# Tree-ring based precipitation reconstruction for Skardu in the Upper Indus Basin

**Syeda Saria Bukhary*, Sadia Moin***

* Civil Engineering Department, NED University of Engineering and Technology, Karachi, Pakistan

***Abstract***- Tree-ring based climate reconstructions are significant for understanding past climate variability, in the context of increasing population, rising water demands, and changing climate. With trees being widespread, precipitation patterns can be reconstructed in various regions, including areas with limited instrumental data. This study presents a tree-ring based multi-century precipitation reconstruction for Skardu, located in Upper Indus Basin (UIB) in northern Pakistan, using a stepwise linear regression model. The reconstruction, spanning the period 1472-1993, revealed significant variability in precipitation patterns. The results showed a strong correlation between tree-ring data and precipitation, with a calibration $R^2$ value of 0.52 and a predicted $R^2$ value of 0.35. The reconstruction highlighted a rich history of wet and dry periods. The presence of notable wet periods in the late 15th and late 16th/early 17th centuries suggested that the Skardu region has experienced significant hydrological variability over the centuries. In contrast, the late 18th century and the early 20th century, and the mid-16th and mid-17th centuries recorded some of the lowest precipitation values, pointing to dry conditions that could have impacted agriculture and water resources. Future work directions for this study include enhancing the reconstruction with the addition of new tree-ring chronologies, combining tree-ring data with other climate proxies to enhance the reconstruction methodology, and applying this methodology to additional regions within the UIB for a comprehensive understanding of spatial climate variability.

***Keywords***- tree ring chronology, Upper Indus Basin, streamflow reconstruction, Skardu, Northern Pakistan

## I. INTRODUCTION

Dendroclimatic reconstructions, derived from the meticulous analysis of tree-ring width archives, provide detailed understanding of historical climate variability, highlighting the complexities of climate regimes and their dynamics. By analyzing tree rings, researchers can gain valuable insights into extreme weather events of the bygone times, such as droughts and floods, and support informed water resource management decisions for future challenges related to changing climate (Carrier et al. 2013; Thakali et al. 2016; Bukhary, 2024), increasing population (Bukhary et al. 2018; Bailey et al. 2021) and water scarcity (Wu et al. 2013; Bukhary, 2018).

Tree ring chronologies (TRC) are valuable proxy indicators of past climate due to their unique characteristics (Rao et al. 2018). Each ring represents a year of growth, providing a precise and annual record of past climate conditions. Long-lived tree species offer extensive climate records that surpass the duration of direct measurements, spanning centuries to millennia. Tree growth is influenced by various climate factors, which are reflected in ring width, density, and composition, offering insights into different aspects of past climate conditions. These characteristics make tree rings a robust proxy for reconstructing past climate conditions, helping scientists understand past climate variability and inform future climate predictions (Bukhary et al. 2021; Bukhary et al. 2014). For instance, tree rings have been used to reconstruct temperature variations over the past millennium in the Northern Hemisphere, famously illustrated by the "hockey stick" graph showing a sharp 20th-century temperature increase (Mann et al., 1999). Region-specific reconstructions, such as those from the European Alps or the Rocky Mountains, reveal local temperature histories (Büntgen et al., 2006; Salzer and Kipfmueller, 2005). Streamflow and river discharge reconstructions, such as those for the Colorado River and China's Yangtze River, inform long-term water resource management through drought and flood history (Meko et al. 2007; Xing et al. 2024). Tree-rings also elucidate precipitation patterns, identifying severe droughts like the 13th-century "Great Drought" in the American Southwest and Asian monsoon variability over centuries (Cook et al., 2004 & 2010). The current study focuses on reconstructing precipitation in the Upper Indus Basin (UIB) in northern Pakistan, utilizing tree ring data. Tree ring-based reconstructions for streamflow, precipitation and temperatures have been generated by other studies for UIB (Khan et al. 2024, Bukhary and Masood, 2024; Rao et al. 2018; Khan et al. 2018).

Several studies have achieved precipitation reconstruction using TRC (Cleaveland et al. 2003; Peng et al. 2013; Wang and Liu, 2017; Arsalani et al. 2018). Peng et al. (2013) reconstructed precipitation (1828-2010) for northwestern Liaoning province which accounted for 35.4% of the variance in the observed precipitation. Cleaveland et al. (2003) reconstructed winter precipitation for Durango, Mexico. The reconstructions spanning over 6 centuries explained 56% of the variance in the measured precipitation. Arsalani et al. (2018) developed reconstructions of precipitation for southern Zagros Mountains, Iran, between the years 1796 and 2017 and explained a variance of 44% in the instrumental precipitation data. Precipitation reconstructions were developed for Qianshan Mountains in northeastern China by Wang and Liu, (2017), which explained 43% of the variance in the measured precipitation and extended the precipitation record to the year 1745.

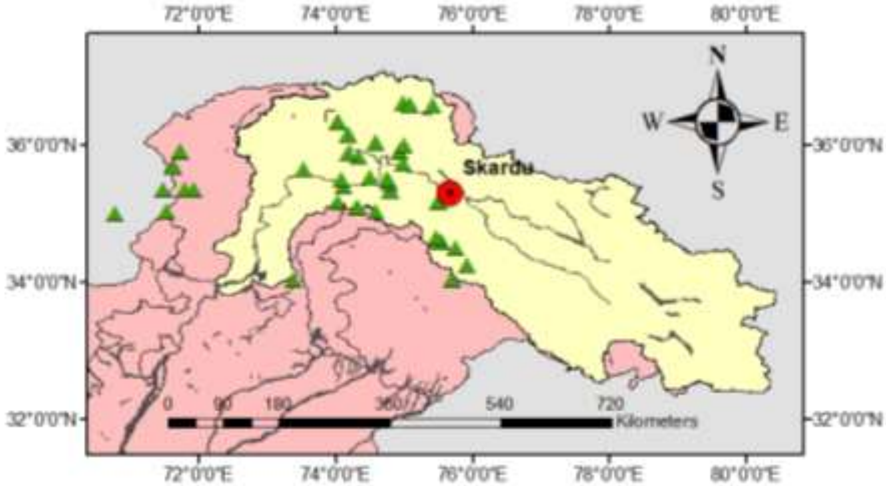


Figure 1. Map of the study area showing the location of Skardu weather station and the tree ring chronology data used in the current study, located in the Upper Indus River Basin in Northern Pakistan.

The economic backbone of Pakistan, the River Indus, supports vast areas of irrigated agriculture and a significant portion of the country's installed hydropower capacity. The flow emerging into the lower Indus Basin is largely fed by snowfields and glaciers (70%) and monsoon rainfall (30%) (Immerzeel et al. 2009). However, the Indus is vulnerable to short-term fluctuations and long-term climate change, impacting agricultural productivity and rural livelihoods (Fowler and Archer, 2005). In the UIB, where rainfall is scarce (<150 mm annually), inhabitants rely on irrigated agriculture fed by snow and glacier meltwater. Annual temperature and precipitation variability significantly affect agricultural viability and productivity. Therefore, reconstructing rainfall data at a local scale in UIB is vital to understand past climate variability, predict future changes, and develop climate-resilient agricultural strategies, ultimately supporting food security and sustainable development in the region.

In this study, precipitation/rainfall was reconstructed for Skardu area, located in UIB, in northern Pakistan, using TRC as a predictor in a stepwise linear regression model.

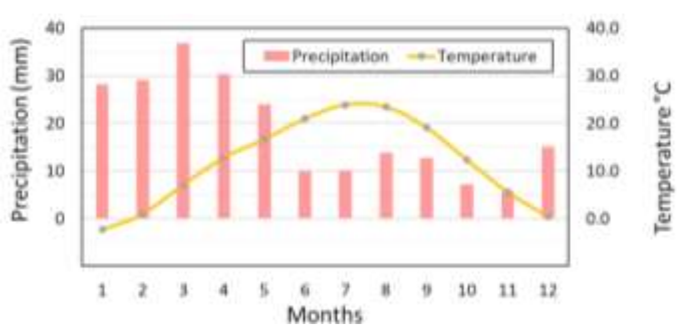


Figure 2. Monthly precipitation totals and average monthly temperatures for Skardu between the years (1961-2021).

## II. STUDY AREA

The UIB is a critical region for Pakistan, with significant implications for water resources management. The area experiences two main climates: monsoon rains originating from the Bay of Bengal and Arabian Sea, and westerlies from the Caspian Sea and Mediterranean region during winter and spring. Most of the annual precipitation in the UIB falls during winter and spring, mainly as snow and rain due to the westerlies. Water resources in the basin depend on three main sources: seasonal snowmelt and meltwater from glaciers (70%), and direct runoff from rainfall (30%) during both winter and summer seasons, according to Immerzeel et al. (2009).

Skardu, a renowned tourist destination, is nestled in the western Himalayas in Gilgit Baltistan, in UIB, at an elevation of 2500 meters, with a width of approximately 10 km and a length of 40 km (Figure 1). The weather station, located at an altitude of 2394 meters (Archer, 2004), recorded a mean monthly temperature range of 24°C in the hottest months to 12°C in October (Figure 2). The valley is surrounded by prominent glaciers, including Raikot, Rupal, Diamir, and Patro, and lies at the confluence of the Indus and Shigar rivers, with other significant rivers like Balradu and Basha Basna flowing into the Indus.

The region's climate is characterized by a mean precipitation/rainfall total of 227.3 mm, with a standard deviation of 94.4 mm, based on 60 years of measured precipitation data (1961-2021). About 67% of the annual rainfall occurs between January and May. The summer months (June to August) receive only 15% of the total rainfall due to the barrier effect of the mountains which block the monsoon rains from reaching the area (Figure 2). Sadpara lake, a natural lake near the semi-arid Skardu, is a vital source of water for the valley's agricultural and domestic needs.

The economy of Gilgit Baltistan relies heavily on the hospitality industry, with Skardu and Gilgit being top tourist destinations. However, the large number of tourists visiting the region annually puts immense strain on the water resources, which are already scarce due to the lack of infrastructure, particularly water storage facilities. Agriculture activities in the region rely on snowmelt and glacier melt. However, this resource is only available in summer from May onwards and the availability decreases with decreasing temperature. Additionally, the future availability of glacier melt might be uncertain due to rising temperatures and climate change (Khan et al. 2020; Lutz et al. 2016). The current study aims to reconstruct rainfall data using TRC to better understand the long-term climatic variability of the region.

## III. METHODOLOGY

In this study, a stepwise linear regression model was utilized to reconstruct Skardu precipitation, which is a commonly used method for reconstructing hydrologic variables using TRC as predictors. Several studies have used it to reconstruct precipitation (Touchan et al. 2005; Meko et al. 2011; Kostyakova et al. 2018). The method used in the current study combines forward selection and backward elimination to develop regression models, using a threshold alpha value of 0.05 for adding predictors during forward selection process and 0.10 for removing them during backward elimination, thus resulting in a robust regression model (Anderson et al. 2012a&b). The performance of the precipitation reconstruction model was evaluated using various statistical metrics, including calibrated $R^2$, predicted $R^2$, standard error of the estimate, and Durbin-Watson statistic; these metrics assess the model's goodness of fit, predictive ability, accuracy, and absence of autocorrelation, respectively (Anderson et al. 2019; Bukhary et al. 2015).

The tree ring dataset for 43 locations in Pakistan, obtained from the international tree-ring database, was processed to extract the environmental signals. Non-climatic growth trends were removed through detrending and standardization, employing methods such as the conservative negative exponential method. To eliminate autocorrelation and isolate the environmental signal, autoregressive modeling was applied to the standardized series. This processing was facilitated by the ARSTAN software (Cook et al., 2017), which enabled the detrending, standardization, and autoregressive modeling steps, ultimately producing the residual chronologies used in the present study. The rainfall data of Skardu (1961-2021) was obtained from Pakistan Meteorological Department.

## IV. RESULTS AND DISCUSSION

The tree ring data, downloaded from the international tree-ring data bank, was detrended and standardized to remove non-climatic growth trends and highlight annual environmental signals, using the conservative negative exponential method. The Skardu precipitation data was analyzed against each of the 43 TRC using Pearson's correlation method. Only chronologies with a significant positive correlation ($p < 0.05$) were selected. To assess the long-term stability of the relationship between tree-ring data and precipitation, correlation coefficients were calculated using a 20-year moving window. Chronologies showing a positive correlation at a confidence level of 90% or higher for all windows, indicating a stable relationship over time, were retained.

Application of stepwise linear regression model yielded promising results for the reconstruction of annual precipitation for Skardu station, as shown in Figure 3. The model accounted for 52% of the variance in precipitation, indicating a good fit between predicted and observed values during the calibration period. The predicted $R^2$ value was 0.35. The Durbin-Watson statistic of 1.5 suggested no significant autocorrelation, demonstrating good model quality. The low Standard Error of Estimate (139.3 $m^3$/sec) and a Nash-Sutcliffe Efficiency (NSE) value of 0.52 confirmed the model's reasonable fit to observed data during calibration. The Relative Standard Error (RSR) of 0.59, being below 0.7, indicated satisfactory model performance, based on the model evaluation criteria defined by Moriasi et al. (2007).

Successful precipitation reconstruction was achieved for the period from 1472 to 1993 (Figure 3a-3c). The average reconstructed precipitation was 201 mm, with a standard deviation of 59 mm. Particularly, the late 15th century experienced exceptionally high precipitation, suggesting unusually wet conditions (Figure 3a). Reconstructed precipitation showed that four of the five highest values occurred in this period, with 391 mm in the year 1487, 388 mm in 1488, 368 mm in 1496, and 363 mm in the year 1484. Similarly, the late 16th and early 17th centuries also exhibited significant precipitation events, indicating another period of increased rainfall and three of the ten highest values in the reconstructed precipitation occurred in the late 16th and early 17th centuries, with 390 mm in the year 1607, 348 mm in 1575, and 329 mm in the year 1594. In contrast, the late 18th century and the mid-16th and mid-17th centuries recorded some of the lowest precipitation values, pointing to drier climatic phases or prolonged droughts that could have severely impacted agriculture and water resources. Two of the eight lowest values, observed in the late 18th century, were 2 mm in the year 1785 and 51 mm in 1768. While, four of the ten lowest values were recorded in the mid-16th and mid-17th centuries, with 14 mm in the year 1541, 43 mm in 1572, 45 mm in 1662, and 61 mm in the year 1652. The early 20th century also experienced low precipitation values, with 46 mm observed in the years 1902 and 1917. Interestingly, the instrumental record highlights a contrasting trend for the late $20^{th}$ century, with the highest recorded precipitation (495 mm) occurring in the year 2010, along with other measured highs in the year 1996 (450 mm), 1974 (405 mm), and 1972 (388 mm), and an overall increasing trend in precipitation. The lowest measured precipitation was 68 mm in 1971, 81.5 mm in 1965 and 96.7 in the year 1968.

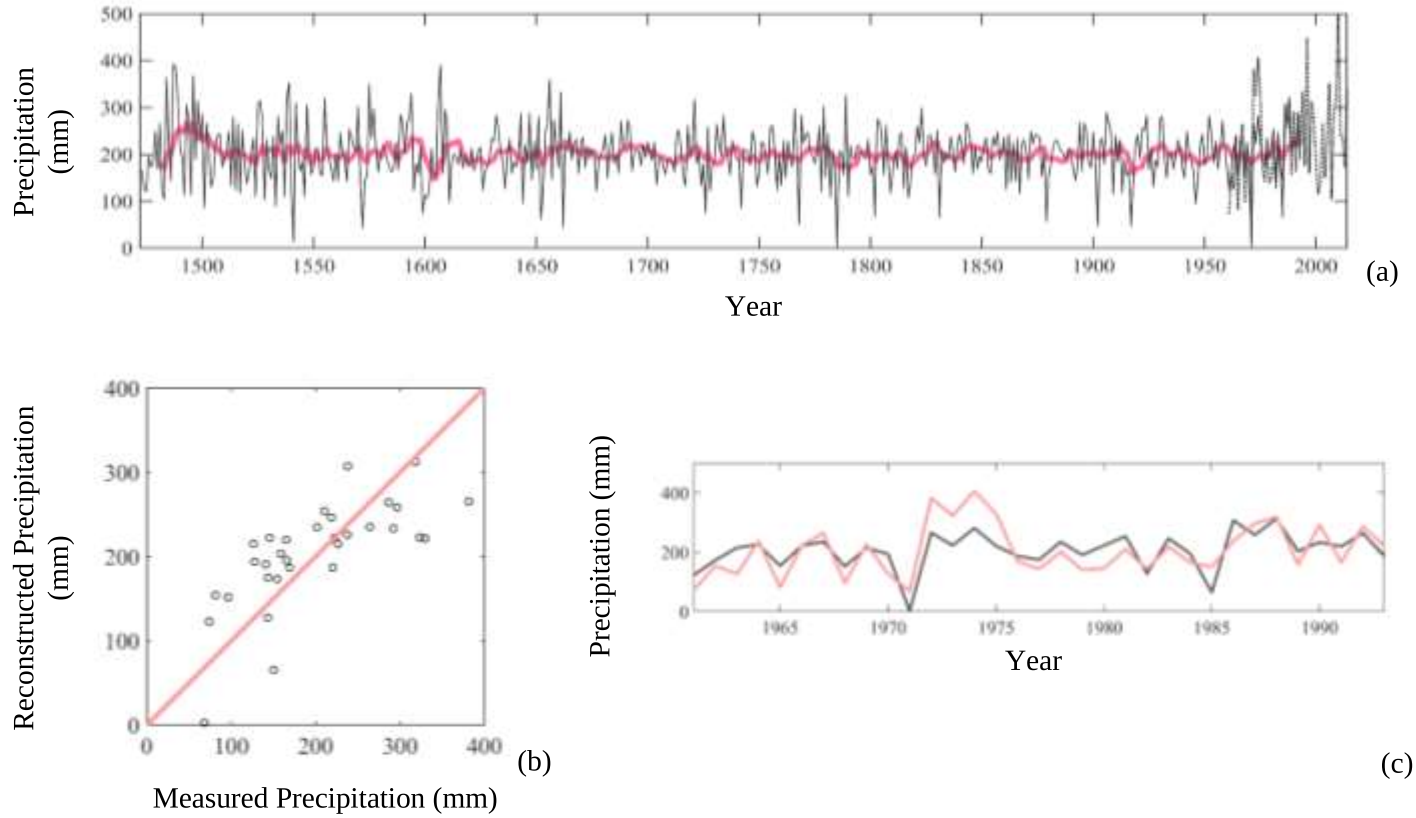


Figure 3. The precipitation reconstruction achieved for Skardu weather station. (a) Black line represents reconstructed precipitation, pink line shows 10-year moving average of the reconstructed precipitation, and dotted black line displays the measured precipitation. (b) Scatter plot displays the relationship between the measured and the reconstructed precipitation. (c) Showcasing the comparison of the reconstructed precipitation (black line) and the measured precipitation (pink line) for Skardu weather station for the overlap period of 1961-1993.

A 10-year moving average is also plotted in figure 3a, this value reduces the year-to-year variability, providing a clearer view of the underlying trend. The scatter plot (Figure 3b) displays good agreement between reconstructed and measured precipitation (Figure 3c). These results provide valuable insights into past precipitation patterns and trend. Thus, the reconstructed precipitation data from 1472 to 1993, along with the instrumental records, reveal notable trends and variations in Skardu's climate history. These variations underscore the complex and changing nature of the region's climate over the centuries.

In Skardu, analysis of long-term precipitation records from 1894 to 1999, from a study by Fowler and Archer, (2005) showed no significant trend in annual or seasonal precipitation over the past century. However, since 1961, there has been a statistically significant ($P < 0.05$) upward trend in winter precipitation, with an increase of 18% per decade. Regarding annual mean temperatures, Skardu exhibited a warming trend, particularly pronounced in winter. Since 1961, winter maximum temperatures in Skardu have significantly ($P < 0.05$) increased by 0.55°C per decade (Fowler and Archer, 2005).

Other studies have also reconstructed precipitation using TRC in the region. Khan et al. (2024) reconstructed precipitation/rainfall for Chitral, located in Khyber Pakhtunkhwa Province, and extended the record to over 600 years using linear regression model and explained 53% of the variance in the instrument data. Khan et al. (2018) used gridded precipitation data for Karakoram region in Pakistan to reconstruct rainfall since 1540 to present using TRC. Treydte et al. (2006) also reconstructed precipitation for the regional Karakoram using tree-ring data.

## V. CONCLUSION

This study successfully achieved reconstruction of precipitation/rainfall for Skardu, located in UIB, and extended the precipitation record to the year 1472. The statistical performance of the tree-ring based reconstruction model was robust, explaining 52% of the variance in the measured precipitation, with a predicted $R^2$ value of 0.35. The Durbin-Watson statistic of 1.5 suggests no significant autocorrelation, demonstrating good model quality. NSE value of 0.52 and RSR of 0.59, indicates satisfactory model performance.

The precipitation reconstruction for Skardu revealed a rich history of hydrological variability over the past 521 years (1472-1993). The presence of notable wet periods in the late 15th and late 16th/early 17th centuries suggested that Skardu region has experienced significant hydrological variability over the centuries. In contrast, the late 18th century and the early 20th century, and the mid-16th and mid-17th centuries recorded some of the lowest precipitation values, pointing to drought conditions that could have impacted agricultural activities. The long-term precipitation variability revealed by this study has important implications for water resource management, agriculture, and climate change research in the UIB.

Further research is needed to investigate the causes of this long-term variability and its potential impacts on this region. A multi-proxy approach for precipitation reconstruction could potentially provide a more comprehensive understanding of past hydrological variability. Assessing the impacts of precipitation variability on agriculture, water resources, hospitality industry and local communities can inform adaptive strategies to mitigate adverse effects and enhance resilience. Developing infrastructure such as dams and other water storage facilities, promoting efficient irrigation techniques, and raising awareness among local communities about sustainable practices are crucial steps. Engaging with policymakers to integrate climate research findings into regional planning and decision-making processes will ensure that adaptive strategies are effectively implemented.

## REFERENCES


[1] Anderson, S., Aziz, O., Tootle, G., Grissino-Mayer, H. and Barnett, A., 2012a. Using Pacific Ocean climatic variability to improve hydrologic reconstructions. Journal of hydrology, 434: 69-77.

[2] Anderson, S., Tootle, G. and Grissino-Mayer, H., 2012b. Reconstructions of Soil Moisture for the Upper Colorado River Basin Using Tree-Ring Chronologies 1. JAWRA Journal of the American Water Resources Association, 48(4), pp.849-858.

[3] Anderson, S., Ogle, R., Tootle, G. and Oubeidillah, A., 2019. Tree-Ring Reconstructions of Streamflow for the Tennessee Valley. Hydrology, 6(2): 34.

[4] Arsalani, M., Pourtahmasi, K., Azizi, G., Braeuning, A. and Mohammadi, H., 2018. Tree-ring based December–February precipitation reconstruction in the southern Zagros Mountains, Iran. Dendrochronologia, 49, pp.45-56.

[5] Bukhary, S., Kalra, A. and Ahmad, S., 2021. Incorporating Pacific Ocean climate information to enhance the tree-ring-based streamflow reconstruction skill. Journal of Water and Climate Change, 12(5), pp.1891-1909.

[6] Bukhary, S., Masood, A., 2024. A dendrohydrological analysis for reconstructing river discharge to understand long-term hydrologic variability. Journal of Xi'an Shiyou University, Natural Science Edition, Volume 20 Issue 07

[7] Bukhary, S.S. and Masood, A. A dendrohydrological analysis for reconstructing river discharge to understand long-term hydrologic variability. 2024

[8] Bailey, J.R., Bukhary, S., Batista, J.R. and Ahmad, S., 2021. Renewable energy generation and GHG emission reduction potential of a satellite water reuse plant by using solar photovoltaics and anaerobic digestion. Water, 13(5), p.635.

[9] Bukhary, S., Batista, J. and Ahmad, S., 2018, May. Sustainable desalination of brackish groundwater for the Las Vegas Valley. In World Environmental and Water Resources Congress 2018 (pp. 311-322). Reston, VA: American Society of Civil Engineers.

[10] Bukhary, S., Chen, C., Kalra, A. and Ahmad, S., 2014. Improving streamflow reconstructions using oceanic-atmospheric climate variability. In World Environmental and Water Resources Congress 2014 (pp. 846-855).

[11] Bukhary, S., Kalra, A. and Ahmad, S., 2015, May. Insights into reconstructing sacramento river flow using tree rings and Pacific Ocean climate variability. In World Environmental and Water Resources Congress 2015 (pp. 1040-1049).

[12] Bukhary, S., Batista, J. and Ahmad, S., 2019, May. Using solar and wind energy for water treatment in the southwest. In World Environmental and Water Resources Congress 2019 (pp. 410-416). Reston, VA: American Society of Civil Engineers.

[13] Bukhary, S., Batista, J. and Ahmad, S., 2020. Design aspects, energy consumption evaluation, and offset for drinking water treatment operation. Water, 12(6), p.1772.

[14] Bukhary, S.S., 2024. The renewable energy–water nexus. In The Renewable Energy-Water-Environment Nexus (pp. 143-176). Elsevier.

[15] Bukhary, S.S., 2018. Water-Energy Nexus Approaches for Solar Development and Water Treatment in the Southwestern United States. Dissertation 3224, University of Nevada, Las Vegas, Las Vegas, NV, USA, 2018.

[16] Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K.U., Wanner, H. and Luterbacher, J., 2011. 2500 years of European climate variability and human susceptibility. science, 331(6017), pp.578-582.

[17] Carrier, C., Kalra, A. and Ahmad, S., 2013. Using paleo reconstructions to improve streamflow forecast lead time in the western u nited s tates. JAWRA Journal of the American Water Resources Association, 49(6), pp.1351-1366.

[18] Cleaveland, M.K., Stahle, D.W., Therrell, M.D., Villanueva-Diaz, J. and Burns, B.T., 2003. Tree-ring reconstructed winter precipitation and tropical teleconnections in Durango, Mexico. Climatic Change, 59, pp.369-388.

[19] Cook, E.R., Palmer, J.G., Ahmed, M., Woodhouse, C.A., Fenwick, P., Zafar, M.U., Wahab, M. and Khan, N., 2013. Five centuries of Upper Indus River flow from tree rings. Journal of hydrology, 486, pp.365-375.

[20] Cook, E.R., Krusic, P.J., Peters, K., Holmes, R.L., 2017. Program ARSTAN, Autoregressive tree–ring standardization program. Tree–Ring Laboratory of Lamont–Doherty Earth Observatory.

[21] Fowler, H.J. and Archer, D.R., 2005. Hydro-climatological variability in the Upper Indus Basin and implications for water resources. Regional Hydrological Impacts of Climatic Change—Impact Assessment and Decision Making, 295, pp.131-138.

[22] Khan, A.J., Koch, M. and Tahir, A.A., 2020. Impacts of climate change on the water availability, seasonality and extremes in the Upper Indus Basin (UIB). Sustainability, 12(4), p.1283.

[23] Khan, N., Gaire, N.P., Rahmonov, O. and Ullah, R., 2024. Multi-century (635-year) spring season precipitation reconstruction from northern Pakistan revealed increasing extremes. Scientific Reports, 14(1), p.92.

[24] Khan, A., Chen, F., Ahmed, M. and Zafar, M.U., 2020. Rainfall reconstruction for the Karakoram region in Pakistan since 1540 CE reveals out-of-phase relationship in rainfall between the southern and northern slopes of the Hindukush-Karakorum-Western Himalaya region. International Journal of Climatology, 40(1), pp.52-62.

[25] Immerzeel, W.W., van Beek, L.P.H., Bierkens, M.F.P., 2010. Climate change will affect the Asian water towers. Science 328, 1382–1385.

[26] Immerzeel, W.W., Droogers, P., De Jong, S.M. and Bierkens, M.F.P., 2009. Large-scale monitoring of snow cover and runoff simulation in Himalayan river basins using remote sensing. Remote sensing of Environment, 113(1), pp.40-49.

[27] Kostyakova, T.V., Touchan, R., Babushkina, E.A. and Belokopytova, L.V., 2018. Precipitation reconstruction for the Khakassia region, Siberia, from tree rings. The Holocene, 28(3), pp.377-385.

[28] Lutz, A.F., Immerzeel, W.W., Kraaijenbrink, P.D., Shrestha, A.B. and Bierkens, M.F., 2016. Climate change impacts on the upper Indus hydrology: sources, shifts and extremes. PloS one, 11(11), p.e0165630.

[29] Mann, M.E., Bradley, R.S. and Hughes, M.K., 1999. Northern hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. Geophysical research letters, 26(6), pp.759-762.

[30] Meko, D.M., Woodhouse, C.A., Baisan, C.A., Knight, T., Lukas, J.J., Hughes, M.K. and Salzer, M.W., 2007. Medieval drought in the upper Colorado River Basin. Geophysical Research Letters, 34(10).

[31] Meko, D.M., Stahle, D.W., Griffin, D. and Knight, T.A., 2011. Inferring precipitation-anomaly gradients from tree rings. Quaternary International, 235(1-2), pp.89-100.

[32] Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D. & Veith, T. L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50 (3), 885–900.

[33] Peng, J., Sun, Y., Chen, M., He, X., Davi, N.K., Zhang, X., Li, T., Zhu, C., Cai, C. and Chen, Z., 2013. Tree-ring based precipitation variability since AD 1828 in northwestern Liaoning, China. Quaternary International, 283, pp.63-71.

[34] Rao, M.P., Cook, E.R., Cook, B.I., Palmer, J.G., Uriarte, M., Devineni, N., Lall, U., D'Arrigo, R.D., Woodhouse, C.A., Ahmed, M. and Zafar, M.U., 2018. Six centuries of Upper Indus Basin streamflow variability and its climatic drivers. Water Resources Research, 54(8), pp.5687-5701.

[35] Salzer, M.W. and Kipfmueller, K.F., 2005. Reconstructed temperature and precipitation on a millennial timescale from tree-rings in the southern Colorado Plateau, USA. Climatic Change, 70(3), pp.465-487.

[36] Treydte, K.S., Schleser, G.H., Helle, G., Frank, D.C., Winiger, M., Haug, G.H. and Esper, J., 2006. The twentieth century was the wettest period in northern Pakistan over the past millennium. Nature, 440(7088), pp.1179-1182.

[37] Thakali, R., Kalra, A. and Ahmad, S., 2016. Understanding the effects of climate change on urban stormwater infrastructures in the Las Vegas Valley. Hydrology, 3(4), p.34.

[38] Touchan, R., Xoplaki, E., Funkhouser, G., Luterbacher, J., Hughes, M.K., Erkan, N., Akkemik, Ü. and Stephan, J., 2005. Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation. Climate dynamics, 25, pp.75-98.

[39] Wang, Y. and Liu, Y., 2017. Reconstruction of March–June precipitation from tree rings in central Liaoning, China. Climate Dynamics, 49, pp.3111-3121.

[40] Wu, G., Li, L., Ahmad, S., Chen, X. and Pan, X., 2013. A dynamic model for vulnerability assessment of regional water resources in arid areas: a case study of Bayingolin, China. Water resources management, 27, pp.3085-3101.

[41] Xing, P., Bai, M., Zhang, Q.B. and Lyu, L., 2024. Tree-Ring Inferred Drought Variations in the Source Region of the Yangtze, Yellow, and Mekong Rivers over the Past Five Centuries. Water, 16(8), p.1186.

**Correspondence Author** – Dr. Syeda Saria Bukhary,