COMPARATIVE ANALYSIS OF ENERGY BALANCE MODELS FOR MAPPING THE SPATIOTEMPORAL DISTRIBUTION OF EVAPOTRANSPIRATION UNDER DIFFERENT HYDROMETEOROLOGICAL CONDITIONS IN PAKISTAN

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ABSTRACT

ET (evapotranspiration), being an important component of the terrestrial water cycle, plays a vital role in shaping the connectivity of the global energy, water, and biogeochemical cycles, and in explaining ecological responses to global environmental change. The mapping of ET is crucial for hydrological modeling, efficient agricultural water management, runoff estimation, crop water requirements, and long-term water budgeting under environments. Long-term trends in evapotranspiration and its key variables are important indicators of how agricultural water consumption and water resources respond to an individual factor and varying climatic conditions. However, modeling and estimating the spatiotemporal distribution of ET across a vast area remains difficult, limiting our understanding of how a given ecosystem responds in this era of climate change. The tools for ET modeling based on remote sensing imagery have been used extensively over the past three decades to manage water resources as well as better understanding of interactions between land and atmosphere. In this context, the current thesis analyzes the various energy balance models for estimating evapotranspiration on a regional scale under diverse climatic conditions in Pakistan. It is critical for comprehending climate change, particularly for Pakistan's ongoing water resource management policy under the United Nations' Sustainable Development Goals (SDGs), which prioritize water.

Following the 1st chapter of introduction to the topic, the second chapter of this dissertation explains the evaluation of the Surface energy balance algorithm for land (SEBAL) to estimate

the ET for selected study sites with different hydrometeorological conditions. The Landsat 8 OLI/TIRS images were analyzed for these sites including; Skardu, Kalam, Peshawar, D.I. Khan, Quetta, and Tando Jam for the summer months from 2013 to 2020. A sensitivity analysis for albedo was performed in this study to test its interaction over multiple land covers, including snow, vegetation, built-up, and water. Standard albedo values for various land cover classes were also compared to the generated values. For accuracy assessment of the model, the modelled ET has been validated with in situ ET data. SEBAL exhibited very good results at Tando Jam with correlation (r), RMSD, and MBE values of 0.90, 0.025 and 0.01 mm/hr, respectively. Following Tando Jam, Peshawar stands second with r, RMSD and MBE values of 0.80, 0.028 and 0.02 mm/hr, respectively. D.I. Khan comparatively exhibits a lower r-value of 0.75 and shows the deviation in terms of RMSD as 0.033 and MBE of 0.02. The Skardu region produced similar results to D.I. Khan except slightly different RMSD of 0.032. Due to a paucity of on-site observations, the ET of other test sites (Quetta and Kalam) has been used solely for discriminating ET rates over different land cover types. In both of these regions, the snow cover shows the highest value of ET in the range of 0.46 - 0.59 mm/hr followed by forest cover and open water bodies with values of 0.37 - 0.50 mm/hr and 0.32 - 0.50 mm/hr, respectively.

The third chapter provides a comparative analysis of two energy balance models i.e., METRIC (Mapping Evapotranspiration with Internalized Calibration) and S-SEBI (Simplified-Surface Energy Balance Index) for the estimation of ET over diverse climatic conditions of Pakistan. Landsat 8 satellite data was used for three different test sites namely, Peshawar, D.I. Khan, and Tando Jam. The modelled results were then validated with in situ measurements. Tando Jam had the best correlation with in situ data, with r values of 0.92 (METRIC), 0.78 (S-SEBI), and RMSD of 0.02 (METRIC), 0.03 (S-SEBI), and MBE of 0.01 for both models. Following Tando Jam, Peshawar also exhibited a good correlation in terms of r value of 0.79 for METRIC and

0.43 for S-SEBI, RMSD value of 0.03 for METRIC and 0.01 for S-SEBI, while MBE value of 0.02 for both models. Through the Taylor diagram, the performance of both models was compared. This comparative study demonstrated that the METRIC model produced more reliable results than the S-SEBI model under the selected climatic conditions.

The fourth chapter provides the evaluation of spatiotemporal trends of ET using non-parametric trend tests in semi-arid to arid regions. The monthly and annual trend variation of ET has been analyzed for 14 years 2007-2020, using the in situ ET data products. The modified Mann-Kendall and Spearman's rho test was used for ET trend evaluation. The obtained results revealed a significantly positive trend at a 95% confidence level in the Skardu region on monthly as well as annual scales (except November and December). All other test sites showed a negative trend of ET.

In broader terms, the purpose of this study was to explore the suitability of various energy-balancing methods on freely available remote sensing imagery for mapping spatiotemporal ET with no or limited on-site data. Methods used in this dissertation will lead to the estimation of ET (with improved accuracy) over vast geographical regions, especially in a region where no or less in situ data of ET is available.