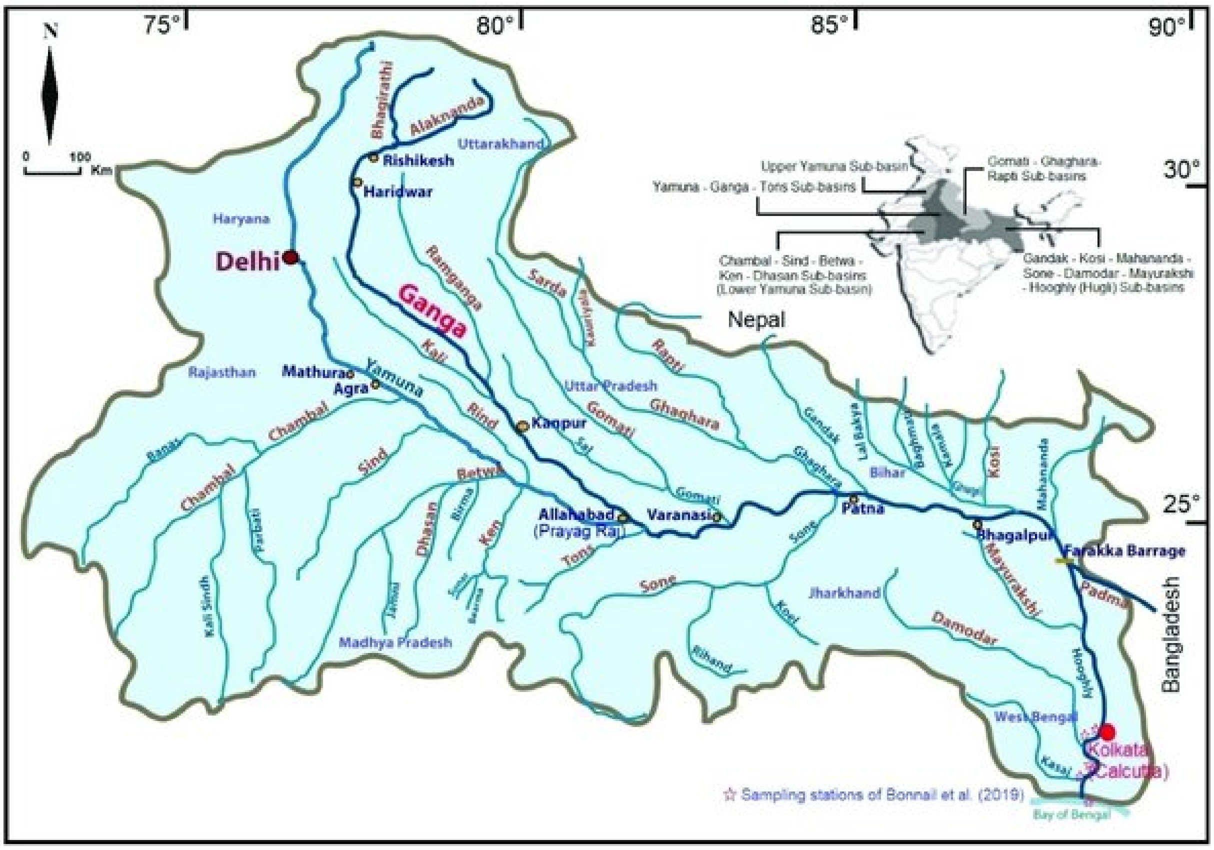

Figure 1: Flow of the Ganges and the Locations of Kanpur, Prayagraj, and Varanasi

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