IMPACT OF CLIMATIC VARIABILITY ON RIVER DISCHARGE TRENDS IN THE GOMTI, SAI, AND SARAYAN RIVERS IN LUCKNOW, UTTAR PRADESH, INDIA: A 30-YEAR ANALYSIS

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ABSTRACT

This study analyses long-term trends in river discharge, rainfall, temperature, surface pressure, wind speed, and specific humidity in the Gomti, Sai, and Sarayan rivers near Lucknow, India, using data from 1993 to 2023. Additionally, it examines the variation in river discharge of the Gomti, Sai, and Sarayan rivers in response to changes in climate variables and rainfall patterns. The findings indicate significant hydrological changes driven by climatic variability and anthropogenic activities. The Gomti River showed a notable increase in maximum discharge, rising from 70.935 cumecs in 1993 to 157.95 cumecs in 2022, while the Sai and Sarayan rivers exhibited reductions in discharge over the same period. Rainfall trends show a marked increase, with maximum daily rainfall rising from 8.28 mm in 1993 to 15.82 mm/day in 2023, and annual rainfall increasing from 790.80 mm to 1097.40 mm. Temperature analysis revealed a seasonal rise of 3 to 5℃ over the years, while wind speed and specific humidity also showed variations. These shifts are likely linked to deforestation, urbanization, energy demands, and land-use changes, contributing to climate change. Mitigating these impacts through sustainable practices is essential for preserving hydrological balance and water resources.

Keywords:
Surface Pressure, River Discharge, Rainfall, Temperature, Climate Change, Hydrology.

Introduction

Lucknow, the capital city of Uttar Pradesh, is situated within the Indo-Gangetic plains, an area characterized by a vast network of rivers. The Gomti River is the most prominent watercourse, essential for supporting both the urban population and surrounding agricultural lands. This study focuses on the long-term discharge trends in the Gomti, Sai, and Sarayan rivers, examining the effects of climatic variability over the past 30 years.The Gomti River, which originates from Gomat Taal in Pilibhit and flows through Lucknow before merging with the Ganga near Saidpur, spans approximately 960 kilometers. Its hydrology is crucial for drinking water, irrigation, flood control, urban planning, and ecological balance. Alongside the Gomti, smaller tributaries like the Sai and Sarayan rivers also influence regional water dynamics, with the Sai River flowing from Bhijwan Jheel in Hardoi and the Sarayan River originating from Hyderabad Gola in Lakhimpur.

Climatic conditions, particularly seasonal monsoons, significantly impact river discharge. Over the past three decades, variations in rainfall, temperature, and other climate variables have caused substantial shifts in discharge patterns. These changes are linked to broader climate change impacts, including deforestation and land-use alterations. Notably, while the Gomti River has exhibited marked increases in maximum discharge, the Sai and Sarayan rivers have experienced declines, likely due to altered precipitation patterns and environmental stressors.

This analysis aims to investigate the interplay between climatic variability and river discharge trends in the Gomti, Sai, and Sarayan rivers. By examining data from 1993 to 2023, the study will provide insights into how climate change affects water resources in Uttar Pradesh. The findings will inform strategies for sustainable urban and environmental management, highlighting the need to adapt to shifting hydrological dynamics driven by climatic factors

Literature

Xinfeng Fan et al. (2022) examined river discharge dynamics in the Yellow River Basin (YRB), China, emphasizing the influence of high-altitude headwaters on downstream water availability. Their study revealed that climate, land cover, and human activities in these regions significantly impact discharge patterns, especially with increased precipitation in the 21st century. By comparing the early 21st century with the late 20th century, they identified significant shifts in discharge patterns. Using the Choudhury-Yang equation, they quantitatively analyzed the contributions of various factors, highlighting precipitation in the headwaters as the primary driver of increased discharge. The findings are vital for developing sustainable water management strategies in the YRB, addressing the region's vulnerability to drought and water scarcity. Andualem Mekonnen Hiruy et al. (2022) investigated the effects of urban wastewater pollution on river microbiomes in the Akaki catchment, Addis Ababa, Ethiopia. The study assessed correlations between untreated wastewater discharge and the prevalence of fecal, antibiotic-resistant, and potentially pathogenic bacteria at six locations during dry and wet seasons. Significant spatiotemporal variations in bacterial hazards were found, with variations up to 6 $\log_{10}$ units. Sewage pollution markers, including the HF183 gene, were linked to the presence of *Vibrio cholerae*. The research highlighted the human impact on river microbiomes, especially in downstream areas during the dry season, and used molecular microbiology methods, such as qPCR assays, to enhance detection of human-associated pathogens. Ling Hong Ke et al. (2022) explored long-term water level and storage variations in the upper Brahmaputra River (UBR), an area lacking gauged data due to its high-altitude environment. Using remote sensing techniques, the authors derived inundation area data from 2000 to 2020 and filled gaps using a percentile cut method. The reconstructed water levels correlated well (average R^2 of 0.79) with existing data from Hydro web and gauged discharge data. The integration of reconstructed water levels and inundation area data provided insights into river storage variations, accounting for about one-tenth of the net terrestrial water storage in the basin. Sameh A. Abou RafeeL and et al. (2022) examined the impacts of Land Use and Cover Changes (LUCC) and climate change on river discharge in the Upper Paraná River Basin (UPRB), vital for agriculture and energy in Brazil. The study utilized numerical simulations with three LUCC scenarios for 1500, 1960, and 1985. Results showed a more than 20% increase in average annual median precipitation post-1970s climate shift, significantly affecting southern regions. Precipitation changes were found to have a greater impact on observed discharge variations than LUCC alone. This research highlights the need for integrated water management strategies to address both land use changes and climate variability. Kazuyuki Sakuma et al. (2021) estimated tritium (^3H) discharge from river catchments in the Fukushima coastal region to assess the environmental impacts of tritium release from the Fukushima Dai-ichi Nuclear Power Plant (FDNPP). Using a tank model that integrated observed ^3H concentrations in river water, the study estimated ^3H discharge from the Abukuma River and 13 other rivers from June 2013 to March 2020, revealing a discharge range of 1.2 to 4.0 TBq/year from 2014 to 2019, which was 2 to 22 times larger than the annual ^3H discharge from the FDNPP after 2016. The findings underscore the significant contribution of riverine inputs to coastal ^3H concentrations, providing insights for environmental impact assessments. B.O.M Lamine et al. (2021) developed two innovative methods for estimating river cross-sections and discharge in the Niger River basin using satellite imagery and altimetry data. The first approach, called the "lateral-method" (LM), tracks river water evolution using daily Planet Scope imagery and satellite altimeters. The second approach, the mixed method (MM), incorporates a Digital Elevation Model (DEM) with topographical and bathymetric data. The study achieved a Nash-Sutcliffe efficiency of 0.93 and a relative bias of 3.3% in discharge estimates at four cross-sections over 30 km near Niamey, demonstrating the potential of remote sensing technologies for reliable hydrological data in data-deficient areas. Damaris

Mutia et al. (2021) explored the relationship between Tana River discharge and phytoplankton biomass in Ungwana Bay, Kenya. The Tana River contributes about 50% of the total river discharge to Kenyan coastal waters. Analyzing over 20 years of satellite-derived chlorophyll-a data alongside river discharge and rainfall, they found a significant positive correlation ($r = 0.63$, $p < 0.0001$) between river discharge and phytoplankton biomass during the rainy inter-monsoon period (March–April). The study noted a one-month lag in chlorophyll response to river discharge and a two-month lag for chlorophyll concentrations. Higher chlorophyll-a levels remained localized in the bay, underscoring the importance of understanding nutrient dynamics for coastal management. Juan D. Restrepo et al. (2020) addressed challenges in managing river discharge data and flood magnitudes in Colombia, particularly during severe La Niña events, which caused over $7.2 billion in damages. They proposed a satellite-based technique to measure river discharge in the Magdalena River, allowing back-calculation of daily discharges over 20 years to assess flood return intervals. Analyzing data from 1998 to 2016, the authors noted the limitations of ground-based monitoring in conflict-affected areas and advocated for integrating satellite and in situ data to improve river planning and decision-making amid climate change. Daisuke Tsumune et al. (2020) investigated the environmental impacts of the Fukushima Dai-ichi Nuclear Power Plant accident, focusing on the release of radioactive cesium-137 (137Cs) into the ocean. Using the Regional Ocean Model System (ROMS), the study simulated 137Cs activity from various sources, including direct releases and river discharges. From March 26, 2011, to December 31, 2016, the direct release rate of 137Cs started at 2.2×10^{14} Bq day^{-1} and declined to 3.9×10^{9} Bq day^{-1} by 2016, with an estimated total leakage of 3.6 ± 0.7 PBq in the first year. In contrast, 1.1×10^{12} Bq of dissolved 137Cs was discharged from 16 rivers between 2013 and 2016, significantly lower than the direct releases. This study emphasizes the need for ongoing monitoring of marine radioactivity and the role of rivers in oceanic contamination. Yuanfang Chai et al. (2019) investigated global trends in seasonal water discharge using data from 5,668 hydrological stations covering two-thirds of the Earth's land area. The study identified two key trends: homogenization, which reduces the disparity between dry and flood seasons affecting about 40% of land area (mainly in Eurasia and North America), and polarization, where seasonal discharge patterns become more pronounced. The analysis revealed that dam operations contribute significantly to homogenization (41.9%), followed by polarized evaporation, homogenized precipitation, and premature glacial melting. For polarization, homogenized evaporation and polarized precipitation account for 56.0% and 41.2%, respectively, with premature glacial runoff also playing a crucial role, particularly in GEP river basins. These findings highlight the complex interactions between climatic and human factors influencing global water discharge patterns, stressing the need for integrated water resource management strategies. Shetu Akter et al. (2019) examined rainfall patterns and river discharge trends in the Surma River area of northeastern Bangladesh, a deltaic region influenced by the Ganges, Brahmaputra, and Meghna basins. Using time series data from 1973 to 2016, the study analyzed various statistical parameters, including mean, variability, and correlation, to assess the relationship between precipitation changes and river discharge. The findings highlighted the significant impact of climatic factors, especially rainfall, on the hydrology of the Surma River. Statistical tools like the Mann-Kendall test and Pearson's correlation were used to identify trends, emphasizing the need for adaptive water management strategies to address the implications of changing precipitation and discharge patterns on local ecosystems and livelihoods. Da'u Abba Umar et al. (2018) assessed 36 years (1980–2015) of hydrological trends in the Hadejia River catchment. The study revealed irregularities in runoff patterns, with decreasing discharge at two downstream stations and increasing, though statistically insignificant, discharge at three upstream stations. Using Mann-Kendall tests, a significant decreasing trend was confirmed at the downstream stations, while upstream stations showed an increasing trend without statistical significance. Monthly analysis showed a significant increase in July at Challawa and significant decreases in May, June, August, and September at other stations. These findings underscore the need for continuous monitoring and adaptive management in tropical semi-arid catchments. Zhang et al. (2014) investigated discharge dynamics from the Pearl River into the sea, focusing on three key gauge stations: Wuzhou, Shijiao, and Boluo. The study found a significant increase in annual mean discharge across all stations, with notable dry-season changes at Boluo. There was a decrease in annual maximum discharge and an increase in minimum discharge. The study highlighted the impact of dams and reservoirs, particularly in the East River, where the flood discharge ratio to annual discharge significantly decreased. However, seasonal discharge variations at Wuzhou and Shijiao remained largely unchanged, underscoring the influence of human activities on regulated rivers. Kim et al. (2014) studied the influence of river dynamics on seasonal variations in terrestrial water storage (TWS) across 29 global basins. Their hydrological simulations, validated against GRACE data, showed that including river storage improved model accuracy, especially in active hydrological regions. In the Amazon basin, river storage explained up to 73% of TWS variations. The study highlighted rivers' role as buffers that smooth out seasonal TWS changes, particularly in snow-dominated areas. Omitting river storage led to errors in both the magnitude and timing of TWS variations, underscoring the importance of integrating river dynamics in hydrological models. Kundzewicz et al. (2014) analyzed climatic changes and river discharge in the Aksu River Basin, which contributes approximately 75% of the Tarim River's discharge. Their study found a significant increase in temperature and river discharge over time. Strong correlations were observed between daily temperature and discharge in two headwater sub-catchments. However, in late summer and early autumn, Glacial Lake Outburst Floods from Lake Merzbacher caused anomalies, particularly at the Xiehela station. In the highly glacierized Xiehela sub-catchment, summer discharge was mainly influenced by temperature, while in the Shaliguilanke sub-catchment, precipitation had a more substantial impact. Seasonal variations and differing time scales of climate-streamflow relationships were also analysed.

Research Gap

The existing literature reveals a significant paucity of research focused on the comparative analysis of river discharge within Uttar Pradesh. Most studies have primarily addressed individual river systems without evaluating their discharge dynamics relative to one another.There is insufficient clarity regarding the extent to which climate variables influence variations in river discharge. A systematic examination of the relationship between climatic factors (e.g., precipitation, temperature, and humidity) and river discharge patterns is lacking, necessitating further investigation to elucidate these dynamics.

Objectives. To systematically analyze the seasonal variations in river discharge across various river systems in Uttar Pradesh, identifying trends and patterns that may impact floodplain inundation. To conduct a comparative analysis of river discharge variations over time within Uttar Pradesh, assessing changes in discharge capacity and their implications for flood management and water resource planning.To identify and evaluate the major climatic factors influencing river discharge in Uttar Pradesh, including precipitation, temperature, and humidity, and their respective roles in shaping discharge patterns.

Methodology

Data Collection and Analysis: Discharge data for the Gomti, Sai, and Sarayan rivers from 1993 to 2023 has been sourced from the Irrigation Department of Uttar Pradesh, providing insights into long-term hydrological behavior. Weather data, including temperature, humidity, wind speed, and surface pressure, has been obtained from NASA's Power dataset, while rainfall data has been acquired from the India Meteorological Department (IMD). This synchronized data acquisition allows for a comprehensive analysis of the interactions between climatic factors and river discharge patterns. The combined analysis will enhance understanding of the impacts of climatic variability on the discharge dynamics of these rivers in Uttar Pradesh.

Data Analysis

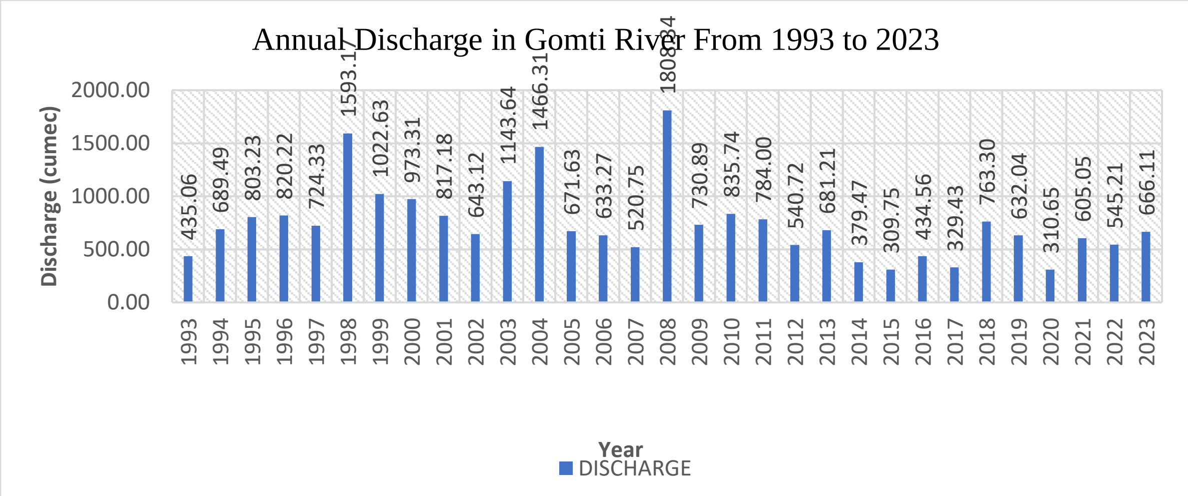

Figure: 1. Annual Discharge in Gomti River From 1993 to 2023

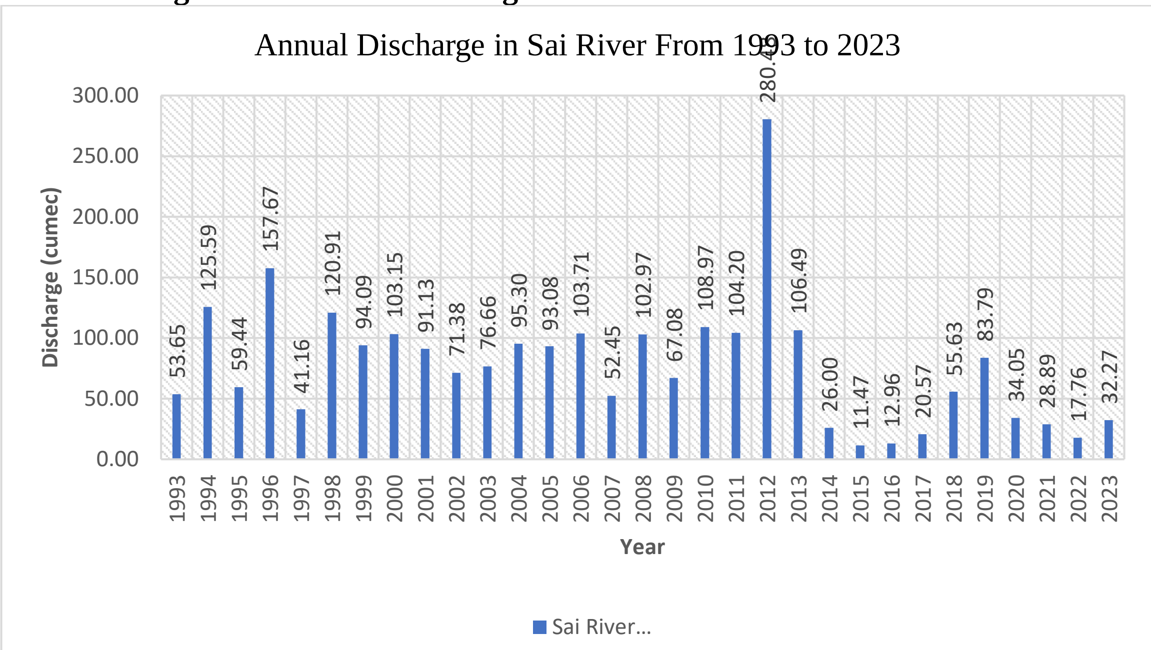

Figure: 2. Annual Discharge in Sai River from 1993 to 2023

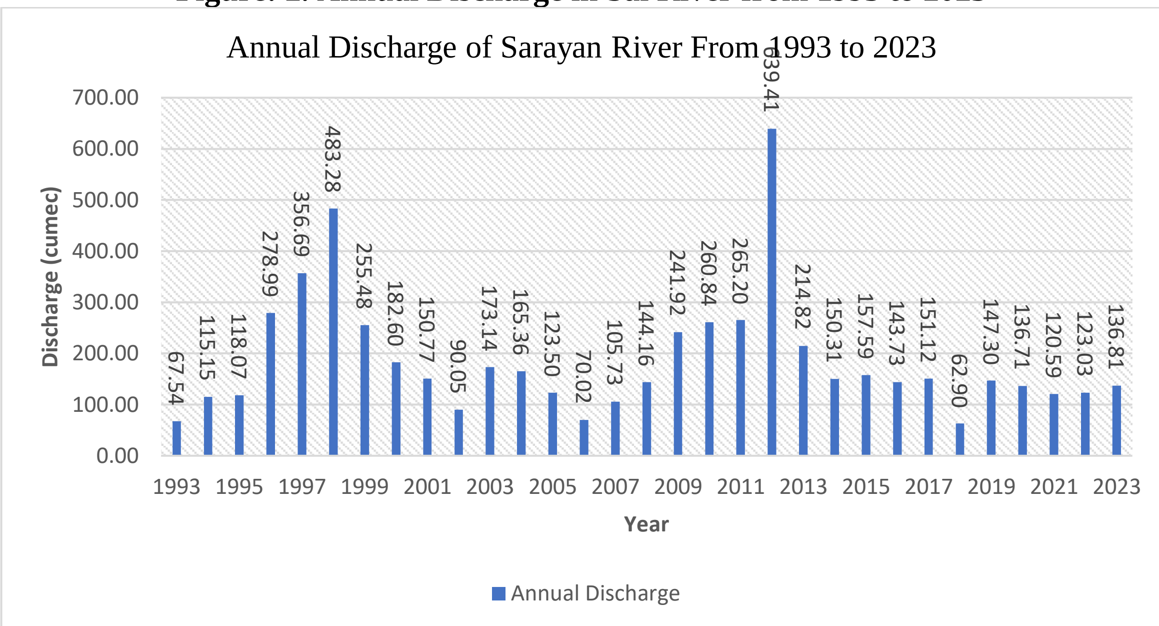

Figure: 3. Annual Discharge of Sarayan River From 1993 to 2023

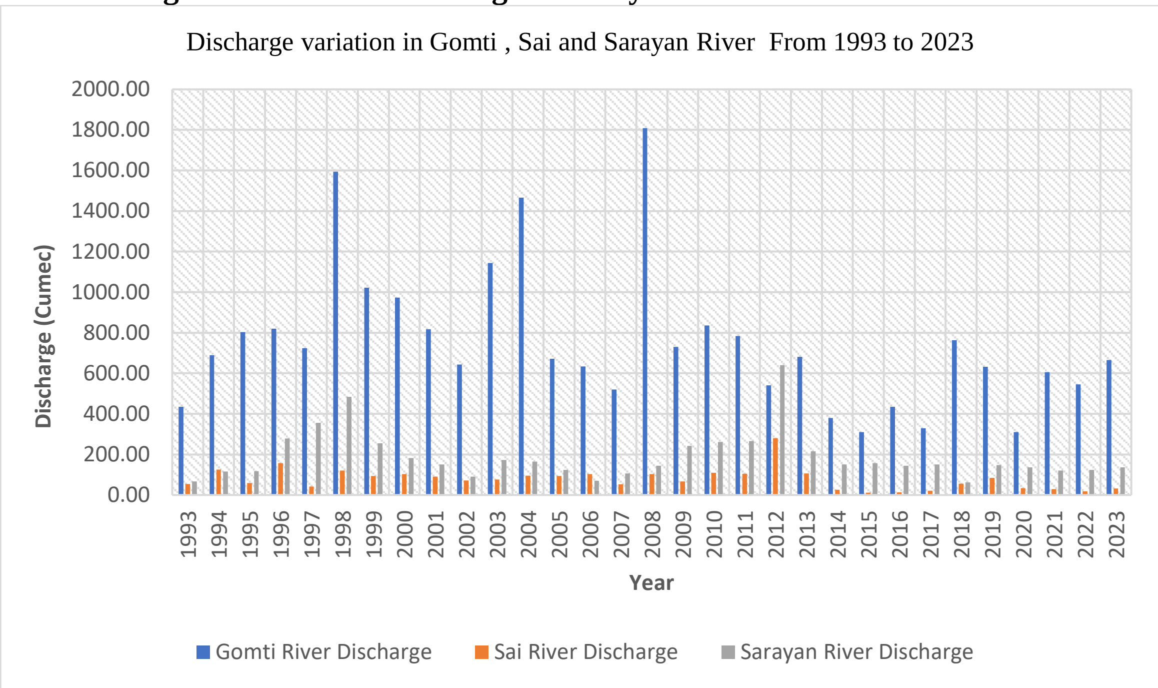

Figure :4. Discharge variation in Gomti, Sai and Sarayan River From 1993 to 2023

The analysis of discharge variation in these rivers from 1993 to 2023 reveals distinct patterns. The Gomti River exhibits significant variability, with extreme peaks such as 1593.17 Cumec in 1998, 1466.31 Cumec in 2005, and a maximum of 1808.34 Cumec in 2008. After 2008, the discharge values show a noticeable decline, with smaller peaks like 835.74 Cumec in 2011 and 666.11 Cumec in 2023, suggesting a reduction in extreme hydrological events in recent years. In comparison, the Sai River maintains relatively stable discharge values throughout the 30-year period, with moderate peaks such as 278.99 Cumec in 1996, 255.48 Cumec in 1999, and 309.75 Cumec in 2017. The discharge generally fluctuates between 50 Cumec and 300 Cumec, with no extreme outliers or sharp declines, indicating more consistent flow patterns.

The Sarayan River shows consistently low discharge levels, rarely exceeding 60 Cumec, with minor peaks such as 58.89 Cumec in 2017 and 41.16 Cumec in 1996. The discharge typically remains low, with values dropping to 10.72 Cumec in 2013 and 7.22 Cumec in 2023, suggesting minimal variation in flow over the years. Overall, while the Gomti River is prone to more extreme events, the Sai and Sarayan rivers demonstrate more stable and lower discharge patterns over the studied period.

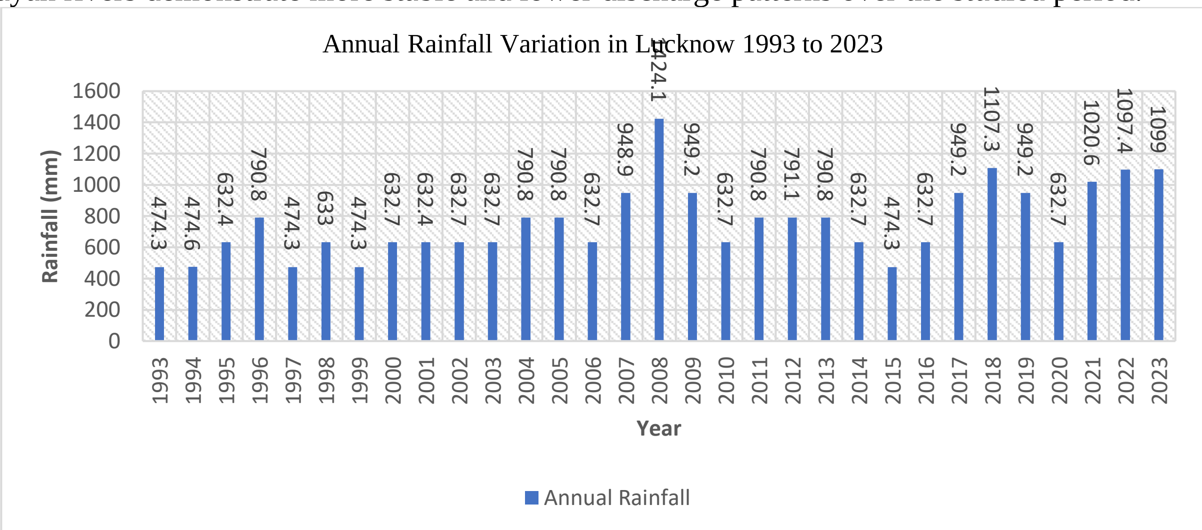

Figure: 5. Annual Rainfall Variation in Lucknow from 1993 to 2023.

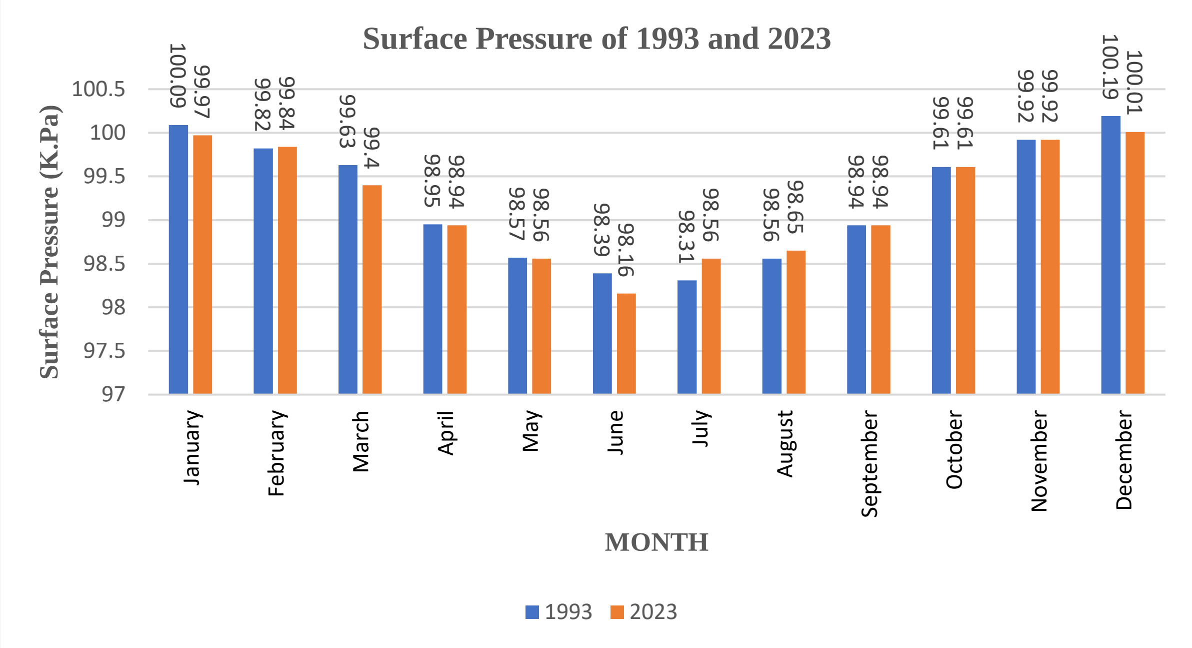

Figure: 6. Surface Pressure of 1993 and 2023

The graph of seasonal monthly average surface pressure variation between the years 1993 and 2023 reveals a notable similarity in trends across the two time periods. Both datasets exhibit a pronounced seasonal cycle, with the highest pressures recorded in winter months (December and January) and the lowest pressures during the summer months (May and June). The Key observations from the data include:

- The highest average surface pressure occurs in **January** for both years, with slight variations between 1993 (100.09 kPa) and 2023 (99.97 kPa).
- The lowest average surface pressure is observed during **June**, where 1993 recorded a pressure of 98.39 kPa compared to a slightly lower value of 98.16 kPa in 2023.
- The difference in surface pressure between the two years appears minimal across all months, with pressures remaining within a small range of variation.

Overall, the surface pressure trends show that while there have been slight variations in individual months, the general pattern and magnitude of seasonal surface pressure have remained relatively stable over the three decades. These findings suggest that surface pressure in this region has not experienced significant long-term shifts, indicating stable atmospheric conditions during the period under review.

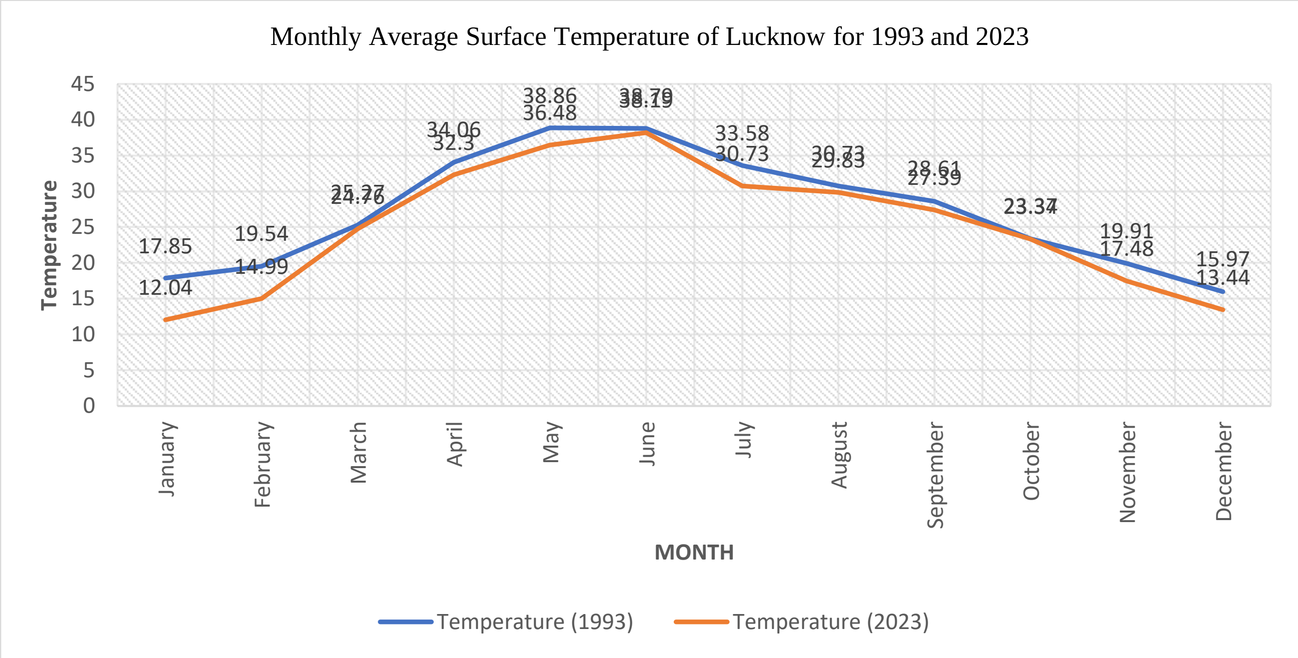

Figure: 7. Surface Temperature of 1993 and 2023

The seasonal monthly average variation of surface temperatures between 1993 and 2023, as illustrated in the graph, shows noticeable shifts over time. Although the overall seasonal pattern remains similar, with peak temperatures occurring in the summer and the lowest temperatures in winter, there are significant differences between the two periods.

Key observations:

- Winter months (December to February): Surface temperatures in 2023 are consistently lower than those in 1993, particularly in January and February, where the temperature difference is most pronounced. January in 2023 recorded 12.04°C, whereas it was 17.85°C in 1993. This suggests a cooling trend during the winter season.
- Summer months (April to June): Despite similar seasonal peaks in both years, 2023 shows slightly lower temperatures in May and June compared to 1993. In May, the surface temperature decreased from 38.86°C (1993) to 36.48°C (2023). This slight cooling could indicate minor shifts in summer temperature dynamics.
- Autumn and Post-monsoon (October to December): The temperature differences during this period are relatively smaller, but 2023 temperatures remain slightly lower than in 1993, indicating a consistent cooling trend across most months.

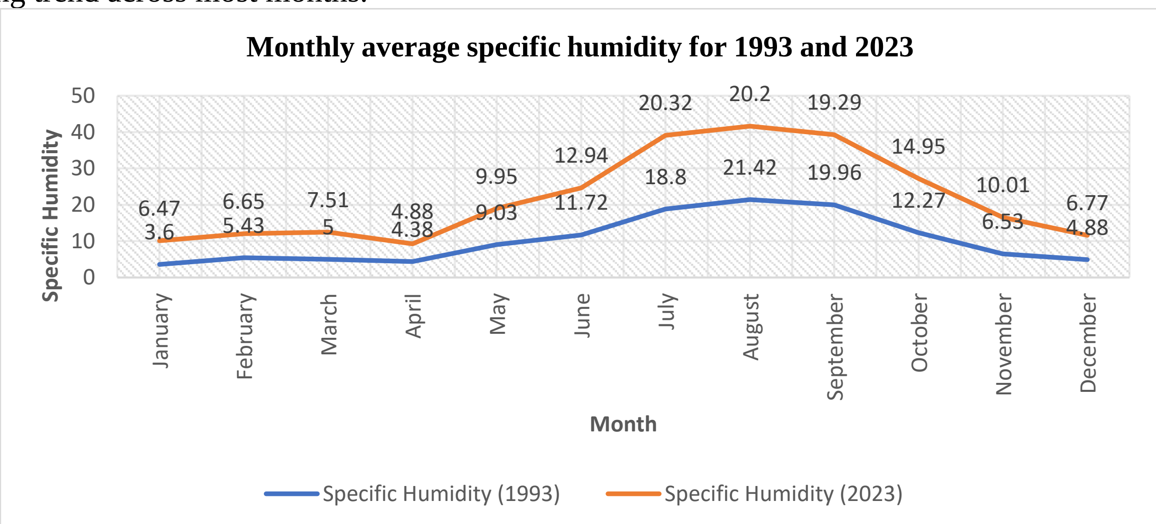

Figure: 8. Specific Humidity for 1993 and 2023

The seasonal monthly average variation of specific humidity between 1993 and 2023, as illustrated by the graph, demonstrates notable differences in atmospheric moisture content across the two periods. While the overall trend follows a similar seasonal pattern, with higher humidity during the monsoon season and lower values during the winter months, there are significant variations in specific humidity levels.

Winter and Pre-monsoon Months (January to April): Specific humidity in 2023 is consistently higher than in 1993. For instance, in January, the specific humidity increased from 3.60 g/kg in 1993 to 6.47 g/kg in 2023. Similar trends are observed in the subsequent months, indicating an overall increase in atmospheric moisture during this period.

Monsoon Season (June to September): Specific humidity during the peak monsoon months (July and August) shows a slight increase in 1993 compared to 2023. For instance, July 1993 had a specific humidity of 18.80 g/kg, which increased to 20.32 g/kg in 2023. However, by August, the specific humidity in 2023 decreased slightly compared to 1993, suggesting subtle changes in the monsoon dynamics over time.

Post-monsoon and Autumn (October to December): In the post-monsoon months, the specific humidity in 2023 remains elevated compared to 1993. For example, October shows a rise from 12.27 g/kg in 1993 to 14.95 g/kg in 2023, while December increased from 4.88 g/kg in 1993 to 6.77 g/kg in 2023. This indicates increased atmospheric moisture content towards the end of the year.

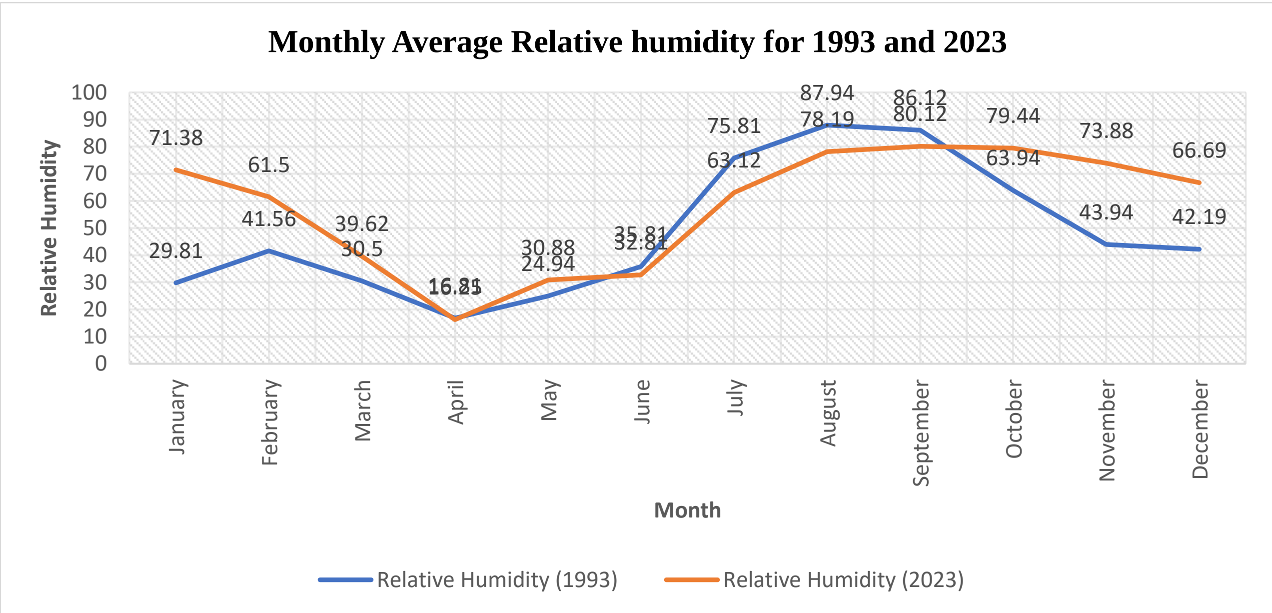

Figure: 9. Relative Humidity for 1993 and 2023

The comparison between the monthly average relative humidity in 1993 and 2023 reveals significant differences in humidity levels over time.

- Early Months (January to April): Relative humidity in 2023 is considerably higher than in 1993, with January showing a stark contrast: 71.38% in 2023 compared to only 29.81% in 1993. This pattern continues in February and March, although the gap narrows.
- Mid-Year (May to September): During the mid-year months, relative humidity levels tend to be higher in 2023 than in 1993. For example, in July, the relative humidity in 2023 reaches 78.19%, whereas in 1993, it is lower at 63.12%. August and September also show consistently higher values in 2023.
- End of the Year (October to December): Toward the end of the year, relative humidity in 1993 surpasses that of 2023. For instance, in November, relative humidity in 1993 is 63.94%, higher than the 43.94% recorded in 2023. The trend continues into December.

General Trend:

Overall, relative humidity levels appear to have shifted significantly between 1993 and 2023, with 2023 generally showing higher humidity in the early and middle months and lower humidity toward the end of the year. These shifts in humidity may reflect broader climatic changes, potentially impacting agriculture, weather patterns, and comfort levels in the region. The elevated humidity in 2023 could lead to more moisture in the air during certain seasons, possibly influencing rainfall and weather conditions.

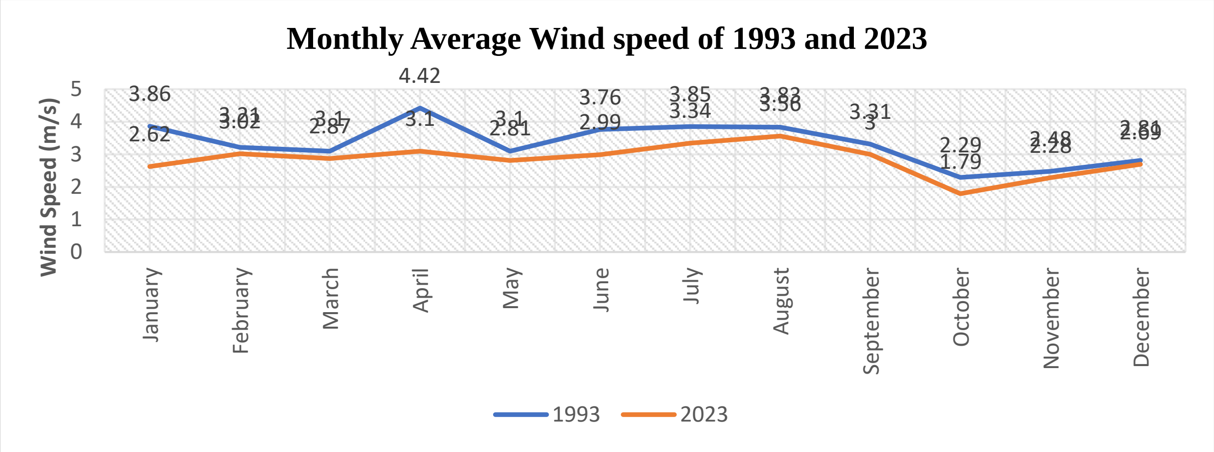

Figure: 10. Wind Speed for 1993 and 2023

The comparison between the monthly average wind speeds in 1993 and 2023 shows a noticeable decline in wind speeds over time. The wind speeds in 2023 are consistently lower across most months compared to 1993, reflecting a reduction in average wind speeds. This is especially significant in April, where in 1993 the wind speed reached 4.42 m/s, whereas in 2023, it is much lower, closer to 3.1 m/s. The reduction in wind speeds over time could be linked to broader climatic changes, which may have an impact on sectors such as renewable energy generation, especially wind power, as well as weather patterns in the region. This trend might suggest less potential for wind energy exploitation in 2023 compared to 1993.

Results and Conclusion:

After the analysis of all climate variable, Precipitation and three river discharge during the period 1993 to 2023. It has been observed that Gomti River had Maximum discharge (1808.34) Cumec in 2008 and minimum (309.75) Cumec in 2015 respectively. Sai River discharge had maximum (280.48) Cumec in 2012 and minimum (11.47) Cumec in 2015 respectively. Sarayan River had maximum discharge (639.41) Cumec in 2012 and minimum (62.90) Cumec in 2018 respectively. Annual rainfall of Lucknow is analysed between the year 1993 to 2023 and found that rainfall was maximum (1424.1 mm) in 2008 and minimum (474.3 mm) in 2015. Surface Pressure and surface temperature are Observed almost similar to 1993 and 2023. Surface pressure is minimum in June and surface temperature is maximum in June. Surface Temperature is also analyzed between the year 1993 to 2023 for given study area and found that maximum increased temperature difference in 5 to 3℃ from January to December month. Seasonal monthly average variation of wind speed is analyzed between the year 1993 to 2023 for given study area and found maximum wind speed were 4.42 m/s and 3.86 m/s for the year 1993 and 2023 respectively. Minimum wind speed were 1.79 m/s and 2.28 m/s for the year 1993 and 2023 respectively.

In conclusion, the analysis of climate variables and river discharges from 1993 to 2022 reveals several significant trends and patterns. The Gomti River experienced its highest discharge in 2008 and its lowest in 2015, while the Sai River had its peak discharge in 2012 and the lowest in 2015. The Sarayan River saw its maximum discharge in 2012 and its minimum in 2018. Annual rainfall in Lucknow recorded the highest levels in 2008 and the lowest in 2015. Surface pressure and temperature remained relatively consistent over the years, with surface pressure being lowest in June and surface temperatures peaking in June. A notable increase in temperature of 3 to 5 degrees Celsius from January to December was observed over the study period. Wind speed analysis showed a decrease in maximum wind speeds from 4.42 m/s in 1990 to 3.86 m/s in 2022, while minimum wind speeds increased from 1.79 m/s in 1990 to 2.28 m/s in 2022. These findings illustrate the significant variability in climate and hydrological patterns in the region, underscoring the importance of continuous monitoring to understand and manage the impacts of these changes.

Reference:

1. Fan, X., et al. (2022). Examining river discharge dynamics in the Yellow River Basin: The influence of headwater regions on downstream water availability. *Journal of Hydrology*, 608, 127462. https://doi.org/10.1016/j.jhydrol.2022.127462.
2. Hiruy, A. M., et al. (2022). Effects of urban wastewater pollution on river microbiomes in the Akaki catchment, Addis Ababa, Ethiopia. *Water Research*, 215, 118228. https://doi.org/10.1016/j.watres.2022.118228.
3. Ke, L. H., et al. (2022). Long-term water level and storage variations in the upper Brahmaputra River: Insights from remote sensing. *Remote Sensing of Environment*, 269, 112866. https://doi.org/10.1016/j.rse.2022.112866.
4. Abou RafeeL, S. A., et al. (2022). Impacts of Land Use and Cover Changes and climate change on river discharge in the Upper Paraná River Basin. *Environmental Research Letters*, 17(3), 034003. https://doi.org/10.1088/1748-9326/ac558b.
5. Sakuma, K., et al. (2021). Estimating tritium discharge from river catchments in the Fukushima coastal region. *Journal of Environmental Radioactivity*, 238, 106715. https://doi.org/10.1016/j.jenvrad.2021.106715.
6. Lamine, B. O. M., et al. (2021). Innovative methods for estimating river cross-sections and discharge using satellite data. *Hydrological Processes*, 35(4), e14138. https://doi.org/10.1002/hyp.14138.
7. Mutia, D., et al. (2021). Relationship between Tana River discharge and phytoplankton biomass in Ungwana Bay, Kenya. *Marine Pollution Bulletin*, 172, 112823. https://doi.org/10.1016/j.marpolbul.2021.112823.
8. Restrepo, J. D., et al. (2020). Satellite-based technique for river discharge measurement in the Magdalena River, Colombia. *Journal of Hydrology*, 590, 125315. https://doi.org/10.1016/j.jhydrol.2020.125315.
9. Tsumune, D., et al. (2020). Environmental impacts of the Fukushima Dai-ichi Nuclear Power Plant accident: Cesium-137 releases into the ocean. *Environmental Science & Technology*, 54(14), 8594-8604. https://doi.org/10.1021/acs.est.0c00596.
10. Chai, Y., et al. (2019). Global trends in seasonal water discharge: Homogenization and polarization. *Nature Communications*, 10, 1234. https://doi.org/10.1038/s41467-019-09112-4.
11. Akter, S., et al. (2019). Rainfall patterns and river discharge trends in the Surma River area, Bangladesh. *Hydrological Sciences Journal*, 64(9), 1063-1078. https://doi.org/10.1080/02626667.2019.1649410.
12. Umar, D. A., et al. (2018). Hydrological trends in the Hadejia River catchment: Implications for water management. *Water*, 10(8), 1064. https://doi.org/10.3390/w10081064.
13. Zhang, X., et al. (2014). Discharge dynamics from the Pearl River into the sea: Impacts of dams and reservoirs. *Journal of Hydrology*, 514, 112-123. https://doi.org/10.1016/j.jhydrol.2014.04.018.
14. Kim, H., et al. (2014). River dynamics and terrestrial water storage variations across global basins. *Geophysical Research Letters*, 41(8), 2773-2781. https://doi.org/10.1002/2014GL059744.
15. Kundzewicz, Z., et al. (2014). Climatic changes and river discharge in the Aksu River Basin, Tarim River. *Climate Research*, 62(2), 103-116. https://doi.org/10.3354/cr01272.