Assessing hydrological uncertainty for river basin management in Asia: a case of Himalayan watershed

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Abstract

Mountainous Himalayan watersheds, collectively known as "*Water-Towers of Asia*", are important hydrologic systems. Increasing anthropogenic & climate-related pressures have led to higher variability & uncertainty in resource availability, thereby higher vulnerability of communities. Adaptive strategies require implementation of "*decentralized solutions*" with minimum uncertainties. We propose a framework of designing decentralized "community based" adaptive strategies using integrated water-energy-climate models & spatial-temporal analysis.

As a proof-of-concept, the study evaluates a real on-ground case that tests & validates an integrated GIS & remote sensing based Decision Support System (DSS). This has been successfully applied to assess dynamic hydrological behavior of a "partially" gauged mountainous watershed in Sikkim.

Validation has been performed. Simulation results on surface flows show a good comparison with the observed flows. Daily Flow Duration Curve was estimated. Hydrological behaviour was understood by assessing uncertainty & parameter sensitivity using a multi-objective criteria.

Study Area: Upper Hee Khola watershed, West Sikkim district, Sikkim, India (Figure 1 and 2).

Weir location: Latitude: 27°14'32''N; Longitude: 88°10'37''E

Climate and Land-use: Temperate climate conditions with average annual total precipitation of around 2300 mm. Almost 80 percent of the watershed is covered under evergreen forests. Mean maximum and minimum temperatures range 20°C to sub-zero at high elevation in the North-west.

Literature Review: Predictions in Ungauged Basins (PUB), launched by the International Association of Hydrological Sciences (IAHS 2003-2012), focuses on estimation of predictive uncertainty (Sivapalan et al. 2003). The use of hybrid-modeling techniques that use remote sensing and GIS has been an interesting development. The state-of-the-art research today is focused on the integrated handling of parameter estimation and uncertainty assessment, using multiple objectives within Bayesian inference techniques (Efstratiadis & Koutsoyiannis, 2010).

Approach: Water-DSS makes use of physical, computationally efficient, time-continuous, GIS and "readily available" satellite-data based new generation hybrid modeling techniques. The stochastic-deterministic hybrid approach makes use of multi-objective criteria through integrated use of SWAT, SWAT-CUP (SUFI-2) uncertainty analysis, and Bayesian inference, thereby providing spatially explicit parameterization approach applicable to un-gauged or partially gauged watersheds. It accounts for watershed's spatial heterogeneity by segmenting it into a series of sub watersheds.

Implementation: Following the above approach, various components of the land phase of the hydrological cycle have been estimated for the watershed (Figure 3 to 5). Uncertainty analysis and multi-objective criteria further enables appropriate decision making by simultaneous optimization of numerical measures that represent the components (criteria) of objective functions (NSE, bR^2, R^2) (Figure 6 and 7).

Conclusions: The study provides an evidence-based solution for designing reliable decentralized distributed water and energy systems which can help enhance lives and livelihoods of the people. The approach is useful in identifying the best-compromise solution. On the basis of the Pareto optimality notion, we locate a subset of the feasible parameter space corresponding to minimization of the residuals. Application of such a hybrid approach ensures consistent and reliable applications for river basin management in Asia.

Results

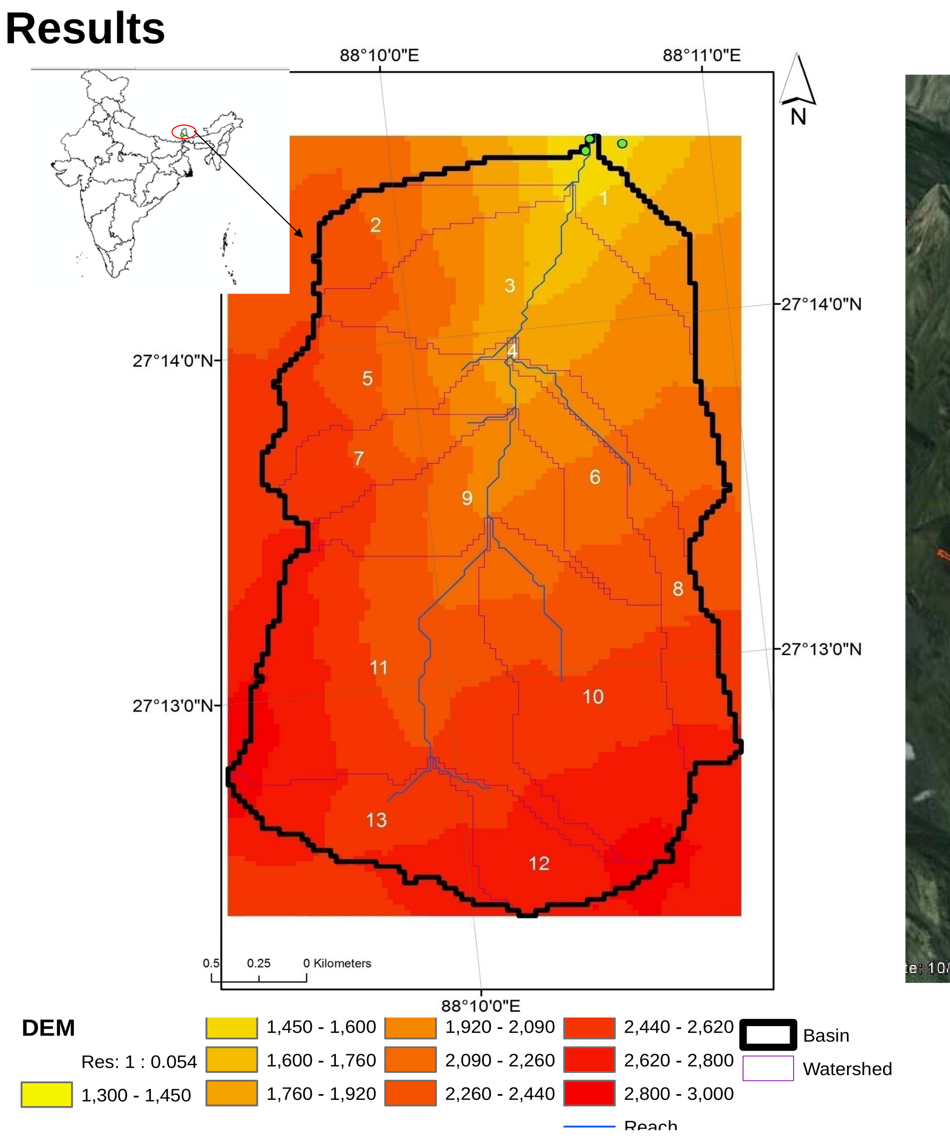

Figure 1: Digital Elevation Model (DEM) of Upper Hee Khola watershed

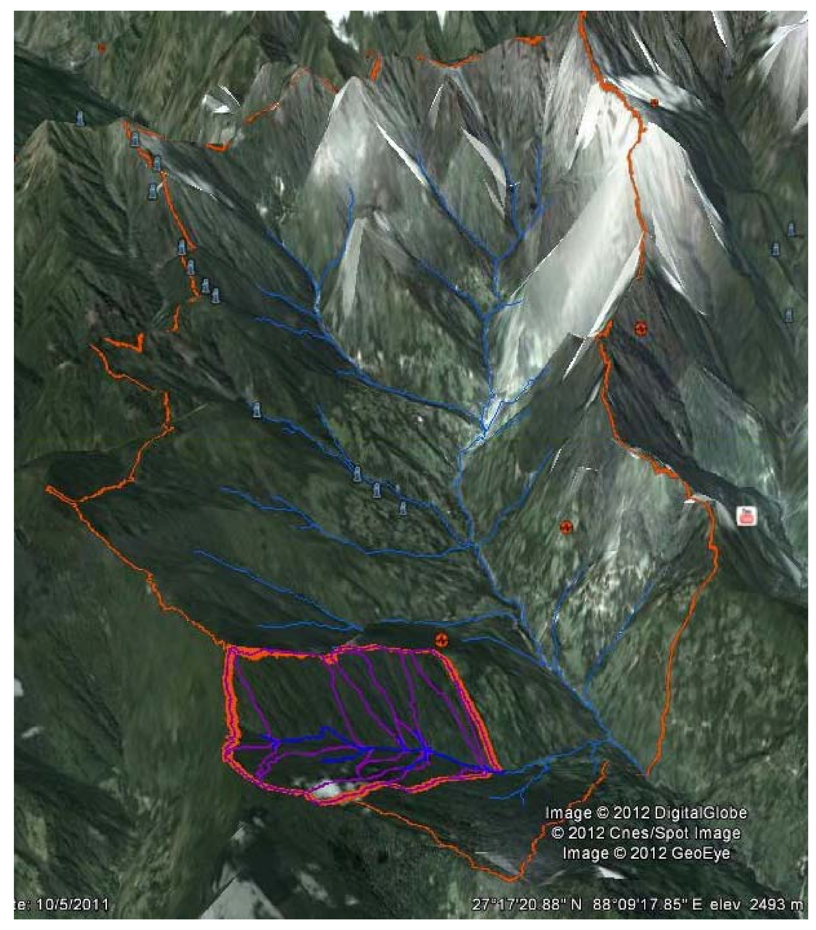

Figure 2: Delineated watershed in the context of larger watershed superimposed on Google image

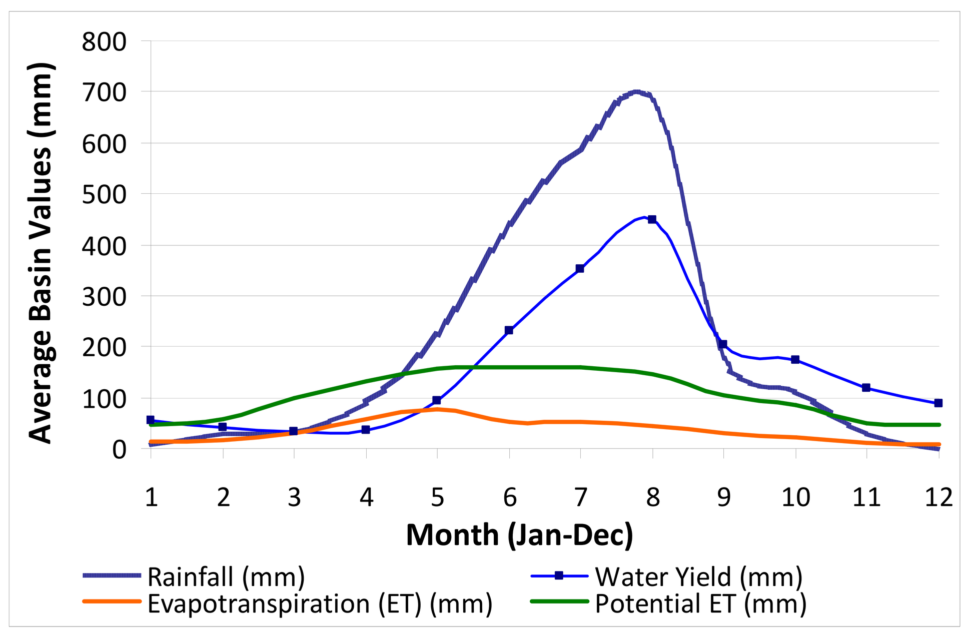

Figure 3: Simulated (monthly) hydrological components of watershed

Validation has been done by comparing simulated discharges with limited observed discharge and use of performance efficiency criteria i.e., Nash-Sutcliffe and R^2 correlations. Balance between stream flow and power generation, has been evaluated through the Flow Duration Curve or FDC, a Pareto curve of a stream's daily flow rate vs. frequency. Daily FDC was estimated for 50 year duration (1960-2010) using Weather Generator, a stochastic tool within the Water-DSS.

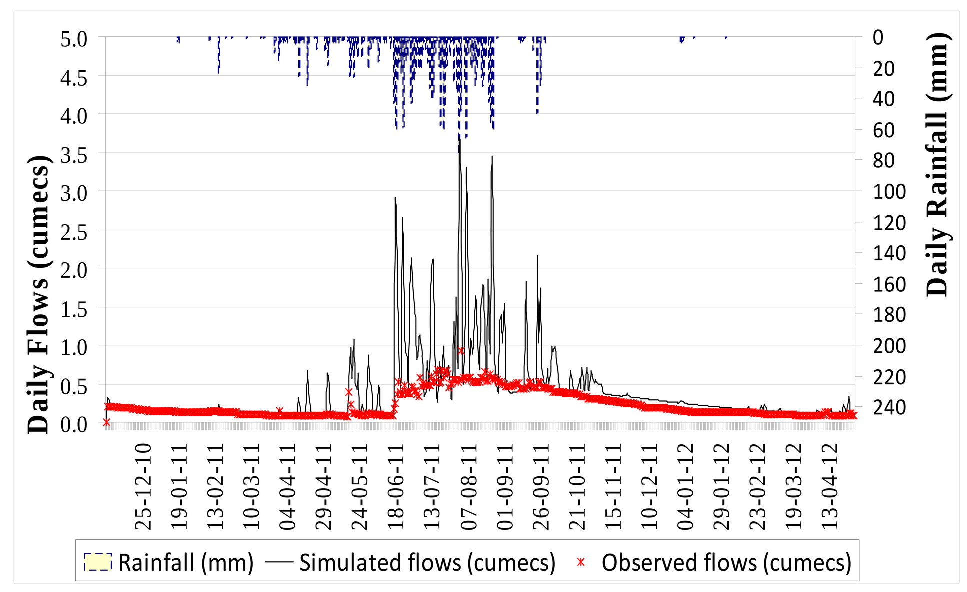

Figure 4: Comparing observed and simulated flows for Upper Hee Khola watershed

(**Note:** Observed flows here reflect only non-monsoon flows as U-Notch put on the stream for discharge measurement could only capture flows up to 0.5 cumecs maximum)

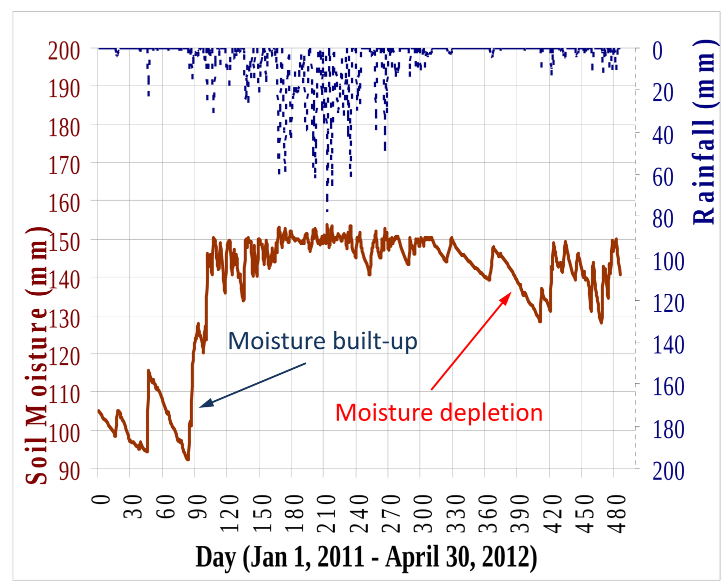

Figure 5: Soil moisture dynamics - built-up during the wet season (monsoon) and moisture depletion during the dry spells

Finally, the hydrological behaviour of the watershed has been understood by assessing uncertainty and parameter sensitivity (SUFI-2) that helped identify key input variables, the combined reduction of which, predicted runoff with the least error (as depicted by values of bR^2, R^2, NSE, p-, d- factors; values closer to 1 are ideal).

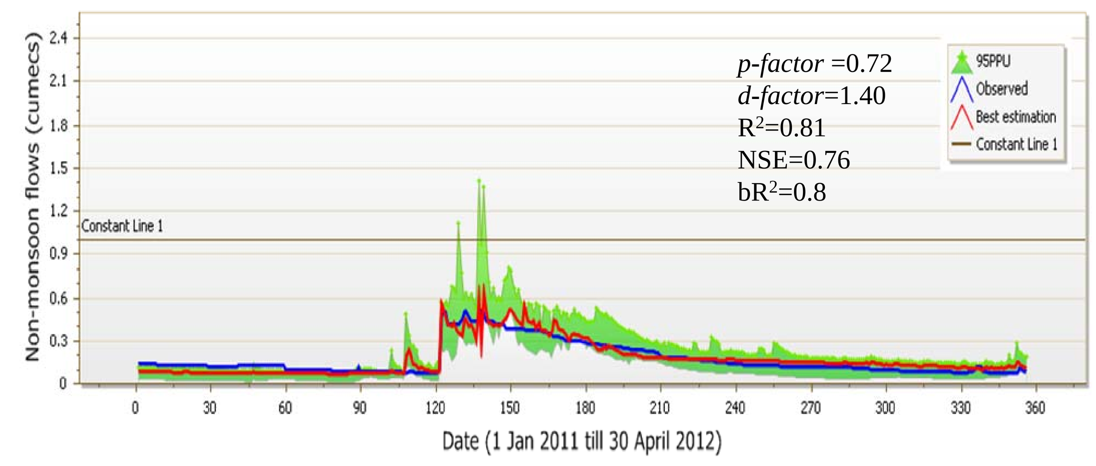

Figure 6: 95 % Parameter uncertainty based on 95%Prediction Uncertainty (PPU) band and coefficients of determination, R^2, Efficiency criterion NSE, and bR^2

In addition, DSS can be applied to following areas:

- Water resource sustainability & Climate
  - -Mapping variability, vulnerability and uncertainty
  - -Understanding & predicting interactions between water systems and land use changes.
- Analytics and Decision-support - extreme events such as floods, droughts.
- Hydrologic Information and ICT application -agrimet, soil moisture based telemetry etc

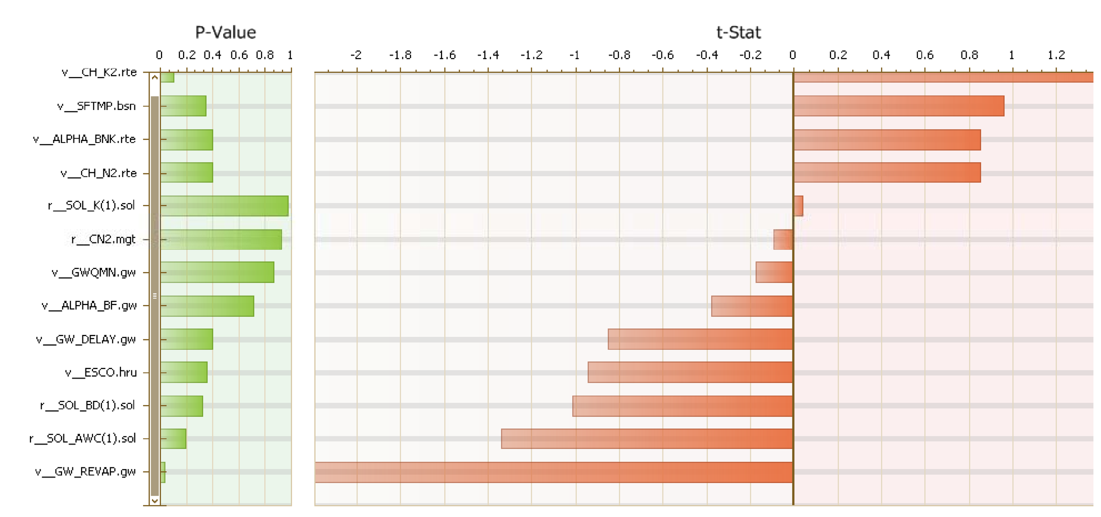

Figure 7: Determining parameter sensitivities

t-value indicates parameter sensitivity. The large t-value, more sensitive the parameter

p-value indicates significance of t-value. The smaller p-values, less chance of a parameter being accidentally assigned as sensitive

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