MAPPING WATER BALANCE COMPONENTS IN VARIOUS CLIMATIC REGIONS OF PAKISTAN USING REMOTE SENSING AND IN SITU TECHNIQUES

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Abstract

Accurate estimation of water balance components plays a vital role for planning water/rainwater conservation, irrigation systems, water resource management, and flood/drought mitigation. The core purpose of this research was to assess the applications of geospatial data and techniques [Geographical Information System (GIS) and Satellite Remote Sensing] to measure/monitor the water balance components; 1) rainfall patterns, 2) groundwater recharge potential zones, 3) river discharge. All these components were validated with ground-based data.

This study has particularly focused on the validation of the satellite-based rainfall product, namely Global Precipitation Measurement (GPM) Integrated Multi-satellite Retrievals (IMERG), version 06, using rain gauges data collected across Pakistan over seven years (2014 to 2020). The research findings revealed more significant correlation coefficients (CC = 0.85 to 0.94) in medium to low elevated areas like Nawabshah, Panjgur, and Kakul. In contrast, a moderate correlation (0.60) was observed in the highly elevated region of Astore with a cold, snowy and warm summer (Dsb) climate. Islamabad exhibited the highest root mean square deviation (RMSD) at 3.24 mm/day, contrasting with the lowest value in Nawabshah at 0.37 mm/day. Kalam (NW of Pakistan) displayed the highest relative bias (rB) at 50%, whereas Islamabad recorded the minimum value at -35%. On a seasonal scale, GPM performance excelled during the winter (CC > 0.90) across a range of topographical and climatic conditions over Pakistan. Notably, during the winter, Malam Jabba (in the north) showed the maximum RMSD at 1.26 mm/day, while Quetta (central west) exhibited the minimum RMSD at 0.66 mm/day. However, pre-monsoon emerged as the season with the least favorable results, characterized by relative bias (>30% and <-30%) and a lower Pearson's correlation coefficient (0.55). Moreover, a shift in the rainfall pattern towards northern parts of the country was observed, with most high-elevated northern areas displaying a slight positive temporal trend, in contrast to the slight negative trend in the southern plains. In conclusion, this study affirms that GPM (IMERG-V06) delivers accurate precipitation measurements across various topographic regions and climatic zones in Pakistan, albeit with a manageable margin of error. The research outcomes hold significant value as they enhance the validation of GPM rainfall products for different regions, augmenting their utility for quantitative analysis. Accurate rainfall estimates lead to the accuracy of other components of hydrological water cycle, including groundwater recharge potential and surface runoff.

In this study, the GPM rainfall data was used to demarcate groundwater recharge potential zones in southern Khyber Pakhtunkhwa province of Pakistan under arid to semi-arid conditions Multi-Influence Factors (MIF) method. The study area was categorized into four distinct classes as very

high, high, moderate, and poor, with classes extent across an area of 340 km^2 (1%), 4997.11 km^2 (13%), 17615.14 km^2 (45%), and 16355.46 km^2 (41%), respectively, within the study area of 39307.72 km^2. The groundwater potential map of the study shows that the southern part, comprising D.I. Khan, Tank, and Lakki Marwat, primarily comprises poor potential zones; the north and northeast regions, including Hangu, Orakzai, and Kohat, are characterized by high to very high potential zones; and the southwest segment, encompassing South Waziristan, is identified as a moderate zone. These designations have been validated and correlated with high-resolution geophysical methods, the Vertical Electrical Sounding (VES) technique, in Karak, Lakki Marwat, and D.I. Khan. The VES survey results are closely aligned with the results obtained through the MIF technique. For instance, water-bearing layers in district Karak were detected at depths ranging from 10 to 137 meters at various points. In Lakki Marwat, the water-saturated layers were identified 31.9 m, 194 m and 42 m deep at different locations. In D.I. Khan, where five VES points were sampled, water-bearing geo-electric layers were found at 80 m, 119 m, and 125 m depths. It is interpreted that the areas with 'very high' potential are characterized by water located near the surface or at depths less than 40 m. 'High potential' zones water is found at depths ranging from 40 to 70 m, 'high to moderate' zones feature water depths between 70 and 120 m, 'moderate' zones encompass depths of 120 to 150 m, and 'poor' zones exhibit water depths ranging from 150 to 180 m. These results are significant for understanding the changing patterns of water cycle including rainfall, infiltration and surface runoff.

This study has innovatively focused on estimating various river properties by combining remote sensing and river gauge data. Integrating geospatial techniques offers a promising path for comprehensively assessing river properties across extensive geographic regions. The research successfully showcased the utilization of roughness coefficients, velocity, and slope parameters to derive estimations for river discharge, velocity, and depth. Notably, the findings revealed a peak flow velocity of 1.8 m/s, along with spatial velocity profiles of 0.40 m/s and 1.30 m/s for the upstream and downstream sections of the Teri Toye River (south Khyber Pakhtunkhwa). The study established an empirical relationship for estimating river depth through precise extraction of the river's geometry and incorporating these parameters. The results indicated a maximum depth of 95 to 105 feet in the upstream section, with a gradual reduction in depth observed downstream in the river. Within the river channel, the research identified a river discharge of 81.75 cubic feet per second (cfs) in the upstream region. However, this discharge decreased to 10.83 cfs downstream, attributed to factors like water distribution in tributaries, infiltration, evaporation, and agricultural use.

Validation and comparison of geospatial techniques with ground data, in this PhD dissertation, have demonstrated that geospatial techniques provide a reliable means of estimating and mapping water balance components over larger spatial and temporal extents under various topographic and climatic conditions. The significant advantage of satellite remote sensing over ground /in situ measurements is quantifying the water balance components, including precipitation, surface runoff, and infiltration, with more extensive geographical coverage. These are the essential components of the water cycle, and they play a vital role in maintaining water balance between the surface and atmosphere. The results from this study will assist in establishing innovative solutions for water resource management.