Modeling the Efficacy of the Ganga Action Plan's Restoration of the Ganga River, India

By

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Abstract.

To combat rising levels of water pollution in the Ganges River, the Indian government initiated the Ganga Action Plan (GAP) in 1984. After twenty years, it is a common perception that the GAP has failed to achieve the goals of a cleaner river. Using available government data on pollution levels and hydrology, I undertook an of the GAP efficacy for fifteen pollution parameters across 52 water quality sampling points monitored by India's Central Pollution Control Board (CPCB) within the Ganga Basin. Dissolved oxygen, BOD, and COD showed a significant improvement of water quality after twenty years. In addition, fecal and total coliform levels, as well as concentrations of calcium, magnesium, and TDS all showed a significant decline. Building on this analysis, a GIS analysis was used to create a spatial model of the majority of the Ganga River network using a reach-based ecological classification approach. Using recent GAP monitoring data, a multiple linear regression model of expected pollutant loads within each reach (VSEC unit) was created. This model was then used to inventory water quality across the entire basin, based on CPCB criteria. My analysis showed 208 river km were class A, 1,142 river km were class B, 684 river km were class C, 1,614 river km were class D, and 10,403 river km were class E. In 2004, field measurements were taken at six major cities along the Ganga mainstem which showed lower concentrations of nitrogen predicted from my model, and roughly the same values of phosphate as the model provided. Although the GAP did not result in significant improvements in all major water quality parameters, the fact that most water quality parameters did not significantly decline, even after a doubling of the region's population during the twenty-year period, does reflect a significant level of success with the law.

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Table of Contents

Preface.

All geographic information system (GIS) layers and raw data can be found in the attached CD-ROM. GIS layers are saved as both the Environmental Systems Research Institute (ESRI) shapefiles and ESRI personal geodatabases files. Pre-Ganga Action Plan (GAP) and Post-GAP data from India's Central Pollution Control Board are saved in Microsoft Excel 2002 format.

Introduction.

The Ganga[1] River basin (Figure 1) covers an area of roughly 1 million square kilometers located in North-central India, the majority of Nepal, and extreme southwestern China. The middle Ganga Plain includes 144,409 km^2 of land between the Himalaya Mountains to the north, and the Vindhaya Mountains in the south (Figure 2, Ray 1998). The mainstem of the river is roughly 2,500 km in length, if measured from the river's source in the Gangotri Glacier to the Bay of Bengal, through the Hooghly River distributary (Basu 1992).

Six major tributaries originate in the Himalaya Mountains (Figure 3). These are (in geographic order from West to East) the Yamuna[2] River, the Ramganga River, the Ghaghara River, the Gandak River, the Bhuri Gandak River, and the Kosi River. Although flowing north-to-south with the Himalayan Rivers, the Gomati River[3] does not originate in the mountains. Six major tributaries originate from the Vindhya Mountains to the south. In geographic order from West to East the Chambal River, the Sind River, the Betwa River, and the Kens River conflue with the Yamuna River. The Tons River and the Sone River both conflue directly into the Ganga River. At the Farakka Barrage[4], the river is redirected southward into the Hooghly River distributary system. A long-term watersharing agreement between India and Bangladesh was reached in 1997 that regulates this water withdrawal (Iyer, 2003).

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[1] Also known as the 'Ganges River'. Place names and geographical features have several names in India that have changed in usage throughout history. Geographic places and features will be presented with their most current name, with an explanatory footnote, where needed.
[2] Known as the 'Jumna River' or 'Jamuna River' during the period of the British Empire. This is not to be confused with the Jumna River found in Bangladesh, which is a different river system.
[3] Also known as the 'Gomti River'.
[4] The Farakka Barrage was constructed in 1974. One of the major waterworks on the Ganga River, this barrage (dam) detains water, diverting it to the Hooghly River. This diversion maintains the deep water port of Kolkata.

Water levels vary greatly throughout the year, due primarily to the effects of the yearly summer monsoons (Figure 4), which move over the watershed from the south-east to the north-west, (Ray 1998) following a course that is roughly opposite to the flow of the river.

Human Significance of the Ganga River Basin

The Ganga river basin is one of the most densely populated river basins in the world, supporting 29 Class-I cities, 23 Class-II cities[5], 48 towns, and thousands of villages (Figure 5). Over 500 million people were estimated to be living in the entire Ganga river basin in 2000, and this number is expected to grow to over 1 billion by 2030 (Markandya & Murty 2000).

The ever-increasing regional population has contributed to water scarcity and water quality degradation throughout much of the river system. Nearly all of the sewage from these populations enters the basin waterways untreated, totaling 1.3 billion liters per day of human waste, and 260 million liters of industrial waste, primarily from agricultural fertilizers and pesticides (Markandya & Murty 2000). In addition to these domestic and industrial pollutants, hundreds of human corpses and thousands of animal carcasses are released to the river each day for spiritual rebirth. Ray (1998) reported that waste discharge exceeded available river water in the state of Uttar Pradesh, just prior to the yearly monsoon.

With an increasing population, India also faces a future of water scarcity. According to the UNDP, the population of a country whose renewable fresh water availability falls below 1,700 m^3/person/year (m^3/ppy) will experience “water stress,” and a “chronic

[5] Class-I cities: population ≥100,000 people. Class-II cities: population 50,000 to 99,999 people.

water shortage" when availability falls below 1,000m^3/ppy (Hinrichsen & Tacio 1997, Ahmad *et al* 2001, Shiva 2002). The average water availability in India in 1951 was 3,540 m^3/person/year (m^3/ppy). By the late 1990s, it had fallen to 1,250 m^3/ppy. By 2050, some project a drop below 750 m^3/ppy (Shiva 2002). Currently, many river basins in India are already well below the 1,000 m^3/ppy level and look for replenishment from the Ganga Basin rivers.

Population pressures, lack of proper investment in water quality infrastructure, governmental corruption, and a lack of empowerment of the people all continue to contribute to the deteriorating state of the Ganga (Raina *et al* 1997, Shiva 2002).

Impacted Aquatic Ecology of the Ganga River

As the remnants of the eastern edge of the Tethys Sea, the Ganga basin is the home for wide variety of relic species, including the Ganga River dolphin (*Platanista gangetica*), the Ganga River shark (*Glyphis gangeticus*), Ganga soft shell turtle (*Aspideretes gangeticus*), gharials (*Gavialis gangeticus*), and several species of endemic freshwater crabs. Within the Ganga River system, 141 different fish species, comprising 72 genera and 30 families were reported in fishery surveys carried out during the 1970s. Of these, upland water species totaled 60 different species (Ray 1998).

The impacts of increased population growth, industrial development, deforestation, and dam construction have had serious adverse impacts on fisheries, with a steady decline seen in populations of prized carp and hilsa, as well as catfish and minnows (Ray 1998). The construction of the Farakka Barrage (starting in 1973) had a significant impact on fisheries as far upstream as Allahabad. Catches are reported to have declined from an average of 19.2 tons *Hilsa ilisha*/year to 0.9 tons *Hilsa ilisha*/year (Ray 1998).

Many recent ecological surveys and studies have focused on zooplanktonic and phytoplanktonic taxonomy, especially in these species' use as bioindicators for specific pollutants (Krishna Murti *et al* 1991, Sabata & Nayar 1995). Several studies have shown high levels of metals, heavy metals, and pesticides in captured fishes, crustaceans, and mollusks throughout much of the basin (Ray 1998). Recent studies by Rao (2001) indicate a significant amount of animal diversity along the length of the river, but very little is known of the total variety of species, their relative abundances, ecological interactions, or the effects of pollutants on these populations (Rao 2001).

The Ganga Action Plan

Prior to independence from Great Britain in 1947, the pollution loads in the Ganga River are thought to have been practically negligible next to the comparatively-huge volume of water in the river (Ray 1998), but little actual data is available. Pollution studies within the Ganga basin began the mid-1960s. These studies reported sewage dilution ratios of 1:11 in the Gomati River, wide-spread fish kills due to dead zones in the Kali River, severe industrial impacts on the Son River, 108 major industrial polluters within the deltaic Damodar River basin, and major silting of the Yamuna River (Ray 1998). By the 1970s, the region's growing population's pollution inputs had even more serious impacts on the rivers' assimilative capacity, and large stretches (some over 600 kilometers long) were ecologically dead and posed direct serious public health hazards (Markandya & Murty 2000).

The government was finally pushed into action by Prime Minister Indira Gandhi, who ordered a government-led study of water pollution in the Ganga River. These studies, conducted by the Central Board for the Prevention and Control of Water Pollution from

1979 to 1984, suggested that 70% of the total pollution load came from 27 Class-I cities, 15 Class-II cities, and 25 smaller towns; 20% was derived from industries and 10% from other sources (Basu 1992, Ray 1998).

The Ganga Action Plan (GAP) was initiated in 1985 with the goal of cleaning up the entire mainstem of the Ganga (2,500 km) to Class B, or "outdoor (organized) bathing" class (Table 1) (Ministry of Environments and Forests 1995, National River Conservation Directorate 1999b). This was to be achieved by identifying and mitigating major sources of wastewater and other point-source discharges into the river. Approved mitigation measures focused primarily on the construction of interceptor sewers, sewage diversion mechanisms, and sewage treatment plants. Under the first phase of GAP (1985-1990), 88 sewage interception and diversion, 35 sewage treatment plants, 43 low-cost toilet facilities, 28 electric crematoria, 35 riverfront developments and 32 miscellaneous schemes were enacted at an estimated cost of Rs 3.5 billion (NRCD 1999b). The final cost of the first phase of GAP totaled Rs 7 billion (~$78 million). The estimated cost of phase-II is Rs 4.2 billion (~$93 million), with a total annual operating cost (as of 2000) at roughly Rs 356 million (~$8 million).

Under the provisions of the GAP, the Central Pollution Control Board (CPCB) is charged to monitor the concentrations of up to nineteen major pollutants (Central Pollution Control Board 1985, 1998, 2003) (Table 2). The GAP was set up primarily to clean up the mainstem of the Ganga River, and ignored, except as a point-source input of pollutants, all tributary rivers. Although a series of successive river action plans on the tributaries have been implemented, there is little evidence of a system-wide, watershed-based management strategy in the Ganga watershed (Iyer 2003, Alley, personal communication).

The government of India states that the GAP has improved water quality of the river. It bases this assertion on changes in monitored water pollution concentrations (NCRD 1999a), but gives no data on seasonal estimates or loading estimates. Most previous analyses of the GAP have focused on the economic impacts of the plan (Markandya & Murty 2000), or certain river reaches between major cities (Ray 1998, Krishna Murti 1995, Tare *et al* 2003). As of 2005, there has not been a publicly-available comprehensive assessment of the impact of the GAP on the water quality in the Ganga watershed.

The question of how successful the GAP has been is an important and timely one. The GAP was initiated in 1984, just over twenty years ago. During the interim, the GAP stimulated many governmental reforms relating to the river, both positive and negative. In recent years, many NGOs and news organizations regularly assert that that the GAP has failed, and concerns about the future of the Ganga continue to be raised (Tare *et al* 2003, Alley, 2002).

In this report, I review the efficacy of the GAP and provide an overview of the current state of water quality in the Ganga basin through the development of empirical flow and pollutant loading models. This study attempts a preliminary answer to the question, "After twenty years, did the Ganga Action Plan bring about positive water quality change to the Ganga watershed?" Using publicly-available historic water quality and water quantity data, supported by my own observations during a field sampling trip in January and February 2004, I have developed several different analyses of the efficacy of the GAP. As discussed below, my analysis indicated that the GAP did, in fact, improve mainstem waster quality of some parameters, but also raises questions about the sustainability of current levels of water pollution in the Ganga basin.

Methods

In order to analyze GAP performance using CPCB data, it was necessary to first construct a basin-wide hydrologic model for annual average flows. This hydrologic model was necessary because flow and discharge data were classified as confidential material in 1974 (coincident with the completion of the Farakka Barrage), and have not been declassified since (Iyer, personal communication). The constructed hydrologic model estimated pollutant loading rates from CPCB-reported annual average pollutant concentrations. The results from the hydrologic model were used to develop a simple empirical pollutant loading model for each CPCB subwatershed unit as a part of my evaluation of the current status of Ganga River waters. They were also used to statistically evaluate the historical effectiveness of the GAP. I also developed a second pollution prediction model based on total per capita loading rates used in environmental engineering.

In addition to CPCB water quality data, I collected water samples during January and February 2004 at six different Indian cities that were analyzed for the standard pollutants of nitrate, phosphate, COD, and ammonia.

Construction of an annual average discharge (Q) model

There is a strong logarithmic relationship between drainage area and average basin hydraulic parameters, including discharge, generally described as the hydraulic geometry (Leopold 1997). Taking advantage of this relationship, a regression model was constructed for annual average discharge in the Ganga basin as a function of tributary watershed area using data average annual flows for 1963-1973 (Rao 1975) (Table 3). Upstream watershed areas of CPCB sampling points on were estimated using ArcMap, version 9.1 (ESRI 2005).

Because I would need to extrapolate to smaller and larger subbasins than provided by the available Ganga hydrographic data, I used an Analysis of Covariance (ANCOVA) to test slope and intercept of the Ganga's derived linear regression equation against a similar linear regression equation I produced of major and minor world rivers which spanned a greater range of basin sizes. (Figure 6). No significant difference was found in either slope or intercept between the regression equations of the Ganga River and other world rivers (Table 4, Table 5). On the basis of these analyses, I concluded it was reasonable to extrapolate from the available range of data making up the Ganga linear regression discharge model to larger and smaller basins within the Ganga system.

The Himalaya Mountains contain vast glaciers, the melting of which provides 60% of the water in the Ganga Basin (Ray 1998). Because this significant input to the Ganga is known, the Himalayan mountain range was delineated, and the percentage of each subwatershed in the Himalayan Mountains (% Himalaya) has been incorporated into the model. The percentage of a subwatershed in the southerly Vindhya Mountains proved to be a non-significant model parameter, and was not used. Similarly, since the yearly monsoon was known to have significant impacts on river discharge (Figure 4), each subwatershed's average yearly precipitation has been incorporated into the model. Although several major canal projects exist within the Ganga Basin, some removing up to 325 m^3/s (cms) from the river (Ray 1998), these removals were not included in the model due to lack of accurate spatial data. Effects of dams and other major water projects were not included in the model for the same reason. The final multiple linear regression model used total subwatershed basin area (A), annual precipitation within the subwatershed (P), and the percentage of the subwatershed in the Himalaya mountains (*% Himalaya*) to predict annual discharge (Table 9).

$$\ln(Q) = \ln(A)(0.846) + (P)(0.001) + (\%\text{Himalaya})(1.001) - 4.698 \quad (R^2{=}95.5\%)$$

EQUATION 1

This model overestimated flows by 10.2% on average (-30.2% to 60.8%). Watersheds originating in the Himalayas were over-estimated by roughly 11.8%. Modeled discharge values of the Ganga at Allahabad before the Sangam were under-predicted by 29.5% the reported value. The Gandak, Sone, and Ghaghara rivers were all under-represented by 30.2%, 23.0%, and 22.2%, respectively. The Bhuri Gandak was greatly over-represented by 60.8%. The Kosi was over-represented in the model by 20.6% and the Tons by 20.5%. The only non-Himalayan river that was greatly divergent from its estimated value was the Gomati, the model yielding a discharge of 44.7% above the reported value of 209 cms (Table 7).

These regression analyses and all other statistical methods employed in this study, apart from the ANCOVA tests, were performed using Data Desk, version 6.1 (Data Description 1996). The ANCOVA tests were calculated by hand.

Central Pollution Control Board Data

The CPCB water quality monitoring sites were acquired from published Water Quality Yearbooks (CPCB 1985, 1998, 2003). The location of each city was found by using a variety of paper (US Army Map Service 1955) and online (National Imagery and Mapping Agency 1998, Google 2005) maps to determine the longitude and latitude of each site. 104 of the 156 reported sampling sites were located. When a city had more than one site associated with it, with no additional information other than "upstream" and "downstream," a distance of roughly 20 kilometers was used to separate sites.

Watershed boundaries for each CPCB water quality sampling station were delineated using the *watercrsl* and *inwatera* shapefile layers from the "vector map level 0" (VMAP-0)[6] data sets (NIMA 1998). Publicly-available VMAP-1 layers included only the western Ganga Basin, and were therefore not used. The area of each watershed was determined using the analysis tools in ArcMap 9.1 (ESRI, 2005). No significant difference was observed between derived tributary watershed areas delineated in this process and the values cited by Rao (1975) (Table 8).

Using the constructed multiple linear regression discharge model (Equation 1), average annual loads were calculated for each chemical component at each CPCB station. Values for total dissolved solids (TDS) were not available pre-GAP. Based on sites where TDS and conductivity were available post-GAP, values for TDS were calculated based on the regression-calculated conversion factor of $TDS = \frac{conductivity}{1.59}$ ($y = 0.6305x$, $R^2 = 0.3704$, $n = 52$). Total nitrogen was calculated by summing NO_x and TKN values for each site.[7]

All available CPCB annual average pollutant values pre-GAP implementation (1980-1984) were averaged at each site to obtain a grand mean. Similarly, data values for 1998 and 2003 were averaged at each site to obtain mean post-GAP pollutant values.

[6] VMAP-0 level data has a spatial resolution of 1:1,000,000, covers the entire world, and is publicly available for download from various websites. The world is divided into four regions, North America (NOAMER), Europe and North Asia (EURNASIA), South America, Africa, and Antarctica (SOAMAFR), and South Asia and Australia (SASAUS).

[7] Loads values for total coliforms, fecal coliforms, dissolved oxygen, temperature, and pH are nonsensical measures, and were not calculated.

Most pollutant load values were found to be right-skewed, and were normalized using a log-transformation. Changes in water quality were analyzed using paired, two-tailed, t-tests and compared “pre-GAP” and “post-GAP” pollutant levels to determine the GAP policy in monitored regions of the Ganga River basin.

Construction of the Ecological Valley Segment Model

Large portions of the Ganga watershed, mostly in Nepal and less-populous regions of the watershed were not monitored by the CPCB (Figure 7). In order to obtain pollution estimates for these regions, it was necessary to delineate regions within which extrapolations could be made based on available CPCB data.

A preliminary ecological valley segment (VSEC) model (Seelbach & Wiley, 2005) was created for the Ganga by delineating segments based on watershed boundaries and river planform. A more complete model could have been based on land cover/land use, ground water flux, inputs from secondarily-significant tributaries, major water abstractions, impoundments, etc. However publicly-available, land cover data was scarce, not uniformly representative of the watershed, and usually out-of-date. A recently-created land use layer of the Indus and Ganga river basins, described by Thenkabail, *et al* (2005) may be useful for future revisions.

The VSEC classifies the river into ecologically-homogenous reach units. Significant changes in land cover, ground water flux, surficial geology, river discharge, etc. indicates potential significant changes in river inputs and lead to new ecological conformation in the channel (Seelbach *et al* 1997). A comprehensive valley segment classification provides useful units for extrapolation and regional modeling efforts (Seelbach & Wiley 2005).

River planform[8] was used as a primary means of characterizing changes in valley segment character, since the measurement of sinuosity is correlated with the type of surficial geology, average annual discharge, and slope of a river (Leopold 1997). Mapping of VSEC units was based on the publicly-available *waterscrsl* and *inwatera* shapefiles (National Imagery and Mapping Agency 1998) used in deriving river discharge.

Estimating Pollution Beyond CPCB Basins

The CPCB water quality monitoring focused primarily upon population centers within the Ganga River watershed. However, not all major cities' water quality data were reported, one obvious omission being Patna, the capital city of Bihar, with an estimated population of 1.3 million people in 2000 (Census of India 2000). Furthermore, the lack of water quality information from most major tributary streams of the Ganga makes it difficult to conduct a basin-wide review of water quality. Two methods were used to estimate pollutant loading across the Ganga watershed: a potential loads-based model on average *per capita* pollutant loading estimates, and the multiple linear regression model based on observed patterns of pollutant loading. Estimates were only made for the period of time contemporary to the "Post-GAP" (1998, 2003), because population data during the "Pre-GAP" period were not available at a finer resolution scale than the administrative district level.

Empirical Pollutant Loading Estimates

Multiple linear regression (MLR) models of average annual BOD_5 (Table 10), total nitrogen (Table 11), and TDS (Table 12) pollutant loading (mg/s) were created based on recent observed average CPCB values (1998 and 2003). Regression analyses of

[8] The river's planform is its shape as viewed from above, or on a map.

estimate pollutant loads were based on the parameters of upstream subbasin area, discharge, and regional population[9], and produced the following equations:

$$\ln(BOD_5) = -0.542 + \ln(Q_{cms})(0.320) + \ln(Pop'n_{watershed})(0.435) \quad (R^2=73.4\%)$$
EQUATION 2

$$\ln(N_{total}) = -3.553 + \ln(Q_{cms})(0.067) + \ln(Pop'n_{watershed})(0.724) \quad (R^2=67.9\%)$$
EQUATION 3

$$\ln(Coliforms_{Total}) = -5.725 + \ln(Q_{cms})(-1.515) + \ln(Pop'n_{watershed})(1.677) \quad (R^2=30.7\%)$$
EQUATION 4

$$\ln(TDS) = 1.231 + \ln(Q_{cms})(0.212) + \ln(Pop'n_{watershed})(0.698) \quad (R^2=69.4\%)$$
EQUATION 5

$$\ln(Calcium_{total}) = -0.893 + \ln(Area_{watershed})(0.583) + \ln(Pop'n_{watershed})(0.342) \quad (R^2=94.8\%)$$
EQUATION 6

$$\ln(Chloride) = -2.29183 + \ln(Pop'n_{watershed})(0.806) \quad (R^2=100\%)$$
EQUATION 7

The modeled values of each parameter were calculated with each VSEC basin in order to gain a better understanding of the potential current state of water quality in regions that fall outside the purview of the CPCB's monitoring programs. Using a slightly modified classification (Table 16), each VSEC unit was then categorized into CPCB water quality codes.

Per capita Potential Loads

It is possible to estimate the maximum BOD_5, total nitrogen, and total phosphate loading in a basin based on standardized values for municipal sewage. The maximum expected impacts of the estimated upstream population within a 50 km radius of each VSEC node was calculated to help estimate phosphate loads.

[9] Population at 100km radius upstream from the subbasin discharge point.

Following Schwoerbel (1987), I estimated the maximum potential daily inputs of BOD_5, nitrogen, and phosphate as:

$$(\mathrm{BOD}_5)_{load} = (\mathrm{Population}_{total})(0.00135\mathrm{kg\ BOD_5/person/day})(c_1) \qquad \text{Equation 8}$$

$$(\mathrm{N})_{load} = (\mathrm{Population}_{total})(0.00225\mathrm{kg\ N/person/day})(c_2) \qquad \text{Equation 9}$$

$$(\mathrm{PO}_4)_{load} = (\mathrm{Population}_{50km})(0.0015\mathrm{kg\ PO_4/person/day})(c_3) \qquad \text{Equation 10}$$

where c_i is the respective delivery ratio of the pollutant to the river[10]. Knowing that the MLR-based pollutant loading values of BOD and nitrogen indicate post-GAP loading rates, it was possible to estimate the average pollution treatment levels at each VSEC, and thereby obtain the values for c_1 and c_2 by regressing the maximum potential daily pollutant input against the MLR loading estimate from above. The value of the slope coefficient of the maximum potential daily loading was used as the estimated dimension of c_i. This gave estimated c_i values of BOD_5 and N of 0.734179 and 0.285403, respectively. The estimated delivery ratio of phosphate was arbitrarily set at $c_3 = 0.6$; a delivery ratio that assumes processing equivalent to full secondary treatment.

Pollution Analysis

Using the pollution estimates obtained from the empirical pollutant loading MLR models, and the modeled river discharges, pollutant concentrations of Total Coliforms[11], BOD_5, and conductivity were calculated for VSEC segment[12]. A modified version (Table 16) of the CPCB criteria for assessing water quality was used to assign the water quality of each segment based on individual pollutants. Then, the overall water quality class was

[10] c_i= kg of pollutant/day
[11] Although the total coliform parameter had only a 30.7% R^2 value, it was extrapolated across the basin because it is a vital component of the CPCB's water quality classification scheme.
[12] Conductivity was calculated as TDS*1.59=conductivity.

determined by assigning the maximum criteria standard. For example, if a VSEC segment was rated a class A for conductivity, but a class D because of total coliform counts, that segment was assigned an overall class of D.

Sampling in India

In January and February 2004, I collected water samples were collected in India along the Ganga at the cities of Hardwar[13], Kanpur, Allahabad[14], Varanasi[15], Patna[16], and Kolkata[17] (Figure 9). Collected water samples were tested at each site for ammonia (NH_4), total soluble phosphate (TSP), nitrate/nitrite (NO_3-N), and COD content. COD values exceeded what could be measured with the reagents available onsite, so a lower-bound of COD was calculated for each site. Load estimates were not calculated, because daily flow values were not publicly available for these sites.

Sampling Sites

Hardwar: Sampling in Hardwar took place above the city and the canal headworks of the Upper Ganga Canal, at the site of the large statue of Shiva (Figure 10) This site is situated immediately of a dam that was constructed to divert water to run either through the city of Hardwar and into the Upper Ganga Canal, or along the original course of the Ganga. The Ardh Kumbh Mela[18] was just starting at Hardwar, and areas in and just below

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[13] Also known as Haridwar.
[14] Also known as Prayag. 'Prayag' is rarely used outside a Hindu religious context.
[15] Also known as Varanassi, Benares, Banares, and Banaras.
[16] Also known as Pataliputri. Although many city and place names have been reverted from their British transliterations of the local Hindi, 'Patna' is preferred over the historical 'Pataliputri.'
[17] Also known as Calcutta.
[18] The Ardh Kumbh Mela is a Hindu pilgrimage held once every twelve years, and compliments the more popularly-attended Kumbh Mela pilgrimage. During the Ardh Kumbh Mela, Hindu pilgrims travel to holy sites in the cities of Hardwar and Allahabad. The city of Hardwar may have up to 1 million pilgrims over the course of one month. The city of Allahabad, being both easily reached, and a more holy city, can have up to 50 million pilgrims over the course of the same month.

the city was already closed off for the exclusive use of pilgrims, limiting the choice of sampling sites.

Kanpur: Two sites were sampled in Kanpur (Figure 11). The first site was at one of the municipal water intake points for the city. The pumping station was built in the mid-1960s on the banks of the Ganga, but during the intervening 40 years, the river has shifted its course to the north and east by six kilometers. The site gets its water from two feeder canals that lead from the Ganga. Slum development has taken place along both banks of the canals (Figure 12). The second site was on the Ganga itself, downstream from Kolya Ghat; near the eastern end of the city, but upstream of the major industrial tanneries (Figure 13).

Allahabad: Two sites were sampled in Allahabad (Figure 14). The first site was 2 kilometers below the Sangam, river right (Figure 15). The majority of the flow at this point, from the Yamuna River, converges from the west and south of the Ganga. The second site was above the Sangam (confluence of the Ganga and Yamuna Rivers), on the Ganga, below two rail bridges and a road bridge (Figure 16). Sampling in Allahabad was made difficult by the ongoing Ardh Kumbh Mela pilgrimage and celebrations taking place at the Sangam itself.

Varanasi: Sampling was done at one site, opposite of Asi Ghat, at the downstream end of the city's pilgrimage area (Figure 17). The city of Varanasi is a major pilgrimage city, and although not one of the Ardh Kumbh Mela pilgrimage cities, does have a large number of pilgrims arriving every day. However, this sampling site, located in the middle of the river, should not have been affected by the pilgrims and religious rituals taking place along the ghats because of the low level of mixing between river edge and midriver (Figure 18).

Patna: Sampling in Patna was done downstream of the confluence with the Gandak and Bhuri Gandak Rivers (Figure 19, Figure 20). Upstream of this sampling site, the Ganga is intercepted by the Ghaghara and Gandak from the north and the Sone from the south. None of these major tributaries have any cities of over 1 million people directly along their banks.

Kolkata: Sampling in Kolkata was conducted on the Hooghly River[19], just outside that grounds of the Botanical Gardens (Figure 21). Samples were collected during the period of the rising tide, and the river was moving south-to-north. Sampling, during the falling tide was not done, due to safety concerns.

[19] Also known as the Bhagirathi or Hugli River, the Hooghly River one of the major distributaries of the Ganga River. The majority of water entering the Hooghly is diverted south from the Farakka Barrage, 18km upstream from the border with Bangladesh to maintain the deep water port of Kolkata (Adel 2001).

Results

Pre-Post GAP Comparisons

Water quality reported by the Central Pollution Control Board before the implementation of the Ganga Action Plan was poor, with DO as low as 0.1 mg/L (mean: 7.4 mg/L), BOD as high as 175 mg/L (mean: 5 mg/L), COD at 770 mg/L (mean: 27 mg/L), NO_x at 80 mg/L (mean: 5.9 mg/L), pH ranging from 1.5 to 13.8 (mean: 8.0), fecal coliform levels of 2.4 x 10^8 MPN/100 mL (mean: 2.2 x 10^5 MPN/100 mL), total coliform levels of 2.4 x 10^8 MPN/100 mL (mean: 2.5 x 10^5 MPN/100 mL), conductivity of 20,000 mg/L (mean: 449 mg/L), chloride at 3234 mg/L (mean: 38 mg/L), sulfate at 2100 mg/L (mean: 29 mg/L), sodium at 16200 mg/L (mean: 32.9 mg/L), calcium at 340 mg/L (mean: 78.3 mg/L), and magnesium at 995 mg/L (mean: 49.2 mg/L). After roughly twenty years of GAP implementation, DO levels were as low as 0.3 (mean: 7.3 mg/L), BOD as high as 230 mg/L (mean: 6.6 mg/L), COD at 999.9 mg/L (mean: 36.5 mg/L), NO_x at 3.5 mg/L (0.1 mg/L), pH ranging from 2.0 to 10.0 (mean: 7.9), fecal coliform levels of 1.9 x 10^{10} MPN/100 mL (mean: 2.3 x 10^7 MPN/100 mL), total coliform levels of 9.5 x 10^9 MPN/100 mL (mean: 9.2 x 10^6 MPN/100 mL), conductivity of 11,660 mg/L (mean: 514.9 mg/L), chloride at 4674 mg/L (mean: 83 mg/L), sulfate at 9999 mg/L (mean: 157.3 mg/L), sodium at 1328 mg/L (mean: 83.4 mg/L), calcium at 1140 mg/L (mean: 122 mg/L), and magnesium at 1330 mg/L (mean: 75.5 mg/L) (Table 17).

While overall basin means of most measured Ganga water quality parameters did not significantly differ before and after GAP, a paired t-test comparison of the pre- and post-GAP samples by sampling location showed that accounting for site to site variation, the water quality in the Ganga River had significantly improved (preGAP – postGAP >

0) for some important parameters. Improving water quality parameters included BOD (t: 1.904, p: 0.0323), dissolved oxygen (t: -1.515, p: 0.0690), and nitrogen (t: 5.209, p: 0.0004) concentrations. However, several factors indicated a decline in quality after twenty years of GAP (preGAP – postGAP < 0), including Fecal Coliform count (t: -1.439, p: 0.0793), Total Coliform count (t: -1.321, p: 0.0974), and concentrations of calcium (t: -1.578, p: 0.0639), magnesium (t: -1.968, p: 0.0304), and TDS (t: -2.139, p: 0.0195). Differences between pre- and post-GAP levels of COD, pH, temperature, alkalinity, chloride, sulfates, and sodium were not statistically significant (Table 18).

Indian Field Data

The water samples from my January/February 2004 trip revealed that during that period, water quality was highest at Hardwar and Patna, and lowest near Kanpur, and at Allahabad, below the Sangam. (Table 19).

At Hardwar, both ammonia and phosphate were below detection levels, and level of NO_x (0.02 mg/L) was the lowest observed among all the sampling locations. Kanpur's water intake site had the highest ammonia level (2.75 mg/L), and the second highest phosphate concentration (1.26 mg/L) among all sampling locations. The site opposite Kanpur's Kolya Ghat had the highest phosphate (6.2 mg/L) and NO_x (0.74 mg/L) concentrations among all sites. Allahabad above the Sangam had relatively very low concentrations of ammonia (0.02 mg/L) and phosphates (0.03 mg/L), and a slightly-above-median concentration of NO_x (0.29 mg/L). Below the Sangam (and past the thousands of pilgrims bathing at the confluence point), increased concentrations of ammonia (0.20 mg/L), phosphate (0.29 mg/L), and NO_x (0.39mg/L) were observed. At Varanasi, ammonia (0.22 mg/L) and NO_x (0.20 mg/L) were similar to Allahabad below the Sangam. The phosphate concentration was relatively low (0.04 mg/L), but still elevated by natural standards. At Patna, ammonia was not detected. Phosphate was elevated (0.13 mg/L) but NO_x (0.09 mg/L) were relatively low. Kolkata had a relatively low level of NO_x (0.12 mg/L), elevated ammonia (0.54 mg/L) and very high levels of phosphate (2.95 mg/L).

Estimated water quality using empirical loading models

The empirical load models (Equation 2, Equation 3, Equation 4, Equation 5) and estimated average annual flows (Equation 1) were used to estimate BOD, nitrogen, and TDS for all of the delimited VSEC units in the Ganga Basin (Table 20). BOD loading estimates ranged from 9.04 kg/day to 4097.52 kg/day (median: 198.41 kg/day, mean: 430 kg/day), with BOD concentrations ranging from 1.18 mg/l to 42.68 mg/l (median: 9.75 mg/l, mean 10.27 mg/l). Nitrogen loading estimates ranged from 2.16 kg/day to 757.78 kg/day (median: 89.16 kg/day, mean: 139.12 kg/day), and nitrogen concentrations ranged from 0.11 mg/l to 49.79 mg/l (median: 3.70 mg/l, mean 6.43 mg/l). TDS loading estimates ranged from 366.37 kg/day to 1,417,185.22 kg/day (median: 36,275.81 kg/day, mean: 112,882 kg/day), and TDS concentrations ranged from 60.13 mg/l to 5,498.66 mg/l (median: 1,850.92 mg/l, mean: 1,918.04 mg/l). Chloride loading estimates ranged from 12.16 kg/day to 47,713.23 kg/day (median: 1,563.07 kg/day, mean: 4,544.35 kg/day), and chloride concentrations ranged from 1.66 mg/l to 435.52 mg/l (median: 84.88 mg/l, mean: 97.57 mg/l). Calcium loading estimates ranged from 62.49 kg/day to 75,948.38 kg/day (median: 1,852.59 kg/day, mean: 5,975.65 kg/day) and calcium concentrations ranged from 10.27 mg/l to 209.5 mg/l (median: 95.34 mg/l, mean: 94.61 mg/l). Total coliform concentrations ranged from 20.97 MPN/100 mL to 860,949.03 MPN/100 mL (median: 90,650 MPN/100 mL, mean: 187,163.62 MPN/100 mL).

Per capita Potential Loads

The *per capita* potential loads model was able to give estimates of BOD, total nitrogen, and phosphate throughout all the VSEC basins (Table 21). BOD loading estimates ranged from 0.91 kg/day to 26,226 kg/day (median: 377.34 kg/day, mean: 1,875.34 kg/day). BOD concentrations ranged from 0.01 mg/l to 7.75 mg/l (median: 1.92 mg/l, mean: 2.30 mg/l). Nitrogen loading estimates ranged from 5.91 kg/day to 169,922 kg/day (median: 2,444.80 kg/day, mean: 12,150.27 kg/day), and nitrogen concentrations ranged from 0.09 mg/l to 50.21 mg/l (median: 12.44 mg/l, mean: 14.87 mg/l). Phosphate loading estimates ranged from 0.17 kg/day to 387.22 kg/day (median: 18.74 kg/day, mean: 30.94 kg/day), and phosphate concentrations ranged from effectively 0 mg/l to 2.30 mg/l (median: 0.07 mg/l, mean: 0.17 mg/l).

Based on the *per capita* phosphate model predictions, concentrations of phosphate were more dilute as the total discharge in the river increased (Figure 28). The highest concentrations are seen in the Gomati River, the Tons river, and the Yamuna river above the confluence with the Chambal River. This is expected because the populations of the regions are very high, including the cities of Delhi (14.1 million), Chandigarh (9 million), Gwalior , and Lucknow (2.3 million) (Census of India, 2001). These estimates are likely understating the actual average annual concentrations of PO_4, since agriculture is very prolific throughout the Ganga Basin, even into the foothills of the Himalayas.

The modeled phosphate values at Hardwar, Allahabad (above Sangam), and Varanasi were all within 0.05 mg/L of the observed field values. The measured values at Kanpur (Kolya Ghat), Allahabad (below Sangam), and Patna were all markedly higher than the modeled values. The values measured in Kanpur (6.2 mg/L) exceeded the modeled value of the VSEC river segment by roughly 6 mg/L. Part of this is likely due to a modeling error, since the VSEC unit including Kanpur terminated further than 50 km downstream of the city (Figure 34). For this reason, this VSEC unit did not include the city in the analysis. However, even if the city's estimated population of 2.9 million (Census of India 2001) had been included in the calculation, the estimated annual average concentration would be 0.32 mg/L, far lower than measured. Similarly, the estimated phosphate levels at Allahabad (below Sangam) (0.29 mg/L) and Patna (0.13 mg/L) are both much lower than measured in 2004.

Estimate Comparisons

The two basin-wide pollution estimation methods provided different values for each site (Table 22). The MLR estimates for nitrogen loading and concentrations were on average 76.25 times greater (stdev=79.58) than the per capita estimates. The estimates ratio for BOD_5 were closer to each other, but the MLR estimates were on average 12.76 times greater (stdev=19.90) then the per capita estimates. Comparisons for total coliforms, chlorine, calcium, and TDS were not done, as there was no available per capita equation estimate for these pollutants. Conversely, a comparison for phosphate was not done, as there was no available empirical data available.

VSEC Basin Water Quality Classes

Using the empirical loading models, water quality classes were derived for each VSEC basin. Classification of water quality classes A, B, and C were assigned based on values of BOD and total coliforms. Estimates of BOD indicated that 658 river miles (1,059 km) were class A, 624 river miles (1,004 km) were class B, 168 river miles were class C, and the remaining 7281 river miles (11,717 km) exceeded class C BOD requirements (Figure 29). Based on total coliform estimates, 129 river miles (208 km) were class

A, 776 river miles (1,249 km) were class B, and 359 river miles (578 km) were class C. The remaining 7,467 river miles (12,017 km) exceeded class C total coliform requirements (Figure 30).

Of the 7,467 river miles (12,017 km) that exceeded class C requirements of total coliform counts or BOD concentration, 983 river miles (1,582 km) met the class D requirement of nitrogen (Figure 31). Of the remaining 6,484 river miles (10,485 km), 1,236 river miles (1,989 km) met the class E conductivity requirement, leaving 5,249 (8,447 km) river miles as being worse than class E (Figure 32).

Combining the water classification results, 5,249 river miles (8,447 km) were worse than class E, 1,236 river miles (1,989 km) were class E, 983 river miles (1,582 km) were class D, 425 river miles (684 km) were class C, 710 river miles (1,143 km) were class B, and 129 river miles (208 km) were class A (Figure 33). In the Ganga River mainstem, 129 river miles (208 km) were class A, 103 river miles (166 km) were class B, 81 river miles (130 km) were class C, 466 river miles (750 km) were class D, and 654 river miles (1,053 km) were worse than class E. Himalayan rivers (excluding the Ganga) generally had higher water qualities than non-Himalayan rivers, with 608 class B river miles (975 km), 344 class C river miles (554 km), 517 class D river miles (832 km), 827 class E river miles (1,331 km), and 1,237 river miles (1,991 km) that were worse than class E. Non-Himalayan rivers had no class A, B, C or D waters, 409 river miles (658 km) of class E, and 3,358 river miles (5,404 km) that were worse than class E (Table 19).

Discussion.

GAP evaluation

Based on the pre-GAP vs. post-GAP statistical analysis, it appeared that the key factors of DO, BOD, and nitrogen improved since the implementation of the Ganga Action Plan. These average annual declines in concentrations indicate that, overall, environmental conditions in the river have improved *vis-à-vis* the chemical components of domestic sewage. In this sense, a portion of the primary goal – reaching class B or better (MoEF, 2004) – of the GAP appears to be working.

However, total coliforms and fecal coliform levels appear to have deteriorated in the same period. This is most likely the direct impact of population growth without a commensurate increase in the region's pollution management infrastructure. Indeed, the story of much of the water infrastructure in the Ganga basin is one of bad planning, neglect, and failure (Niemzcynowicz *et al* 1998, MoEF 2004). Since total coliform counts are a central part of classifying a water's quality as class C or better (Table 1), unless coliform counts are greatly diminished, the water quality goals of the GAP will not be reached.

Implications of Increased Fecal Coliform Levels

The increased levels of total coliforms post-GAP was the major reason why so many sites did not achieved even class C status[20]. The associated increased levels of fecal coliform levels point to a looming public health crisis caused by a inexorable loss and pollution of existing water sources, which is only exacerbated by an ever-increasing poor population (Niemczynowizc *et al* 1998). Water development post-independence focused

[20] Classes A, B, and C all have a total coliform requirement. Classes D, and E do not have this requirement.

primarily on agriculture and industry, and India has still not been able to provide safe, potable drinking water to its populace through public infrastructure (Chaturvedi 2001). People living in cities and towns in the Ganga basin that receive their water directly from the Ganga suffer many enteric diseases (Gourdji *et al* 2005). In 1955 and 1956, 40,000 Delhi residents fell victim to infective hepatitis contracted from drinking water from the Yamuna River, and an estimated 50-75% of the human population of India's major cities suffers from several stomach ailments and digestive diseases (Maruthanayagam & Kumar 2002). Pandey (1991) also made a connection between elevated coliform counts downstream of Kanpur and increased enteric diseases of local villagers who used water drawn from the river. During a visit to a health clinic in Hardwar in January 2004, doctors were expecting to have several thousand patients complaining of gastrointestinal disease.

One possible major source of such high levels of fecal coliforms is public defecation, which is common in many places in northern India, and personally witnessed in all the cities visited. Part of this is a lack of public restrooms, or a lack of sanitary public restrooms, where such are constructed. Krishnan & Sujatha (2002) reported public defecation rates of 18.4 ± 0.83 visits/½ hour on the banks of an urban river in southern India. Rates upstream and downstream of the city were lower. Interestingly, public defecation rates increased during the monsoon. This increase was hypothesized to be due to the increased accessibility to water. Added to defecation levels of a city's human occupants is the defecation rate of the animals, which may be found roaming the streets, or freely accessing the river.

Presence of fecal coliforms indicates a lack of proper sewage treatment. In regions where fecal coliforms are high, other bacteria or intestinal parasites may also be found in the water, posing additional health risks to bathers. Indirect contraction of these parasites through eating fish – a major source of protein – that are infected is also possible (UNESCO 2006).

Part of the solution is the construction and maintenance of public toilet facilities to decrease the amount of unsewered fecal discharge. Without these facilities, construction of additional sewage treatment plants is not useful. However, in many areas, the construction and maintenance of, and assured power for sewage treatment plants is still required (MoEF, 2004). A short- to medium-term solution of lower cost may be the construction and encouraged use of pit latrines (UNESCO 2006), especially in areas with little or no effective sewage infrastructure.

Changing the Criteria

An interesting point to mention was the one-year change of water quality criteria that occurred in 2002. Although there is no indication as per motive, the CPCB adopted a "Revised Water Quality Criteria" (Table 24), splitting the existing six water quality classes (A-E, worse than E) to three classes (A-C) (CPCB, 2002). The 2002 classification system was, while having a greater number of parameters, less stringent in terms of conductivity and BOD than the original, and none of the new classes include those of extremely poor water quality as the original classes D and E. Whether this was an attempt at changing the standard to accommodate reality (and thereby proclaim success), or an attempt at conducting a systematic change unrelated to water quality goals is not clear; no explanation is available for the changes.

On a quick assessment of the 2002 data, 9 sites (8.7%) were class A, 43 sites (41.7%) were class B, and 51 sites (49.5%) were class C[21]. With the revised criteria, over half of the monitored sites were "in attainment" of the Ganga Action Plan. In 2003, the CPCB reverted to the original water quality criteria. The reasons why they reverted to their original criteria remain unexplained. The reported water quality data for 2002 remain as nominal categories (A, B, and C), rather than the otherwise-normal array of minimum, maximum, and mean observations. Using the original classification system with the 2003 data, there were no sites achieving class A, 11 sites (9.7%) were class B, 29 sites (25.7%) were class C, 19 sites (16.8%) were class D, 46 sites (40.7%) were class E and 8 sites (7.1%) were worse than class E (Table 25).

Although there is no evidence for why the CPCB returned to the original water quality classification system, the discrepancy between the range of water quality reported under the "Revised Water Quality Criteria" and the original criteria may have provoked a public outcry, especially if the CPCB used the new criteria to show a greater number of sites achieving class B status.

Current water quality on Ganga

Based on the CPCB's original water quality criteria, the majority of the river is in poor shape; even in regions of the watershed that are not monitored by the CPCB. With near consistency, it would appear that the GAP has failed to effectively return the Ganga River to bathing (B) class. Furthermore, based on the model output, the CPCB should focus their monitoring and enforcement efforts within the southern tributary systems, the Gomati River watershed, the upper half of the Yamuna River, and the parallel portion of

[21] 2002 data from the CPCB were given in A, B, and C classes.

the Ganga River. These, coincidently, are regions of low flow and high population density.

The modeled phosphate concentrations indicate the additional need for the CPCB to monitor and control phosphate levels. The model does not include any possible inputs from agriculture, but with phosphate inputs from pesticides and fertilizers, the actual levels can be much higher than modeled (see below).

Variation of phosphate between modeled and measured values

The highly-divergent observed phosphate value found at Kanpur (Kolya Ghat) may have been due to several factors. The first factor was the non-inclusion of Kanpur's population within the VSEC arc's watershed, as mentioned earlier. However, even if the city's population were included, it would not approach the observed value of 6.2 mg/L. Two observed phenomena at Kanpur were untreated sewage and a vast amount of floodplain agriculture. In addition to the possibility of agricultural phosphate, Panday (1991) lists six different pollution sources at Kanpur, including 16 untreated sewers, dead bodies, dairies housing over 80,000 milk cows, night soil disposal, and 160 tanneries. There is, unfortunately, no published value of the amount of phosphate fertilizers used in and around the city, nor a baseline phosphate value against which to base the measured result. If a majority of the sewage in Kanpur is not treated, and phosphates are used extensively in regional agriculture, these will have a major impact on the observed phosphate levels in the river, as the discharge of the Ganga River is relatively smaller than at other measured sites.

The major impacts to the phosphate values at Allahabad (below Sangam) may have been due to two phenomena: the Ardh Kumbh Mela pilgrimage, and primary sewage discharge into the Yamuna River. The sampling day in Allahabad was also republic Day, a national holiday, and the shores of the Yamuna-Ganga confluence were full to capacity with people. In addition, there were seemingly thousands of bathers in boats and constructed jetties, dipping into the Ganga to bathe (Figure 35). No public restrooms were in evidence, but walking on the far shore from the Sangam, there was plenty of evidence of human feces. One might imagine a similar picture on the Sangam shore. The presence of a lot of human bodily waste from pilgrims at the Sangam would indicate why measured phosphate and ammonia were quite high. This hypothesis is somewhat corroborated by a previous study that reported increases in turbidity, total solids, BOD, COD, chlorides, alkalinity, phosphates, fecal coliforms, and total coliforms all due to mass bathing at and near the city of Allahabad (Sinha 1991).

Regarding the second point – sewers in the Yamuna River vs. sewers in the Ganga – our group was informed that seven sewers carried the majority of Allahabad's sewered waste into the Yamuna River, much more than what was delivered to the Ganga. Although this could not be independently verified based on the hydrological evidence, this makes intuitive sense, as the Yamuna (3,045 cms) has more water than the Ganga (1,361 cms) at Allahabad (Figure 14), especially during the dry season (Figure 36). In addition, a large portion of the Ganga's flow is removed from the river at various points between Kanpur and Allahabad for use in irrigation, with little return flow (Gourdji et al 2005). For these reasons, if assimilative capacity of the river *vis-à-vis* domestic sewage production was an important concern to Allahabad's planners and civil engineers, it would have made greater sense to deliver more effluent to the Yamuna River as opposed to the Ganga River.

This hypothesis was not borne out in the phosphate model, since the Yamuna River at Allahabad was modeled to have a relatively low phosphate concentration (0.02 mg/L). The model assumed that roughly half the sewage discharge at Allahabad went to the Yamuna River, with the city being split roughly in half between the Yamuna and Ganga basins (Figure 37). However, in a report by the Indian Public Accounts Committee (2004), Allahabad was found to be treating only 60 MLD[22] of the estimated 210 MLD of sewage produced within the city. This shortfall could go a long way to explaining the elevated levels of pollutants.

The causes of high phosphate at Patna are a little less clear than at Kanpur and Allahabad. Here, the average discharge of the Ganga is 7,406 cms, and yet the observed phosphate concentration was 0.13 mg/L, as compared to the modeled 0.01 mg/L. One explanation may be organo-phosphates which are widely-used in agriculture (Maruthanayagam & Kumar 2002), since the entire region surrounding Patna is agricultural fields. Untreated sewage from the city may also have elevated PO_4, but it seems that emphasizing the impacts of a city of 2 million people may overstate the importance of Patna city's human pollution contribution to the measured value, since the estimated input of the city's human pollution was far smaller than observed.

The extremely high phosphate concentration measured at Kolkata (2.96 mg/L) was likely due to the impacts of a highly-industrial city of over 11 million people (Census of India, 2001), with large non-sewered areas, and little industrial pollutant mitigation or oversight. Phosphate estimates were not done for Kolkata, since its more complex hydrology precluded the estimation of an annual average discharge value. However, using a reported discharge value of 13,705 cms (from Rao 1975) and the *per capita* loading

[22] MLD: "millions of liters per day"

model provides explanation for only 0.1 mg/L of the phosphate assuming secondary treatment (0.16 mg/L assuming no treatment). However, the Hooghly river downstream of Kolkata is affected by tides, and (as noted in methods), at the time of measurement, the river was flowing slightly North, indicating a potential buildup of pollutants behind the rising tide. Further, although the Farakka Barrage diverts water from the Ganga and into the Hooghly River to flow eventually to Kolkata, the river system at this point is deltaic, and is comprised of several distrubutary systems that, even though a significant portion of Ganga water may be diverted toward Kolkata, the Hooghly may well now receive less than the reported 13,705 cms.

Comparison of the MLR and per capita *models*

Although the magnitude of the modeled results differ between the *per capita* models and the MLR models for BOD and nitrogen, my *per capita* models showed less difference in BOD and nitrogen concentrations between the Vindhya Mountains and the Himalaya Mountains than was shown in the MLR models. The primary reason for this is the inclusion of discharge as a factor within the MLR model, which therefore implicitly includes the lower discharge values of the southern tributaries.

The estimated values from the MLR model more-closely matched the reported values from the CPCB, since it was upon these data that the MLR is based. These MLR values implicitly include some estimate of human waste, as well as animal waste, agriculture and industry. More generally:

$$MLR_{estimate} = waste_{total} + Q + error$$

where $waste_{total} = waste_{human} + waste_{animal} + waste_{agriculture} + waste_{industry}$

The *per capita* model values represent a rough calculation based on standard estimates of pollutant from domestic human sources alone:

$$percapita_{estimate} = waste_{human} .$$

In other words, the *per capita* models are conservative estimates of pollutant production, and a portion of the difference between the MLR and *per capita* model results may be construed of as the non-human inputs to the river.

If the estimate differences between the two models were consistent to phosphorus, estimates would be much higher than the *per capita* model predictions, and the magnitude of this difference would likely be even greater in the southern rivers. However, the difference between the two BOD models (BOD_{MLR}=12.76*$BOD_{percapita}$) and the two nitrogen models (N_{MLR}=76.25*$N_{percapita}$) were not consistent, making any extrapolation from the *per capita* model of phosphate impossible.

Spatial and temporal variation

The analyses conducted in this study had to be based on average discharges and average pollutant concentrations. Seasonal flow variations were not included due to a lack of adequate discharge data throughout the river network. However, as mentioned previously, the story of the Ganga is one with two parts: the dry season when water is scarce, and the monsoon season, when river flow can be as much as 25 times higher (Figure 4). The CPCB's water yearbooks, which report results as minimums, maximums, and mean values, and number of samples reported per year do not describe adequately the hydrologic and hydraulic impacts of the yearly monsoon cycle – the period when the vast majority of precipitation falls in the system. Without knowing the impacts of this seasonal flow variation, it is impossible to tell what the ranges of conditions are during the dry and wet seasons. One could surmise that it was more likely that minimum pollutant concentrations occurred during the monsoon, when higher discharge values can dilute pollutants and vice-versa with high concentrations occurring during the dry season. However, the available evidence does not bear this out.

Bilgrami (1991) showed that total coliform and streptococci counts were up to 200 times greater during the monsoon period at the cities of Sultanganj and Bhagalpur. Saha *et al* (2002) also reported higher bacteria levels in some study areas during the wet season, possibly due to decreased osmotic pressure and lower levels of toxics; but, in other areas, numbers dropped because of dilution. Regardless, it was found that fecal coliform and salmonella counts significantly increased in canal systems due to increased "leaching" from contaminated areas during the monsoon.

Mathur (1991) showed that the pollutant parameters of TSS, alkalinity, chloride, BOD, and COD all varied by season and location in a more complex manner than hypothesized above. For example, BOD was shown to be the highest during the monsoon season at the confluence of the Song River, and again from the city of Balawi (just downstream of Hardwar) to the city of Narora (midway between Allahabad and Varanasi). COD increases were not as pronounced, except at the confluence of the Song River. Turbidity was shown to be up to 16 times greater during the monsoon in the upper half of the Ganga River (upstream of Narora), but not so greatly increased in the river's lower half. Chloride was shown to have an opposite relationship from that of turbidity, and was almost 2 times higher during the monsoon for much of the lower half of the river, but was roughly the same as the rest of the year in the upper half of the river.

In addition to the complicated spatial and seasonal variation in pollutant concentrations, the frequency of water quality reporting is itself variable between different sites, with reporting occurring anywhere between 1 and 12 times each year. It is unknown whether reporting is done on a regular interval, or done on a more *ad hoc* basis. Additionally, sites with fewer than six samples may very well not include the critical 15-day period of the monsoon, even if samples were taking at regular intervals. Similarly, sites in the Himalaya headwaters may not be accessible for much of the year, thus limiting sampling to as few as one sample per year. This is another reason why one cannot assume that the value of the pollutant concentration is directly related to the season.

The range of observed pollutant concentrations in the river (Table 17) indicated that river pollution in the Ganga River basin suffers from both extreme episodic pollution events, as well as generally elevated long-term pollution levels. Episodic pollutant discharges could not be quantified with the available data, however, and only average pollutant levels were available for analysis. Looking only at the mean values provided by the CPCB, the Ganga River system had similar values for DO, BOD, COD, NO_X, pH, and conductivity (Table 17) to that of the Danube River (ICPDR 2003) – a highly populated river of similar drainage area, also suffering from industry-related pollution problems. Values of fecal ($2.3x10^7$ MPN/100mL) and total coliforms ($9.2x10^6$ MPN/100mL) in the Ganga River were very high compared to what is allowable under either the United States' Clean Water Act's requirement (126 MPN/100mL, USEPA 1986) or the EU's "bathing waters" requirement of 500 MPN/100mL for total coliforms, and 100 MPN/100mL for fecal coliforms (EU 2005).

The CPCB reported maximum pollution levels of DO, BOD, COD, NO_X, pH, and conductivity, which far exceed the maximum values reported for the Danube River. With few samples taken per year, the presence of so many large pollution events present in a monthly (or greater-than-monthly) sampling of the river is troubling. This could indicate that pollution events were serendipitously measured; that pollution events initiated a monthly water monitoring check; even greater extreme pollution events occurred that were not measured; or that water pollution was relatively continuous during those parts of the year when industries operated.

By contrast, the majority of EU standards for bathing class waters are expected to be measured every two weeks while standards are being met, and more frequently – depending on the pollutant – when water quality falls below the standard. In addition to regular testing, some pollutant measurements are only to be made in a situation where the water quality had deteriorated, and continued until the parameter requirements had been met (EU 2005). While this is a more costly measure, conducting a more-regimented set of tests throughout the basin would produce a data set with higher temporal resolution, as well as provide better enforcement and management possibilities.

Conclusions.

In March 2000, Phase I of the GAP (construction of STPs to treat 870 MLD of sewage) was completed, 10 years behind schedule. Phase II of the GAP was a reaction to the realization that not enough pollution was being treated under Phase I, and a new goal of treating a total of 1912 MLD of sewage was set. This goal is expected to be reached in 2008 (MoEF 2004). However, major shortfalls in the execution of both phases have caused both public and governmental anger and impatience. Even with the construction of a greater number of STPs, however, there continues to be no monitoring for phosphate, heavy metals, and pesticides, all of which are known to be entering the river (Datta 1991; Mathur 1991; Pandey 1991; Sinha 1991; Maiti and Banerjee 2002; Saha *et al* 2002, Maruthanayagam and Kumar 2002).

So far, the Ganga River appears to have continued to be robust against a majority of these failures of management. With apparently serious continued governmental discussion of interbasin water diversions out of the Ganga (Gourdji *et al* 2005), the future of the GAP may be its real testing period. The water needs of an ever-increasing regional population will compete with the regions ability to maintain its own water quality and fisheries while the growing richer populations of Central and Southern India will be clamoring for increased national water parity. Under the current methods of the GAP, treatment costs for sewage are likely to increase in the future as effluent from STPs must be more heavily treated in order to meet the same pollutant concentration standard in a river with less water. It is likely that the provisions of the GAP must change to incorporate the impacts of interbasin water transfers. If the plans for inter-basin water transfers go forward, the story of the next 20 years of Ganga River water quality will be an interesting one to follow.

Caveats, problems, future analysis

Quality Assurance Quality Control

Throughout this analysis, I have had to trust that the publicly-available CPCB data were accurate. Although the implicit accuracy of CPCB data regarding the underlying veracity of using pollutant means has been discussed, the reporting of data was not always accurate. There were several obvious reporting errors, as well as some highly-dubious values. One example was the reporting of a negative pH. A DO value of 92mg/L is also obviously incorrect. The measurement of very low pollutant concentrations did not always make logical sense, since they majority of CPCB sites were located in or near cities and towns. The possibility of a conductivity of 4 mmho/cm is also suspect. However, the reported values of the CPCB are the only comprehensive data source available, and if there is some misreporting of values, they must be removed where possible, and noted in general.

Modeling phosphate

The phosphate prediction model I developed was very simple, and would require several other factors to make the model more closely reflect reality. However, this is the first basin-wide attempt at predicting average annual levels of phosphate. Some other variables that may be of significant importance are land use, a decay rate of phosphate as a function of distance and river discharge from a known point source, and a city-by-city phosphate treatment value (since full secondary treatment is known not to occur, even in major cities). The level of resolution, as with the other VSEC estimates, may still be too coarse. However, even the availability of even a coarse tool for predicting phosphate in a river system as important as the Ganga River should be pursued further. Phosphate monitoring by the CPCB needs to be done, since the impact of phosphate in freshwater systems is well known.

Modeling the Effects of the Monsoon

Since the monsoon is so central to the hydrology of the Ganga river system, its inclusion in future models is of great importance. However, due to the lack of seasonal data, as mentioned above, this may not easily be done without having greater access to the raw data making up the publicly-available CPCB data[23]. In addition, the longitudinal climate differences through the watershed make a good estimation of discharge at and within each tributary system quite complicated. Gourdji *et al* (2005) produced a basic HEC-HMS model for the Ganga River, which may prove a good basis around which to organize future modeling efforts as more environmental variables are quantified.

[23] It was hinted that if the raw data upon which the CPCB water yearbooks were produced were still available, they would likely be kept at regional headquarters, due to the decentralized nature of each reporting unit.

Tables.

TABLE 1
Indian Central Pollution Control Board's classification of water quality criteria.

Designated Best Use	Class of Water	Criteria
Drinking water source without conventional treatment but after disinfection	A	1. Total Coliforms ≤ 50 MPN/100 ml 2. pH between 6.5 and 8.5 3. Dissolved Oxygen ≥ 6 mg/l 4. BOD_5 ≤ 2 mg/l
Outdoor bathing (organized)	B	1. Total Coliforms ≤ 500 MPN/100 ml 2. pH between 6.5 and 8.5 3. Dissolved Oxygen ≥ 5 mg/l 4. BOD_5 ≤ 3 mg/l
Drinking water source	C	1. Total Coliforms ≤ 5000 MPN/100 ml 2. pH between 6 and 9 3. Dissolved Oxygen ≥ 4 mg/l 4. BOD_5 ≤ 3 mg/l
Propagation of wildlife, fisheries	D	1. pH between 6.5 and 8.5 2. Dissolved Oxygen ≥ 4 mg/l 3. Free ammonia (as N) ≤ 1.2 mg/l
Irrigation, Industrial Cooling, Controlled Waste	E	1. pH between 6.0 and 8.5 2. Electrical Conductivity ≤ 2250 μmhos/cm 3. Sodium absorption ratio max 26. 4. Boron max 2 mg/l

TABLE 2
Water quality parameters reported by the CPCB.

Parameter	Unit
Temperature	ºC
Dissolved Oxygen	mg/L
pH	--
Turbidity	JTU/NTU
Hardness	mg/L
Total Coliforms	MPN/100mL
Fecal Coliforms	MPN/100mL
Conductivity	M mho/cm
Alkalinity	mg/L
Calcium (Ca)	mg/L
Chloride (Cl)	mg/L
Magnesium (Mg)	mg/L
Sulfates (SO4)	mg/L
Sodium (Na)	mg/L
Nitrate/Nitrite (NOx)	mg/L
Total Kjeldahl Nitrogen (TKN)	mg/L
Total Dissolved Solids (TDS)	mg/L
Biological Oxygen Demand (BOD)	mg/L
Chemical Oxygen Demand (COD)	mg/L

TABLE 3
Basic regression analysis of Ganga River basin river discharge (Q) based on upstream watershed area (A).

R^2 = 88.3% R^2 (adjusted) = 87.8%
s = 0.4937 with 24 - 2 = 22 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	40.6554	1	40.6554	167
Residual	5.36134	22	0.243697	

Variable	Coefficient	s.e. of Coeff	t-ratio	Prob
Constant	-3.54445	0.78	-4.54	0.0002
ln(A)	0.924866	0.07161	12.9	≤ 0.0001

TABLE 4
ANCOVA test between 26 world rivers' annual average discharges and 16 Ganga Basin annual average discharges. Analysis of regression lines' y-intercepts. There is no significant difference between the two datasets.

F	**$df_{world\ rivers}$**	**$df_{Ganga\ Basin}$**	**Sig.**
0.874494	24	16	> 0.05

TABLE 5
ANCOVA test between 26 world rivers' annual average discharges and 16 Ganga Basin annual average discharges. Analysis between regression lines' slopes. There is no significant difference between the two datasets.

F	$df_{world\ rivers}$	$df_{Ganga\ Basin}$	Significance
0.548758	24	16	> 0.05

Q = annual average discharge
Computing using $\alpha = 0.05$, $R^2 = 0.80209$

TABLE 6

Regression line slope analysis between 14 Ganga River basin annual average discharge sites and 4 Yamuna River basin annual average discharge sites.

F	df_{Yamuna}	df_{Ganga}	Significance
-2.05448	2	12	> 0.05

Q = annual average discharge

Computing using $\alpha = 0.05$, $R^2 = 0.7977$

TABLE 7
Modeled discharge values based on reported discharge values (Rao 1975). Difference in river discharge values (Reported Q – Modeled Q) also given.

River	Station	Observed Q (cms)	Predicted Q (cms)	% Difference
Ganga	Hardwar	677	963	+29.7%
	Allahabad before Sangam	1670	1290	-29.5%
	Allahabad after Sangam	4304	6302	+31.7%
	Patna	10307	11639	+11.4%
	Farakka	12998	16953	+23.3%
Yamuna	Delhi	388	568	+31.7%
	Allahabad before Sangam	2634	2963	+11.1%
Ramganga	Confluence w/Ganga	432	416	-3.8%
Gomati	Confluence w/Ganga	209	378	+44.7%
Ghaghara	Confluence w/Ganga	2673	2188	-22.2%
Gandak	Confluence w/Ganga	1478	1135	-30.2%
Tons	Confluence w/Ganga	167	210	+20.5%
Sone	Confluence w/Ganga	900	732	-23.0%
Kosi	Confluence w/Ganga	1743	2194	+20.6%
Bhuri Gandak	Confluence w/Ganga	201	513	+60.8%
Chambal	Confluence w/Yamuna	851	854	+0.4%
Betwa	Confluence w/Yamuna	283	329	+14.0%
Ken	Confluence w/Yamuna	320	297	-7.7%
			Average difference	+11.06

TABLE 8

Paired t-test comparison between reported and mapped watershed areas.

H_0: $\mu[\ln(Area_{mapped}) - \ln(Area_{reported})] = 0$	
H_a: $\mu[\ln(Area_{mapped}) - \ln(Area_{reported})] \neq 0$	
	Mean of Paired Differences = 0.003992532
	t-Statistic = 0.04466
	df = 18
	p = 0.9649

TABLE 9
Multiple regression analysis of average annual discharge prediction model based on tributary watershed areas (km^2), regional annual precipitation (mm/year), and the percentage of the watershed originating in the Himalaya mountains.

R squared = 95.5% R squared (adjusted) = 94.4%
s = 0.369 with 16 - 4 = 12 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	34.8317	3	11.6106	85.3
Residual	1.63416	12	0.13618	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-4.69783	0.7848	-5.99	≤ 0.0001
ln(Area)	0.876326	0.06088	14.4	≤ 0.0001
Precipitation	0.001192	4.53×10^{-04}	2.63	0.0218
%Himalaya	1.00083	0.3267	3.06	0.0098

TABLE 10

Multiple regression analysis of the natural log of average annual BOD_5 load prediction model based on total watershed population.

R squared = 74.5%   R squared (adjusted) = 73.4%
s = 0.7787 with 52 - 3 = 49 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	86.6972	2	43.3486	71.5
Residual	29.7133	49	0.606394	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-0.541658	1.038	-0.522	0.6040
ln(Q)	0.319948	0.1585	2.02	0.0491
$\ln(Pop_{total})$	0.435226	0.1193	3.65	0.0006

Q = river discharge (cms)
Pop_{total} = Total upstream population

TABLE 11
Multiple regression analysis of the natural log of average annual total nitrogen load prediction model based on total watershed population.

R squared = 69.4% R squared (adjusted) = 67.9%
s = 1.062 with 44 - 3 = 41 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	104.969	2	52.4843	46.6
Residual	46.2236	41	1.12741	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-3.55265	1.442	-2.46	0.0180
ln(Q)	0.0671292	0.2327	0.288	0.7744
$\ln(Pop_{total})$	0.723896	0.1681	4.31	0.0001

Q = river discharge (cms)
Pop_{total} = Total upstream population

TABLE 12
Multiple regression analysis of the natural log of average annual total dissolved solid load prediction model based on watershed population, and annual average discharge.

R squared = 70.6% R squared (adjusted) = 69.4%
s = 1.1 with 52 - 3 = 49 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	142.2	2	71.1002	58.8
Residual	59.2365	49	1.20891	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	1.23104	1.465	0.84	0.4049
ln(Q)	0.212352	0.2238	0.949	0.3474
$\ln(Pop_{total})$	0.698074	0.1685	4.14	0.0001

Q = river discharge (cms)
Pop_{total} = Total upstream population

TABLE 13
Multiple regression analysis of the natural log of average annual total coliform concentration prediction model based on watershed population, and annual average discharge.

R squared = 33.4% R squared (adjusted) = 30.7%
s = 2.42 with 52 - 3 = 49 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	144.02	2	72.0101	12.3
Residual	287.045	49	5.85806	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-5.7248	3.225	-1.78	0.0821
ln(Q)	-1.51544	0.4927	-3.08	0.0034
$\ln(Pop_{total})$	1.67745	0.3709	4.52	≤ 0.0001

Q = river discharge (cms)
Pop_{total} = Total upstream population

TABLE 14
Regression of MLR-based nitrogen load calculation results against per capita maximum potential daily maximum nitrogen load. The slope coefficient of "N_{load}" is the value of the estimated delivery ratio.

R squared = 25.0% R squared (adjusted) = 24.2%
s = 8885 with 91 - 2 = 89 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	2.34675×10^9	1	2.34675×10^9	29.7
Residual	7.02654×10^9	89	78.9499×10^6	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-338.433	1256	-0.269	0.7882
N_{load}	2.85403	0.5235	5.45	≤ 0.0001

Calculated nitrogen load based on MLR model.

TABLE 15

Regression of MLR-based BOD_5 load calculation results against per capita maximum potential daily maximum BOD_5 load. The slope coefficient of "BOD_{load}" is the value of the estimated delivery ratio of BOD_5.

R squared = 98.1% R squared (adjusted) = 98.1%
s = 840.6 with 91 - 2 = 89 degrees of freedom

Source	Sum of Squares	Df	Mean Square	F-ratio
Regression	3.31149×10^9	1	3.31149×10^9	4.69×10^3
Residual	62.8936×10^6	89	706669	

Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	-1105.44	103.1	-10.7	≤ 0.0001
BOD_{load}	0.734179	0.01073	68.5	≤ 0.0001

Calculated BOD_5 load based on MLR model.

TABLE 16
Modified classification of water quality, based on available modeled pollution parameters.

Class of Water	Criteria
A	1. Total Coliforms ≤ 50 MPN/100 ml 2. $BOD_5 \leq 2$ mg/l
B	1. Total Coliforms ≤ 500 MPN/100 ml 2. $BOD_5 \leq 3$ mg/l
C	1. Total Coliforms ≤ 5000 MPN/100 ml 2. $BOD_5 \leq 4$ mg/l
D	1. N ≤ 1.2 mg/l
E	1. Electrical Conductivity ≤ 2250 µmhos/cm

TABLE 17
Pre-GAP and post-GAP reported pollution concentrations from Central Pollution Control Board, with comparison with the Danube River.

	Danube (2002)		Pre-GAP			Post-GAP		
	Range of Yearly Means	Total Range	Mean	Min	Max	Mean	Min	Max
DO	6.7 - 11.6	3.2-26.3	7.4	0.1	92	7.3	0.3	22.8
BOD	1.2 - 10.2	0.4-48.0	5.0	0.1	175	6.6	0.3	230
COD	5.0 - 42.8	1.9-160	27.0	0.6	770.4	36.5	1	999.9
NOx	0.55 - 4.69	0.05-8.23	5.9	0.001	80	0.1	0.001	3.54
pH	7.2 - 8.3	6.4-9.0	8.0	1.5	13.8	7.9	2	10
Fcoli	N/A	N/A	2.2 x105	1	2.4x108	2.3x107	1	1.87x1010
Tcoli	N/A	N/A	2.5 x105	2	2.4x108	9.2x106	1	9.55x109
Cond	217 - 954	140-1092	449.7	4	20000	514.9	10	11660
Cl	N/A	N/A	38.7	1	3234	83.0	2	4674
SO4	N/A	N/A	29.2	1	2100	157.3	1	9999
Na	N/A	N/A	32.9	1	16200	83.4	3	1328
Ca	N/A	N/A	78.3	1	340	122.0	18	1140
Mg	N/A	N/A	49.2	1	995	75.5	4	1330

TABLE 18

Water quality factors measured by the CPCB pre-GAP and post-GAP.

	μ(Pre-Post)≠0 P-value	**μ(Pre-Post)>0 P-value**	**μ(Pre-Post)<0 P-value**	**Pre-GAP Mean (ln)**	**Pre-GAP σ^2 (ln)**	**Post-GAP Mean (ln)**	**Post-GAP σ^2 (ln)**	**t-stat**	**df**	**mean paired difference (ln)**
lnDO	0.1380	0.9310	*0.0690*	1.93	0.36	1.95	0.34	-1.515	38	0.256
lnBOD	*0.0647*	**0.0323**	0.9677	1.25	0.90	1.04	0.87	1.904	37	0.251
lnCOD	0.5885	0.2943	0.7057	3.04	0.79	2.92	0.79	0.546	38	0.078
lnNOx	**0.0008**	**0.0004**	0.9996	-0.41	1.58	-3.55	1.77	5.209	8	3.054
pH	0.8131	0.5934	0.4066	2.00	0.54	2.07	0.03	-0.238	33	-0.010
Temp	0.4520	0.7740	0.2260	3.14	0.67	3.16	0.23	-1.259	37	-0.212
Fcoli	0.1586	0.9207	*0.0793*	9.09	3.01	8.67	4.04	-1.439	37	-0.851
Tcoli	0.1947	0.9026	*0.0974*	9.94	2.91	10.62	3.48	-1.321	37	-0.684
lnAlkalinity	0.3041	0.8480	0.1520	4.69	1.08	4.94	0.61	-1.048	26	-0.253
lnChloride	0.3355	0.8323	0.1677	3.08	1.23	3.11	1.13	-0.977	34	-0.134
lnSO4	0.6578	0.3289	0.6711	3.16	0.94	3.29	1.16	0.447	32	0.072
lnNa	0.3359	0.8320	0.1680	2.66	1.01	2.97	0.82	-0.990	17	-0.113
lnCa	0.1277	0.9361	*0.0639*	4.13	0.94	4.49	0.56	-1.578	24	-0.367
lnMg	*0.0608*	0.9696	**0.0304**	3.61	0.95	3.98	0.60	-1.968	24	-0.418
lnTDS	**0.0391**	0.9805	**0.0195**	5.35	1.25	5.58	0.65	-2.139	37	-0.460

H_0: $\mu[\ln(GAP_{before})-\ln(GAP_{after})] = 0$, H_a as indicated in the table. *Italics* indicate $\alpha<0.1$. **Bold** indicates $\alpha<0.05$

TABLE 19

Field sample results. Note that many of the samples needed to be diluted in order to be read by the instruments. Only half of the samples could gain a COD reading. The remainders indicate a known lower bound.

City	Date	NH_4	PO_4	NO_3-N	COD
Hardwar	1/19/2004	< 0.01	< 0.01	0.02	> 5
Kanpur (Water intake)	1/23/2004	2.75	1.26	0.14	> 25
Kanpur (Kolya Ghat)	1/23/2004	0.1	6.2	0.74	>50
Allahabad (Above Sangam)	1/26/2004	0.02	0.03	0.28	20
Allahabad (Below Sangam)	1/26/2004	0.2	0.29	0.39	> 50
Varanasi	2/8/2004	0.22	0.04	0.2	10
Patna	1/29/2004	< 0.01	0.13	0.09	13
Kolkata	2/4/2004	0.54	2.96	0.12	> 20

TABLE 20
Empirical loading estimates of calcium, chloride, BOD_5, NO_x, and TDS in Ganga River VSEC basins.

	Q	Watershed	Pollutant Loading (kg/day)					Pollutant Concentration (mg/L)					Concentration (MPN/100 mL)
Station ID	cms	Population	Calcium	Chloride	BOD_5	NO_x	TDS	Calcium	Chloride	BOD_5	NO_x	TDS	Total Coliforms
3900	181.84	58972	273.72	61.14	31.66	9.97	1911.00	17.42	3.89	2.02	0.63	121.64	123.55
3820	138.22	15988	144.11	21.35	16.43	3.81	724.87	12.07	1.79	1.38	0.32	60.70	20.97
3810	286.11	35848	253.77	40.93	29.48	4.68	1486.45	10.27	1.66	1.19	0.19	60.13	26.97
3801	55.32	7948	62.49	12.16	9.04	2.16	366.37	13.07	2.54	1.89	0.45	76.65	26.00
3800	546.13	519372	1120.10	353.07	116.04	44.20	11021.60	23.74	7.48	2.46	0.94	233.58	897.37
3700	594.61	8039404	4006.36	3212.14	392.84	361.01	75965.78	77.98	62.52	7.65	7.03	1478.68	78116.13
3360	113.61	50120	141.76	53.63	25.38	8.59	1543.74	14.44	5.46	2.59	0.87	157.27	191.83
3350	129.96	59312	164.78	61.42	28.51	2.54	1786.60	14.67	5.47	2.54	0.23	159.11	207.54
3340	131.26	102416	213.66	95.40	36.28	7.78	2621.46	18.84	8.41	3.20	0.69	231.15	511.09
3330	238.35	2611828	1233.82	1297.90	179.76	153.40	28540.23	59.91	63.02	8.73	7.45	1385.87	47349.78
3320	326.30	6937900	2455.50	2852.43	304.07	232.38	60339.44	87.10	101.18	10.79	8.24	2140.31	151475.61
3310	416.15	12335106	3896.59	4535.72	422.23	277.23	94949.54	108.37	126.15	11.74	7.71	2640.77	275089.41
3230	45.12	2875606	796.32	1402.56	110.05	151.40	21435.03	204.28	359.79	28.23	38.84	5498.66	693222.59
3220	91.77	6121966	1653.63	2578.81	191.89	173.36	42235.56	208.57	325.26	24.20	21.87	5327.05	839655.06
3210	94.07	6355062	1702.81	2657.66	196.60	25.80	43581.06	209.50	326.98	24.19	3.17	5361.91	860949.03
3200	891.51	32241574	10263.00	9839.39	818.50	296.25	218294.58	133.24	127.74	10.63	3.85	2834.02	434514.85
3100	1289.70	34756938	10823.23	10453.56	951.76	172.10	248811.71	97.13	93.81	8.54	1.54	2232.90	281652.96
3000	67.53	40466	124.51	45.13	19.58	7.10	1190.52	21.34	7.74	3.36	1.22	204.04	294.71
2900	265.86	882464	889.06	541.27	116.08	70.10	13695.11	38.70	23.56	5.05	3.05	596.20	6500.30
2800	283.61	950532	952.00	574.68	122.40	11.40	14623.50	38.85	23.45	5.00	0.47	596.78	6676.33
2700	293.17	9806106	2586.02	3769.91	341.59	387.52	75098.04	102.09	148.83	13.49	15.30	2964.76	318314.45
2620	300.25	440972	931.24	309.44	89.24	44.25	8658.93	35.90	11.93	3.44	1.71	333.78	1688.42
2610	318.83	3204200	2089.34	1530.36	215.65	167.72	35015.27	75.85	55.55	7.83	6.09	1271.11	42931.35
2600	362.01	17442768	4482.85	5996.90	469.54	238.16	117403.35	143.32	191.73	15.01	7.61	3753.58	607590.76
2500	508.44	27046112	7371.50	8540.06	633.54	426.42	171388.43	167.81	194.41	14.42	9.71	3901.50	757872.68
2400	530.86	29719962	7910.33	9214.28	669.26	169.48	184732.80	172.46	200.89	14.59	3.70	4027.60	831508.31
2361	58.81	551120	539.84	370.36	58.36	46.61	7156.55	106.25	72.89	11.49	9.17	1408.52	29036.35
2360	131.70	2765934	1602.57	1359.28	152.44	134.67	26189.53	140.84	119.46	13.40	11.84	2301.60	128090.38
2350	172.65	4153454	2205.14	1886.35	198.41	97.76	36843.12	147.82	126.45	13.30	6.55	2469.82	168070.92
2340	197.77	4581490	2495.98	2041.53	216.26	42.11	40608.44	146.07	119.48	12.66	2.46	2376.56	161276.90
2330	396.80	9479410	4931.70	3668.35	370.82	257.59	78211.23	143.85	107.00	10.82	7.51	2281.31	190096.31
2320	408.22	10073226	5292.33	3852.46	384.22	56.03	82092.83	150.05	109.23	10.89	1.59	2327.56	201636.51
2310	853.61	24402686	11944.19	7860.67	715.04	589.87	178067.63	161.95	106.58	9.70	8.00	2414.40	290842.22
2230	61.84	813630	593.80	506.98	70.27	62.00	9493.74	111.14	94.89	13.15	11.60	1776.96	51721.64
2220	110.15	1843378	1238.57	980.10	120.66	76.43	18994.54	130.14	102.99	12.68	8.03	1995.88	85017.34
2210	213.59	6042650	2888.00	2551.84	250.03	221.05	50077.02	156.49	138.28	13.55	11.98	2713.55	228335.23
2200	1804.23	61143876	22330.74	16481.06	1355.01	88.87	396349.57	143.25	105.73	8.69	0.57	2542.57	436770.11
2150	156.04	2432214	1285.35	1225.47	152.18	145.76	24819.19	95.34	90.90	11.29	10.81	1840.93	79841.96
2140	220.71	3769774	1945.79	1744.60	205.76	96.78	36275.81	102.04	91.49	10.79	5.08	1902.32	98462.97
2130	255.16	5493840	2597.13	2363.33	253.92	117.44	48659.97	117.81	107.20	11.52	5.33	2207.21	148652.49
2120	210.27	6201706	2883.58	2605.85	251.61	60.86	50824.26	158.72	143.43	13.85	3.35	2797.52	244234.86
2114	15.88	131148	103.52	116.44	20.55	15.10	1989.35	75.46	84.88	14.98	11.01	1450.18	19003.75
2113	36.13	550656	292.22	370.11	49.92	37.02	6449.57	93.61	118.55	15.99	11.86	2065.93	60657.45
2112	118.76	2064662	1079.84	1073.87	129.85	101.54	20890.08	105.24	104.66	12.66	9.90	2035.89	91739.19
2111	97.37	2366802	1242.81	1198.83	129.32	31.20	22030.64	147.73	142.51	15.37	3.71	2618.81	155873.83
2110	328.92	9705132	4395.18	3738.59	352.81	88.35	76401.54	154.66	131.55	12.41	3.11	2688.39	262777.53
2100	2101.68	71827586	26116.34	18765.29	1526.11	89.79	458114.27	143.82	103.34	8.40	0.49	2522.87	454085.25
2050	206.79	2471328	1558.68	1241.33	167.69	150.27	26643.77	87.24	69.48	9.39	8.41	1491.22	53519.30
2040	245.57	2739900	1810.21	1348.96	185.30	30.49	29697.53	85.32	63.58	8.73	1.44	1399.70	49042.14
2030	281.46	3289390	2110.07	1563.07	209.59	51.66	34730.90	86.77	64.28	8.62	2.12	1428.17	54191.89
2020	300.98	3758964	2309.35	1740.56	226.94	46.32	38668.29	88.80	66.93	8.73	1.78	1486.96	61237.68
2010	297.24	4695888	2658.37	2082.52	249.03	76.30	45047.51	103.51	81.09	9.70	2.97	1754.06	90650.35
2000	2962.77	80915690	29376.52	20656.61	1793.98	272.45	535502.57	114.76	80.70	7.01	1.06	2091.95	329557.60
1900	3976.72	116064052	38689.54	27626.83	2306.22	48.28	733279.89	112.60	80.41	6.71	0.14	2134.18	386379.32
1820	196.75	2313420	1474.25	1176.99	160.36	142.78	25176.06	86.72	69.24	9.43	8.40	1480.98	51661.10
1810	210.07	2762638	1636.23	1357.97	176.91	43.78	28895.22	90.15	74.82	9.75	2.41	1592.04	63002.01
1800	4143.22	123241684	40733.08	28995.81	2398.52	279.70	771337.03	113.79	81.00	6.70	0.78	2154.73	401544.02
1722	18.10	605010	193.39	399.29	41.69	46.07	5946.94	123.70	255.39	26.66	29.47	3803.71	202578.57
1721	93.45	5750880	1469.66	2452.06	187.83	242.27	40587.76	182.03	303.71	23.26	30.01	5027.13	735528.88
1720	203.98	10174366	2651.16	3883.61	309.08	228.82	71343.22	150.43	220.36	17.54	12.98	4048.06	586741.21
1715	4.93	233736	72.05	185.51	18.18	21.21	2322.98	169.15	435.52	42.68	49.79	5453.49	294806.42
1714	71.88	2978142	1035.20	1442.73	129.70	151.01	24249.22	166.68	232.30	20.88	24.32	3904.48	362971.62
1713	132.59	4230246	1393.74	1914.41	183.80	89.16	35282.81	121.66	167.11	16.04	7.78	3079.83	258577.99
1712	165.15	5514826	1766.08	2370.61	221.30	92.17	44484.38	123.77	166.14	15.51	6.46	3117.53	289244.60
1711	178.14	5927268	1903.70	2512.50	233.95	40.71	47539.64	123.69	163.24	15.20	2.64	3088.71	291055.26
1710	377.51	16538532	4456.49	5745.04	464.98	44.63	114132.01	136.63	176.14	14.26	1.37	3499.21	521490.28
1700	4565.66	149770404	46816.21	33929.54	2693.29	508.44	902199.94	118.68	86.01	6.83	1.29	2287.10	480686.18
1640	422.48	208950	553.45	169.49	71.91	26.37	5527.47	15.16	4.64	1.97	0.72	151.43	287.47
1630	1332.09	622730	1769.05	408.69	167.03	46.70	15118.15	15.37	3.55	1.45	0.41	131.36	315.03
1620	1389.98	696920	1852.59	447.50	177.82	13.50	16502.35	15.43	3.73	1.48	0.11	137.41	356.75
1614	28.58	183622	142.97	152.72	28.72	20.04	2850.64	57.91	61.86	11.63	8.12	1154.58	13716.16
1613	185.51	3121136	1396.23	1498.31	179.28	169.06	30644.50	87.11	93.48	11.19	10.55	1911.89	93336.00
1612	246.98	5053576	2033.33	2209.46	242.32	127.27	45587.00	95.29	103.54	11.36	5.96	2136.34	135761.10
1611	270.24	5831798	2292.23	2479.83	265.44	66.28	51352.90	98.17	106.21	11.37	2.84	2199.40	150618.45
1610	2187.76	22223930	11083.24	7289.91	927.74	671.14	203717.30	58.63	38.57	4.91	3.55	1077.74	59718.11
1540	29.94	193654	180.39	159.41	29.83	20.89	2988.00	69.73	61.62	11.53	8.08	1154.93	13970.48
1530	45.61	380708	300.73	274.88	45.80	20.96	5237.36	76.32	69.76	11.62	5.32	1329.13	22948.54
1520	71.96	887870	544.12	543.94	76.62	44.49	10420.47	87.52	87.49	12.32	7.16	1676.13	47592.58
1512	31.04	137864	164.50	121.22	26.03	16.38	2375.12	61.33	45.20	9.70	6.11	885.55	7480.85
1511	172.51	1551050	1178.12	852.76	129.20	99.06	18520.52	79.04	57.21	8.67	6.65	1242.60	32245.43
1510	732.40	10297188	5889.81	3921.35	467.70	377.94	94379.90	93.08	61.97	7.39	5.97	1491.48	86273.94
1450	668.22	1119322	1333.00	655.61	172.89	91.64	19662.71	23.09	11.36	2.99	1.59	340.57	2396.48
1440	1132.03	2519634	2498.34	1260.85	291.33	111.65	38747.85	25.54	12.89	2.98	1.14	396.17	4204.72
1430	1137.98	2577128	2526.65	1283.99	294.69	11.07	39406.78	25.70	13.06	3.00	0.11	400.80	4332.36
1420	1133.86	5074490	3466.11	2216.82	395.31	169.74	63190.19	35.38	22.63	4.04	1.73	645.02	13574.03
1410	1134.69	5596828	3626.54	2398.98	412.63	54.69	67673.71	36.99	24.47	4.21	0.56	690.28	15980.91
1400	7406.21	190911170	64164.25	41260.52	3494.44	221.07	1184396.53	100.27	64.48	5.46	0.35	1850.92	346969.21
1310	513.40	14501974	4292.14	5167.67	484.53	575.04	111154.02	96.76	116.50	10.92	12.96	2505.83	262511.41
1220	2880.65	1281360	2601.39	731.08	292.65	111.47	29470.26	10.45	2.94	1.18	0.45	118.41	328.41
1210	2194.30	7019050	5285.18	2879.29	562.33	324.00	91177.43	27.88	15.19	2.97	1.71	480.93	8600.18
1200	9532.41	228625306	75948.38	47713.23	4097.52	757.78	1417185.22	92.22	57.93	4.98	0.92	1720.72	320273.53

TABLE 21

Per capita loading estimates of BOD, nitrogen, and TDS in Ganga River VSEC units.

	Population	Q	Population	Pollutant Loading (kg/day)			Pollutant Concentration (mg/L)		
Station ID	50 km U/S	cms	Watershed	Nitrogen	BOD_5	Phosphate	Nitrogen	BOD_5	Phosphate
3900	17990	181.84	58972	43.83	6.77	18.74	0.24	0.04	0.10
3820	4754	138.22	15988	11.88	1.83	0.50	0.09	0.01	0.00
3810	7723	286.11	35848	26.64	4.11	0.80	0.09	0.01	0.00
3801	3892	55.32	7948	5.91	0.91	0.41	0.11	0.02	0.01
3800	166931	546.13	519372	386.02	59.58	17.39	0.71	0.11	0.03
3700	500833	594.61	8039404	5975.18	922.24	52.17	10.05	1.55	0.09
3360	1621	113.61	50120	37.25	5.75	0.17	0.33	0.05	0.00
3350	8155	129.96	59312	44.08	6.80	0.85	0.34	0.05	0.01
3340	38529	131.26	102416	76.12	11.75	4.01	0.58	0.09	0.03
3330	557278	238.35	2611828	1941.21	299.62	58.05	8.14	1.26	0.24
3320	376811	326.30	6937900	5156.50	795.88	39.25	15.80	2.44	0.12
3310	6996	416.15	12335106	9167.91	1415.03	0.73	22.03	3.40	0.00
3230	249298	45.12	2875606	2137.26	329.88	25.97	47.37	7.31	0.58
3220	138467	91.77	6121966	4550.07	702.28	14.42	49.58	7.65	0.16
3210	256325	94.07	6355062	4723.32	729.02	26.70	50.21	7.75	0.28
3200	237069	891.51	32241574	23963.13	3698.61	24.69	26.88	4.15	0.03
3100	208396	1289.70	34756938	25832.64	3987.16	21.71	20.03	3.09	0.02
3000	14720	67.53	40466	30.08	4.64	1.53	0.45	0.07	0.02
2900	29887	265.86	882464	655.88	101.23	3.11	2.47	0.38	0.01
2800	139724	283.61	950532	706.47	109.04	14.55	2.49	0.38	0.05
2700	3717277	293.17	9806106	7288.26	1124.91	387.22	24.86	3.84	1.32
2620	61355	300.25	440972	327.75	50.59	6.39	1.09	0.17	0.02
2610	529412	318.83	3204200	2381.48	367.57	55.15	7.47	1.15	0.17
2600	1000882	362.01	17442768	12964.11	2000.96	104.26	35.81	5.53	0.29
2500	1228627	508.44	27046112	20101.67	3102.61	127.98	39.54	6.10	0.25
2400	405726	530.86	29719962	22088.98	3409.34	42.26	41.61	6.42	0.08
2361	57000	58.81	551120	409.61	63.22	5.94	6.97	1.08	0.10
2360	117529	131.70	2765934	2055.74	317.30	12.24	15.61	2.41	0.09
2350	174517	172.65	4153454	3087.00	476.47	18.18	17.88	2.76	0.11
2340	133970	197.77	4581490	3405.13	525.57	13.96	17.22	2.66	0.07
2330	858789	396.80	9479410	7045.45	1087.44	89.46	17.76	2.74	0.23
2320	126079	408.22	10073226	7486.79	1155.55	13.13	18.34	2.83	0.03
2310	69387	853.61	24402686	18136.98	2799.37	7.23	21.25	3.28	0.01
2230	109478	61.84	813630	604.72	93.34	11.40	9.78	1.51	0.18
2220	45710	110.15	1843378	1370.07	211.46	4.76	12.44	1.92	0.04
2210	319770	213.59	6042650	4491.12	693.19	33.31	21.03	3.25	0.16
2200	425572	1804.23	61143876	45444.39	7014.15	44.33	25.19	3.89	0.02
2150	269891	156.04	2432214	1807.71	279.01	28.11	11.58	1.79	0.18
2140	187261	220.71	3769774	2801.84	432.45	19.51	12.69	1.96	0.09
2130	331617	255.16	5493840	4083.23	630.23	34.54	16.00	2.47	0.14
2120	161840	210.27	6201706	4609.34	711.43	16.86	21.92	3.38	0.08
2114	62241	15.88	131148	97.47	15.04	6.48	6.14	0.95	0.41
2113	100051	36.13	550656	409.27	63.17	10.42	11.33	1.75	0.29
2112	74981	118.76	2064662	1534.53	236.85	7.81	12.92	1.99	0.07
2111	114064	97.37	2366802	1759.09	271.51	11.88	18.07	2.79	0.12
2110	119571	328.92	9705132	7213.21	1113.33	12.46	21.93	3.38	0.04
2100	425572	2101.68	71827586	53384.92	8239.74	44.33	25.40	3.92	0.02
2050	152686	206.79	2471328	1836.78	283.50	15.90	8.88	1.37	0.08
2040	150421	245.57	2739900	2036.40	314.31	15.67	8.29	1.28	0.06
2030	64485	281.46	3289390	2444.80	377.34	6.72	8.69	1.34	0.02
2020	102628	300.98	3758964	2793.80	431.21	10.69	9.28	1.43	0.04
2010	373202	297.24	4695888	3490.16	538.69	38.88	11.74	1.81	0.13
2000	152166	2962.77	80915690	60139.53	9282.28	15.85	20.30	3.13	0.01
1900	806956	3976.72	116064052	86263.10	13314.34	84.06	21.69	3.35	0.02
1820	376218	196.75	2313420	1719.42	265.39	39.19	8.74	1.35	0.20
1810	256731	210.07	2762638	2053.29	316.92	26.74	9.77	1.51	0.13
1800	786654	4143.22	123241684	91597.78	14137.73	81.94	22.11	3.41	0.02
1722	294241	18.10	605010	449.67	69.40	30.65	24.85	3.84	1.69
1721	1021893	93.45	5750880	4274.27	659.71	106.45	45.74	7.06	1.14
1720	191664	203.98	10174366	7561.97	1167.16	19.97	37.07	5.72	0.10
1715	108755	4.93	233736	173.72	26.81	11.33	35.24	5.44	2.30
1714	289882	71.88	2978142	2213.47	341.64	30.20	30.79	4.75	0.42
1713	293241	132.59	4230246	3144.08	485.27	30.55	23.71	3.66	0.23
1712	613068	165.15	5514826	4098.82	632.64	63.86	24.82	3.83	0.39
1711	87843	178.14	5927268	4405.36	679.95	9.15	24.73	3.82	0.05
1710	276199	377.51	16538532	12292.05	1897.23	28.77	32.56	5.03	0.08
1700	158190	4565.66	149770404	111314.90	17180.98	16.48	24.38	3.76	0.00
1640	37129	422.48	208950	155.30	23.97	3.87	0.37	0.06	0.01
1630	48787	1332.09	622730	462.84	71.44	5.08	0.35	0.05	0.00
1620	38784	1389.98	696920	517.98	79.95	4.04	0.37	0.06	0.00
1614	92331	28.58	183622	136.47	21.06	9.62	4.78	0.74	0.34
1613	466759	185.51	3121136	2319.74	358.04	48.62	12.50	1.93	0.26
1612	393856	246.98	5053576	3756.00	579.72	41.03	15.21	2.35	0.17
1611	359338	270.24	5831798	4334.41	669.00	37.43	16.04	2.48	0.14
1610	286339	2187.76	22223930	16517.65	2549.43	29.83	7.55	1.17	0.01
1540	18882	29.94	193654	143.93	22.22	1.97	4.81	0.74	0.07
1530	12924	45.61	380708	282.96	43.67	1.35	6.20	0.96	0.03
1520	263085	71.96	887870	659.90	101.85	27.40	9.17	1.42	0.38
1512	50522	31.04	137864	102.47	15.82	5.26	3.30	0.51	0.17
1511	132988	172.51	1551050	1152.80	177.93	13.85	6.68	1.03	0.08
1510	512476	732.40	10297188	7653.25	1181.25	53.38	10.45	1.61	0.07
1450	198266	668.22	1119322	831.92	128.40	20.65	1.24	0.19	0.03
1440	58868	1132.03	2519634	1872.69	289.04	6.13	1.65	0.26	0.01
1430	216943	1137.98	2577128	1915.42	295.64	22.60	1.68	0.26	0.02
1420	251512	1133.86	5074490	3771.55	582.12	26.20	3.33	0.51	0.02
1410	272520	1134.69	5596828	4159.77	642.04	28.39	3.67	0.57	0.03
1400	1000000	7406.21	190911170	141892.24	21900.46	104.17	19.16	2.96	0.01
1310	311574	513.40	14501974	10778.40	1663.60	32.46	20.99	3.24	0.06
1220	90568	2880.65	1281360	952.35	146.99	9.43	0.33	0.05	0.00
1210	625733	2194.30	7019050	5216.82	805.19	65.18	2.38	0.37	0.03
1200	374577	9532.41	228625306	169922.78	26226.86	39.02	17.83	2.75	0.00

TABLE 22

Ratio of MLR estimates of nitrogen and BOD_5 against *per capita* estimates. *Per capita* estimates are comparatively lower than MLR estimates.

Station ID	MLR estimate/per capita estimate Nitrogen	BOD
3900	261.37	54.30
3820	372.21	104.00
3810	204.03	82.79
3801	421.41	114.67
3800	132.99	22.55
3700	69.96	4.93
3360	265.34	51.18
3350	67.81	48.52
3340	118.98	35.75
3330	91.48	6.94
3320	52.14	4.42
3310	35.00	3.45
3230	81.99	3.86
3220	44.11	3.16
3210	6.31	3.12
3200	14.32	2.56
3100	7.69	2.76
3000	273.94	48.88
2900	123.63	13.26
2800	18.87	13.00
2700	61.55	3.52
2620	156.66	20.42
2610	81.53	6.79
2600	21.25	2.72
2500	24.56	2.36
2400	8.89	2.27
2361	131.65	10.69
2360	75.85	5.56
2350	36.63	4.82
2340	14.29	4.76
2330	42.30	3.95
2320	8.67	3.85
2310	37.65	2.96
2230	118.62	8.71
2220	64.56	6.60
2210	56.98	4.18
2200	2.26	2.24
2150	93.31	6.31
2140	40.02	5.51
2130	33.31	4.66
2120	15.28	4.09
2114	179.34	15.81
2113	104.71	9.15
2112	76.62	6.35
2111	20.53	5.51
2110	14.18	3.67
2100	1.93	2.14
2050	94.68	6.85
2040	17.36	6.82
2030	24.41	6.43
2020	19.18	6.09
2010	25.29	5.35
2000	5.22	2.24
1900	0.65	2.00
1820	96.12	6.99
1810	24.66	6.46
1800	3.53	1.96
1722	118.59	6.95
1721	65.61	3.29
1720	35.01	3.07
1715	141.30	7.85
1714	78.98	4.39
1713	32.81	4.38
1712	26.03	4.05
1711	10.68	3.98
1710	4.21	2.84
1700	5.29	1.81
1640	195.87	34.72
1630	118.00	27.04
1620	29.52	25.73
1614	170.02	15.78
1613	84.37	5.80
1612	39.19	4.84
1611	17.71	4.59
1610	47.02	4.21
1540	168.10	15.54
1530	85.75	12.13
1520	78.07	8.70
1512	185.11	19.04
1511	99.51	8.41
1510	57.13	4.58
1450	127.71	15.56
1440	68.91	11.67
1430	6.54	11.55
1420	52.01	7.87
1410	15.28	7.44
1400	1.83	1.85
1310	61.73	3.37
1220	136.11	23.12
1210	71.93	8.09
1200	5.16	1.81
Mean	76.25	12.76
Std Deviation	79.58	19.90

TABLE 23
Number of VSEC river miles with falling into CPCB-based water quality classes. Himalaya Tributaries include Ramganga, Ghaghara, Gandak, Bhuri Gandak, Kosi, and Yamuna Rivers. Other Tributaries include Gomati, Chambal, Betwa, Kens, Tons, Sone, Sind, and Hooghly Rivers. The Hooghly River and the Ganga River downstream of Farakka were not modeled.

CPCB water quality classes	Entire Watershed	Ganga Mainstem	Himalayan Tributaries	Non-Himalayan Tributaries
A	129	129	0	0
B	710	103	608	0
C	425	81	344	0
D	983	466	517	0
E	1,236	0	827	409
Worse than E	5,249	654	1,237	3,358
Totals	8,731	1,432	3,533	3,767

TABLE 24
CPCB's 2002 "Revised Water Quality Criteria"

Parameter	Criteria A – Excellent	 B – Desirable	 C – Acceptable
pH	7.0 to 8.5	6.5 to 9.0	6.5 to 9.0
DO (% saturation)	90 to 110	80 to 120	60 to 140
BOD (mg/L)	< 2	< 3	< 6
Conductivity	< 1000	< 2250	< 4000
NO_2+NO_3 (mg/L)	< 5	< 10	< 15
Suspended Solids (mg/L)	< 25	< 50	< 100
Fecal coliform (MPN/100 mL)	< 20	< 200	< 2000
Bioassay (Zebra fish)	No death in 5 days	No death in 3 days	No death in 2 days

TABLE 25
Comparison of the number of CPCB sites in each water quality category using the 2002 altered criteria against the original criteria in (year=2003). Percent attainment in years 2002 and 2003 are compared to the percent of river miles in each water quality class based on the results from the MLR models.

	Water Quality Class					
Year	**A**	**B**	**C**	**D**	**E**	**Below E**
2002	9 (8.7%)	43 (41.7%)	51 (49.5%)	- -	- -	- -
2003	0 (0.0%)	11 (9.7%)	29 (25.7%)	19 (16.8%)	46 (40.7%)	8 (7.1%)
Modeled	- (1.5%)	- (8.1%)	- (4.9%)	- (11.3%)	- (14.2%)	- (60.1%)

Figures.

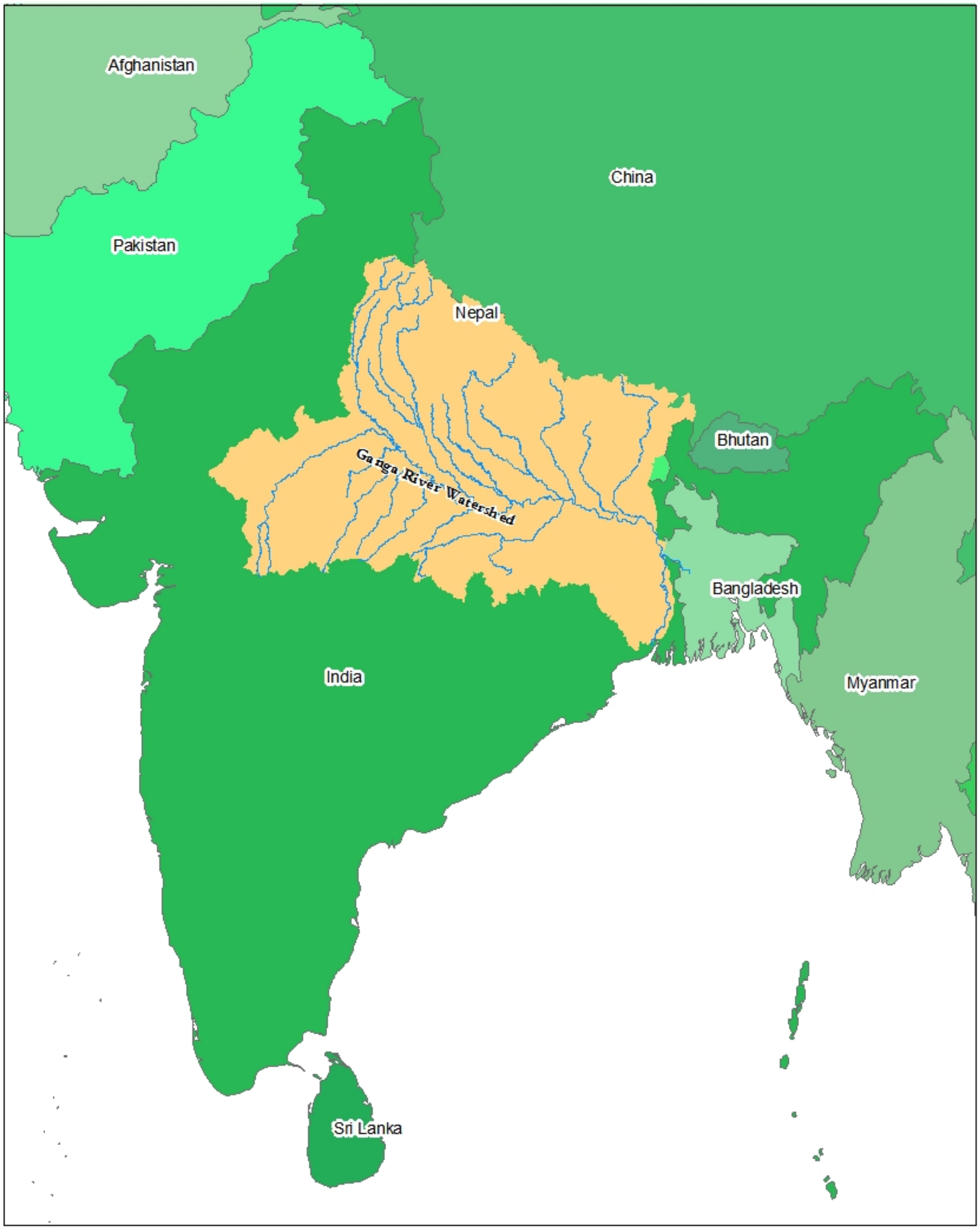

FIGURE 1
Location of the Ganga River watershed in South Asia.

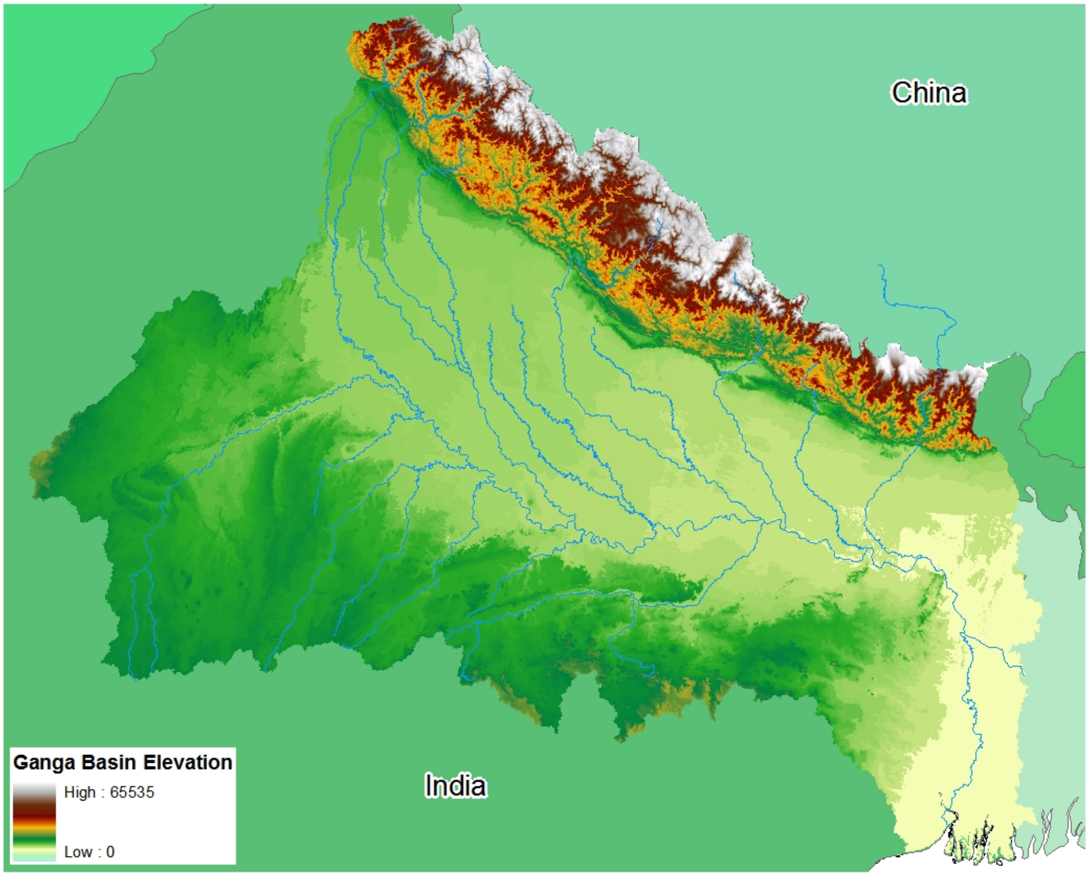

FIGURE 2
The Ganga River basin, with the Himalaya Mountains to the north and the Vindhya Mountains to the south.

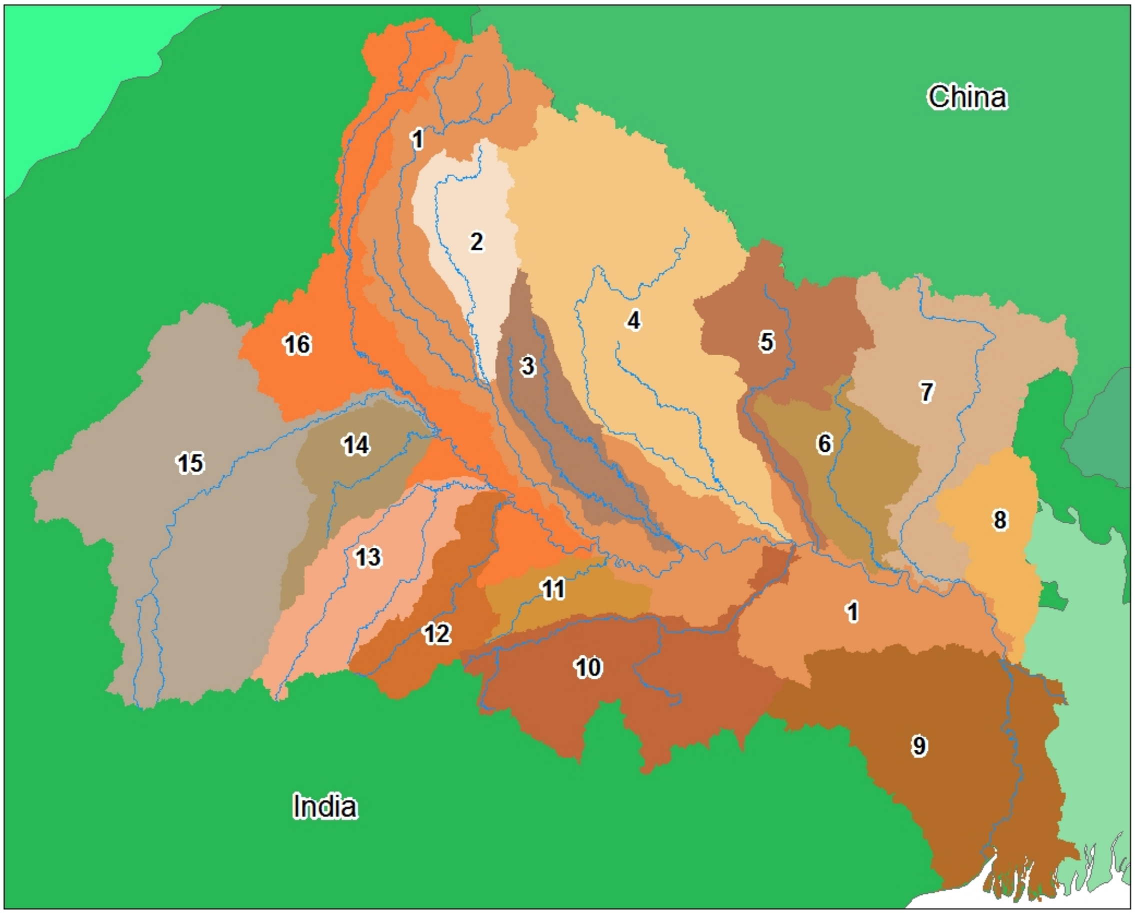

FIGURE 3
Major tributary systems of the Ganga River:

(1) Ganga River
(2) Ramganga River
(3) Gomati River
(4) Ghaghara River
(5) Gandak River
(6) Bhuri Gandak River
(7) Kosi River
(8) Mahabanda River
(9) Hooghly River
(10) Sone River
(11) Tons River
(12) Kens River
(13) Betwa River
(14) Sind River
(15) Chambal River
(16) Yamuna River

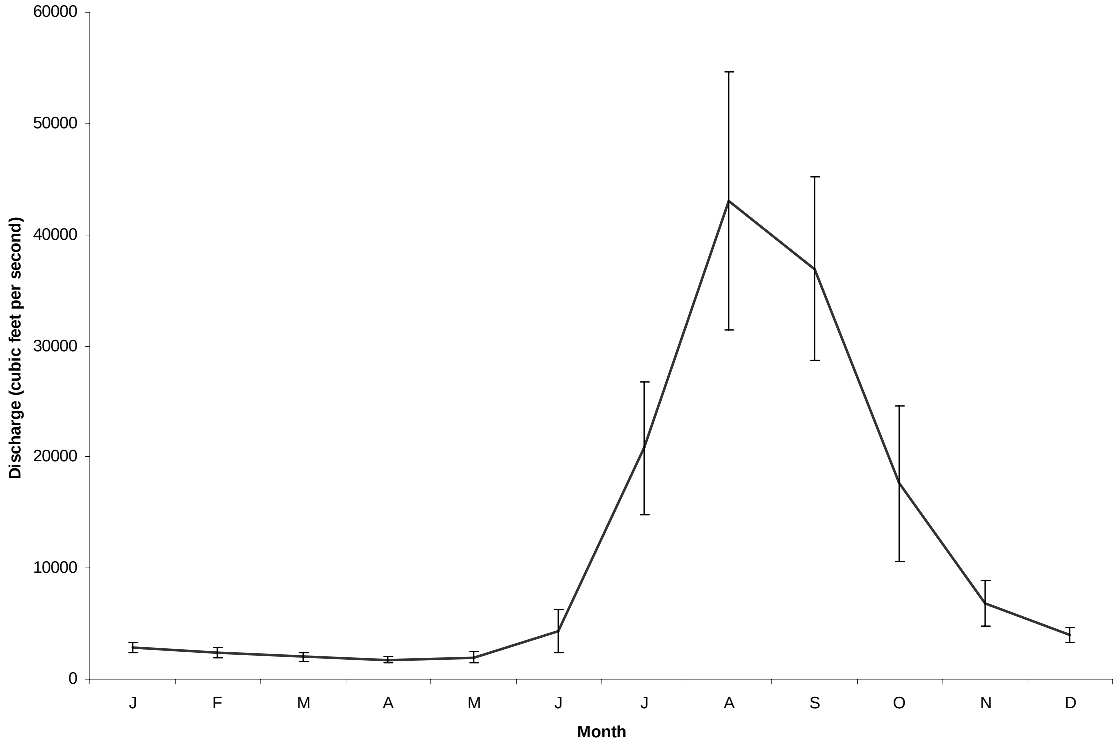

FIGURE 4
Average monthly discharge (1949 – 1960, 1965 – 1973) of the Ganga River at the Farakka. Error bars indicate one standard deviation.

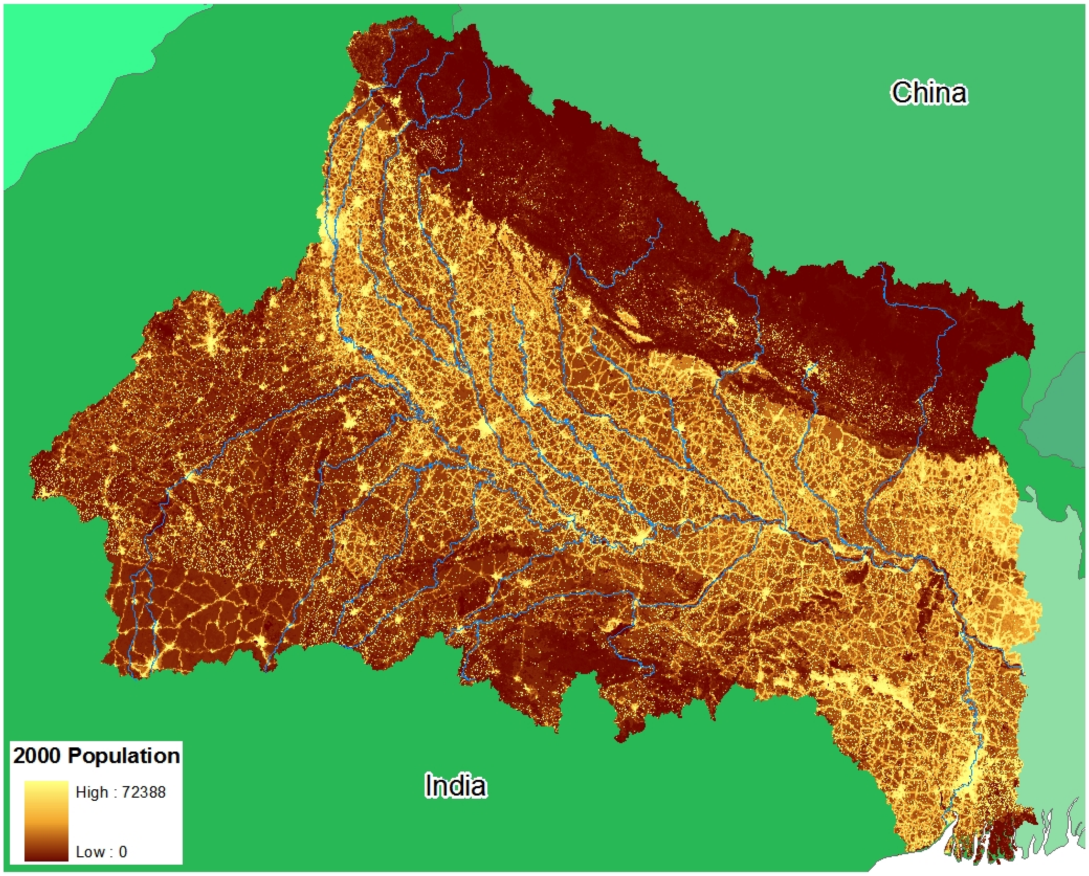

FIGURE 5
Population density map of the Ganga Basin. The majority of the basin's population is located between the Himalayan Mountains to the north and the Vindhya Mountains to the south.

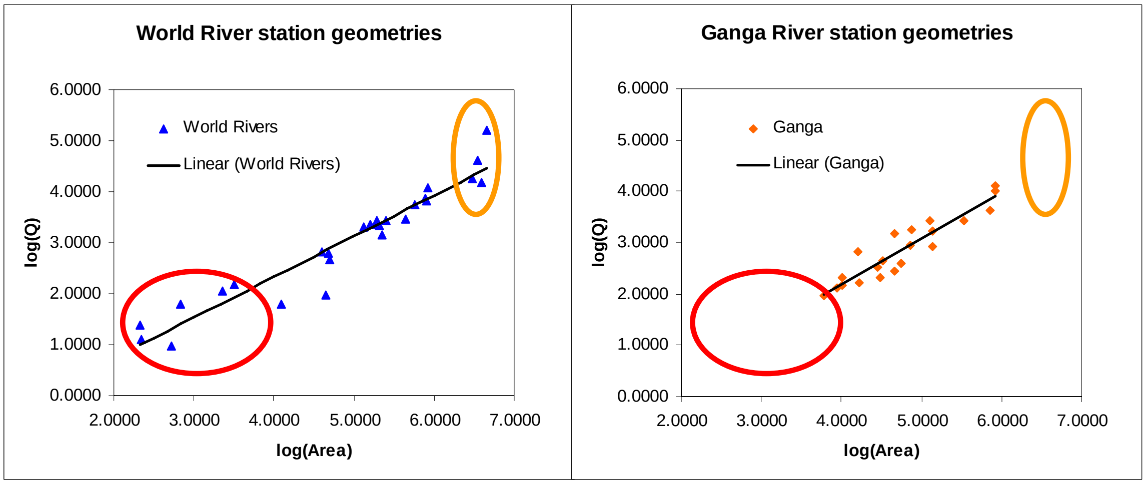

FIGURE 6
Regression analysis of the Ganga basin station geometries requires an extrapolation to larger and smaller basin areas than found in Rao (1975). This was accomplished by using world river data for a wide variety of rivers. Sites with larger and smaller basin areas are indicated in the circles.

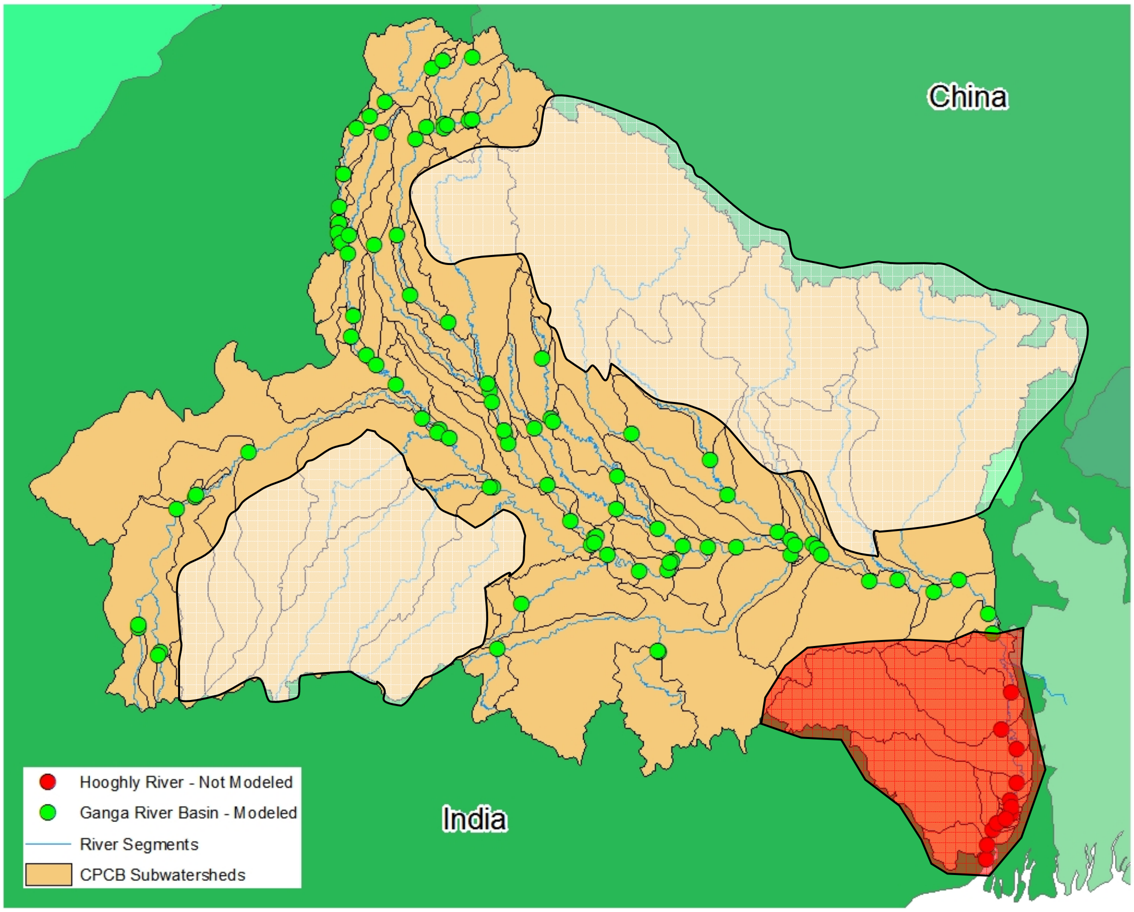

FIGURE 7
Areas of the Ganga Basin not monitored by the CPCB (white shading), and not modeled in this project (red shading). Green points indicate CPCB sampling sites that were modeled in this project.

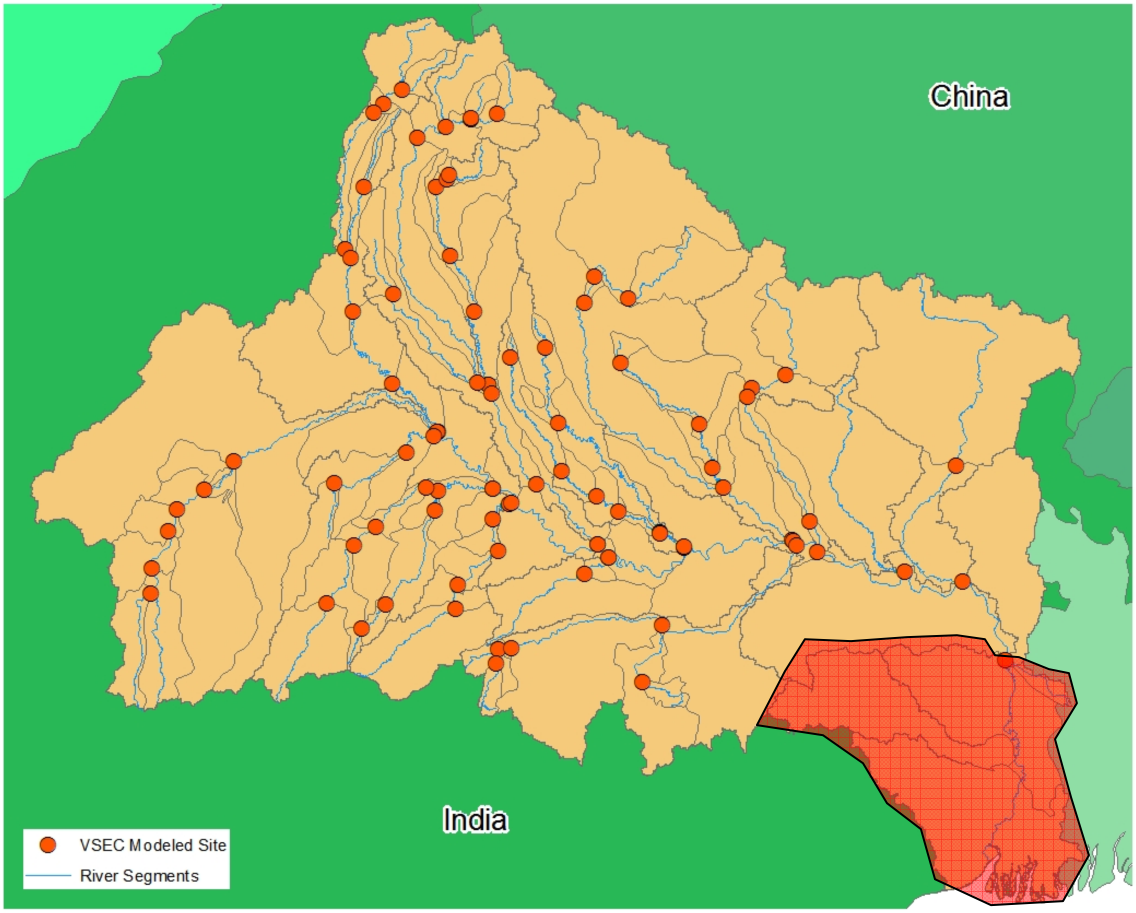

FIGURE 8
Location of modeled ninety VSEC sites, and their corresponding upstream watershed areas. The Hooghly River system (red shading) was not modeled.

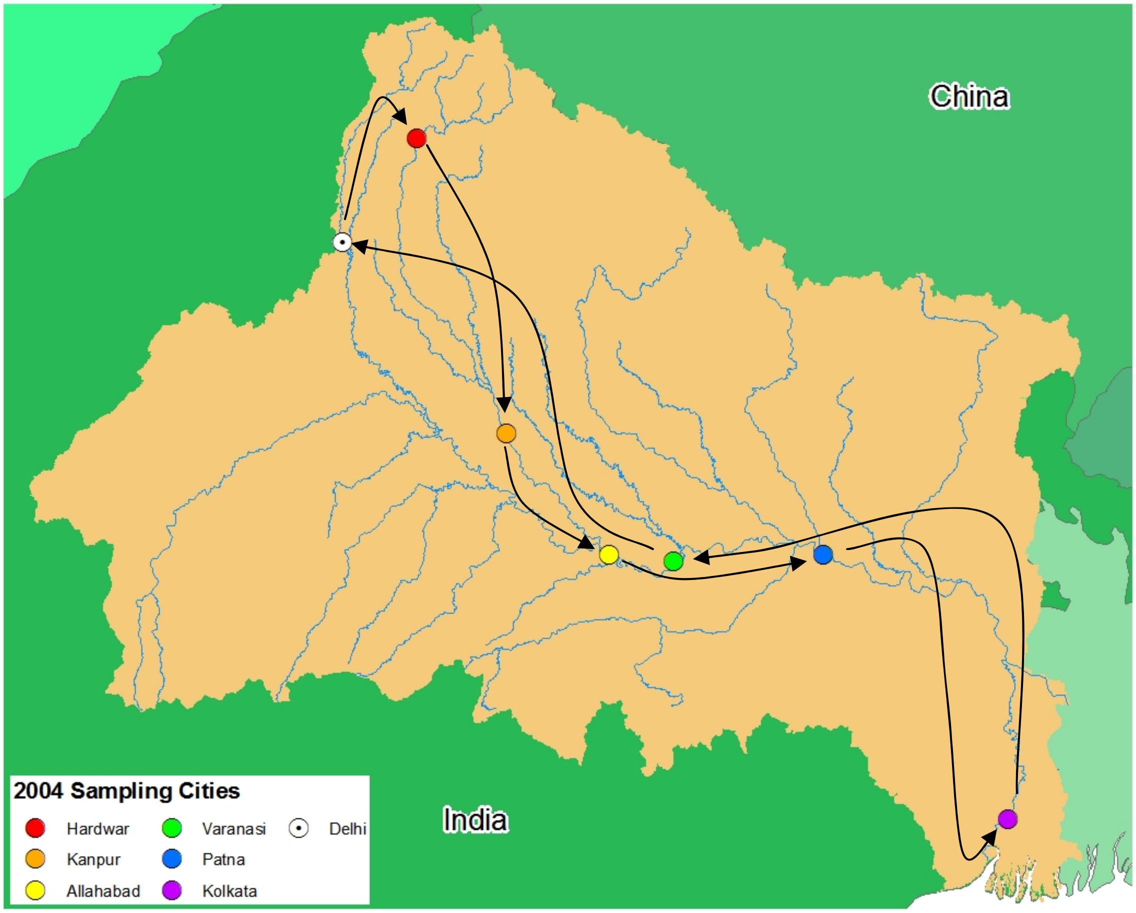

FIGURE 9
Water sampling locations visited during personal trip to India in January and February 2004. Path indicates order of sampling.

FIGURE 10
A 3-D perspective image of Hardwar at the foot of the Himalaya Mountains. The star indicates the water sampling location just below one of the reservoir dams. The Upper Ganga Canal flows to the southwest, through the city. (Digital Globe 2005, EarthSat 2005)

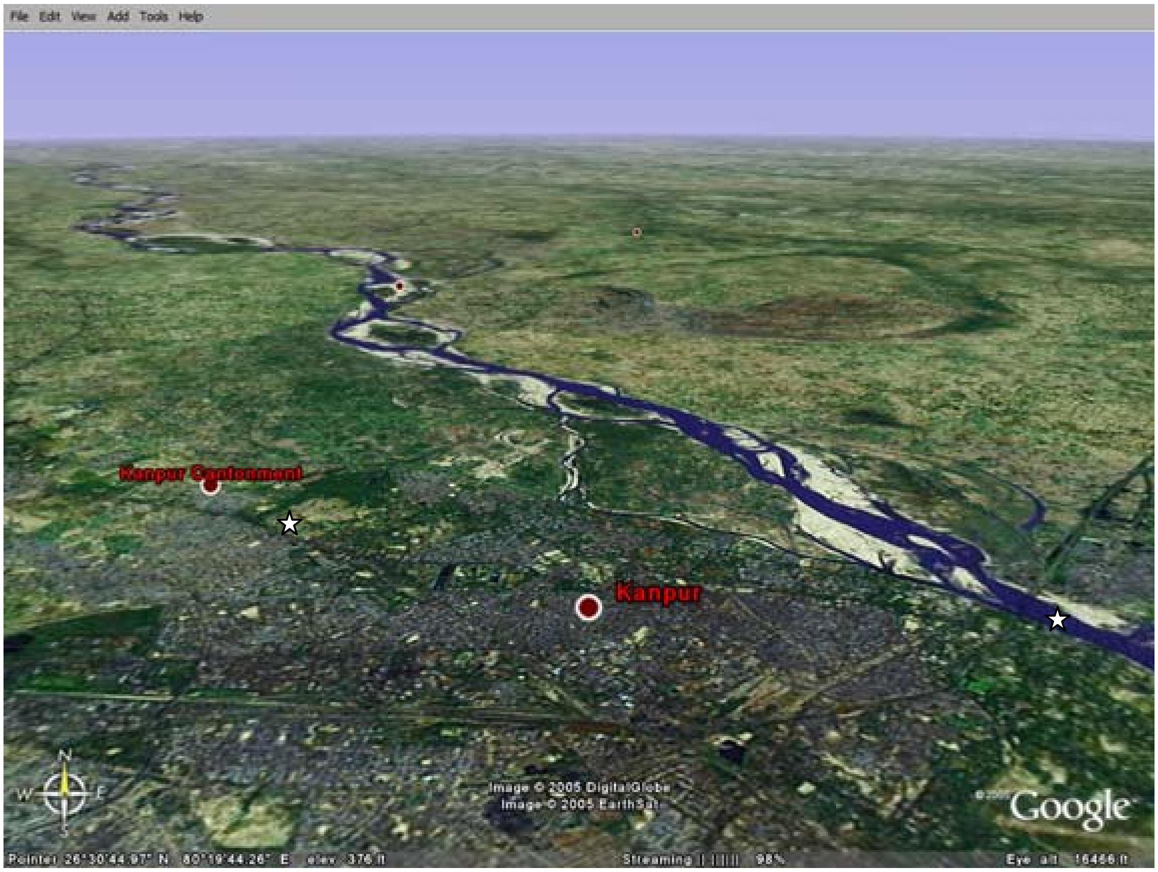

FIGURE 11
A 3-D rendered perspective image of Kanpur, with the two sampling sites shown with stars. The western site is the water intake site, and the other is the Kolya Ghat site. The river is flowing from the northwest to the southeast in this view.

FIGURE 12
Water intake canal in Kanpur. Both banks of the canal are lined with shanties. Upstream of the canal is an outfall from a tuberculosis hospital.

FIGURE 13
Ganga River at Kolya Ghat in Kanpur.

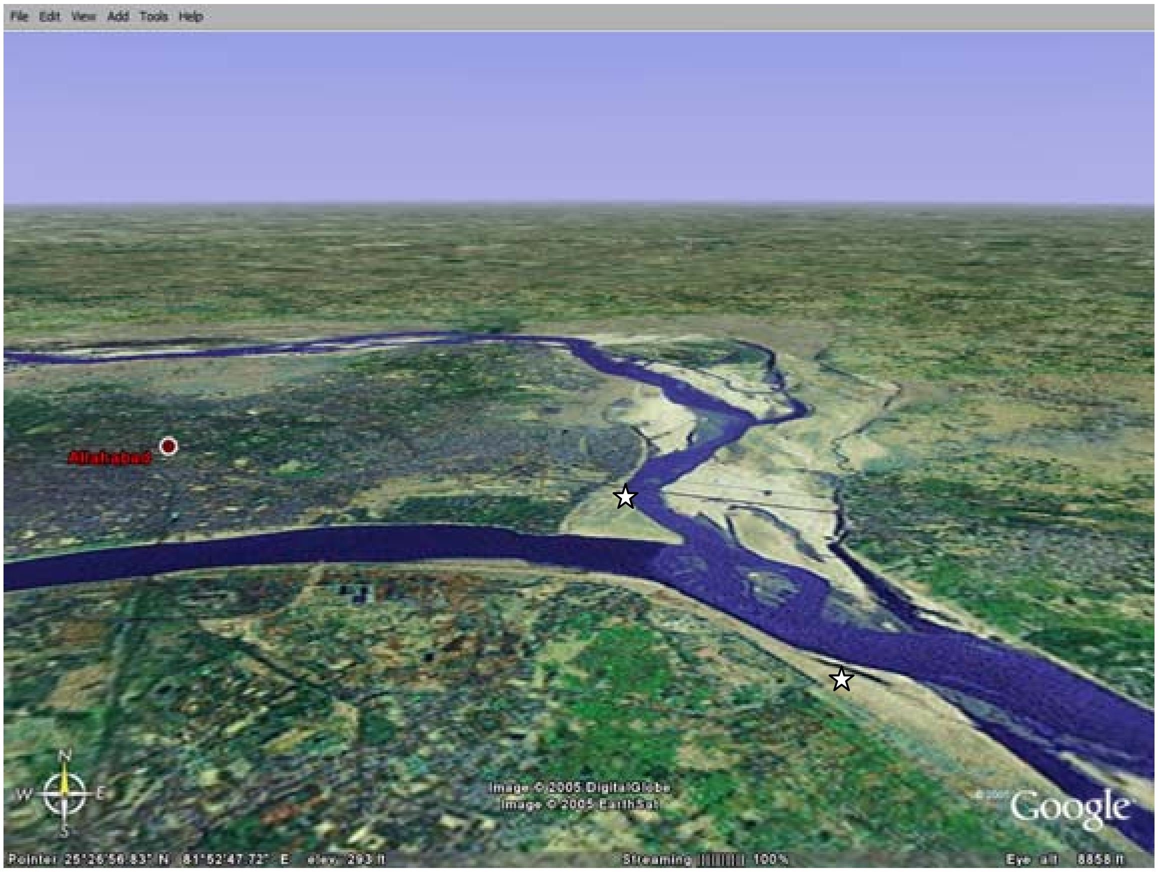

FIGURE 14
A 3-D rendered perspective of Allahabad. The two sampling sites are marked with stars. Note the confluence of the Yamuna River (from the west) with the Ganga River (from the north). the location the sandy spit at the confluence point was the main gathering point of the thousands of Ardh Kumbh Mela pilgrims.

FIGURE 15
Looking downstream along the banks of the Ganga, roughly 2km downstream of the Sangam, near Allahabad.

FIGURE 16
Ganga River, upstream from the Sangam, in Allahabad.

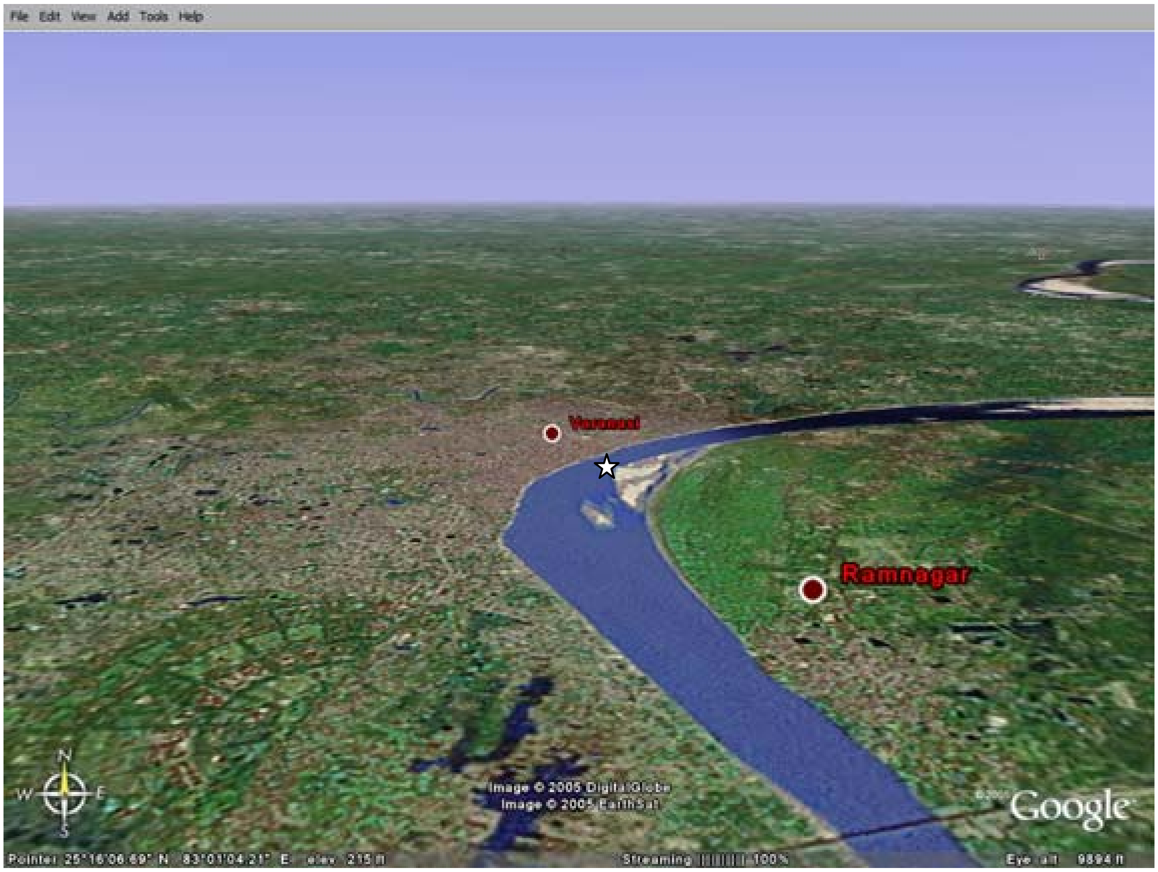

FIGURE 17
A 3-D rendered perspective image of Varanasi. The water sampling site is shown with the star. The Ganga River flows from the south to the east and north.

FIGURE 18
Sampling point in Varanasi, looking downstream.

FIGURE 19

A 3-D rendered perspective of the water sampling site in Patna. Note the confluence of two major tributaries from the northwest and the north. The Ganga continues toward the east, splitting around a major island.

FIGURE 20
Sampling location on the Ganga River, downstream of Patna.

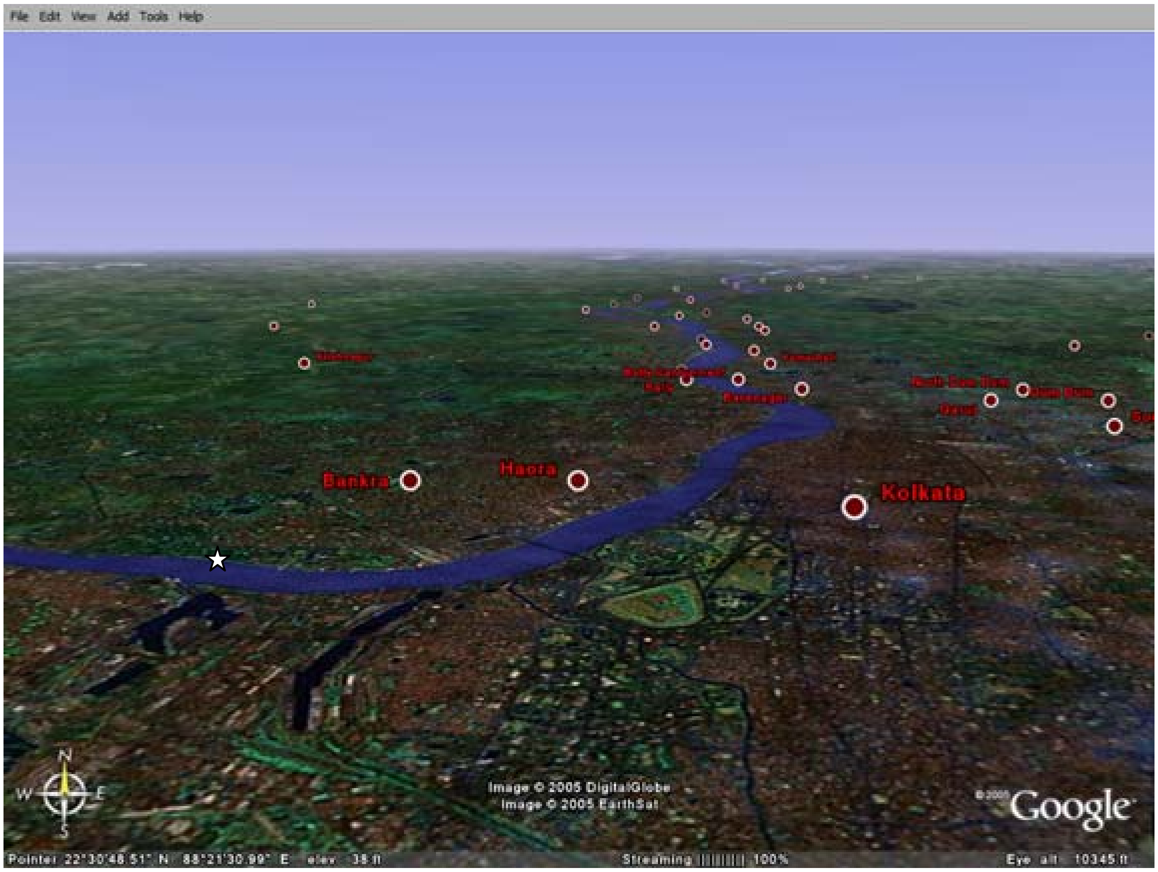

FIGURE 21
A 3-D rendered perspective of the Kolkata metropolitan area. The water sampling site is shown with a star, and is just opposite of the Botanical Gardens. Although this stretch of the Hooghly River is still considered "sweetwater," the flow of the river is heavily influenced by the tides. The river meanders in this aerial view from the north and exits to the west.

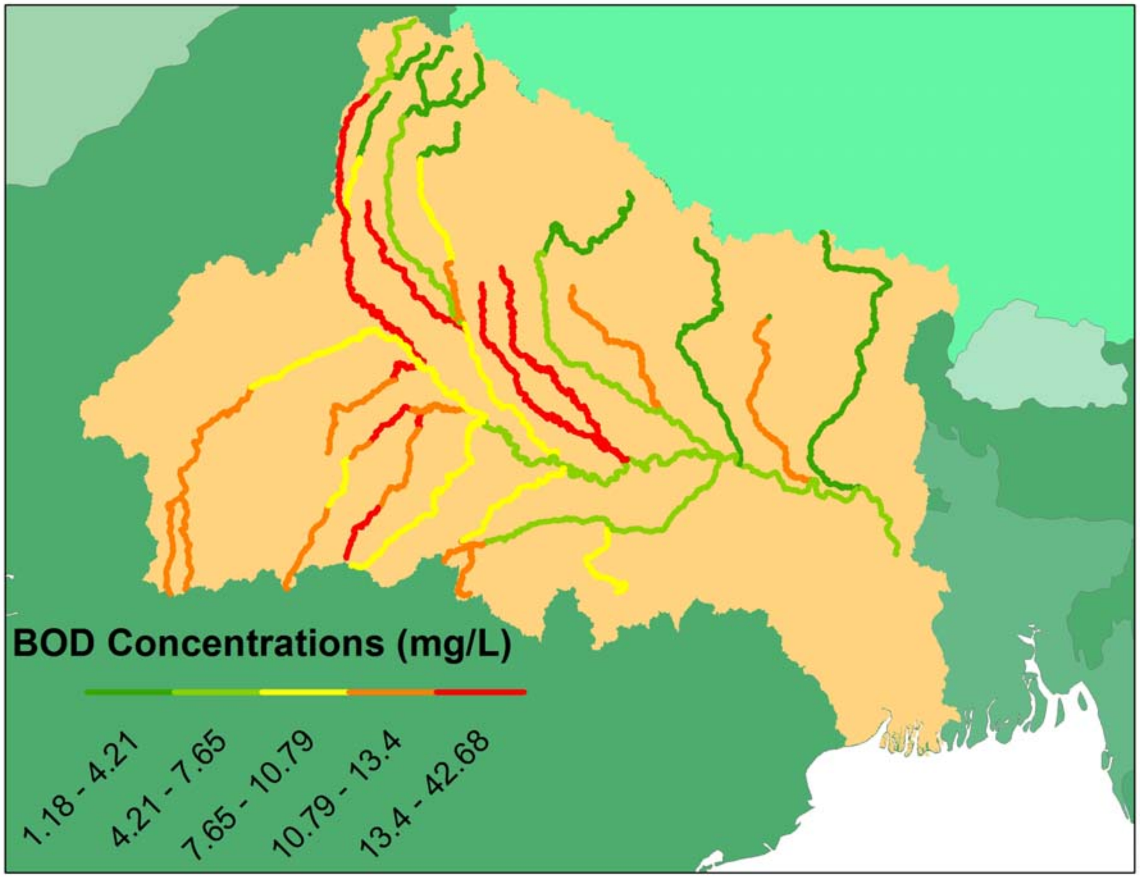

FIGURE 22
Calculated BOD_5 concentrations based on derived MLR equation for each VSEC river unit throughout the Ganga basin. Categories coded by quantiles.

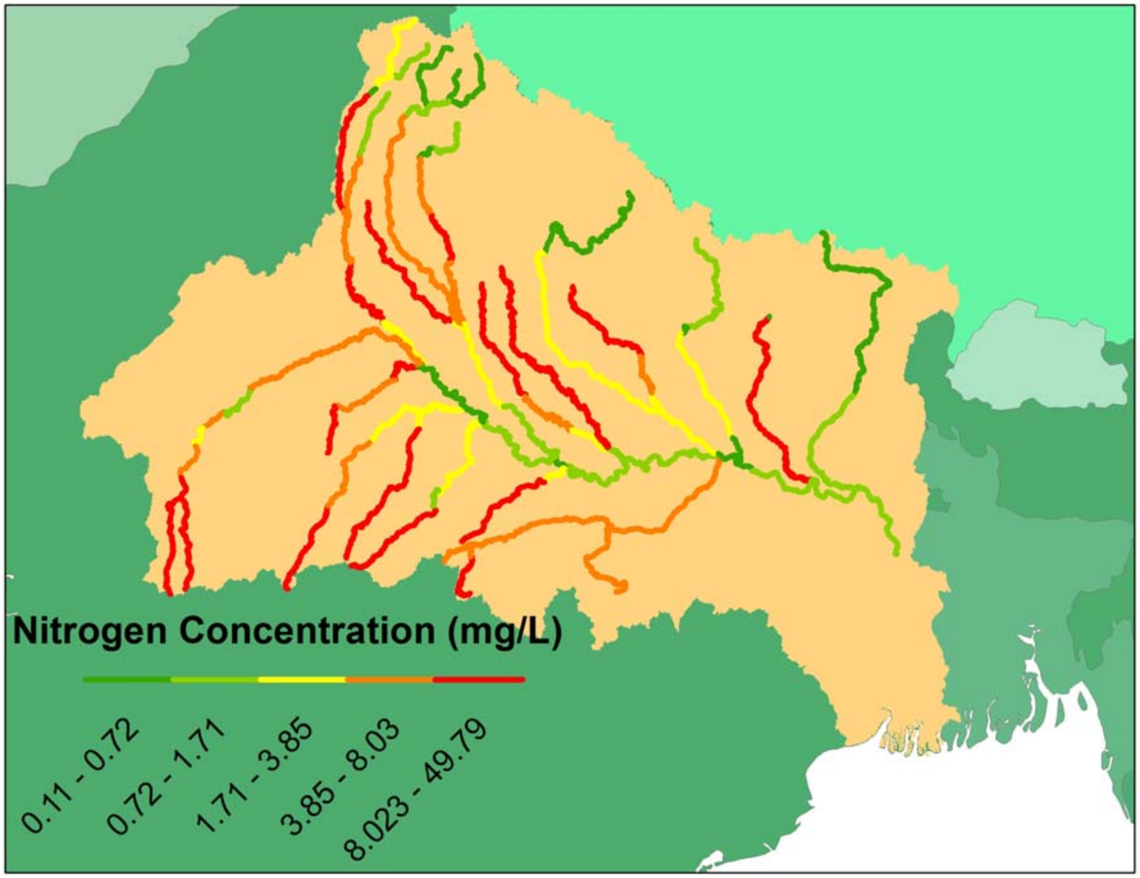

FIGURE 23
Calculated nitrogen concentrations based on derived MLR equation for each VSEC river unit throughout the Ganga basin. Categories coded by quantiles.

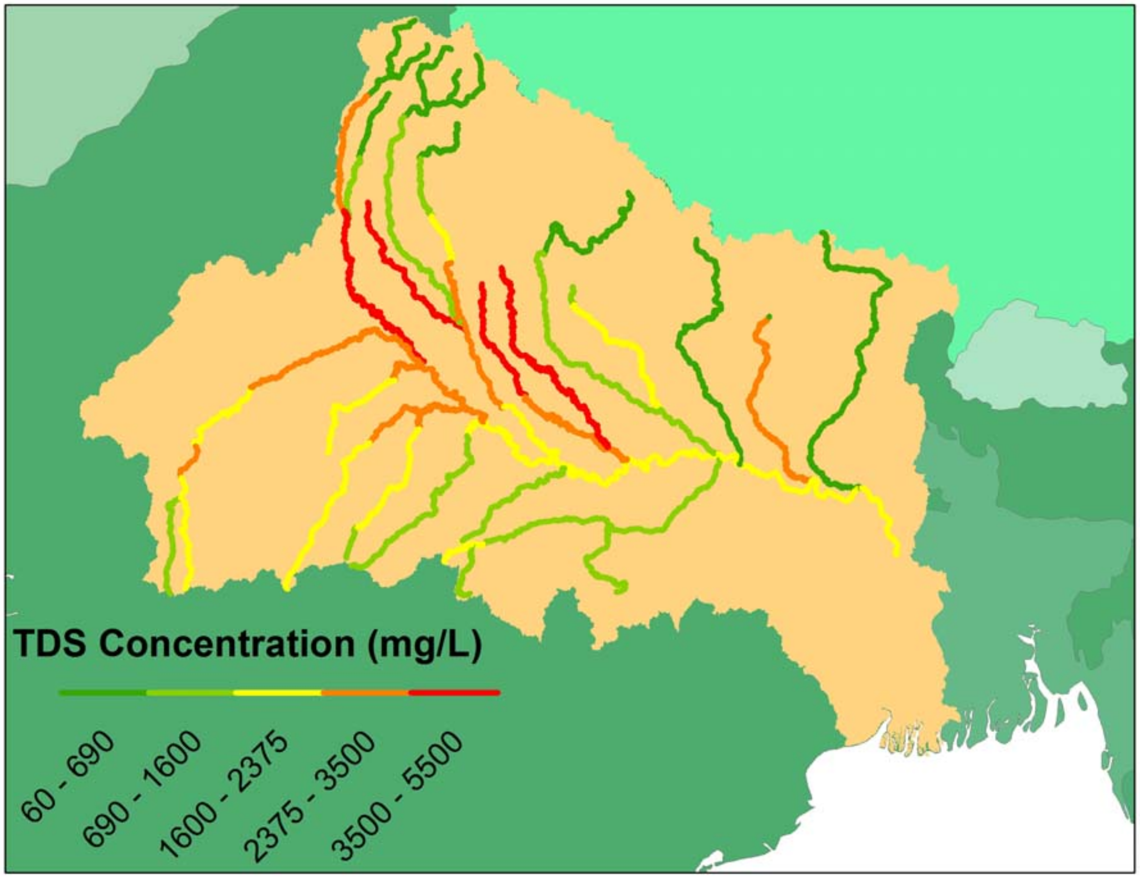

FIGURE 24
Calculated TDS concentrations based on derived MLR equation for each VSEC river unit throughout the Ganga basin. Categories coded by quantiles.

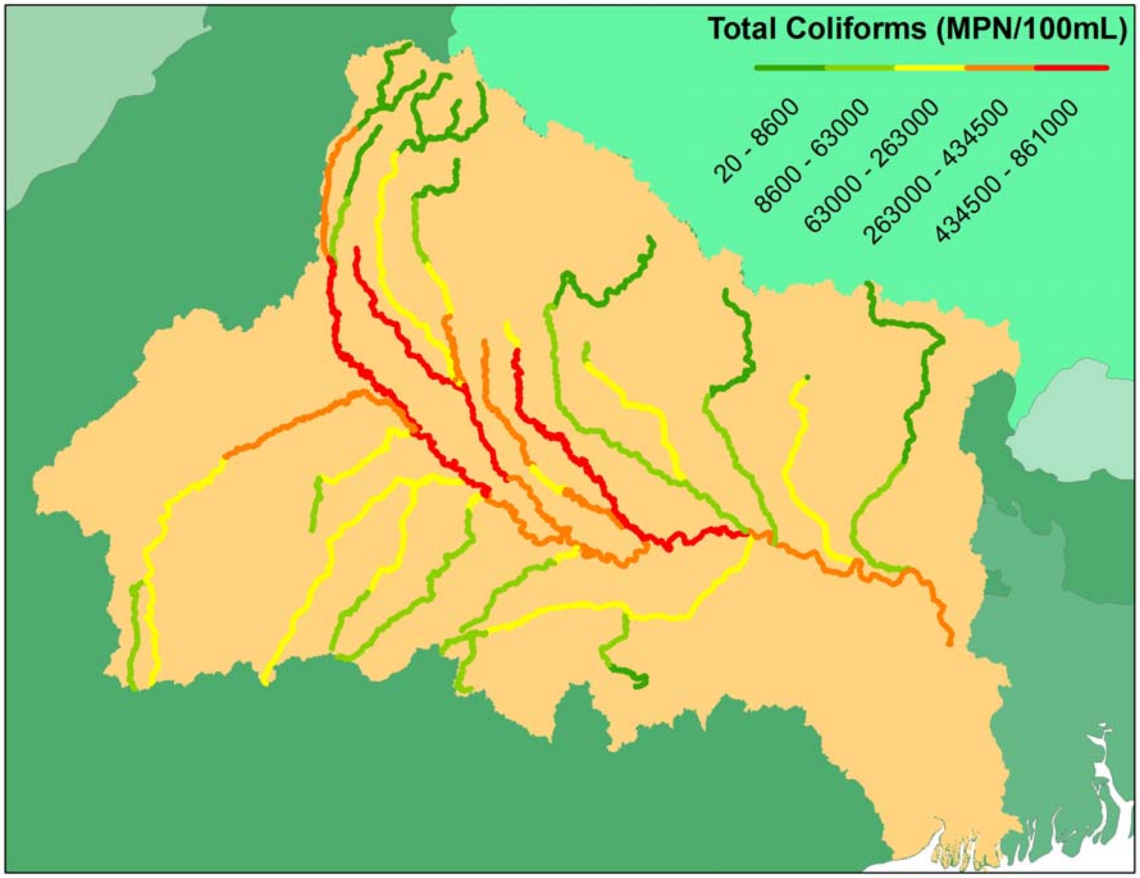

FIGURE 25
Calculated total coliform concentrations based on derived MLR equation for each VSEC river unit throughout the Ganga basin. Categories coded by quantiles.

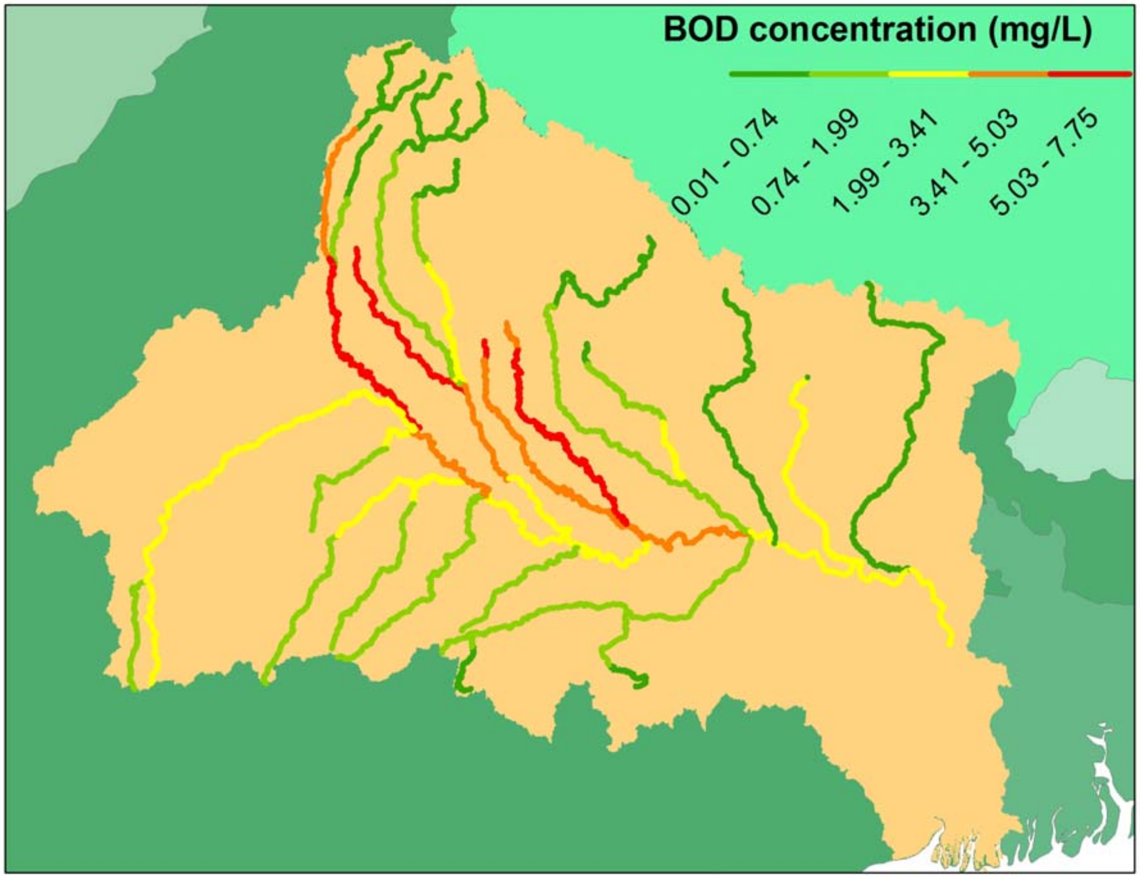

FIGURE 26
Calculated BOD_5 concentrations based on standard per capita equation for each VSEC river unit throughout the Ganga basin. Categories coded by quantiles.

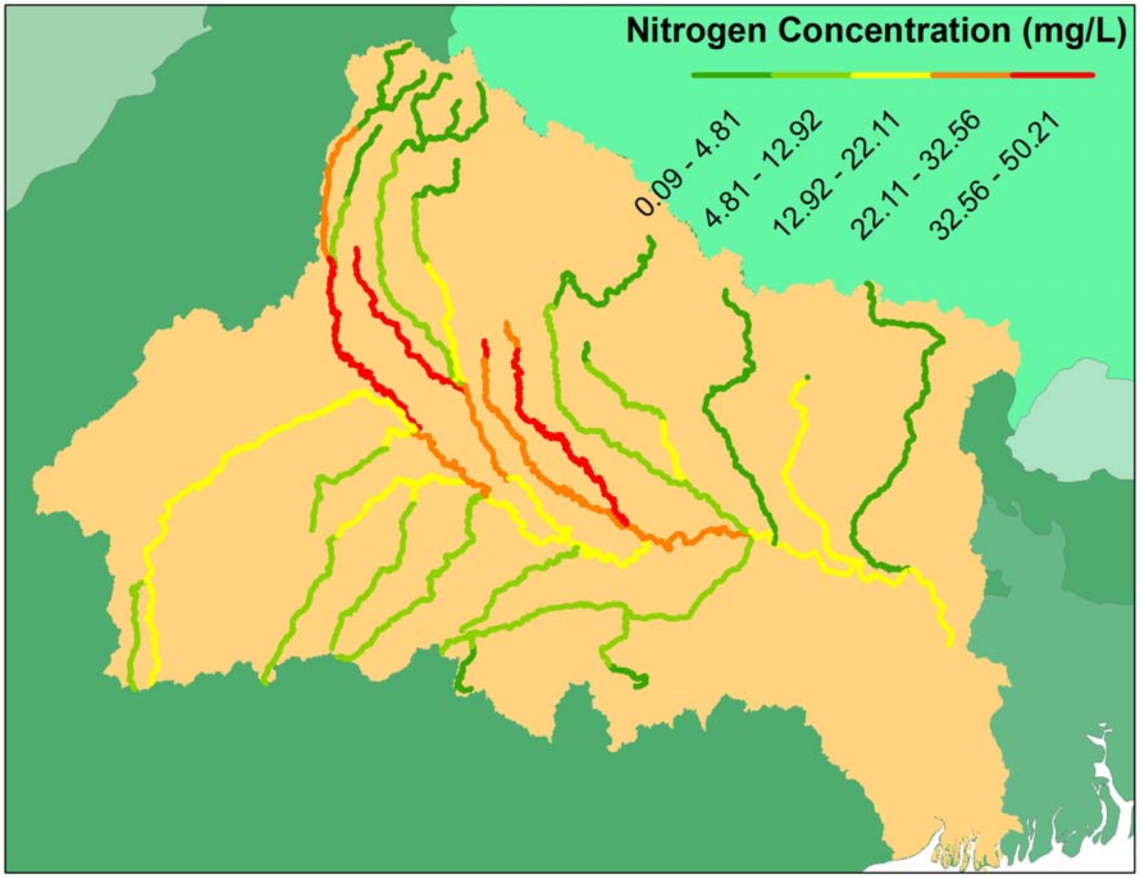

FIGURE 27
Calculated total nitrogen concentrations based on standard per capita equation for each VSEC river unit throughout the Ganga basin. Categories coded by quantiles.

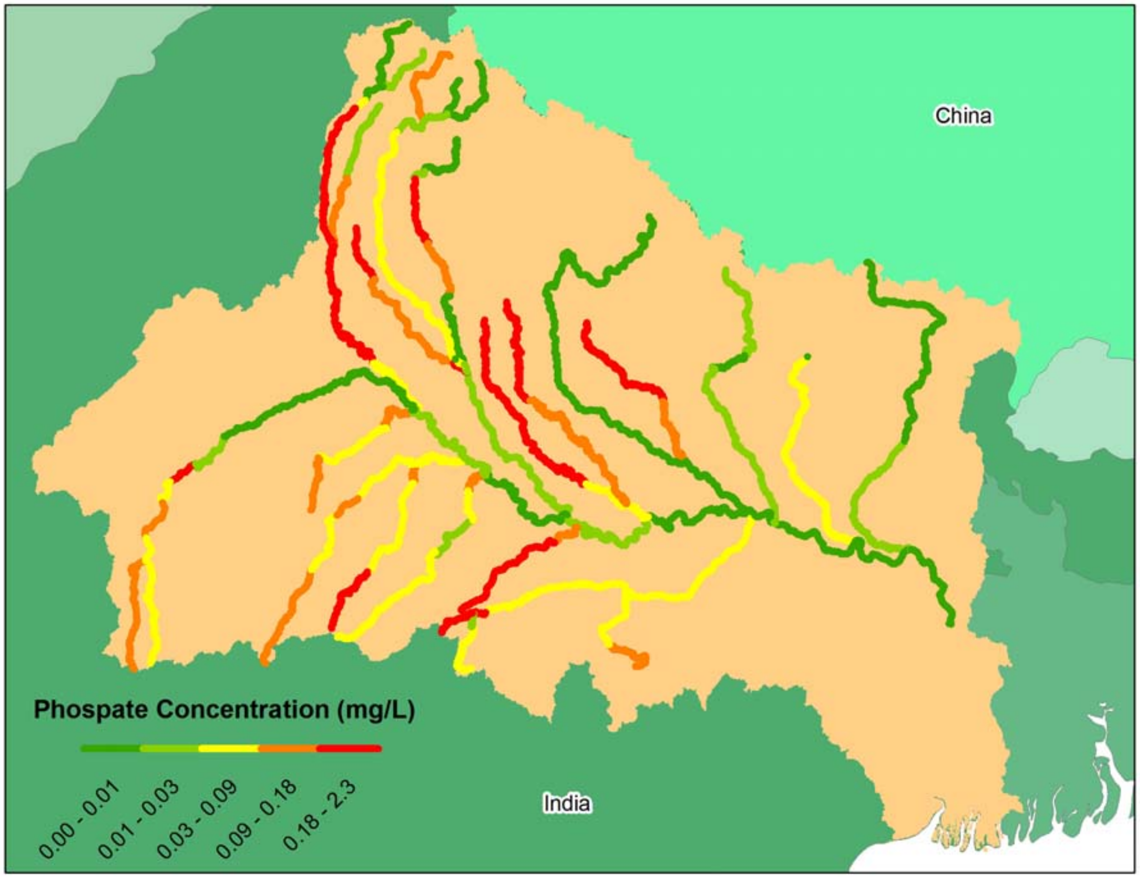

FIGURE 28
Calculated total phosphate concentrations based on standard per capita equation for each VSEC river unit throughout the Ganga basin. Categories coded by quantiles.

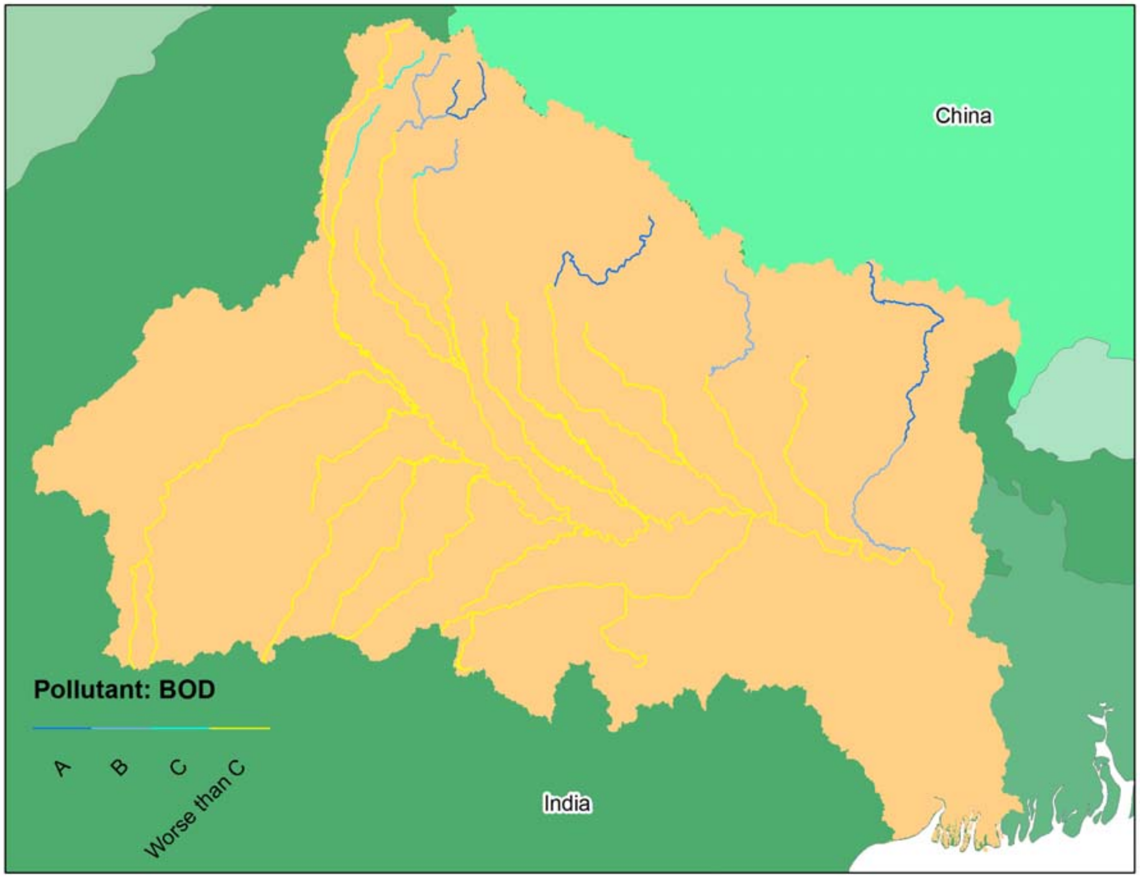

FIGURE 29
Classification of waters into classes A, B, C and "worse than C" based on CPCB's water quality parameters of BOD concentration. Values of BOD estimated using empirical loading model.

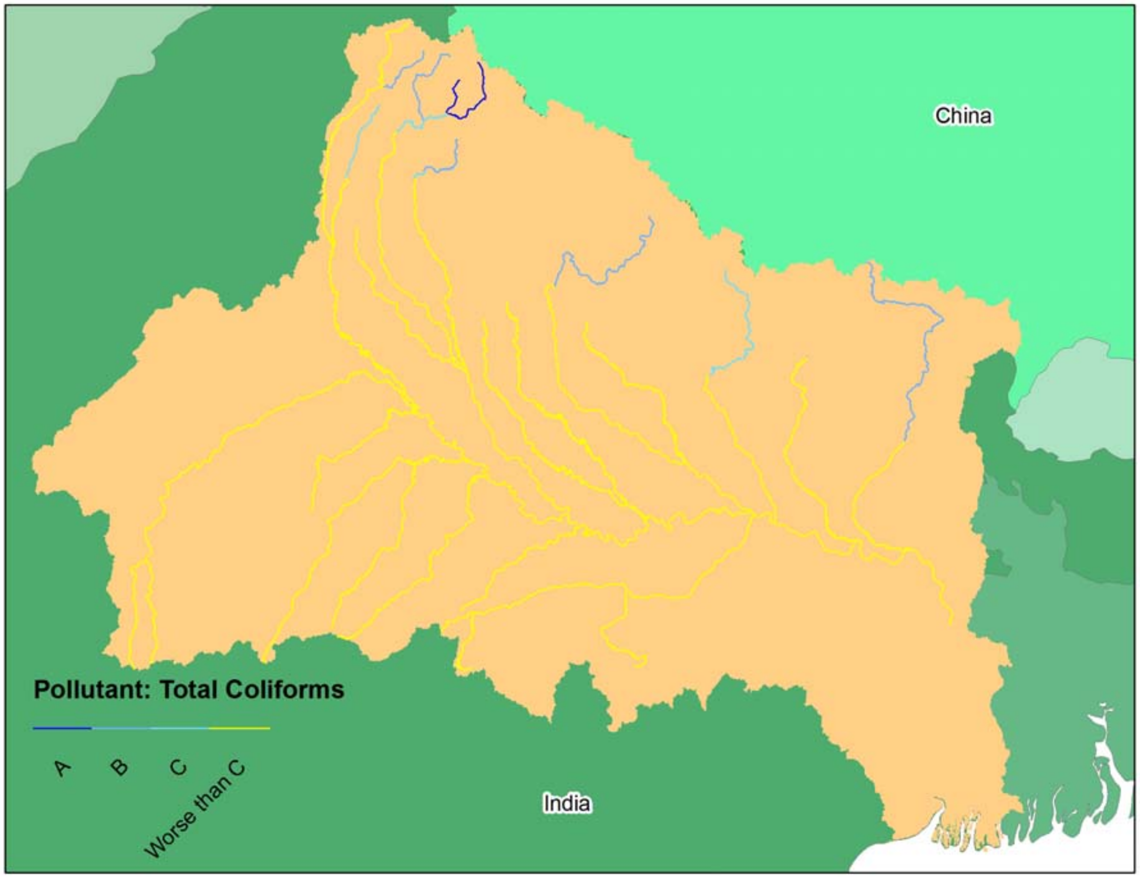

FIGURE 30
Classification of waters into classes A, B, C and "worse than C" based on CPCB's water quality parameters of total coliform counts. Values of total coliforms estimated using empirical loading model.

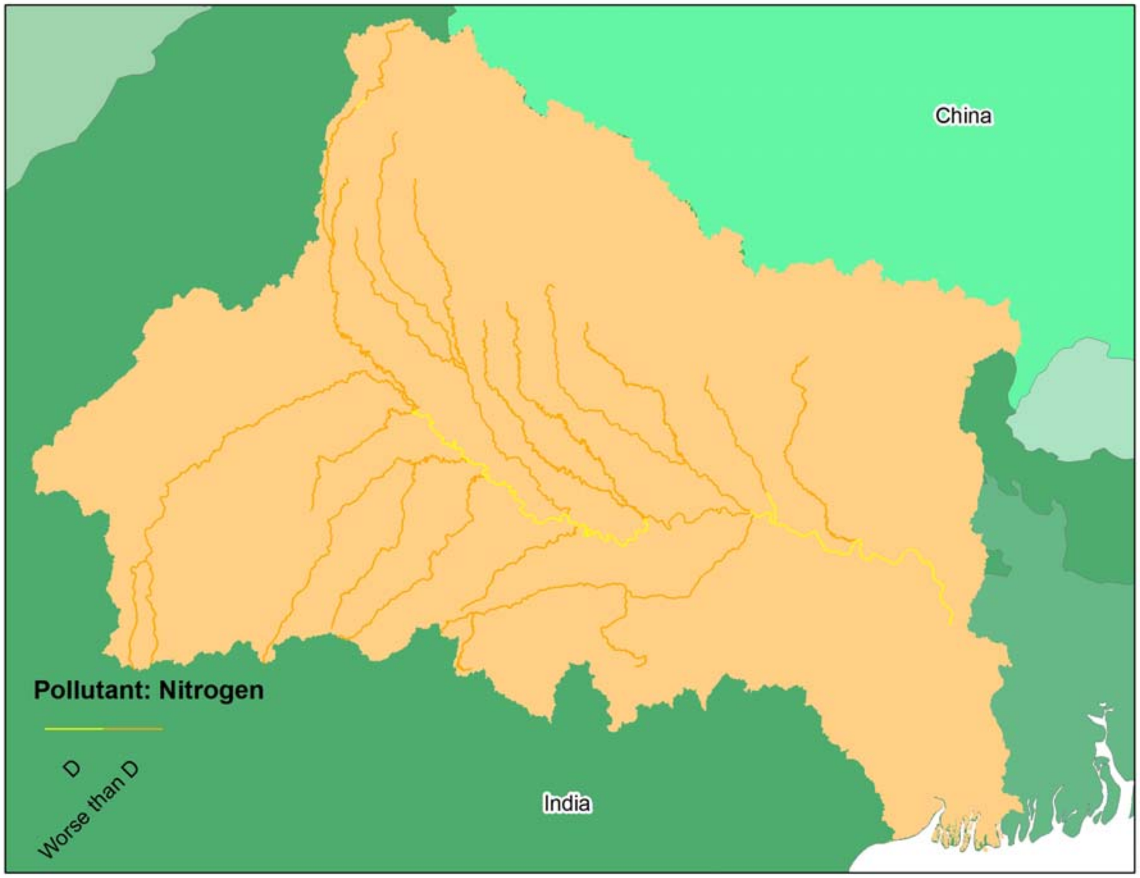

FIGURE 31
Classification of waters into classes D and “worse than D” based on CPCB’s water quality parameters of nitrogen concentration. Values of nitrogen estimated using empirical loading model.

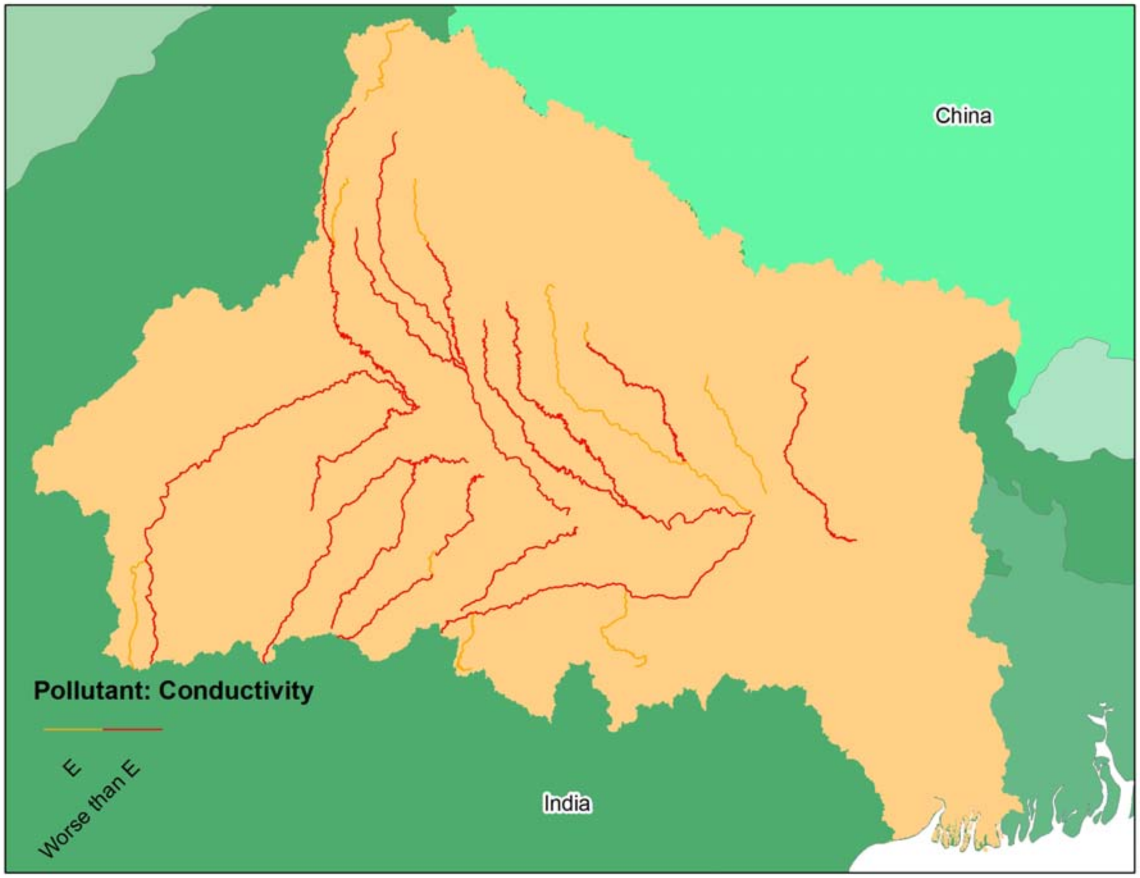

FIGURE 32
Classification of waters into classes E and “worse than E” based on CPCB’s water quality parameters of conductivity. Values of conductivity estimated using empirical loading model.

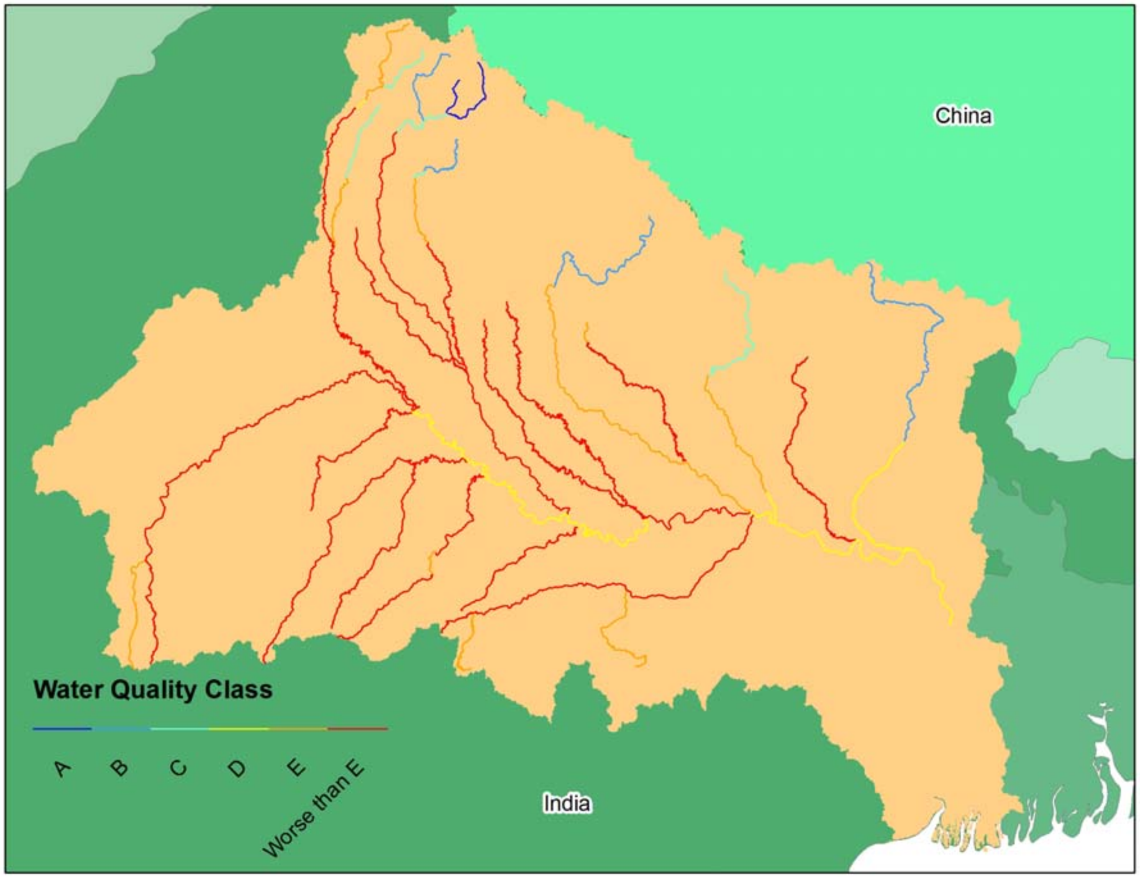

FIGURE 33
Modeled water quality classes of VSEC basins based on modeled pollutant concentrations. Model classification derived from CPCB water quality classification system.

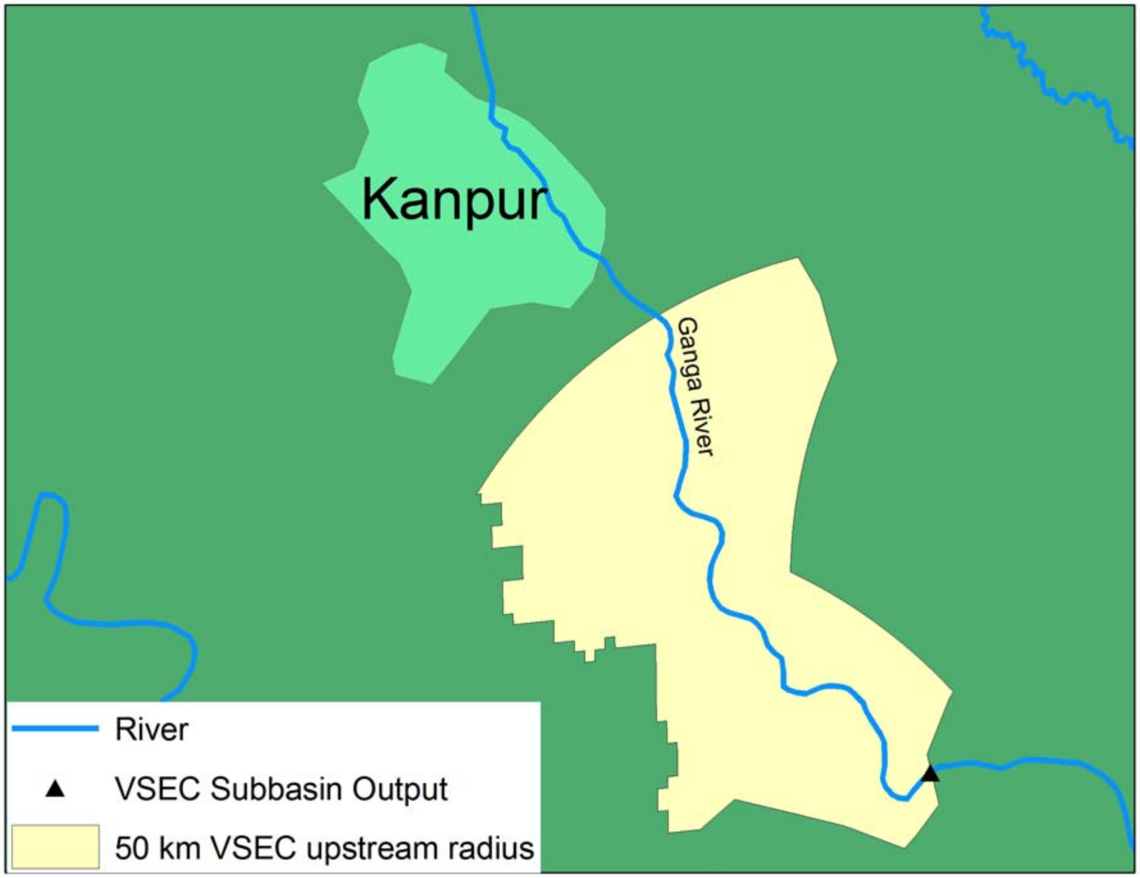

FIGURE 34
The city of Kanpur lies just outside the 50km upstream radius from the VSEC subbasin output point.

FIGURE 35
Section of bathers present at the Ardh Kumbh Mela pilgrimage at the confluence of Yamuna and Ganga Rivers at Allahabad.

FIGURE 36
Relative comparison of water present in the Ganga River (top) and the Yamuna River (bottom) before their confluence, Allahabad.

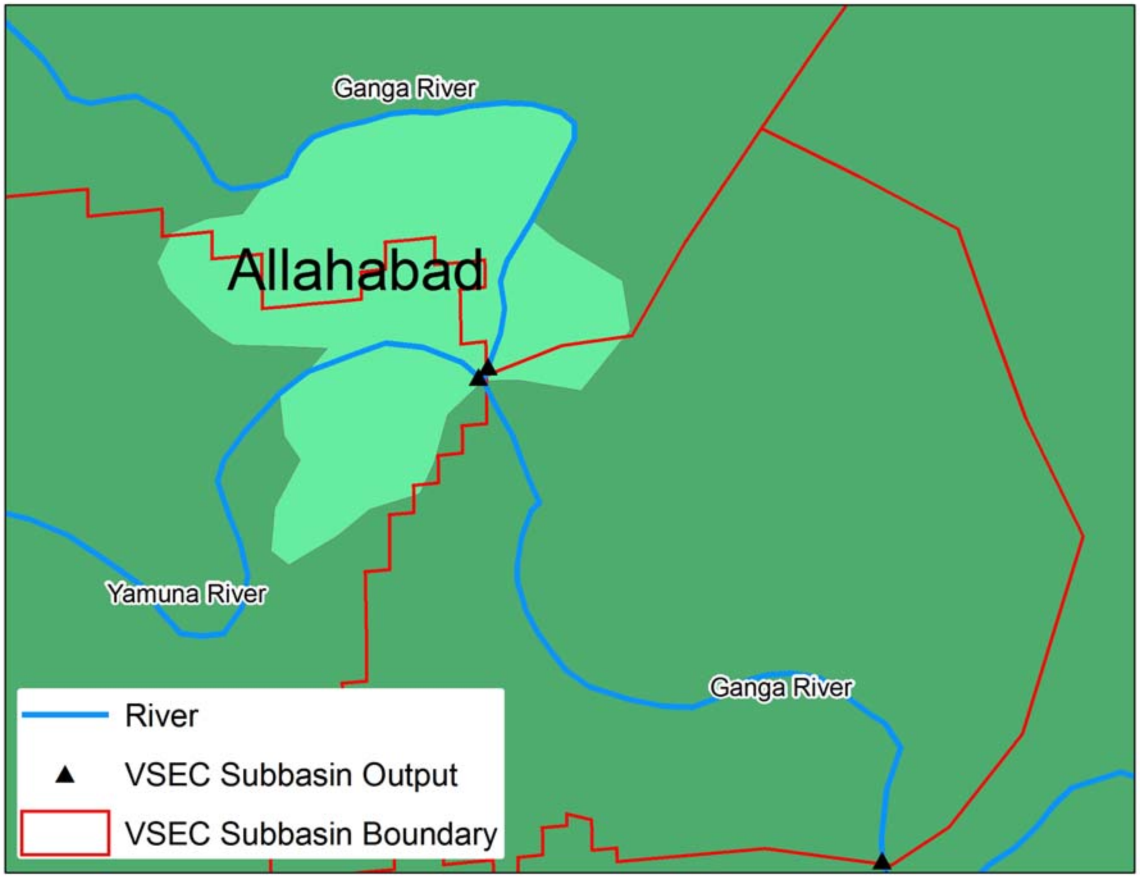

FIGURE 37
Setup of VSEC subbasins around the city of Allahabad. The city is split roughly in half between the Yamuna River and Ganga River subbasins upstream of the confluence point. The entire city of Allahabad is within 50km of the downstream VSEC Subbasin output point, and has been included within the phosphate model at the downstream end.

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Appendix 1. Pre-GAP pollutant concentrations.

Assigned ID	CPCB Station #	River	City	Site	State
5400	1060	Ganga	Rishikesh	Upstream	Uttaranchal
5300	1061	Ganga	Haridwar	Downstream	Uttaranchal
5200	1062	Ganga	Garhmukteshwar		Uttar Pradesh
5000	1130	Ganga	Budaun	Kachhla Road Bridge	Uttar Pradesh
4910	1064	Ramganga	Kannauj	B/C with Ganga	Uttar Pradesh
4900	1063	Ganga	Kannauj	U/S of Rajghat	Uttar Pradesh
4800	1066	Ganga	Kannauj	Downstream	Uttar Pradesh
4600	1067	Ganga	Kanpur	U/S of Ranighat	Uttar Pradesh
4500	1068	Ganga	Kanpur	Downstream of Jajmau Pumping Station	Uttar Pradesh
4400	1132	Ganga	Dalmau	Rae-Bareli	Uttar Pradesh
4300	1047	Ganga	Allahabad	Nagbasuki Temple	Uttar Pradesh
4200	1046	Ganga	Allahabad	Rasoolabad	Uttar Pradesh
4100	1048	Ganga	Allahabad	Shivkuti Ghat	Uttar Pradesh
3990	1117	Yamuna	Hathnikund		Haryana
3960	1118	Yamuna	Panipat		Haryana
3950	1119	Yamuna	Sonipat		Haryana
3940	1120	Yamuna	Wazirabad		Haryana
3930	1121	Yamuna	Delhi	Ring Road	Delhi
3920	1122	Yamuna	Delhi	Agra Canal	Delhi
3900	1123	Yamuna	Mathura	Upstream	Uttar Pradesh
3895	1124	Yamuna	Mathura	Downstream	Uttar Pradesh
3890	1125	Yamuna	Agra	Upstream	Uttar Pradesh
3880	1126	Yamuna	Agra	Downstream	Uttar Pradesh
3860	1127	Yamuna	Etawah		Uttar Pradesh
3830	1128	Yamuna	Hamirpur		Uttar Pradesh
3820	1129	Yamuna	Allahabad		Uttar Pradesh
3800	1049	Ganga	Allahabad	D/S of Sangam	Uttar Pradesh
3720	1144	Tons	Madhavgarh		Madhya Pradesh
3700	1050	Ganga	Mirzapur	Sundar Ghat	Uttar Pradesh
3600	1070	Ganga	Varanasi	U/S of Assighat	Uttar Pradesh
3400	1071	Ganga	Varanasi	D/S of Malviya Bridge	Uttar Pradesh
3312	1137	Gomati	Sultanpur		Uttar Pradesh
3200	1073	Ganga	Ghazipur	Tarighat	Uttar Pradesh
3100	1074	Ganga	Buxar		Bihar
3010	1076	Ghaghara	Near Capra		Bihar
2920	1142	Sone	Chachai		Madhya Pradesh
2910	1075	Sone	Koelwar		Bihar
2800	1077	Ganga	Patna	U/S of Khurji	Bihar
2700	1079	Ganga	Patna	Downstream of Ganga Bridge	Bihar
2600	1138	Ganga	Barhiya		Bihar
2500	1056	Ganga	Monghyr		Bihar
2350	1058	Ganga	Bhagalpur		Bihar
2300	1059	Ganga	Rajmahal		Bihar
2200	1139	Ganga	Farakka		West Bengal
2100	1080	Ganga	Baharampur		West Bengal
2000	1140	Ganga	Katwa		West Bengal
1900	1141	Ganga	Nabadwip		West Bengal
1800	1055	Ganga	Kalyani		West Bengal
1700	1054	Ganga	Palta		West Bengal
1500	1053	Ganga	Dakshineshwar		West Bengal
1200	1052	Ganga	Ulluberia		West Bengal
1000	1051	Ganga	Diamond Harbour		West Bengal

Assigned ID	Upstream Area (km2)	% Hima-laya	Precipitation (mm/yr)
5400	21,787	100.0%	1,055
5300	23,415	100.0%	913
5200	29,305	83.4%	913
5000	34,101	71.9%	991
4910	35,044	43.1%	913
4900	72,953	90.3%	1,245
4800	83,369	37.8%	913
4600	87,096	36.2%	913
4500	87,865	35.9%	913
4400	92,633	34.1%	1,032
4300	93,963	33.6%	1,278
4200	95,003	33.3%	1,278
4100	95,036	51.0%	1,278
3990	11,145	100.0%	913
3960	15,201	82.9%	913
3950	16,153	78.1%	913
3940	16,690	75.6%	913
3930	17,044	74.1%	913
3920	20,860	60.8%	913
3900	30,922	41.7%	913
3895	31,981	40.3%	913
3890	33,143	38.9%	913
3880	36,446	35.5%	913
3860	51,633	25.2%	913
3830	256,992	5.2%	929
3820	303,355	4.4%	1,234
3800	399,639	11.4%	1,278
3720	3,137	0.0%	1,278
3700	417,422	10.9%	1,278
3600	419,763	10.9%	1,278
3400	422,731	10.8%	1,278
3312	15,559	0.0%	1,184
3200	456,832	10.0%	1,278
3100	463,244	9.8%	1,278
3010	133,136	56.5%	1,278
2920	4,751	0.0%	1,278
2910	76,717	0.0%	1,278
2800	686,641	17.8%	1,278
2700	728,790	21.9%	1,278
2600	741,494	21.5%	1,278
2500	761,489	20.9%	1,278
2350	783,891	62.8%	1,562
2300	880,569	26.1%	1,452
2200	882,568	26.0%	1,637
2100	887,133	25.9%	1,595
2000	903,667	25.4%	1,345
1900	904,922	25.4%	1,697
1800	930,800	24.7%	1,327
1700	932,440	24.6%	1,679
1500	933,086	24.6%	1,679
1200	935,779	24.6%	1,674
1000	955,913	24.1%	1,679

Assigned ID	DO	BOD	COD	NOx	TKN	pH	Turbidity	Temperature	Fecal Coliforms	Total Coliforms
5400	7.73	3.05	15.43	0.19	0.26	7.84	52.59	18.55	253	446
5300	7.48	0.17	0.17	0.18	0.18	0.17	0.24	0.21	0	0
5200	7.58	3.55	24.82	0.16	0.40	7.93	79.87	21.58	392	807
5000	5.82	3.96	29.33	0.08	0.81	7.77	35.36	22.11	132	585
4910	7.75	5.82	15.14	0.32	3.31	7.86	119.68	25.38	1,057,046	1,221,604
4900	7.62	6.37	22.59	1.13	1.99	8.09	90.24	25.55	296,044	244,658
4800	1.67	4.30	12.10	0.48	2.98	8.07	134.33	25.57	509,277	1,882,980
4600	7.54	6.01	15.84	0.43	1.78	7.81	94.97	25.60	854,564	491,220
4500	7.00	11.01	26.39	0.53	3.53	7.74	102.26	25.21	10,123,806	7,473,225
4400	7.02	8.40	36.99	0.86	0.75	7.84	74.48	26.13		3,014
4300	7.32	6.28	17.68	0.88	3.95	8.09	219.53	27.50	3,453	11,339
4200	7.20	7.88	22.74	1.30	3.40	7.86	120.38	26.81	1,861	10,805
4100	7.33	6.51	17.41	0.85	3.83	8.09	213.64	27.39	3,230	10,609
3990	8.78	3.33	27.50	0.44	1.23	7.97	36.33	19.68	927	3,671
3960	8.16	3.72	21.80	0.51	1.08	8.15	39.15	22.37	5,374	11,312
3950	8.09	3.80	19.43	0.53	1.20	8.20	70.46	23.14	7,681	11,846
3940	8.06	3.79	16.44	0.39	1.33	8.04	69.64	24.51	4,915	27,983
3930	1.82	15.00	47.16	0.61	11.76	7.55	57.77	26.49	1,551,988	2,404,474
3920	1.54	14.25	45.54	1.32	8.00	7.69	51.62	24.92	1,028,674	1,709,964
3900	8.08	5.88	32.01	0.91	2.41	8.16	56.54	25.56	32,398	37,034
3895	6.72	7.80	39.52	1.01	3.03	8.13	55.00	24.91	30,356	112,564
3890	8.72	7.21	31.99	1.04	1.20	8.19	38.85	25.28	27,356	74,058
3880	5.13	15.06	53.28	1.19	4.80	8.04	48.62	24.50	230,529	388,030
3860	7.42	5.29	28.59	111.20	1.87	8.11	73.38	25.57	12,396	22,743
3830	7.89	3.96	19.66	0.62	2.15	8.06	64.46	25.71	6,652	9,228
3820	7.57	3.29	18.09	212.41	1.89	8.09	53.31	26.39	9,810	24,469
3800	7.08	9.16	25.58	1.52	3.49	7.83	142.27	26.47	1,878	11,017
3720	8.26	1.71	32.12	1.28	0.33	7.87	144.95	24.38	53	48
3700	6.94	6.60	22.34	1.02	3.90	8.06	153.04	28.19	2,828	12,029
3600	7.05	9.16	25.80	0.83	4.04	7.92	107.93	26.57	1,795	7,328
3400	7.07	8.67	25.84	0.98	3.50	7.99	112.11	27.91	1,538	5,437
3312	8.10	1.51	17.58			7.89	424.88	25.88	3,214	11,045
3200	8.29	9.31	25.75	1.11	3.09	7.98	106.61	26.25	1,756	7,114
3100	7.74	1.68	19.70	2.65	0.51	7.80	270.61	25.72	5,816	34,969
3010	7.92	1.48	18.18		0.47	7.98	254.00	26.20	1,588	7,223
2920	8.44	2.16	30.84	0.28	0.52	8.02	338.65	24.59	23	38
2910	8.06	1.79	20.00		0.82	7.70	286.90	25.42	2,864	13,895
2800	7.77	1.81	21.02	8.60	2.14	7.84	306.07	26.29	11,465	53,695
2700	7.72	1.86	23.17			7.83	310.24	26.80	15,417	60,101
2600	7.86	1.52	18.89			7.86	301.39	26.07	1,494	6,748
2500	7.82	2.21	21.09			7.88	326.43	25.64	2,714	10,495
2350	7.72	1.43	17.38			7.95	247.44	25.03	4,929	9,230
2300	7.87	1.51	21.01			7.82	259.81	26.21	5,846	22,258
2200	7.89	0.79	13.60	0.09	0.46	8.04	292.73	25.64	26,969	66,425
2100	7.61	1.10	15.50	0.10	1.37	8.13	292.43	24.47	14,520	33,621
2000	7.24	1.04	13.08	0.14	0.34	8.07	250.39	26.46	36,043	83,908
1900	7.19	1.24	14.70	1.37	0.38	8.09	251.61	26.40	38,698	50,395
1800	7.01	1.64	19.56	0.09	0.37	8.02	230.60	25.60	33,522	86,945
1700	7.12	1.49	17.90	0.13	1.69	8.05	238.25	25.02	54,572	125,690
1500	6.94	3.09	24.67	0.13	2.11	8.08	253.92	25.19	101,258	203,716
1200	6.58	1.91	19.25	0.15	1.98	8.03	256.94	25.13	93,973	190,464
1000	6.69	11.13	126.42	0.37	0.47	7.98	393.21	26.35	29,023	40,649

Assigned ID	Conductivity	Alkalinity	Cl	SO4	Na	Ca	Mg	Hardness
5400	247.76	64.95	8.38	22.12	3.42	80.03	52.08	132.41
5300	0.18	0.18	0.17	0.19	0.18	0.21	0.21	0.21
5200	404.38	93.67	11.31	25.96	11.34	75.55	56.93	134.19
5000	673.46	181.50	11.94	34.96	25.64			109.17
4910	229.44	207.21	24.00	31.32	9.74	75.48	51.82	130.09
4900	301.65	151.06	16.48	26.98	16.67	82.15	52.66	135.73
4800	218.63	156.67	35.33	19.67	6.33	67.43	49.14	119.13
4600	301.58	145.03	15.69	16.77	19.55	72.32	45.80	116.15
4500	316.53	142.03	32.13	21.09	23.51	54.17	43.65	99.22
4400	313.79	136.79	18.92	19.46	9.67			118.88
4300	337.10	105.71	20.43	16.82	14.86	43.38	29.50	72.91
4200	527.65	141.67	35.21	22.30	13.49	51.79	30.79	80.86
4100	330.32	109.74	20.42	17.50	15.53	40.00	29.82	70.45
3990	220.00		3.14	22.63	17.00	28.09	100.31	126.86
3960	325.43		9.67	24.88		40.87	89.90	130.87
3950	274.93		8.00	20.13		63.27	36.87	101.13
3940	344.14		20.70	30.00		55.42	32.11	87.53
3930	609.64		69.10	59.38		43.21	29.50	68.48
3920	561.00		49.80	49.38		94.09	29.27	124.27
3900	1106.14		144.90	89.00		86.92	32.38	119.54
3895	1182.00		156.40	100.00		67.15	25.00	92.54
3890	1212.71		192.80	111.63		77.50	29.50	107.50
3880	1448.50		221.10	143.88		73.00	28.29	94.25
3860	1262.64		186.80	105.88		69.08	21.54	91.54
3830	535.57		35.70	41.13				79.25
3820	478.43		28.00	28.50				123.92
3800	587.46	144.85	40.86	21.30	15.78	49.65	32.48	81.87
3720	325.94	161.27	25.63	34.13	20.00	129.06	31.38	158.42
3700	379.41	140.11	28.70	16.65	17.90	55.00	37.40	92.40
3600	483.55	156.20	44.41	19.94	14.19	66.63	57.87	123.43
3400	475.73	150.68	47.11	21.61	16.35	128.40	10.81	138.25
3312	377.79	145.00	15.92	15.43	18.43	71.00		230.50
3200	468.48	155.05	44.71	21.64	13.44	120.46	20.23	141.00
3100	313.82	150.45	21.99	17.72	17.18	114.53	30.59	143.56
3010	29.40	104.84	8.40	11.00	12.60	88.50	44.00	132.50
2920	227.31	123.43	24.58	30.00	16.60			119.72
2910	174.25	91.18	11.25	10.53	13.05	80.51	59.35	139.43
2800	275.33	132.22	15.82	15.84	19.65	80.75	61.08	142.95
2700	283.60	133.13	15.49	15.04	21.12	70.12	45.47	331.40
2600	357.94	135.10	14.60	15.16	26.44			230.33
2500	367.71	142.64	14.69	14.16	18.29	117.32	212.61	322.06
2350	370.07	141.92	14.30	15.11	16.50	87.61	48.57	136.18
2300	262.38	129.80	14.67	14.13	16.13	79.37	53.38	132.54
2200	361.27	114.76	9.38	20.06	11.97			243.13
2100	282.85	108.58	9.88	15.86	13.09	77.38	43.84	123.47
2000	289.21	122.88	9.21	21.19	13.84			369.30
1900	305.88	123.36	9.36	21.00	10.97			195.86
1800	307.18	125.59	9.60	20.76	10.84	77.24	52.54	125.04
1700	292.05	111.46	11.96	16.75	12.09	74.31	59.91	133.96
1500	318.36	113.49	13.44	19.80	14.08	75.57	45.95	121.82
1200	310.11	110.79	15.38	18.57	15.36	70.87	53.94	124.13
1000	3285.36	115.22	701.53	171.91	739.30	79.53	61.47	141.00

Appendix 2. Post-GAP pollutant concentrations.

Assigned ID	CPCB Station	River	City	Site	State
5700		Bhagirathi	Gangotri		Uttar Pradesh
5600	13	Bhagirathi	Devaprayag	B/C with Alkananda River	Uttar Pradesh
5530	18	Alkananda	Rudraprayag	B/C with Mandakini River	Uttar Pradesh
5522	16	Mandakini	Rudraprayag	B/C with Alkalnada	Uttar Pradesh
5520	17	Alkananda	Rudraprayag	A/C with Mandakini River	Uttar Pradesh
5510	15	Alkananda	Devaprayag	B/C with Bhagirathi River	Uttar Pradesh
5500	14	Bhagirathi	Devaprayag	A/C with Alkananda River	Uttar Pradesh
5400	1060	Ganga	Rishikesh	Upstream	Uttaranchal
5300	1061	Ganga	Haridwar	Downstream	Uttaranchal
5200	1062	Ganga	Garhmukteshwar		Uttar Pradesh
5100	10	Ganga	Narora	Bulandsahar	Uttar Pradesh
5000	1130	Ganga	Budaun	Kachhla Road Bridge	Uttar Pradesh
4910	1064	Ramganga	Kannauj	B/C with Ganga	Uttar Pradesh
4900	1063	Ganga	Kannauj	U/S of Rajghat	Uttar Pradesh
4820	7	Kalinadi	Gulaothi Town	Upstream	Uttar Pradesh
4800	1066	Ganga	Kannauj	Downstream	Uttar Pradesh
4700	1146	Ganga	Kanpur	Bithoor	Uttar Pradesh
4600	1067	Ganga	Kanpur	U/S of Ranighat	Uttar Pradesh
4500	1068	Ganga	Kanpur	Downstream of Jajmau Pumping Station	Uttar Pradesh
4400	1132	Ganga	Dalmau	Rae-Bareli	Uttar Pradesh
4300	1047	Ganga	Allahabad	Nagbasuki Temple	Uttar Pradesh
4200	1046	Ganga	Allahabad	Rasoolabad	Uttar Pradesh
4100	1048	Ganga	Allahabad	Shivkuti Ghat	Uttar Pradesh
4010	11	Yamuna	Yamunotri		Uttar Pradesh
4000	9	Yamuna	Hanumanchatti		Uttar Pradesh
3990	1117	Yamuna	Hathnikund		Haryana
3980	2	Yamuna	Kalanaur		Haryana
3970	8	Yamuna	Dak Patthar	Upstream	Uttar Pradesh
3960	1118	Yamuna	Panipat		Haryana
3950	1119	Yamuna	Sonipat		Haryana
3940	1120	Yamuna	Wazirabad		Haryana
3930	1121	Yamuna	Delhi	Ring Road	Delhi
3920	1122	Yamuna	Delhi	Agra Canal	Delhi
3910	4	Yamuna	Mazawali		Uttar Pradesh
3902	6	Hindon	Saharanpur	Downstream	Uttar Pradesh
3901	3	Hindon	Ghaziabad	Downstream	Uttar Pradesh
3900	1123	Yamuna	Mathura	Upstream	Uttar Pradesh
3895	1124	Yamuna	Mathura	Downstream	Uttar Pradesh
3890	1125	Yamuna	Agra	Upstream	Uttar Pradesh
3880	1126	Yamuna	Agra	Downstream	Uttar Pradesh
3870	12	Yamuna	Bateshwar		Uttar Pradesh
3860	1127	Yamuna	Etawah		Uttar Pradesh
3851	1368	Kshipra	Ujjain	Gaughat	Madhya Pradesh
3850	1369	Kshipra	Ujjain	Ramghat	Madhya Pradesh
3848	1365	Chambal	Nagda	U/S Water intake point	Madhya Pradesh
3847	1366	Chambal	Nagda	Eff. Disc. Of Nagda meets Chambal	Madhya Pradesh
3846	1418	Chambal	Rampura	Ghandi Sagar Dam	Madhya Pradesh
3845	1288	Chambal	Kota	U/S of Water intake near barrage	Rajasthan
3844	1289	Chambal	Kota	2 km away from Kota City	Rajasthan
3843	1	Chambal	Sawaimadhopur	Rameshwarghat	Rajasthan
3842	20	Chambal	Etawah	B/C with Yamuna River	Uttar Pradesh
3841	5	Yamuna	Juhikha	A/C with Chambal River	Uttar Pradesh
3840					
3831	21	Betwa	Hamirpur	B/C with Yamuna River	Uttar Pradesh

3830	1128	Yamuna	Hamirpur		Uttar Pradesh
3820	1129	Yamuna	Allahabad		Uttar Pradesh
3810	1069	Yamuna	Allahabad	Balua Ghat D/S	Uttar Pradesh
3800	1049	Ganga	Allahabad	D/S of Sangam	Uttar Pradesh
3720	1144	Tons	Madhavgarh		Madhya Pradesh
3700	1050	Ganga	Mirzapur	Sundar Ghat	Uttar Pradesh
3600	1070	Ganga	Varanasi	U/S of Assighat	Uttar Pradesh
3500	1133	Ganga	Varanasi	Dashashwamedh Ghat	Uttar Pradesh
3400	1071	Ganga	Varanasi	D/S of Malviya Bridge	Uttar Pradesh
3330	22	Sai	Unnao	After drain outfall	Uttar Pradesh
3320					
3315	23	Gomati	Sitapur	Water intake point U/S	Uttar Pradesh
3314	24	Gomati	Lucknow	Water intake point U/S	Uttar Pradesh
3313	39	Gomati	Lucknow	Downstream	Uttar Pradesh
3312	1137	Gomati	Sultanpur		Uttar Pradesh
3311	26	Gomati	Jaunpur	Downstream	Uttar Pradesh
3310					
3200	1073	Ganga	Ghazipur	Tarighat	Uttar Pradesh
3100	1074	Ganga	Buxar		Bihar
3030	25	Saryu	Ayodhya	Main bathing ghat	Uttar Pradesh
3021	1363	Rapti	Gorakhpur	A/C with Honin River near Domingarh R	Uttar Pradesh
3020	1364	Ghaghara	Deoria	Downstream	Uttar Pradesh
3010	1076	Ghaghara	Near Capra		Bihar
3000					
2920	1142	Sone	Chachai		Madhya Pradesh
2912	27	Rihand	Renukut	Upstream	Uttar Pradesh
2911	28	Rihand	Renukut	Downstream	Uttar Pradesh
2910	1075	Sone	Koelwar		Bihar
2900					
2800	1077	Ganga	Patna	U/S of Khurji	Bihar
2710	1078	Gandak	Patna	Sonepur (Before Conflu-ence)	Bihar
2700	1079	Ganga	Patna	Downstream of Ganga Bridge	Bihar
2600	1138	Ganga	Barhiya		Bihar
2500	1056	Ganga	Monghyr		Bihar
2350	1058	Ganga	Bhagalpur		Bihar
2301		Kosi			
2300	1059	Ganga	Rajmahal		Bihar
2200	1139	Ganga	Farakka		West Bengal
2100	1080	Ganga	Baharampur		West Bengal
2000	1140	Ganga	Katwa		West Bengal
1900	1141	Ganga	Nabadwip		West Bengal
1800	1055	Ganga	Kalyani		West Bengal
1700	1054	Ganga	Palta		West Bengal
1600	31	Ganga	Serampore		West Bengal
1500	1053	Ganga	Dakshineshwar		West Bengal
1400	34	Ganga	Howrah-Shivpur		West Bengal
1300	33	Ganga	Garden Reach		West Bengal
1200	1052	Ganga	Ulluberia		West Bengal
1100	32	Rupnarayan	Near Geonkhali	B/C with Ganga	West Bengal
1000	1051	Ganga	Diamond Harbour		West Bengal

Assigned ID	Upstream Area	% Hima- laya	Precipitation (mm/yr)	Subbasin Population	Upstream Population	50km Up- stream Population
5700	1,570	100.0%	913	2,473	2,473	2,500
5600	7,583	100.0%	913	27,265	29,738	703
5530	8,742	100.0%	1,025	17,921	17,921	734
5522	1,627	100.0%	913	3,167	3,167	1,798
5520	10,399	100.0%	913	165	21,253	5,860
5510	11,138	100.0%	913	16,847	38,100	1,118
5500	18,793	100.0%	913	339	68,177	36,874
5400	21,787	100.0%	1,055	47,877	116,054	31,745
5300	23,415	100.0%	913	250,978	367,032	233,589
5200	29,305	83.4%	913	994,858	1,361,890	118,461
5100	30,410	80.4%	913	254,474	1,616,364	159,224
5000	34,101	71.9%	991	741,281	2,357,645	155,969
4910	35,044	43.1%	913	7,186,320	7,186,320	111,083
4900	72,953	90.3%	1,245	804,680	10,348,645	223,985
4820	2,731	41.6%	913	963,564	963,564	637,943
4800	83,369	37.8%	913	2,011,020	13,323,229	409,442
4700	87,065	36.2%	913	799,084	14,122,313	169,839
4600	87,096	36.2%	913	2,866	14,125,179	2,542
4500	87,865	35.9%	913	168,728	14,293,907	185,278
4400	92,633	34.1%	1,032	1,791,560	16,085,467	354,141
4300	93,963	33.6%	1,278	327,207	16,412,674	270,887
4200	95,003	33.3%	1,278	342,390	16,755,064	4,151
4100	95,036	51.0%	1,278	107,175	16,862,239	445,287
4010	267	100.0%	913	375	375	366
4000	1,134	100.0%	913	1,707	2,082	1,754
3990	11,145	100.0%	913	311,865	313,947	99,494
3980	12,080	100.0%	913	41,489	355,436	109,255
3970	13,373	94.1%	913	179,891	535,327	181,647
3960	15,201	82.9%	913	252,997	788,324	129,451
3950	16,153	78.1%	913	147,249	935,573	72,356
3940	16,690	75.6%	913	244,375	1,179,948	62,852
3930	17,044	74.1%	913	1,031,710	2,211,658	34,489
3920	20,860	60.8%	913	3,330,070	5,541,728	135,937
3910	21,074	60.2%	913	161,200	5,702,928	4,297,010
3902	332	44.0%	913	43,963	43,963	43,452
3901	5,428	2.7%	913	1,170,950	1,214,913	240,819
3900	30,922	41.7%	913	1,297,560	8,215,401	606,888
3895	31,981	40.3%	913	475,202	8,690,603	197,174
3890	33,143	38.9%	913	358,158	9,048,761	523,175
3880	36,446	35.5%	913	1,418,910	10,467,671	825,242
3870	48,252	26.9%	913	2,112,070	12,579,741	620,621
3860	51,633	25.2%	913	1,130,440	13,710,181	309,837
3851	1,969	0.0%	913	648,186	648,186	72,761
3850	2,042	0.0%	913	55,794	703,980	217,244
3848	3,627	0.0%	913	133,631	133,631	49,217
3847	3,686	0.0%	913	28,628	162,259	27,346
3846	24,922	0.0%	919	1,301,320	2,167,559	140,358
3845	40,044	0.0%	919	1,262,770	3,430,329	410,463
3844	40,054	0.0%	913	44,040	3,474,369	39,155
3843	60,674	0.0%	961	1,604,070	5,078,439	161,168
3842	125,990	0.0%	913	5,487,400	10,565,839	80,064
3841	177,874	7.5%	913	30,250	24,306,270	212,064
3840	178,168	7.5%	913	38,962	24,345,232	615,486
3831	44,424	0.0%	1,165	4,925,760	29,270,992	24,188
3830	256,992	5.2%	929	4,709,770	33,980,762	303,080
3820	303,355	4.4%	1,234	5,682,510	39,663,272	58,296
3810	303,422	4.4%	1,278	75,576	39,738,848	410,595
3800	399,639	11.4%	1,278	419,579	57,020,666	427,115

3720	3,137	0.0%	1,278	181,432	181,432	155,886
3700	417,422	10.9%	1,278	564,485	57,766,583	588,506
3600	419,763	10.9%	1,278	611,531	58,378,114	38,127
3500	419,932	10.9%	1,278	132,887	58,511,001	97,352
3400	422,731	10.8%	1,278	868,711	59,379,712	1,142,840
3330	3,209	0.0%	927	668,525	668,525	110,541
3320	11,449	0.0%	1,197	1,903,800	2,572,325	653,090
3315	1,109	0.0%	1,203	321,862	321,862	271,542
3314	9,383	0.0%	1,051	2,177,640	2,499,502	44,987
3313	9,513	0.0%	1,184	332,152	2,831,654	1,040,700
3312	15,559	0.0%	1,184	1,471,570	4,303,224	372,437
3311	17,755	0.0%	1,278	646,914	4,950,138	228,146
3310	32,249	0.0%	1,278	573,015	8,095,478	366,784
3200	456,832	10.0%	1,278	385,925	67,861,115	301,914
3100	463,244	9.8%	1,278	1,076,950	68,938,065	359,084
3030	88,058	75.6%	1,253	4,597,440	4,597,440	488,947
3021	110,108	37.5%	1,278	2,701,020	2,701,020	365,788
3020	124,299	60.4%	1,278	2,369,450	5,070,470	591,514
3010	133,136	56.5%	1,278	2,033,890	11,701,800	397,456
3000	133,670	20.0%	1,278	169,091	80,808,956	421,420
2920	4,751	0.0%	1,278	400,978	400,978	308,953
2912	17,728	0.0%	1,278	671,508	671,508	166,301
2911	17,731	0.0%	1,278	3,697	675,205	3,697
2910	76,717	0.0%	1,278	5,064,380	6,140,563	205,320
2900	76,976	17.8%	1,278	85,645	87,035,164	514,428
2800	686,641	17.8%	1,278	757,631	87,792,795	134,406
2710	41,921	21.9%	1,278	2,320,190	2,320,190	34,033
2700	728,790	21.9%	1,278	361,447	90,474,432	873,220
2600	741,494	21.5%	1,278	2,769,220	93,243,652	123,745
2500	761,489	20.9%	1,278	3,665,840	96,909,492	626,455
2350	783,891	62.8%	1,562	5,149,180	102,058,672	580,919
2301	88,808	62.8%	1,562	7,621,390	7,621,390	926,311
2300	880,569	26.1%	1,452	1,757,270	111,437,332	460,664
2200	882,568	26.0%	1,637	245,543	111,682,875	240,595
2100	887,133	25.9%	1,595	766,732	112,449,607	252,365
2000	903,667	25.4%	1,345	3,942,340	116,391,947	818,720
1900	904,922	25.4%	1,697	445,282	116,837,229	523,846
1800	930,800	24.7%	1,327	8,131,270	124,968,499	718,743
1700	932,440	24.6%	1,679	1,637,770	126,606,269	201,784
1600	932,824	24.6%	1,679	1,041,200	127,647,469	260,732
1500	933,086	24.6%	1,679	926,580	128,574,049	418,703
1400	933,325	24.6%	1,679	1,086,330	129,660,379	581,443
1300	933,766	24.6%	1,679	1,203,870	130,864,249	890,718
1200	935,779	24.6%	1,674	1,036,100	131,900,349	4,780,110
1100	952,329	24.1%	1,408	4,563,230	136,463,579	471,127
1000	955,913	24.1%	1,679	886,481	137,350,060	332,127

Assigned ID	DO	BOD	COD	NOx	TKN	pH	Turbidity	Temp	Fecal Coliforms	Total Coliforms
5700										
5600										
5530										
5522										
5520										
5510										
5500										
5400	7.73	3.05	15.43	0.19	0.26	7.84	52.59	18.55	253	446
5300	7.48	0.17	0.17	0.18	0.18	0.17	0.24	0.21	0	0
5200	7.58	3.55	24.82	0.16	0.40	7.93	79.87	21.58	392	807
5100										
5000	5.82	3.96	29.33	0.08	0.81	7.77	35.36	22.11	132	585
4910	7.75	5.82	15.14	0.32	3.31	7.86	119.68	25.38	1,057,046	1,221,604
4900	7.62	6.37	22.59	1.13	1.99	8.09	90.24	25.55	296,044	244,658
4820										
4800	1.67	4.30	12.10	0.48	2.98	8.07	134.33	25.57	509,277	1,882,980
4700										
4600	7.54	6.01	15.84	0.43	1.78	7.81	94.97	25.60	854,564	491,220
4500	7.00	11.01	26.39	0.53	3.53	7.74	102.26	25.21	10,123,806	7,473,225
4400	7.02	8.40	36.99	0.86	0.75	7.84	74.48	26.13		3,014
4300	7.32	6.28	17.68	0.88	3.95	8.09	219.53	27.50	3,453	11,339
4200	7.20	7.88	22.74	1.30	3.40	7.86	120.38	26.81	1,861	10,805
4100	7.33	6.51	17.41	0.85	3.83	8.09	213.64	27.39	3,230	10,609
4010										
4000										
3990	8.78	3.33	27.50	0.44	1.23	7.97	36.33	19.68	927	3,671
3980										
3970										
3960	8.16	3.72	21.80	0.51	1.08	8.15	39.15	22.37	5,374	11,312
3950	8.09	3.80	19.43	0.53	1.20	8.20	70.46	23.14	7,681	11,846
3940	8.06	3.79	16.44	0.39	1.33	8.04	69.64	24.51	4,915	27,983
3930	1.82	15.00	47.16	0.61	11.76	7.55	57.77	26.49	1,551,988	2,404,474
3920	1.54	14.25	45.54	1.32	8.00	7.69	51.62	24.92	1,028,674	1,709,964
3910										
3902										
3901										
3900	8.08	5.88	32.01	0.91	2.41	8.16	56.54	25.56	32,398	37,034
3895	6.72	7.80	39.52	1.01	3.03	8.13	55.00	24.91	30,356	112,564
3890	8.72	7.21	31.99	1.04	1.20	8.19	38.85	25.28	27,356	74,058
3880	5.13	15.06	53.28	1.19	4.80	8.04	48.62	24.50	230,529	388,030
3870										
3860	7.42	5.29	28.59	111.20	1.87	8.11	73.38	25.57	12,396	22,743
3851										
3850										
3848										
3847										
3846										
3845										
3844										
3843										
3842										
3841										
3840										
3831										
3830	7.89	3.96	19.66	0.62	2.15	8.06	64.46	25.71	6,652	9,228
3820	7.57	3.29	18.09	212.41	1.89	8.09	53.31	26.39	9,810	24,469
3810										
3800	7.08	9.16	25.58	1.52	3.49	7.83	142.27	26.47	1,878	11,017
3720	8.26	1.71	32.12	1.28	0.33	7.87	144.95	24.38	53	48

3700	6.94	6.60	22.34	1.02	3.90	8.06	153.04	28.19	2,828	12,029
3600	7.05	9.16	25.80	0.83	4.04	7.92	107.93	26.57	1,795	7,328
3500										
3400	7.07	8.67	25.84	0.98	3.50	7.99	112.11	27.91	1,538	5,437
3330										
3320										
3315										
3314										
3313										
3312	8.10	1.51	17.58			7.89	424.88	25.88	3,214	11,045
3311										
3310										
3200	8.29	9.31	25.75	1.11	3.09	7.98	106.61	26.25	1,756	7,114
3100	7.74	1.68	19.70	2.65	0.51	7.80	270.61	25.72	5,816	34,969
3030										
3021										
3020										
3010	7.92	1.48	18.18		0.47	7.98	254.00	26.20	1,588	7,223
3000										
2920	8.44	2.16	30.84	0.28	0.52	8.02	338.65	24.59	23	38
2912										
2911										
2910	8.06	1.79	20.00		0.82	7.70	286.90	25.42	2,864	13,895
2900										
2800	7.77	1.81	21.02	8.60	2.14	7.84	306.07	26.29	11,465	53,695
2710										
2700	7.72	1.86	23.17			7.83	310.24	26.80	15,417	60,101
2600	7.86	1.52	18.89			7.86	301.39	26.07	1,494	6,748
2500	7.82	2.21	21.09			7.88	326.43	25.64	2,714	10,495
2350	7.72	1.43	17.38			7.95	247.44	25.03	4,929	9,230
2301										
2300	7.87	1.51	21.01			7.82	259.81	26.21	5,846	22,258
2200	7.89	0.79	13.60	0.09	0.46	8.04	292.73	25.64	26,969	66,425
2100	7.61	1.10	15.50	0.10	1.37	8.13	292.43	24.47	14,520	33,621
2000	7.24	1.04	13.08	0.14	0.34	8.07	250.39	26.46	36,043	83,908
1900	7.19	1.24	14.70	1.37	0.38	8.09	251.61	26.40	38,698	50,395
1800	7.01	1.64	19.56	0.09	0.37	8.02	230.60	25.60	33,522	86,945
1700	7.12	1.49	17.90	0.13	1.69	8.05	238.25	25.02	54,572	125,690
1600										
1500	6.94	3.09	24.67	0.13	2.11	8.08	253.92	25.19	101,258	203,716
1400										
1300										
1200	6.58	1.91	19.25	0.15	1.98	8.03	256.94	25.13	93,973	190,464
1100										
1000	6.69	11.13	126.42	0.37	0.47	7.98	393.21	26.35	29,023	40,649

Assigned ID	Conductivity	Alkalinity	Cl	SO4	Na	Ca	Mg	Hardness
5700								
5600								
5530								
5522								
5520								
5510								
5500								
5400	247.76	64.95	8.38	22.12	3.42	80.03	52.08	132.41
5300	0.18	0.18	0.17	0.19	0.18	0.21	0.21	0.21
5200	404.38	93.67	11.31	25.96	11.34	75.55	56.93	134.19
5100								
5000	673.46	181.50	11.94	34.96	25.64			109.17
4910	229.44	207.21	24.00	31.32	9.74	75.48	51.82	130.09
4900	301.65	151.06	16.48	26.98	16.67	82.15	52.66	135.73
4820								
4800	218.63	156.67	35.33	19.67	6.33	67.43	49.14	119.13
4700								
4600	301.58	145.03	15.69	16.77	19.55	72.32	45.80	116.15
4500	316.53	142.03	32.13	21.09	23.51	54.17	43.65	99.22
4400	313.79	136.79	18.92	19.46	9.67			118.88
4300	337.10	105.71	20.43	16.82	14.86	43.38	29.50	72.91
4200	527.65	141.67	35.21	22.30	13.49	51.79	30.79	80.86
4100	330.32	109.74	20.42	17.50	15.53	40.00	29.82	70.45
4010								
4000								
3990	220.00		3.14	22.63	17.00	28.09	100.31	126.86
3980								
3970								
3960	325.43		9.67	24.88		40.87	89.90	130.87
3950	274.93		8.00	20.13		63.27	36.87	101.13
3940	344.14		20.70	30.00		55.42	32.11	87.53
3930	609.64		69.10	59.38		43.21	29.50	68.48
3920	561.00		49.80	49.38		94.09	29.27	124.27
3910								
3902								
3901								
3900	1,106.14		144.90	89.00		86.92	32.38	119.54
3895	1,182.00		156.40	100.00		67.15	25.00	92.54
3890	1,212.71		192.80	111.63		77.50	29.50	107.50
3880	1,448.50		221.10	143.88		73.00	28.29	94.25
3870								
3860	1,262.64		186.80	105.88		69.08	21.54	91.54
3851								
3850								
3848								
3847								
3846								
3845								
3844								
3843								
3842								
3841								
3840								
3831								
3830	535.57		35.70	41.13				79.25
3820	478.43		28.00	28.50				123.92
3810								
3800	587.46	144.85	40.86	21.30	15.78	49.65	32.48	81.87
3720	325.94	161.27	25.63	34.13	20.00	129.06	31.38	158.42

3700	379.41	140.11	28.70	16.65	17.90	55.00	37.40	92.40
3600	483.55	156.20	44.41	19.94	14.19	66.63	57.87	123.43
3500								
3400	475.73	150.68	47.11	21.61	16.35	128.40	10.81	138.25
3330								
3320								
3315								
3314								
3313								
3312	377.79	145.00	15.92	15.43	18.43	71.00		230.50
3311								
3310								
3200	468.48	155.05	44.71	21.64	13.44	120.46	20.23	141.00
3100	313.82	150.45	21.99	17.72	17.18	114.53	30.59	143.56
3030								
3021								
3020								
3010	29.40	104.84	8.40	11.00	12.60	88.50	44.00	132.50
3000								
2920	227.31	123.43	24.58	30.00	16.60			119.72
2912								
2911								
2910	174.25	91.18	11.25	10.53	13.05	80.51	59.35	139.43
2900								
2800	275.33	132.22	15.82	15.84	19.65	80.75	61.08	142.95
2710								
2700	283.60	133.13	15.49	15.04	21.12	70.12	45.47	331.40
2600	357.94	135.10	14.60	15.16	26.44			230.33
2500	367.71	142.64	14.69	14.16	18.29	117.32	212.61	322.06
2350	370.07	141.92	14.30	15.11	16.50	87.61	48.57	136.18
2301								
2300	262.38	129.80	14.67	14.13	16.13	79.37	53.38	132.54
2200	361.27	114.76	9.38	20.06	11.97			243.13
2100	282.85	108.58	9.88	15.86	13.09	77.38	43.84	123.47
2000	289.21	122.88	9.21	21.19	13.84			369.30
1900	305.88	123.36	9.36	21.00	10.97			195.86
1800	307.18	125.59	9.60	20.76	10.84	77.24	52.54	125.04
1700	292.05	111.46	11.96	16.75	12.09	74.31	59.91	133.96
1600								
1500	318.36	113.49	13.44	19.80	14.08	75.57	45.95	121.82
1400								
1300								
1200	310.11	110.79	15.38	18.57	15.36	70.87	53.94	124.13
1100								
1000	3,285.36	115.22	701.53	171.91	739.30	79.53	61.47	141.00