environmental sciences proceedings

MDPI

Proceeding Paper

Temporal Change Dynamics of the Hydrometeorological Conditions of Upper Subarnarekha River Basin (SRB) Using Geospatial Techniques †

Farhin Tabassum * and Akhouri Pramod Krishna

Department of Remote Sensing, Birla Institute of Technology, Mesra, Ranchi 835215, India; apkrishna@bitmesra.ac.in
* Correspondence: phdrs10008.20@bitmesra.ac.in

† Presented at the 5th International Electronic Conference on Remote Sensing, 7–21 November 2023; Available online: https://ecrs2023.sciforum.net/.

Abstract: Understanding the dynamics of any river basin requires a comprehensive analysis of factors such as urbanization, socioeconomic growth, deforestation, agricultural practices, and mining activities. This study aims to investigate the climatic and land use variations and their implications on the hydrometeorological conditions of the upper Subarnarekha River Basin (SRB). Decadal Land Use and Land Cover (LULC) alterations were assessed for the years 2001, 2010, and 2020. Further, climatic variations were studied using Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) precipitation data and Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) temperature data (2001–2020). Conventional groundwater level data from the India-Water Resource Information System (WRIS) for the same timeframe were also integrated to explore groundwater level fluctuations. Such temporal variations were examined using Theil Sen's Median Trend and Mann-Kendall tests. The study also determines how LULC changes and climate variability influence groundwater level in the upper SRB during pre-monsoon, monsoon, and post-monsoon seasons. Results showed higher precipitation and temperature in the southeastern basin region. A strong connection between rainfall and groundwater levels was inferred, with rainfall exhibiting a non-significant upward trend (9.83 mm/year), while temperature shows a persistently significant increasing trend. These observations emphasize the importance of monitoring the hydrometeorological behavior of the basin, underlining its critical role in ensuring the long-term sustainability of water resources.

Keywords: Subarnarekha River Basin; LULC; Theil Sen's Median trend; Mann-Kendall (MK) test; CHIRPS; FLDAS; groundwater level

Citation: Tabassum, F.; Krishna, A.P. Temporal Change Dynamics of the Hydrometeorological Conditions of Upper Subarnarekha River Basin (SRB) Using Geospatial Techniques. *Environ. Sci. Proc.* **2024**, *29*, 29. https://doi.org/10.3390/ECRS2023-16364

Academic Editor: Riccardo Buccolieri

Published: 6 November 2023

1. Introduction

Global water demand exceeding the supply may jeopardize food security. This crisis can further intensify due to Land Use and Land Cover (LULC) changes, population growth, and water stress. Groundwater, crucial for billions, faces increased vulnerability globally [1]. Climate change and excessive groundwater use for agriculture, industry, and households deplete reserves, lowering water levels. Rising temperature, reduced rainfall, and higher evapotranspiration may further hamper local recharge. Anticipated changes in climate may have a significant impact on aquifers that depend on their recharge areas [2]. Extreme events like floods, droughts, and heatwaves affect the atmosphere and hydrology. Understanding these impacts is crucial for effective adaptation [3].

Remote sensing and GIS can be vital in analyzing time-series data for groundwater and climate trends. Halder et al. [1] investigated the seasonal (pre-monsoon, monsoon, and post-monsoon) groundwater level trends using the Mann-Kendall test for 20 wells, as well as groundwater drought using the Standard Groundwater Level Index of an eastern river basin in West Bengal, India. Kumar et al. [4] used Mann-Kendall and ARIMA to analyze trends in 40 observational wells in Warangal, identifying three positive and 37 negative trends. Patra et al. [5] used the Normalized Built-up Index to quantify land use changes and their impact on groundwater recharge due to urban sprawl.

The 2017–2018 Central Ground Water Board (CGWB) report [6] highlights a concerning trend, with 60% of wells across India experiencing declining water levels. Recent desiccation of water bodies in several parts of Jharkhand state of India can be attributed to the rising temperatures, which caused a noticeable drop in the water levels of wells in the region. Changes in land use have also disrupted natural water recharge. The primary objectives of the study are (1) to assess how alterations in LULC affect groundwater recharge, (2) to analyze spatio-temporal changes in rainfall and temperature to understand their climatological impact, (3) to use the Mann-Kendall non-parametric test to study annual and seasonal trends (pre-monsoon, monsoon, and post-monsoon), and (4) to investigate the relationship between seasonal groundwater level fluctuations and the mentioned climatic factors over two decades (2001–2010 and 2011–2020) in the upper Subarnarekha River Basin (SRB), India.

2. Materials and Methods

2.1. Study Area

Upper SRB region covers an area of 17,037 square kilometers within the states of Jharkhand and West Bengal, situated between 22°01′ to 23°35′ N and 85°05′ to 86°55′ E (Figure 1). The annual average rainfall varies from 1300 to 1800 mm, peaking from June to October [7]. Annual average temperature ranges between 23 °C and 28 °C. Geologically, the basin consists of three main formations: Pre-Cambrian in the upper and middle sections, Tertiary, and Quaternary in the lower part [8].

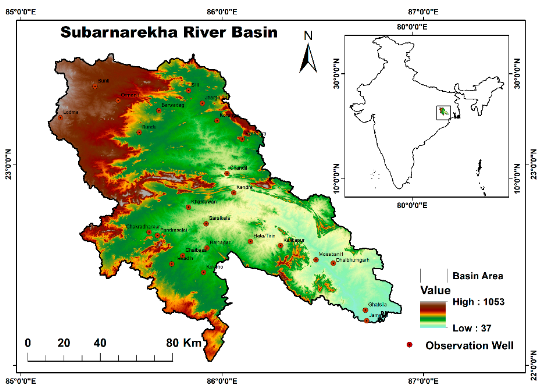

Figure 1. Location map of the upper Subarnarekha River Basin with groundwater observation well points on SRTM 30 m DEM.

2.2. Dataset and Methodology

2.2.1. Dataset

The European Space Agency (ESA) Climate Change Initiative (CCI) Global land cover map (https://www.esa-landcover-cci.org/, accessed on28 January 2023) with a 300 m spatial resolution for 2001, 2010, and 2020 was used for land use and land cover (LULC) analysis. Monthly rainfall data was obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), having a spatial resolution of 0.05° (https://data.chc.ucsb.edu/products/CHIRPS-2.0/, accessed on 25 January 2023). Additionally, the Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) temperature data (https://ldas.gsfc.nasa.gov/fldas/, accessed on 31 January 2023) was used, having a spatial resolution of 0.01° (resampled to 0.05°). Groundwater level data for pre-monsoon, monsoon, and post-monsoon periods were obtained from the India-Water Resource Information System (WRIS) (https://indiawris.gov.in/wris/#/groundWater, accessed on 23 September 2022).

2.2.2. Inverse Distance Weighting (IDW) Method

The spatial distribution of groundwater level was analyzed using the IDW method. This technique is based on Tobler's first law [9], which estimates continuous spatial variations by using known data points to compute values at new locations. The following formulas describe the IDW method:

$$\hat{X}_P = \sum_{i=1}^{N} w_i X_i \quad (1)$$

$$w_i = \frac{d_i^{-\alpha}}{\sum_{i=1}^{N} d_i^{-\alpha}} \quad (2)$$

$\hat{X}_P$ = Unknown rainfall or temperature data, X_i = Data from known stations, N = Number of data stations, w_i = Weight assigned to each relevant data station, d_i = Distance between each data station and the unknown site, and α = Power parameter.

2.2.3. Mann-Kendall Test

The Mann-Kendall test [10,11] was employed to evaluate the significance of trends. Positive Z values signify an upward trend, while negative values denote a downward trend. The Mann-Kendall Test statistics can be expressed as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(x_i - x_j\right) \quad (3)$$

where n = data length, x_i= value of data at the time i, and $sgn\ \left(x_i - x_j\right)$ and Z can be computed using Equations (4) and (5), respectively.

$$sgn\left(x_i - x_j\right) = \begin{cases} 1\ if\ x_i - x_j > 0 \\ 0\ if\ x_i - x_j = 0 \\ -1\ if\ x_i - x_j < 0 \end{cases} \quad (4)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \quad (5)$$

where ∣Z∣ > 1.96 is the significant trend at α = 0.05.

2.2.4. Sens Slope Estimator

Sen's estimator is a non-parametric technique used to assess the magnitude of a trend [12]. The slope was calculated using Equation (6).

$$Q_i = \frac{x_j - x_k}{j - k}\ where\ i = 1,\ 2,\ \ldots, N \quad (6)$$

where, x_j and x_k are time series values at time j and k, respectively, where $j > k$. Positive values signify an upward trend, while negative values signify a downward trend.

3. Results and Discussion

3.1. Spatio-Temporal Assessment of LULC

Figure 2 depicts the spatial patterns of LULC changes in the upper SRB from 2001 to 2020.

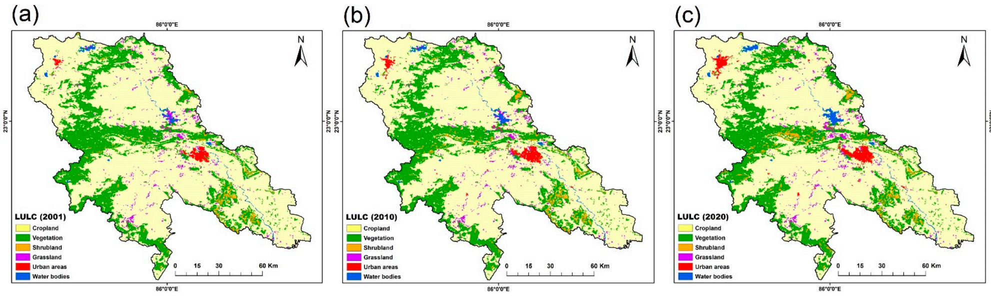

Figure 2. LULC Map of the upper SRB for the year (**a**) 2001, (**b**) 2010, and (**c**) 2020.

Notably, there was significant growth in built-up areas at the expense of vegetation and agricultural land. In 2001, the main categories were vegetation, agriculture, and grassland, with few settlements. However, built-up areas increased by 56.56% (2001–2010) and 35.67% (2011–2020), resulting in a cumulative expansion of 112.6 square kilometers by the year 2020. This expansion led to reduced agricultural land, vegetation, and cropland.

3.2. Spatio-Temporal Assessment of Rainfall and Temperature

Figure 3 shows rainfall and temperature patterns over the two decades (2001–2010 and 2011–2020) during pre-monsoon, monsoon, and post-monsoon periods. A noticeable precipitation and temperature increase is evident in all these seasons. The map highlights consistently higher rainfall in the southeastern part of the basin, with a substantial increase in rainfall during monsoon seasons over the decade 2011–2020. The higher temperature zones have expanded towards the southeastern part of the basin, aligning with rainfall patterns.

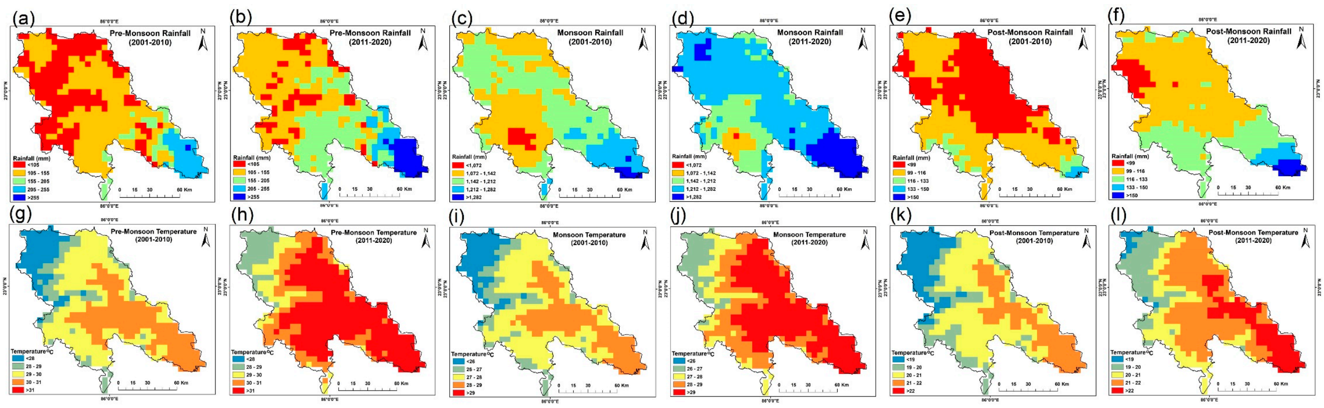

Figure 3. Spatio-temporal variation of rainfall during Pre-Monsoon, Monsoon, and Post-Monsoon in 2001–2010 (**a**,**c**,**e**) and 2011–2020 (**b**,**d**,**f**); and temperature in 2001–2010 (**g**,**i**,**k**) and 2011–2020 (**h**,**j**,**l**).

The Mann-Kendall (MK) trend test revealed a statistically non-significant increase in average annual precipitation at a rate of 9.83 mm/year. Meanwhile, the temperature displayed a consistently significant upward trend at 0.14 °C per year. Tabassum et al. [13] reported increased precipitation levels during the annual, pre-monsoon, monsoon, and post-monsoon periods from 1981 to 2020. Furthermore, their study observed longer precipitation events in the basin after 2005, indicating the potential for higher rainfall in the coming years. Similarly, Mandal et al. [14] projected a substantial rise in precipitation and surface runoff within the Subarnarekha River basin, with percentages ranging from 8% to 48% and 28% to 110%, respectively. Their projections also anticipate an escalation in maximum and minimum temperatures within the basin, with a change ranging from −2.6 °C to 4.7 °C and −0.5 °C to 5.6 °C, respectively, for future timeframes spanning 2030, 2050, 2070, and 2080. Yaduvanshi et al. [15] highlighted the basin's long-term vulnerability to extreme rainfall. They also noted a recent 20-year increase in actual evapotranspiration (AET) and temperatures, which may lead to more extreme rainfall in the near future.

Groundwater levels respond strongly to rainfall variations. Figure 4 represents the interplay between the average groundwater level, rainfall, and temperature across three observation wells. Notably, the graph highlights that elevated levels of rainfall correspond to a rise in groundwater levels.

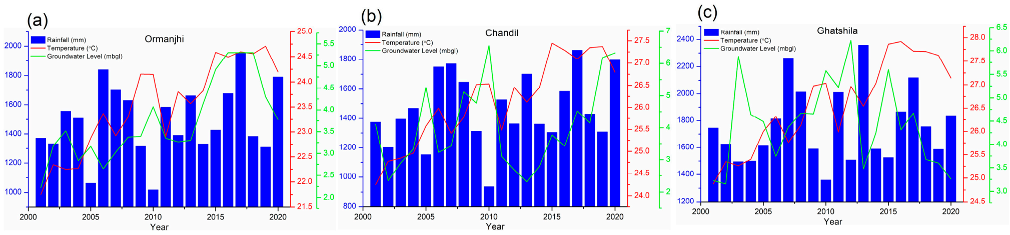

Figure 4. Graphical representation of average monthly rainfall, temperature, and groundwater level (2001–2020) for the three observation wells (**a**) Ormanjhi, (**b**) Chandil, and (**c**) Ghatshila.

3.3. Spatio-Temporal Assessment of GroundWater Level (GWL)

Figure 5 illustrates the spatio-temporal distribution of average GroundWater Level (GWL) during the pre-monsoon, monsoon, and post-monsoon periods over the past two decades (2001–2010 and 2011–2020). Data from twenty-five observation wells falling in upper SRB were analyzed. In the pre-monsoon season, there has been a noticeable decline in the mean water level, with a significant portion of the basin recording groundwater levels below 6 m below ground level (mbgl) in both decades. Such decline may be attributed to extensive groundwater extraction for agricultural and domestic purposes, raising concerns over it. During the monsoon season, there is a slight improvement in the mean groundwater level, ranging between 2 and 4 mbgl. This improvement can be attributed to recharge from precipitation. In the post-monsoon period, the mean groundwater level ranges from 3 to 5 mbgl, reflecting the aquifer's replenishment through infiltration.

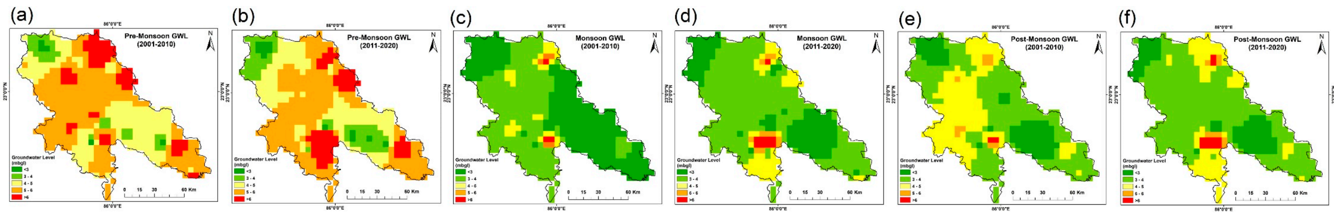

Figure 5. Spatio-temporal representation of average monthly groundwater level during Pre-Monsoon, Monsoon, and Post-Monsoon in 2001–2010 (**a**,**c**,**e**) and 2011–2020 (**b**,**d**,**f**).

The Mann-Kendall trend test was employed on a time series dataset from 2001 to 2020, encompassing the pre-monsoon, monsoon, and post-monsoon seasons. Table 1 represents the results of the MK test for some of the significant observation wells. During the pre-monsoon, two wells (Chaibasa and Mathbura) displayed increasing trends significant at a 95% Confidence Interval (CI). Increasing trends denote a continuous decline over time. In the monsoon, three wells (Chaibasa, Mathbura, and Pandrasalai) and post-monsoon, four wells (Chaibasa, Chandil, Mathbura, and Rajnagar) showed a significant increasing trend (95% CI). Notably, many wells displaying an upward trend of groundwater withdrawal were situated near agricultural land, as indicated by LULC, where extensive extraction occurred.

Table 1. Results of Mann-Kendal trend test for groundwater level on upper SRB (significant trend at 95% CI shown in bold font).

	Pre-Monsoon			Monsoon			Post-Monsoon		
Station	**Kendall Tau**	***p* Value**	**Slope**	**Kendall Tau**	***p* Value**	**Slope**	**Kendall Tau**	***p* Value**	**Slope**
Chaibasa	0.526	**0.001**	0.625	0.432	**0.009**	0.513	0.468	**0.004**	0.416
Chandil	0.132	0.436	0.071	0.247	0.135	0.079	0.332	**0.044**	2.013
Hata/Tirin	−0.337	**0.039**	−0.117	−0.042	0.818	0.000	−0.358	**0.027**	−0.056
Hesadih	−0.426	**0.009**	−0.146	0.042	0.820	0.018	−0.363	**0.027**	−0.134
Kharsawan	−0.395	**0.016**	−0.101	−0.116	0.496	−0.020	−0.268	0.105	−0.098
Mathbura	0.442	**0.007**	0.177	0.400	**0.015**	0.254	0.337	**0.041**	0.151
Pandrasalai	0.026	0.896	0.000	0.411	**0.011**	0.121	0.274	0.095	0.060
Rajnagar	0.063	0.720	0.054	0.295	0.073	0.165	0.353	**0.031**	0.275
Saraikela	−0.447	**0.006**	−0.095	−0.168	0.314	−0.033	−0.316	**0.055**	−0.089

4. Conclusions

This study over the upper Subarnarekha River Basin, India, underscores the crucial changes in LULC, hydrometeorological conditions, and declining groundwater levels. Such changes could lead to decreased water holding capacity in the soil, accelerated runoff, and impaired aquifer recharge, posing challenges to sustainable water management. Temperature and rainfall patterns showed increasing trends with temperature rising significantly. The assessment of groundwater levels, particularly during the pre-monsoon, monsoon, and post-monsoon seasons, indicated declining trends in certain areas, emphasizing the need for effective management strategies. As the region continues to undergo land use changes and faces evolving climate patterns, proactive measures are essential to ensure the availability of this vital resource for future generations. Hence, vigilant monitoring, safeguarding the water resources of the basin, and fostering environmental resilience in the face of ongoing challenges are very much required.

Author Contributions: Conceptualization, F.T. and A.P.K.; methodology, F.T. and A.P.K.; software, F.T.; validation, F.T.; formal analysis, F.T.; investigation, F.T. and A.P.K.; resources, F.T.; data curation, F.T.; writing—original draft preparation, F.T.; writing—review and editing, F.T. and A.P.K.; visualization, F.T. and A.P.K.; supervision, A.P.K.; project administration, A.P.K.; funding acquisition, A.P.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by DST-SERB (Sanction ref. CRG/2019/002351), Government of India.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available on request due to privacy restrictions. The data presented in this study are available on request from the corresponding author. The data are not publicly available due to more research still underway using the same datasets.

Acknowledgments: Authors wish to acknowledge the grant support from DST-SERB including the Research Fellowship support to the first author. They also acknowledge the rainfall data from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), temperature data from Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS), groundwater level data from India-Water Resource Information System (WRIS) and LULC data from the European Space Agency (ESA).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Halder, S.; Roy, M.B.; Roy, P.K. Analysis of Groundwater Level Trend and Groundwater Drought Using Standard Groundwater Level Index: A Case Study of an Eastern River Basin of West Bengal, India. *SN Appl. Sci.* **2020**, *2*, 507. [CrossRef]
2. Jakeman, A.J.; Barreteau, O.; Hunt, R.J.; Rinaudo, J.D.; Ross, A.; Arshad, M.; & Hamilton, S. Integrated groundwater management: An overview of concepts and challenges. In *Integrated Groundwater Management: Concepts, Approaches and Challenges*; Springer: Cham, Switzerland, 2016; pp. 3–20. [CrossRef]
3. van Engelenburg, J.; Hueting, R.; Rijpkema, S.; Teuling, A.J.; Uijlenhoet, R.; Ludwig, F. Impact of Changes in Groundwater Extractions and Climate Change on Groundwater-Dependent Ecosystems in a Complex Hydrogeological Setting. *Water Resour. Manag.* **2018**, *32*, 259–272. [CrossRef]
4. Satish Kumar, K.; Venkata Rathnam, E. Analysis and Prediction of Groundwater Level Trends Using Four Variations of Mann Kendall Tests and ARIMA Modelling. *J. Geol. Soc. India* **2019**, *94*, 281–289. [CrossRef]
5. Patra, S.; Sahoo, S.; Mishra, P.; Mahapatra, S.C. Impacts of Urbanization on Land Use/Cover Changes and Its Probable Implications on Local Climate and Groundwater Level. *J. Urban Manag.* **2018**, *7*, 70–84. [CrossRef]
6. Central Ground Water Board (CGWB). *Groundwater Year Book-India 2017–2018*; Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India: Faridabad, India, 2018.
7. Chatterjee, S.; Krishna, A.P.; Sharma, A.P. Geospatial Assessment of Soil Erosion Vulnerability at Watershed Level in Some Sections of the Upper Subarnarekha River Basin, Jharkhand, India. *Environ. Earth Sci.* **2014**, *71*, 357–374. [CrossRef]
8. Guha, S.; Patel, P.P. Evidence of Topographic Disequilibrium in the Subarnarekha River Basin, India: A Digital Elevation Model Based Analysis. *J. Earth Syst. Sci.* **2017**, *126*, 1–20. [CrossRef]
9. Tobler, W.R. A Computer Movie Simulating Urban Growth in the Detroit Region. *Econ. Geogr.* **1970**, *46*, 234–240. [CrossRef]
10. Mann, H.B. Non-Parametric Test Against Trend. *Econometrica* **1945**, *13*, 245–259. [CrossRef]
11. Kendall, M.G. *Rank Correlation Methods*, 4th ed.; Griffin & Co.: London, UK, 1975; ISBN 0-85264-199-0.
12. Sen, P.K. Estimates of the Regression Coefficient Based on Kendall's Tau. *J. Am. Stat. Assoc.* **1968**, *63*, 1379–1389. [CrossRef]
13. Tabassum, F.; Krishna, A.P. Spatio-Temporal Drought Assessment of the Subarnarekha River Basin, India, Using CHIRPS-Derived Hydrometeorological Indices. *Environ. Monit. Assess.* **2022**, *194*, 902. [CrossRef] [PubMed]
14. Mandal, U.; Sena, D.R.; Dhar, A.; Panda, S.N.; Adhikary, P.P.; Mishra, P.K. Assessment of Climate Change and Its Impact on Hydrological Regimes and Biomass Yield of a Tropical River Basin. *Ecol. Indic.* **2021**, *126*, 107646. [CrossRef]
15. Yaduvanshi, A.; Sinha, A.K.; Haldar, K. A Century Scale Hydro-Climatic Variability and Associated Risk in Subarnarekha River Basin of India. *Model. Earth Syst. Environ.* **2019**, *5*, 937–949. [CrossRef]