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Title of Ph.D. Thesis: Climate Variability Assessment and Water Resource Management in the Lower Thoubal River Watershed, Manipur

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FINDINGS

The thesis provided a comprehensive examination of climate variability and its implications for water resource management in the Lower Thoubal Watershed, Manipur. It offers actionable strategies to address the growing challenges posed by changing climate patterns. The climate components analysis revealed a significant decrease in rainfall across seasons, with annual, winter, and summer rainfall declining at rates of 10.29 mm/year, 0.86 mm/year, and 3.33 mm/year, respectively. Although the monsoon and post-monsoon seasons also showed a downward trend in rainfall (4.06 mm/year and 1.17 mm/year), these changes were not statistically significant. A marked warming trend was observed, with maximum temperature (TMAX) increasing across all seasons, most prominently in winter (0.05°C/year) and post-monsoon (0.037°C/year). Minimum temperature (TMIN) and mean temperature (TMEAN) exhibited similar warming trends, which contributed to an increase in the diurnal temperature range (DTR). Projections using Random Forest (RF) and ANN-MLP models forecasted continued variations in temperature patterns, with RF generally outperforming ANN-MLP. Rainfall is expected to further decline, with notable reductions during the monsoon (-13.85%) and post-monsoon (-7.21%) periods. These changing climate patterns hold significant implications for agricultural productivity, streamflow, groundwater recharge, and water availability for both human use and ecosystems.

The study also revealed a consistent decline in surface water bodies, particularly wetlands like *Waithou Pat* and *Maning Pat*, over the past 31 years. Using Random Forest, the research achieved high accuracy in extracting water bodies, showing a decreasing trend confirmed by simulations for 2030 and 2040. These predictions indicated further reductions in water body areas during both wet and dry months. Morphological Spatial Pattern Analysis (MSPA) supported these findings, identifying a consistent loss in the areal extent of water bodies. The encroachment of wetlands for agriculture and settlements emerged as the key factor driving these declines. The study underscores the urgent need to protect these valuable surface water resources to ensure sustainable water availability in the region.

Groundwater potential mapping revealed that approximately 26.7% of the study area has high potential for groundwater resources, primarily due to flat terrain and favorable alluvial soil conditions. However, 43.6% of the watershed falls into a moderate potential zone, characterized by a mix of favorable and unfavorable groundwater conditions. The remaining 29.7% of the area, mainly in steep, elevated regions, exhibited low groundwater potential due to rapid runoff and limited recharge capacity. The methodology was validated using receiver operating characteristic (ROC) curve analysis, which produced a strong AUC of 0.828, confirming the reliability of the model. This groundwater potential mapping offers a valuable guide for the sustainable extraction of groundwater, which can help meet local water demands.

Water quality analysis revealed that most surface water samples were of good quality (71%), with 17% rated as excellent, 11% as poor, and less than 2% as either very poor or unsuitable for use. In contrast, groundwater quality was generally poor, requiring treatment before it could be used. The study identified biological oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity (EC), and turbidity as the key parameters influencing water quality. Predictive modeling using machine learning highlighted the general linear model (GLM) as the most accurate method for water quality prediction, particularly in handling complex parameter interactions. These findings emphasize the need for targeted pollution mitigation efforts, especially in managing both point and non-point sources of contamination.

Finally, the use of long short-term memory (LSTM) networks for discharge prediction and generation in the Thoubal River demonstrated a high level of accuracy. Analysis of the predicted discharge data revealed significant seasonal variability, with a marked decline in streamflow during winter and monsoon periods. Rainfall was found to moderately influence streamflow, with a peak lag time of two days after significant rainfall events. Long-term rainfall had a more substantial impact on discharge, as indicated by elasticity analysis. Trend analyses using the Mann-Kendall (MK) test and seasonal-trend decomposition (STL) confirmed a declining discharge trend, with flow duration curves (FDCs) showing more frequent low-flow conditions in recent years. These findings indicate a shift in the river's hydrological regime, necessitating adaptive water management strategies to cope with evolving conditions.

In conclusion, this thesis provides a thorough assessment of the intricate relationship between climate variability and water resources in the Lower Thoubal Watershed. It aimed to establish a possible correlation between climate components—such as rainfall and temperature—and water resources, to better understand the long- and short-term impacts of climate on surface water availability and quality. Through detailed analyses, the study identifies declining trends in surface and groundwater availability, shifts in water quality, and evolving hydrological patterns. Based on these findings, the thesis also proposes several policy recommendations and strategies to mitigate the adverse impacts of climate change on water resources in the watershed. These include sustainable groundwater extraction practices, the protection of surface water bodies from encroachment, and targeted efforts to manage pollution sources. The research provides valuable insights and a framework for adaptive water resource management in the context of a changing climate, while also suggesting avenues for future research in this critical domain.