Water quality modelling of the Ganga river basin for pollution and contaminants analysis using SWAT model

Prakrut Kansara[1] and Venkataraman Lakshmi[2]

[1]University of Virginia
[2]University of Virginia Charlottesville VA 22904

November 24, 2022

Abstract

Ganga river basin (GRB) in the Indian subcontinent is one of the most heavily irrigated land in the world. According to a book published in 2005 by Central Water Commission (CWC), 57% of the net irrigated land in India lies inside GRB only. Further GRB is also one of the most populous river basins in the world supporting almost 400 million people of India. With increasing use of fertilizers in agriculture and untreated sewage waste from the booming industries, there is need to assess the water quality and the contamination in surface water. We will use Soil Water Assessment Tool (SWAT) to model the hydrology of the river basin. For water quality analysis, SWAT is able to simulate the impact on hydrology, sediment and nutrients load, due to physical changes brought in the large ungauged river basins. We hypothesize that numerous small, rain-fed rivers in the Indo-Gangetic floodplain that are flowing predominantly through agricultural land are important non-point source of Nitrogen(N) and Phosphorus (P) and will control the nutrient budget of large river system. SWAT model will be used to simulate flow and nutrient/sediment concentrations of nitrogen/nitrates, phosphorus and sediment in the upper reach at Uttarkashi and Rishikesh, in the middle reach at Kanpur, Lucknow and Varanasi, and Farakka at the lower reach. SWAT model will be calibrated at daily/monthly time step for flow and monthly scale for water quality parameters. We will analyze the water quality in the basin using widely used Water Quality Index (WQI) considering pH, TDS, BOD, COD, hardness, nitrates, carbonates and silicates. We will use gridded climate data from Indian Meteorological Department (IMD) and water quality data from CWC. SRTM 90 m DEM, 300 m Land use/land cover map from Climate Change Initiative (CCI) and 7 km soil map from Food and Agriculture Organization (FAO).

Water quality modelling of the Ganga river basin for pollution and contaminants analysis using SWAT model

Abstract number: H33O-2212

Prakrut Kansara[1], Venkat Lakshmi[2]
AGU Fall Meeting, San Francisco, December 2019

Abstract number: H33O-2212

AGU 100 FALL MEETING San Francisco, CA | 9–13 December 2019

Abstract

Ganga river basin (GRB) in the Indian subcontinent is one of the most heavily irrigated land in the world. According to a book published in 2005 by Central Water Commission (CWC), 57% of the net irrigated land in India lies inside GRB only. Further GRB is also one of the most populous river basins in the world supporting almost 400 million people of India. With increasing use of fertilizers in agriculture and untreated sewage waste from the booming industries, there is need to assess the water quality and the contamination in surface water. We will use Soil Water Assessment Tool (SWAT) to model the hydrology of the river basin. For water quality analysis, SWAT is able to simulate the impact on hydrology, sediment and nutrients load, due to physical changes brought in the large ungauged river basins. We hypothesize that numerous small, rain-fed rivers in the Indo-Gangetic floodplain that are flowing predominantly through agricultural land are important non-point source of Nitrogen(N) and Phosphorus (P) and will control the nutrient budget of large river system. SWAT model will be used to simulate flow and nutrient/sediment concentrations of nitrogen/nitrates, phosphorus and sediment in the upper reach at Uttarkashi and Rishikesh, in the middle reach at Kanpur, Lucknow and Varanasi, and Farakka at the lower reach. SWAT model will be calibrated at daily/monthly time step for flow and monthly scale for water quality parameters. We will analyze the water quality in the basin using widely used Water Quality Index (WQI) considering pH, TDS, BOD, COD, hardness, nitrates, carbonates and silicates. We will use gridded climate data from Indian Meteorological Department (IMD) and water quality data from CWC. SRTM 90 m DEM, 300 m Land use/land cover map from Climate Change Initiative (CCI) and 7 km soil map from Food and Agriculture Organization (FAO).

Research objective

- Study the temporal changes in water quality in the Ganga River basin by building Water Quality Index
- Using the calibrated model, predict the changes in water quality over two different scenarios:
  1) Climate change impact in terms of changes in precipitation and temperature
  2) Impact of extensive agriculture leading to land-use changes

Study area

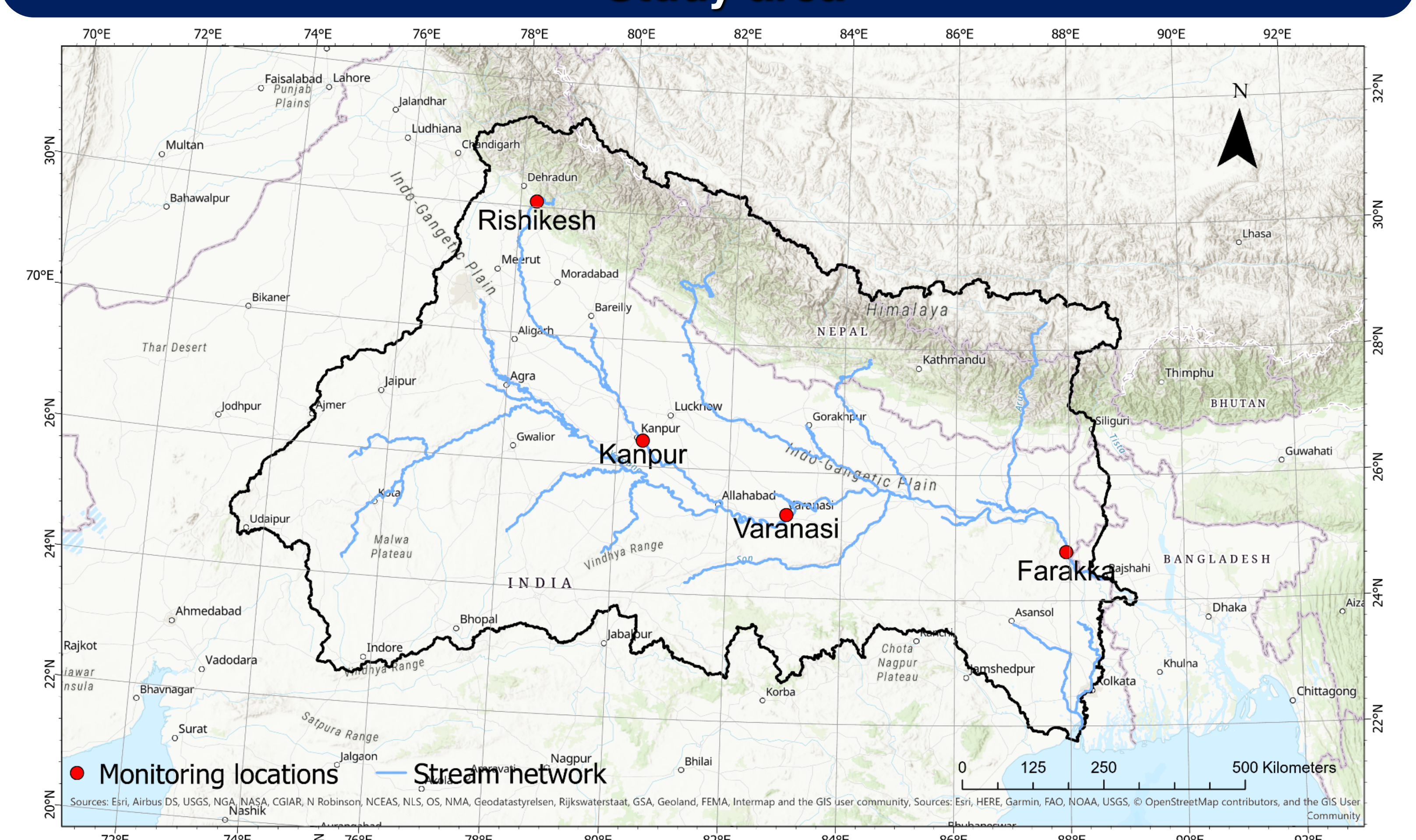

Figure 1: Topographical map of Ganga river basin showing the location of monitoring locations along with the stream network. One station from upper reach (Rishikesh), two stations in the middle reach (Kanpur and Varanasi) and one station in the lower reach (Farakka) were selected to analyze the water quality.

Data

Data	Source	Spatial/ Temporal resolution
DEM	SRTM 3 arc-second void filled	90 m
Land use	Climate Change Initiative	300 m / 2015
Soil	Food and Agricultural Organization (FAO) Global Soils	7 km
Rainfall	Indian Meteorological Department (Gridded product)	0.25° / 1998-2017
Discharge	Central Water Commission India (CWC)	1951 - 1973
Climatology	Climate Forecast System Reanalysis (CFSR)	1998 - 2017

Table 1: List of all the datasets used in the study. Our focus was to use free and publicly available data so that the research can be propagated further without any hindrance or legal abidance.

Data

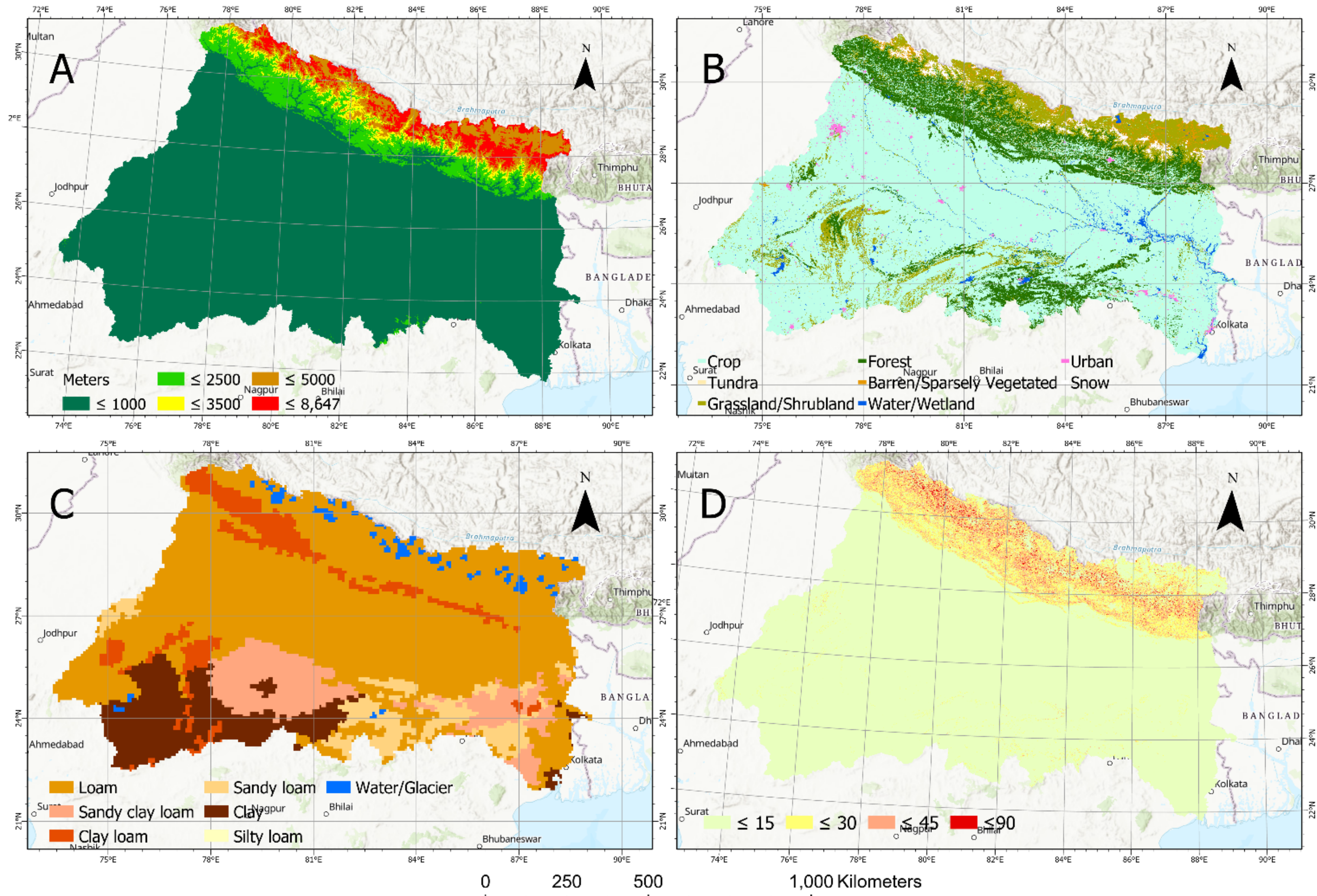

Figure 2 (A-D): This figure shows the spatial data required as input for the SWAT model. From (A) and (D), it can be observed that majority of basin is very flat and has low elevation except for the Himalayas in the Northern part which is covered by snow-clad high-altitude mountain ranges.

Methodology

Step 1: Build the SWAT Model

DEM, Land use and Soils → HRU Generation + Weather data → SWAT Model

Step 2: Calibrate and validate SWAT model for Flow parameters at the outlet

Calibrate model for flow → Validate model for flow

Step 3: Calibrate the model for water quality parameters

Calibrate model for water quality parameters (pH, TDS, BOD, COD, hardness, NO2 + NO3, CO3, HCO3 and SiO2) → Validate model for water quality parameters (pH, TDS, BOD, COD, hardness, NO2 + NO3, CO3, HCO3 and SiO2)

Step 4: Calculate Water Quality Index (WQI) for each locations using weighted parameters

$$WQI = \sum (RW * Q * 100)$$

Where, WQI is the Water Quality Index; RW is the relative weighting of the parameter and Q is the ratio of the value of the water quality parameter to the value of water quality parameter obtained from recommended WHO standards (Alobaidy et. al, 2010)

Results

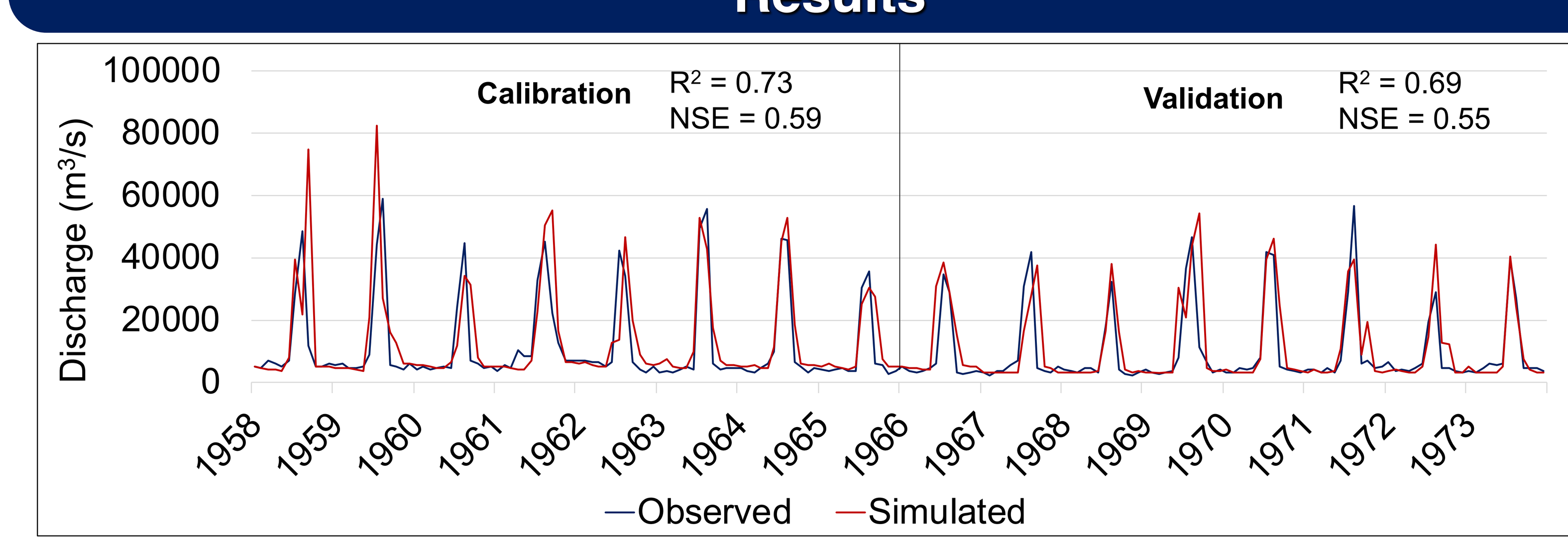

Figure 3: Observed vs. Simulated streamflow for the calibrated and validated model at the Farakka outlet.

Rank	Parameters	Method	Description	Min	Max
1	CN2	Replace	SCS runoff curve number f	79.68	85.57
2	ESCO	Replace	Soil evaporation compensation factor	0.43	0.6
3	GW_Revap	Relative	Groundwater "revap" coefficient	0.1	0.5
4	GW_Delay	Replace	Groundwater delay time (days)	80	100
5	REVAPMN	Relative	Threshold depth of water in the shallow aquifer for "revap" to occur	-0.03	0.2

Table 2: Table shows the parameter ranges for the Ganga river basin calibrated for flow using SWAT-CUP.

Results

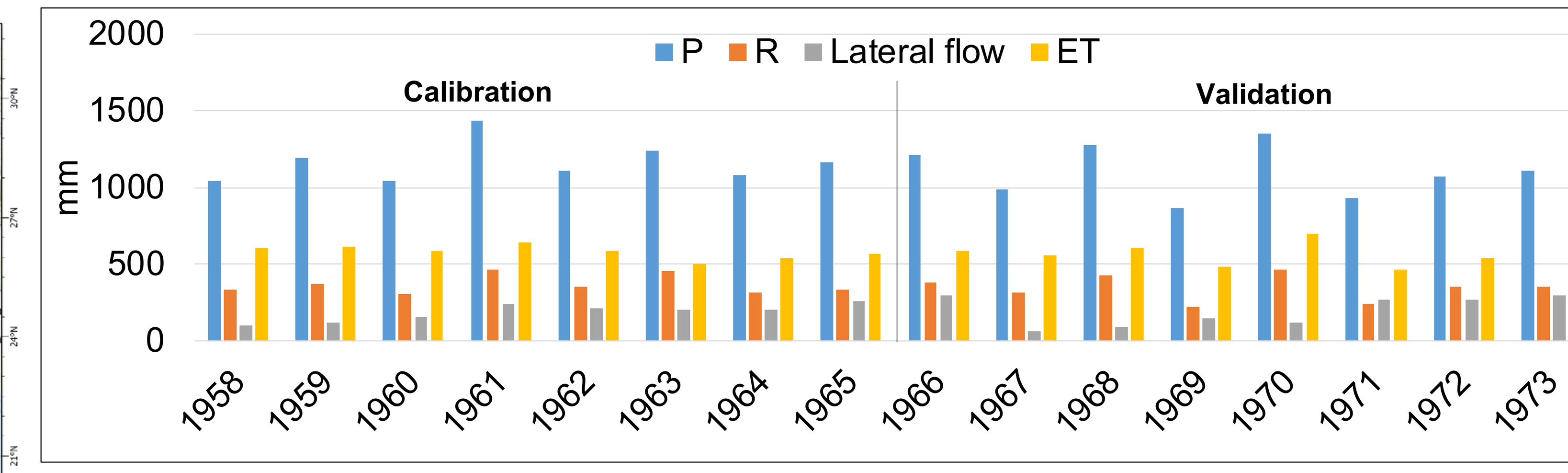

Figure 4: Water balance components for the calibrated model show that ET is roughly 60% of the precipitation.

Parameter	Water quality standard (WHO)	Weight	Parameter	Water quality standard (WHO)	Weight
pH	6.5 – 8.5	5	NO2 + NO3	53	4
TDS (mg/L)	1200	4	CO3 (mg/L)	120	2
COD (mg/L)	13	3	HCO3 (mg/L)	300	3
BOD (mg/L)	5	5	SiO2 (mg/L)	2	1
Hardness (mg/L)	100	5	DO (mg/L)	5	5

Table 3: Table shows the parameters used to estimate the Water Quality Index (WQI) with their acceptable values as standardized by World Health Organization (WHO) and their weights based on the how the parameter affects the water quality standards.

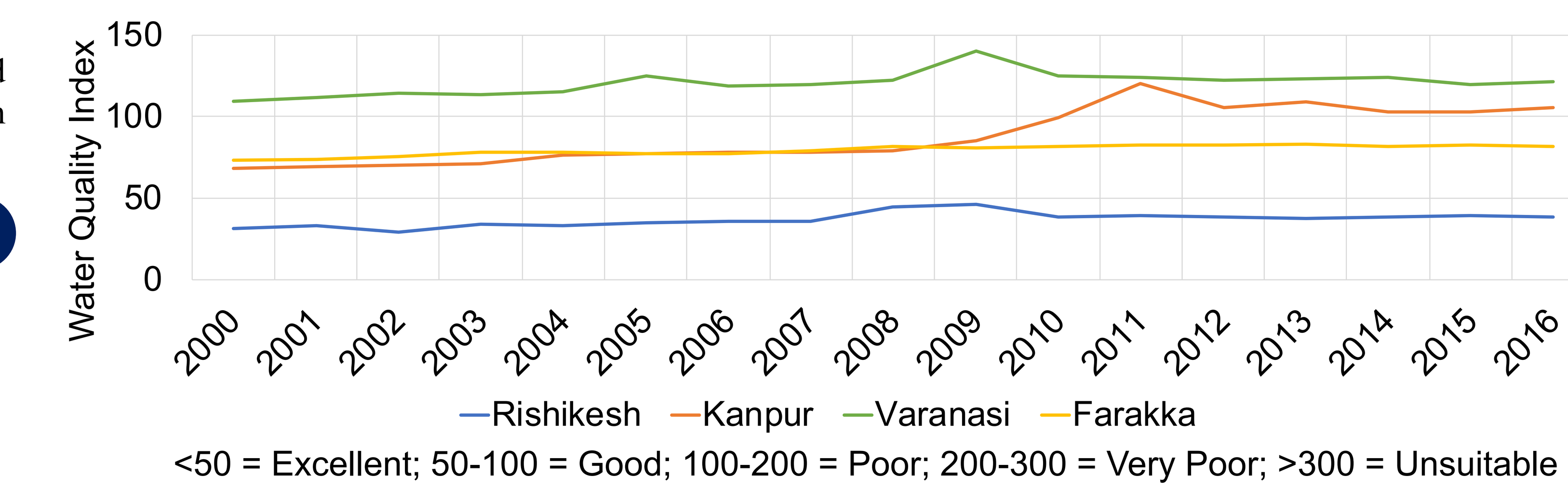

Figure 5: Figure shows the annual variation of the Water Quality Index for each of the monitoring locations. The scale to determine excellent, good and unsuitable conditions was based on Ramakrishnaiah et. al, 2009.

Conclusions and Discussion

1. Preliminary results suggests that the upper reach of the Ganga River basin does not show degradation in the water quality over the analysis period. This is due to the reason that the river reach of Ganga river from the it's origin to Rishikesh does not have much influence of the human activities as it is located in the midst of the densely forested mountains.
2. Middle reach locations – Kanpur and Varanasi show significant degradation of the water quality with Varanasi showing the most adverse conditions. Between Rishikesh and the middle reach (Kanpur and Varanasi), the Ganga river basin passes through very densely populated cities of Uttar Pradesh. The anthropogenic activities along the river near these cities have led to this degradation of Water Quality.
3. Farakka, on the other hand, being the most downstream location does not show as adverse degradation as Varanasi. The river reach going downstream from Varanasi confluences with Kosi river flowing from Nepal, which brings in more fresh and clean water. Therefore, we think that the Farakka location although has significant water quality degradation, it is not to the extent of Varanasi.

Our study used the water quality from CWC, which has lot of missing data values in between. Therefore, we decided to use SWAT to calibrate the model based on the data that we had. Further efforts include the use of our calibrated model to calculate Water Quality Index under the climate change scenario.

Authors

[1] Doctoral Student, Engineering Systems and Environment, University of Virginia, Charlottesville, VA. phk5e@virginia.edu
[2] Professor, Engineering Systems and Environment, University of Virginia, Charlottesville, VA. vlakshmi@virginia.edu

References

Alobaidy, H. Abid and B. Maulood, "Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq," *Journal of Water Resource and Protection*, Vol. 2 No. 9, 2010, pp. 792-798. doi: 10.4236/jwarp.2010.29093.

C. R. Ramakrishnaiah, C. Sadashivaiah and G. Ranganna, "Assessment of Water Quality Index for the Ground Water in Tumkur Taluk," E-Journal of Chemistry, Vol. 6, No. 2, 2009, pp. 523-530.

Ashok Kumar Yadav, Parveen Khan, and Sanjay K. Sharma, "Water Quality Index Assessment ofGroundwater in Todaraisingh Tehsil of Rajasthan State, India-A Greener Approach," E-Journal of Chemistry, vol. 7, no. S1, pp. S428-S432, 2010. https://doi.org/10.1155/2010/419432.