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Risk of nutrient pollution and eutrophication under changing climate and land use land cover

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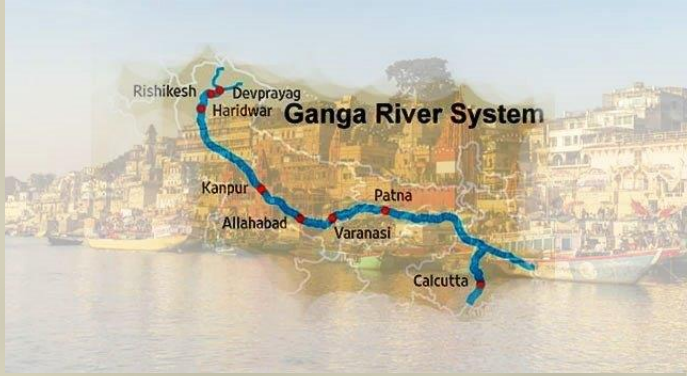
STUDY AREA : Ganga River



Total length= 2525 km

Catchment area = 8,61,404 sq km

238km long river stretch Ankinghat to Shahzadpur

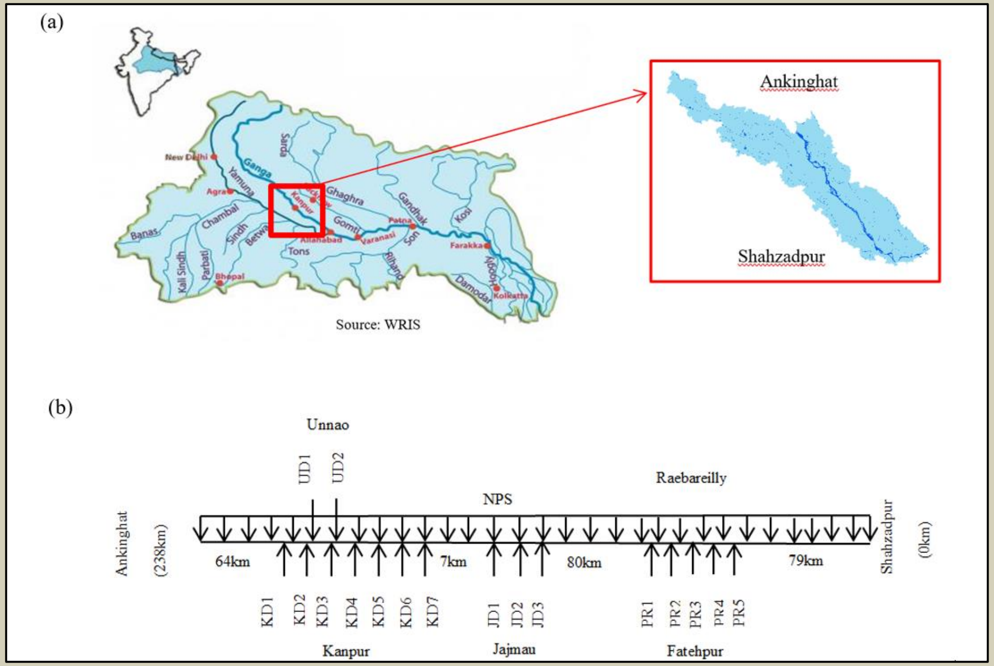


Fig 2. (a) Ganga basin with study area Ankinghat to Shahzadpur highlighted **(b)** Schematic diagram of the study area (KD: Kanpur drain; UD: Unnao drain; JD: Jajmau drain; PR: Pandu river; NPS: non-point source pollution).

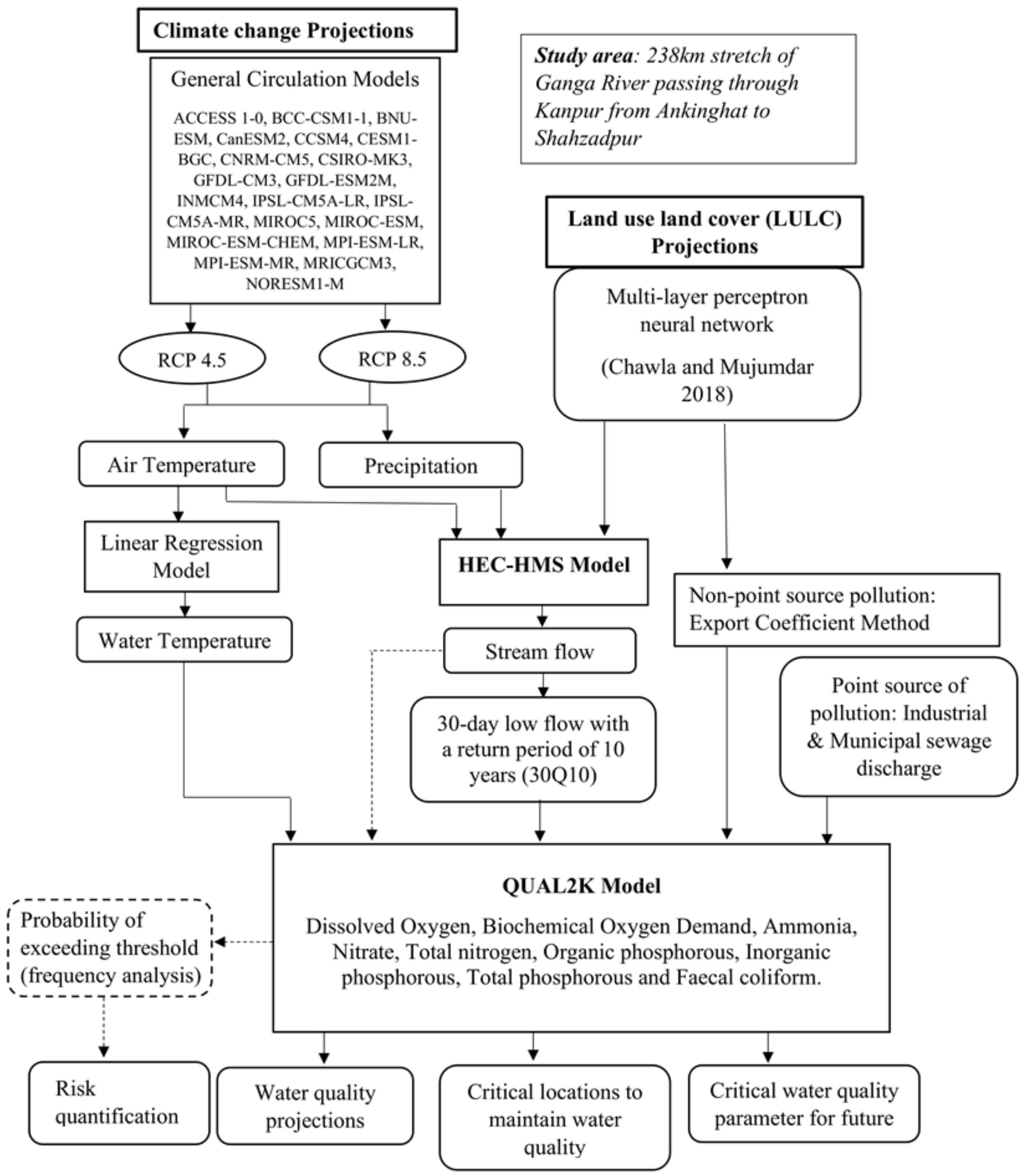
Water quality Parameters: DO, BOD, Ammonia N, Nitrate, Total Nitrogen, Organic P, Inorganic P, Total Phosphorous, Faecal coliform

Sl.no	Drain name	Flow	pH	BOD	NH_3-N	NO_3^-	FC	P
Kanpur drains (KD)								
1.	Ranighat drain	0.02	7.37	173	76.2	2.02	1.6E+08	
2.	Sisamau nala	2.31	7.05	83	36.1	2.71	92000000	
3.	Bhagwatdas nala	0.2	7.24	95	48.7	2.17	92000000	
4.	Golaghat nala	0.02	7.34	143	42.9	0.876	92000000	
5.	Satti chaura	0.02	7.42	56.8	26.7	2.15	13000000	
6.	Permiya	1.75	7.16	138	52.2	2.73	92000000	
7.	Muir mill drain	0.15	7.38	85.3	40.9	2.01	1.6E+08	
Unnao drains (UD)								
1.	Loni drain	1	7.4	736			3300000	
2.	City jail drain	1.24	7.38	109			490000	
Jajmau drains (JD)								
1.	Shetla bazar	0.21	8.09	35.55	232	22.6	13000000	8.95
2.	Wazidpur drain	0.12	8.05	870	206	67.1	790000	4.45
3.	Bhuriyaghat drain	0.6	8.14	523	229	80.6	1.8	5.48
Pandu river (PR)								
1.	Panki Thermal Power Plant Drain	0.225	7.14	14	16.9	2.93	1100000	
2.	ICI Drain	2.44	8.16	42.9	193	9.85	790000	
3.	Ganda Nalla	1.4	7.17	66.6	55.2	2.87	35000000	
4.	COD Nalla	0.72	7.47	54.6	48.9	2.59	49000	
5.	HalwaKhanda Nalla	6.10	7.23	82	50.6	2	3300000	

Data & source

Sl.no	Data (spatial resolution, temporal resolution, time period)	Source
1	Precipitation (0.25-degree grid, daily, 1975-2013); Minimum, maximum and average surface air temperature (1-degree gid, daily,1975-2013)	India Meteorological Department (IMD) (https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html)
2	Stream temperature, streamflow, water quality data, river cross-section, Manning's n (station data, monthly, 1980-2017)	Central Water Commission (CWC), Lucknow
3	Drain data for 2016 (station data, yearly, 2016)	Uttar Pradesh Jal Nigam et al., 2016
4	Evaporation, dew point temperature, wind speed and cloud cover (0.25-degree grid, monthly, 2012-2017)	European Centre for Medium-Range Weather Forecasts (ECMWF) ERA Interim Reanalysis dataset (https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim)
5	ASTER Digital Elevation Model (30m, yearly)	United States Geological Survey (USGS)
6	Land use and land cover data (1:250000, yearly, 2005–06, 2010–11, and 2015–16)	National Remote Sensing Centre (NRSC), Hyderabad
7	Statistically downscaled Climate projections: Precipitation, maximum temperature, and minimum temperature for 20 GCMs (Supplementary Table S2) Historical period (0.25-degree grid, daily, 1975-2005) RCP 4.5, and RCP 8.5 scenarios (0.25-degree grid, daily, 2040-60 & 2080-2100)	NASA Earth Exchange Global Daily Downscaled Climate Projections (NEX-GDDP) (https://portal.nccs.nasa.gov/datashare/NEXGDDP/BCSD/)
8	Stream temperature projection: Air-water temperature linear regression model for Ankinghat (station data, monthly, 1980-2017)	Santy et al., 2020

Overview:



Reference: Chawla I. and Mujumdar P. P., 2018. Partitioning uncertainty in streamflow projections under nonstationary model conditions. Advances in Water Resources 112: 266–282.

Climate models:

Sl.no	CMIP5 models	CMIP5 modeling centre
1	ACCESS 1-0	Australian Community Climate and Earth System Simulator, Australia
2	BCC-CSM1-1	Beijing Climate Centre Climate System Model, China
3	BNU-ESM	Beijing Normal University Earth System Model, China
4	CanESM2	Canadian Centre for Climate Modelling and Analysis (CCma), Canada
5	CCSM4	Community Climate System Model, NCAR, USA
6	CESM1-BGC	
7	CNRM-CM5	Meteo-France/ Centre National de Recherches Meteoroloqiques, France
8	CSIRO-Mk 3-6-0	Common wealth Scientific and Industrial Research Organisation (CSIRO), Australia
9	GFDL-CM3	Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration (NOAA), USA
10	GFDL-ESM2M	
11	INMCM4	Institute for Numerical Mathematics, Russia
12	IPSL-CM5A-LR	Institute Pierre Simon Laplace, France
13	IPSL-CM5A-MR	
14	MIROC5	Centre for Climate System Research (University of Tokyo), National Institute for Environmental Studies and Frontier Research Center for Global Change (JAMSTEC), Japan
15	MIROC-ESM	
16	MIROC-ESM-CHEM	
17	MPI-ESM-LR	Max Planck Institute for Meteorology, Germany
18	MPI-ESM-MR	
19	MRI-CGCM3	
20	NorESM1-M	Norwegian Climate Centre, Norway

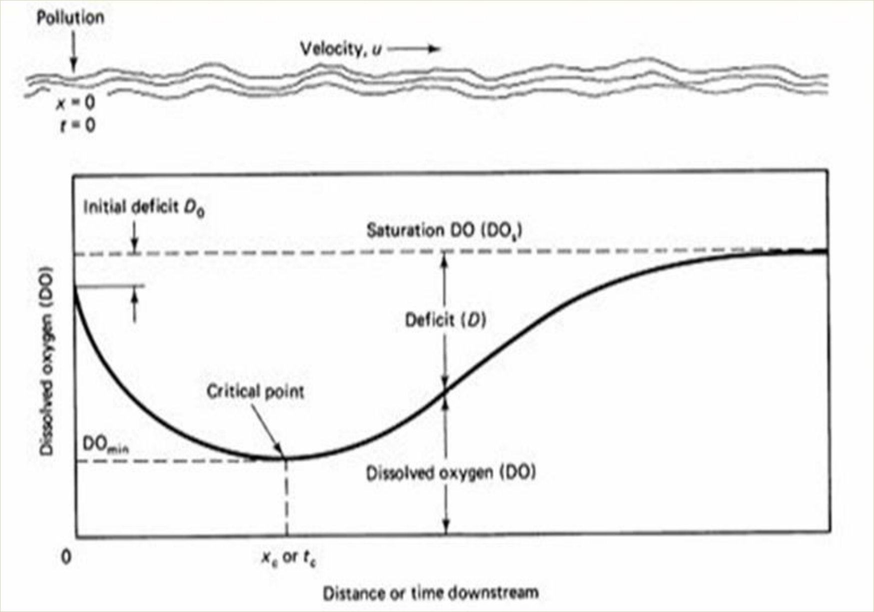
Streamflow simulation: HEC-HMS

- Major components of the model: *basin model, meteorological model, control specification, and time-series data manager*
- The *basin model*: HEC- GeoHMS module of ArcGIS, and the processed data is imported to the HEC-HMS model (DEM processing, delineating streams and watershed characteristics, terrain processing, and basin processing)
- The *meteorological model*: Priestley Taylor for evapotranspiration, Bristow-Campbell model for short wave radiation, and gauge weight method for precipitation.
- *Calibration* period: 1977-2002 and *validation* period: 2003-2012 (monthly scale)
- Methods selected: *Simple Canopy* (Canopy), *Simple Surface* (Surface), *Deficit and Constant method* (loss), *SCS Unit Hydrograph* (transform), *Constant Monthly Baseflow* (baseflow), *Muskingum* (routing)
- The primary inputs: precipitation, air temperature, and monthly air temperature range.

Water Quality Simulation Model : QUAL2K

- *QUAL2K is US EPA endorsed, and written by Dr. Steven Chapra.*
- *River and stream water quality simulation model for the evaluation of surface water quality and to estimate the impacts of pollutants on water quality indicators*

DO sag curve:

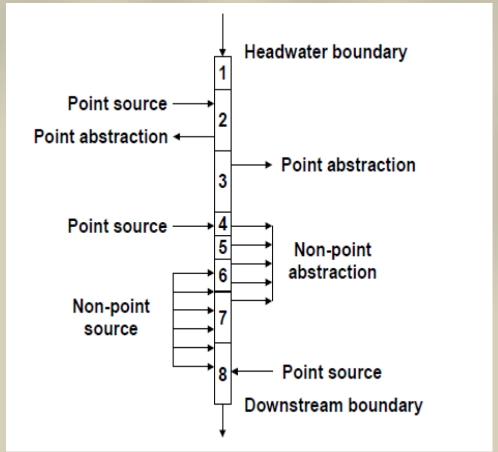


Inputs: Hydro-observation data, Meteorological data, Water quality data at head water, Point and non-point sources of pollution load, Reaction rates

Mass balance, Streeter- Phelps model

Output: Water Quality at downstream points

QUAL2K segmentation scheme :



Source: QUAL2K user manual

Export coefficient method

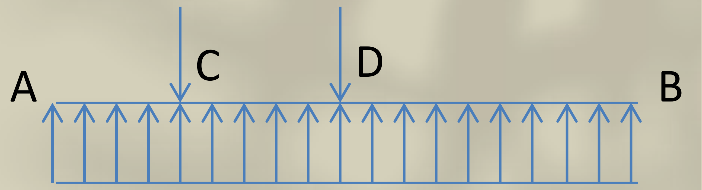


Figure S5(a): Intermediate River stretch with point loads at C, D and non-point load throughout. The loads are indicated by blue arrows.

Non-point source pollution: Export Coefficient Method

$W_{total}=W_{pnt} + W_{non\text{-}pnt}$
$W_{non\text{-}pnt}= \Sigma E_{ij} \times A_i$

E_{ij}: export coefficient of i^{th} landuse for j^{th} parameter (kg/Ha/yr);
A_i: area of i^{th} landuse (Ha)

For example, from Figure S5(a)
$W_B=W_A+W_C+W_D+W_{non\text{-}pnt}$

- The export coefficient for water quality parameters, nitrate, ammonia, phosphorous, BOD and faecal coliform from built up, agricultural, forest, wasteland and water body land use classes is optimized using data for 2005-2015 by minimising RMSE.
- For calibration and validation, the change in flow corresponding to that particular year is used.
- While for the baseline analysis with 30Q10 flow, the average diffuse load in Ankinghat- Kanpur and Kanpur-Shahzadpur reach calculated by considering low flow periods of 2005-2016 is used.

Risk of nutrient pollution

$$Risk = \{P\ (C_l\ > C_{max})\}$$

C_l is the concentration of water quality parameter at location l

C_{min} and C_{max} : the minimum and maximum limits for their concentration

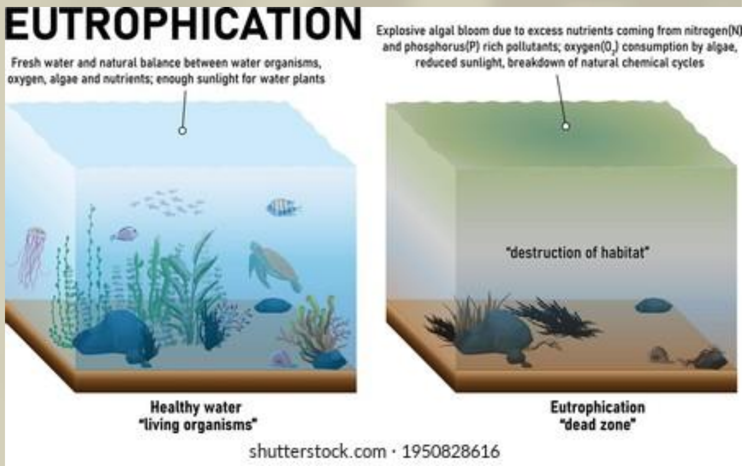
$$Risk\ of\ Eutrophication = \{P\ (Chla_l\ > Chla_{max})\}$$

$Chla_l$ is the concentration of Chlorophyll *a* at location l

$Chla_{max}$ correspond to the maximum threshold limits for Chlorophyll *a* concentration

Risk of eutrophication

- *Eutrophication is excessive plant growth in the water body due to over-nourishment of nutrients*
- *When WT and nutrient concentration increase, algae growth is stimulated*
- *Eutrophication is critical during low flow period*



Empirical equation proposed by Bartsch and Gakstatter 1978 (Chapra, 1997) is used to simulate chlorophyll *a* from total phosphorous concentration

$$\log(Chla) = 0.807\log(p) - 0.194$$

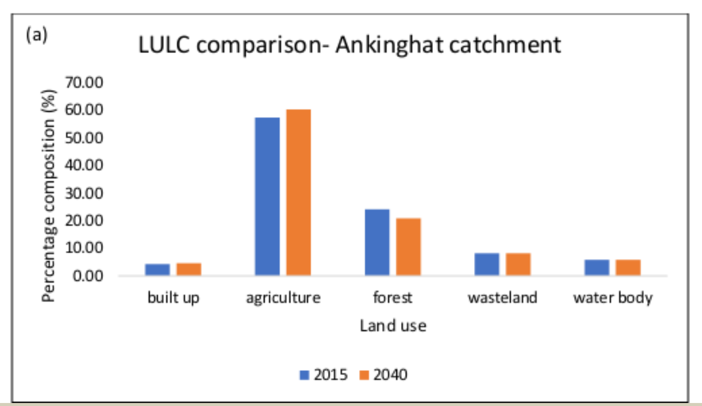
$Chla$ =Chlorophyll *a* concentration (µg/L)

p = total P concentration (µg/L)

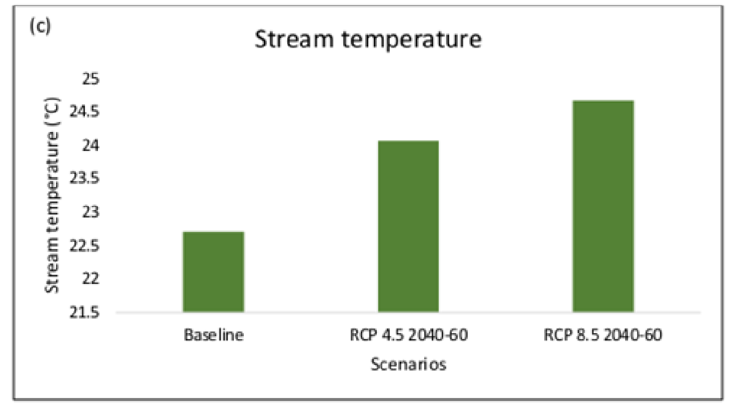
Chlorophyll *a* concentration > 10µg/L : Eutrophic trophic state.

Results

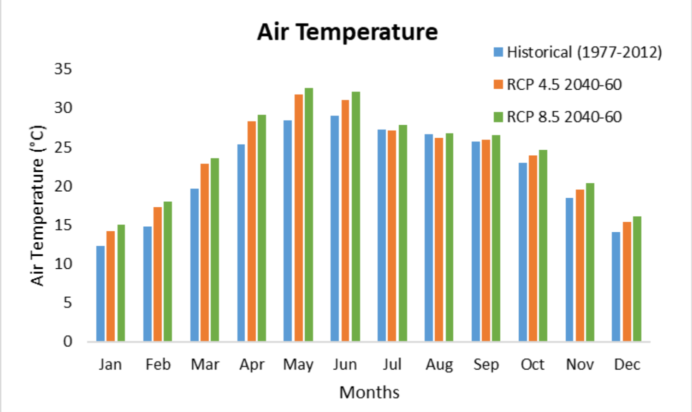
Land use land cover projections:

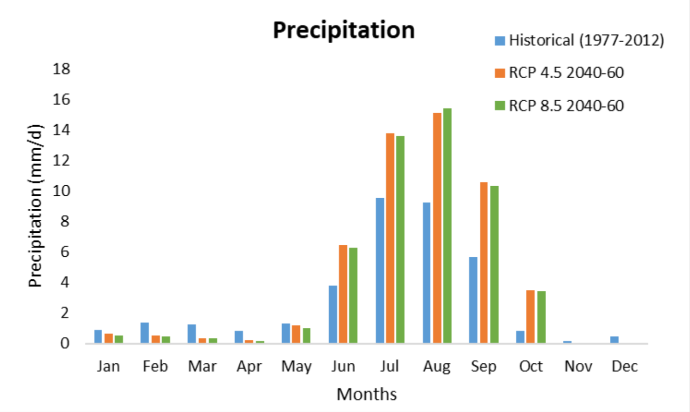


Stream temperature projections:

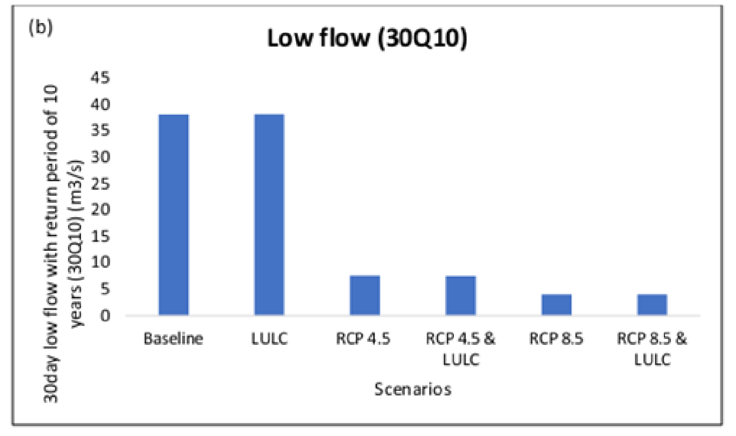


Climate change projections:



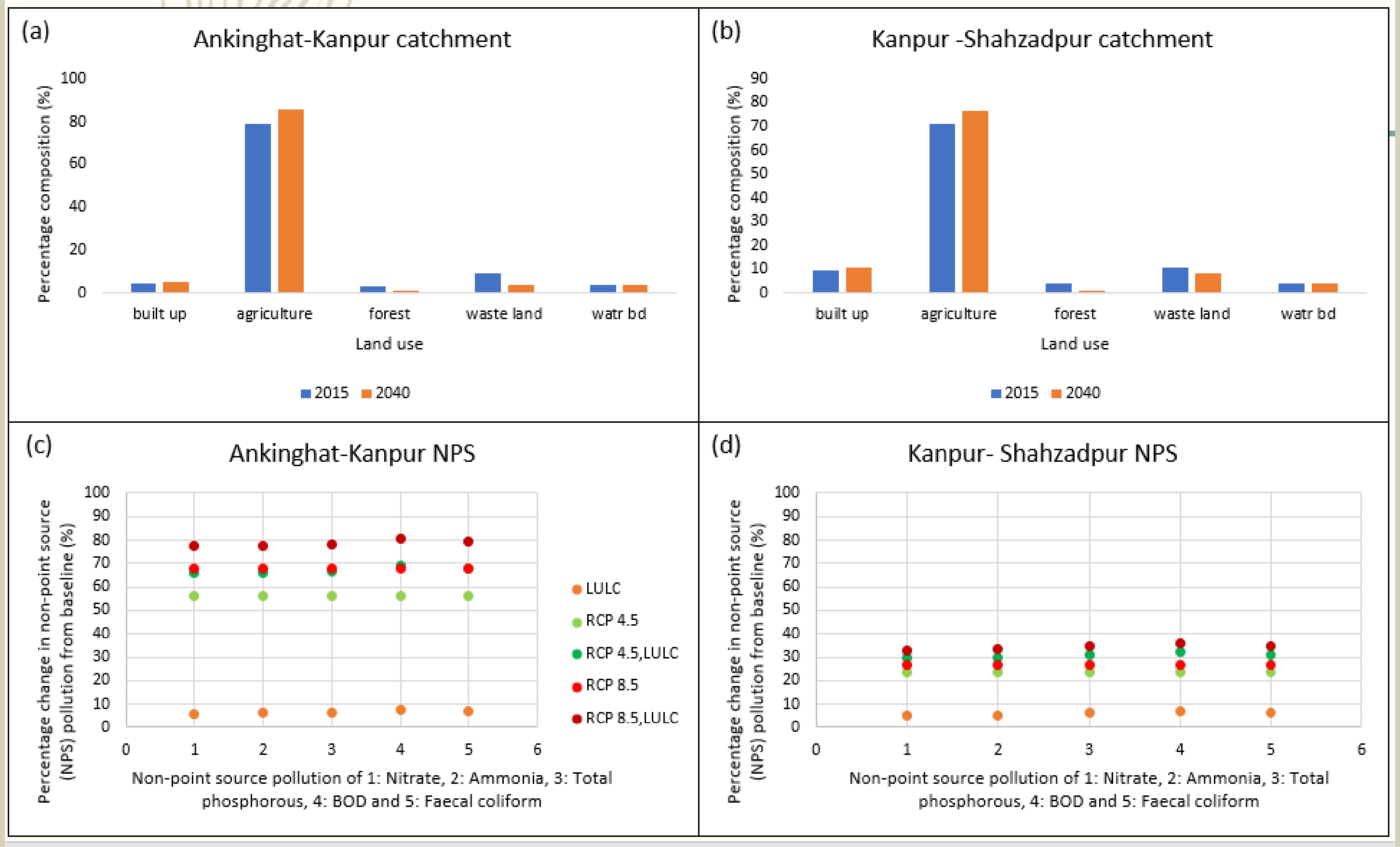


Streamflow projections:



- *An increase in air temperature resulted in an increase in stream temperature*
- *The precipitation in the pre-monsoon months reduced with warming, resulting in a decreased low flow for future.*
- *Land use was not found to influence the streamflow much*

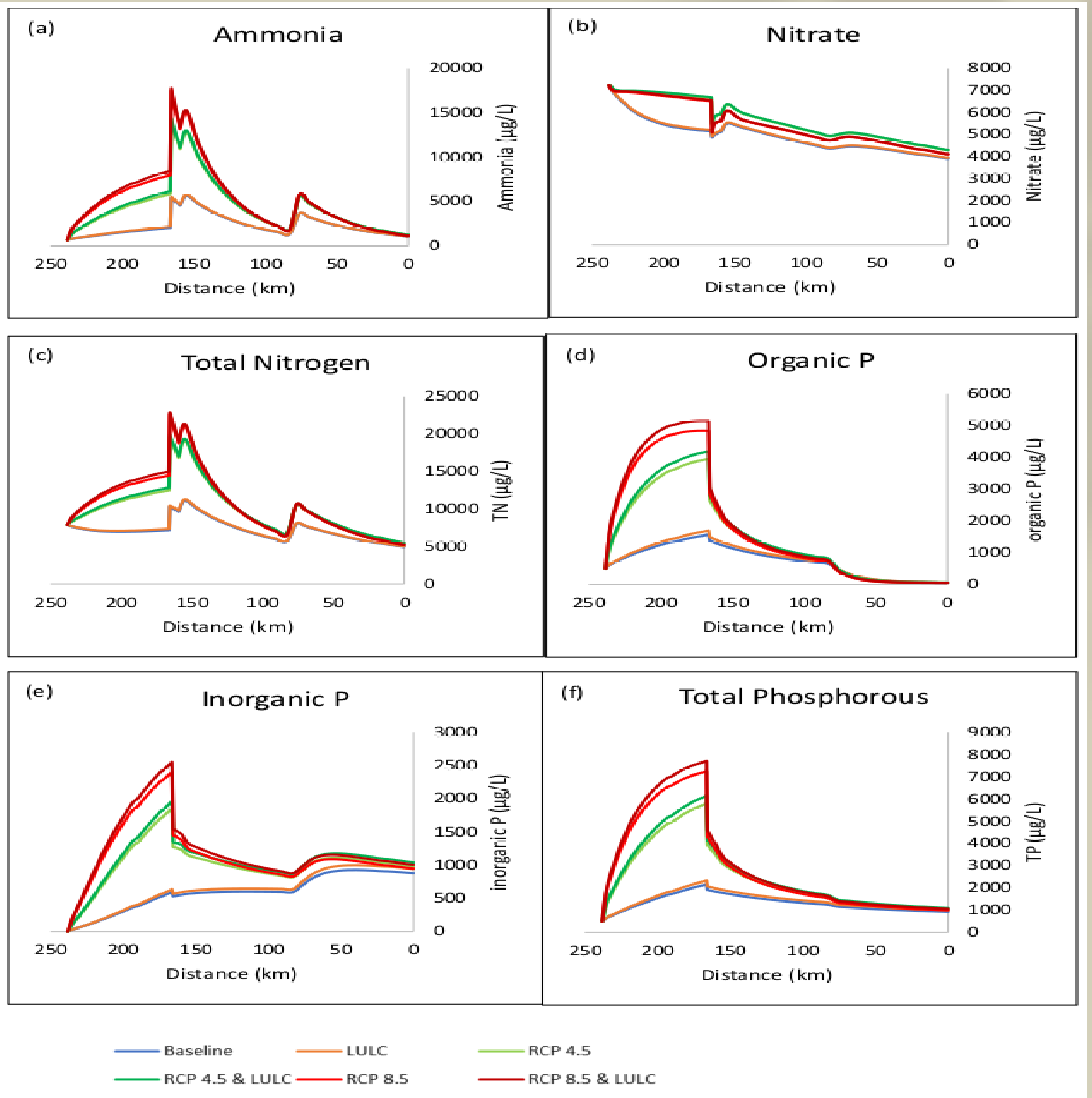
Changes in LULC and resulting changes in non-point source pollution



- *Agricultural land is simulated to increase for future*
- *Non-point source pollution concentration increase by 80% and 35% in the future for the Ankinghat- Kanpur and Kanpur-Shahzadpur stretch respectively.*

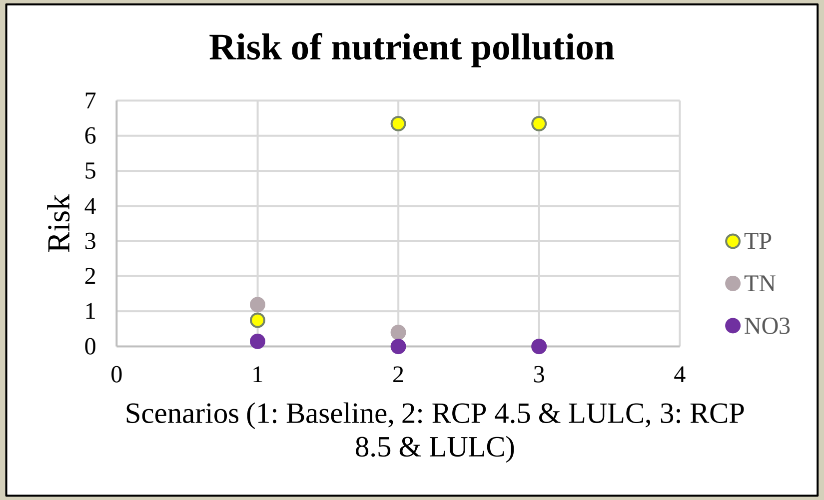
Water quality for future climate and LULC

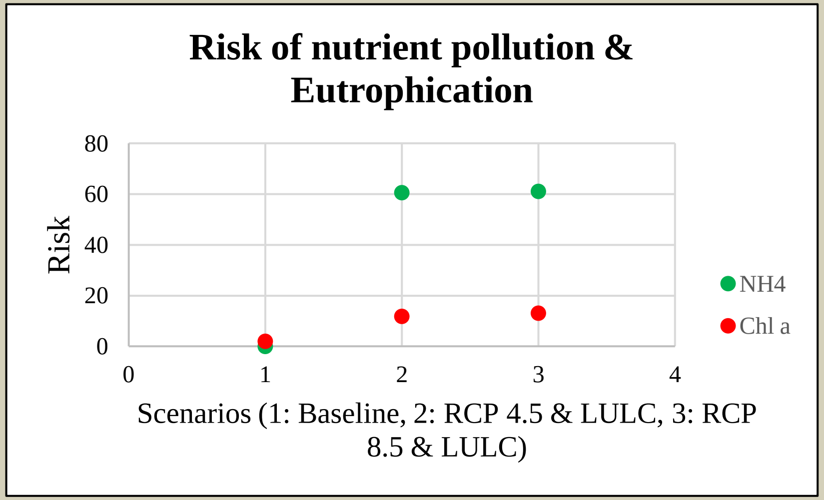
- *Nutrient pollution increases for the future*
- *Climate change is found to have more effect on water quality on comparison with land use land cover change*
- *The major contribution of P is from non-point source, while for N, both point and non-point source cause pollution*
- *The P components reduce the concentration downstream the drain confluence due to the absence of P load from drains.*



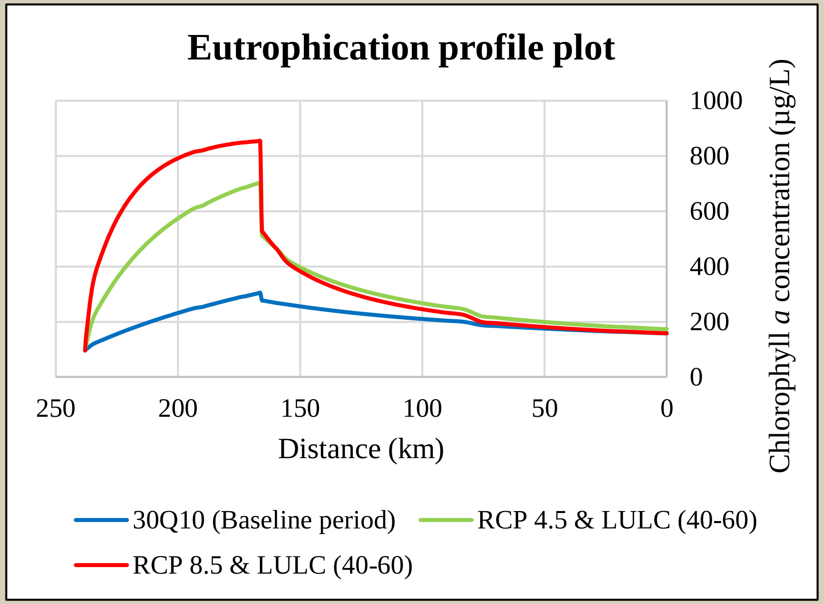
Results

Risk of nutrient pollution & eutrophication





Eutrophication profile plot



- *Risk of nitrate reduces for future due to a higher denitrification rate*
- *Risk of ammonia and total phosphorous increase for future mainly due to an increased pollution in low flow period*
- *Eutrophication profile plot shows an increased eutrophication for future, with more eutrophication corresponding to higher warming scenarios*
- *The hotspot of Eutrophication is identified as Kanpur*

Conclusion

- *Nutrient pollution increases with future climate change and land use land cover*
- *Kanpur and Jajmau are identified as critical hotspots*
- *Risk of nitrate reduces in future due to high denitrification rate with warming*
- *Risk of ammonia, total phosphorous and eutrophication increases for the future*

References

- Santy, S., Mujumdar, P. P. and Bala, G., 2020. Potential Impacts of Climate and Land Use Change on the Water Quality of Ganga River around the Industrialized Kanpur Region. Scientific Reports, 10:9107.
- Chawla I. and Mujumdar P. P., 2018. Partitioning uncertainty in streamflow projections under nonstationary model conditions. Advances in Water Resources 112: 266–282.
- Whitehead, P. G.et al. 2015. Dynamic modeling of the Ganga river system: impacts of future climate and socio-economic change on flows and nitrogen fluxes in India and Bangladesh. Environmental Science: Processes and Impacts. https://doi.org/10.1039/c4em00616j
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Thank you!