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A Comparative Study of Entropy-based Methods for Optimal Design of Streamgauge Monitoring Networks

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There is growth in evidence of intensification of the global hydrological cycle over the past few decades, possibly due to changing climate and/or land-use landcover associated with anthropogenic forcing. For sustainable water management, an efficient and effective streamflow network is essential as it facilitates accurate monitoring of spatio-temporal variations of surface water. However, in recent years a remarkable decline in stream gauge density is observed in both developed and developing countries, possibly due to economic constraints and changing government priorities. World Meteorological Organization recommends periodic reviewal of stream gauge networks (accounting for changes in budgetary, data and end user's needs) to improve the database for better assessment of hydrological uncertainty. However, there is a dearth of such attempts in India. Entropy theory (specifically Shannon entropy-based method (SEBM)) has gained wide recognition over the past few decades for the optimal design of hydrometric networks owing to its advantages. However, the SEBM has some limitations, which include (i) lack of fixed upper bound for entropy when a uniform distribution is considered to determine the probability and (ii) loss of information due to discretization of data in analysis with continuous variables. In this backdrop, there is a need to locate feasible alternatives to the Shannon entropy method. There are various methods for entropy estimation and data discretization, but there is a lack of information on their relative performance. This study is envisaged to investigate these aspects and to propose a novel fuzzy approach for optimal design and performance assessment of a stream gauge monitoring network. The proposed methodology does not require the choice of bin size for the discretization of data to estimate entropy measures/indices. Therefore, it alleviates the associated uncertainty which is a concern in analysis with SEBM and its related theoretical improvement EEBM (exponential entropy-based methodology). This is demonstrated through case studies on 16 river basins of Peninsular India encompassing more than 600,000 km^2 by considering objectives as prioritization of existing gauges, identification of gauge deficient zones and devising options for expansion of the existing stream gauge networks. Further, the effect of choice of bin size on entropy estimates obtained using SEBM and EEBM is demonstrated by considering nine bin size determination methods. Flows in ungauged catchments were simulated using SWAT (Soil and Water Assessment Tool) and optimization of the existing stream gauge network is performed using a Fast-Non-Dominated Sorting Genetic Algorithm (NSGA-II). The study indicated that all the stream gauge networks in peninsular India are inadequate for effective monitoring of flows and there is a growing need for their expansion. This study is first of its kind which evaluates the potential of different entropy-

based methods in stream gauge network design. The proposed methodology could be readily considered for the evaluation of networks monitoring other hydro-meteorological and hydrological variables, and water quality parameters.