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Optimal design of precipitation gauge network using a two-stage clustering procedure utilizing satellite-based data

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Ground-based precipitation observations are the most critical data that provide essential information for the sustainable planning, management, and utilization of water resources. In recent decades, a declining trend in the density of rain gauges has been noted worldwide. It could be due to budgetary constraints and an increase in the availability of remote sensing precipitation products. However, the latter have quantitative uncertainties and biases compared to ground data. Precipitation gauge networks (PGNs) are essential for collecting accurate in-situ data, which are necessary to discern valuable information on spatiotemporal variability of rainfall for a plethora of applications, including bias correction of satellite-based precipitation products. Moreover, an effective network avoids redundancy of data as irrelevant, insufficient, or inefficient data in the incorrect location/time can impede data collection quality. Hence an efficient network design should account for factors such as spatiotemporal variability and non-stationarity in precipitation time-series, physiographic characteristics, and socio-economic aspects, including population density and land-use/land cover patterns. A network design methodology is proposed which tries to address all these factors through a two-level clustering procedure. It harnesses the advantages of the Bayesian framework for regionalization of the study area based on precipitation characteristics in the first level. It integrates information from multiple clustering options in the second level to account for uncertainties in the restructuring of a PGN. The methodology suggests using ground-based precipitation observations and multiple satellite/space precipitation products to identify potential locations for installing new rain gauges and/or decommissioning of existing gauges to effectively re-design an existing network. Advantages of multiple satellite-based precipitation products (e.g., CHIRPS, IMERG) is being used for expansion of existing network if the adequacy criterions are not satisfied. The methodology could readily be used for areas extending over hundreds and thousands of square kilometers. Its potential is illustrated through a case study on a PGN comprising 1128 gauges in Karnataka state (191,791 km²) of India. Adequacy of the gauge network is assessed, and recommendations are made for restructuring the PGN by considering the World Meteorological Organization's (WMO) minimum density criterion. Analysis in the first stage is based on precipitation characteristics discerned from India Meteorological department data extending over 39 years. In the second level, multiple partitional clustering algorithms are considered for arriving at optimal network density to meet the WMO criterion. The study is of significance, as effective/efficient PGNs that provide accurate and non-redundant

ground-based observations are essential for studies focusing on different applications such as sustainable agricultural water management, detection of climate variability, and forecasting floods and droughts.