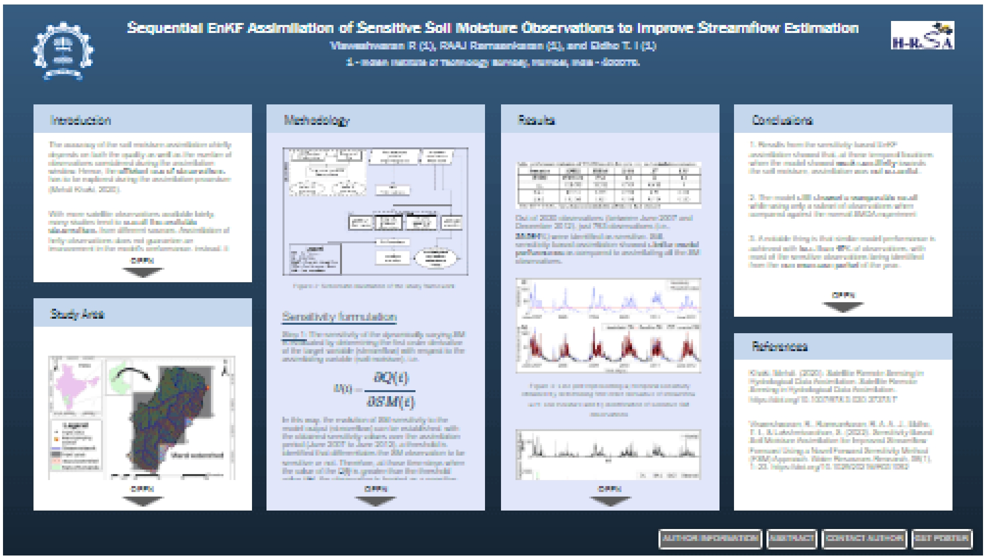
# Sequential EnKF Assimilation of Sensitive Soil Moisture Observations to Improve Streamflow Estimation

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# INTRODUCTION

The accuracy of the soil moisture assimilation chiefly depends on both the quality as well as the number of observations considered during the assimilation window. Hence, the **efficient use of observations** has to be explored during the assimilation procedure (Mehdi Khaki, 2020).

With more satellite observations available lately, many studies tend to **use all the available observations** from different sources. Assimilation of hefty observations does not guarantee an improvement in the model's performance, instead, it makes the simulation process much **more complicated and computationally expensive** (Visweshwaran R., et. al., 2022).

A potential solution to this is to identify a subset of observations that are relevant and **sensitive** to the target variable (streamflow in the case of rainfall-runoff models), which can help in discarding the unnecessary information and improving the **DA efficacy**.

# STUDY AREA

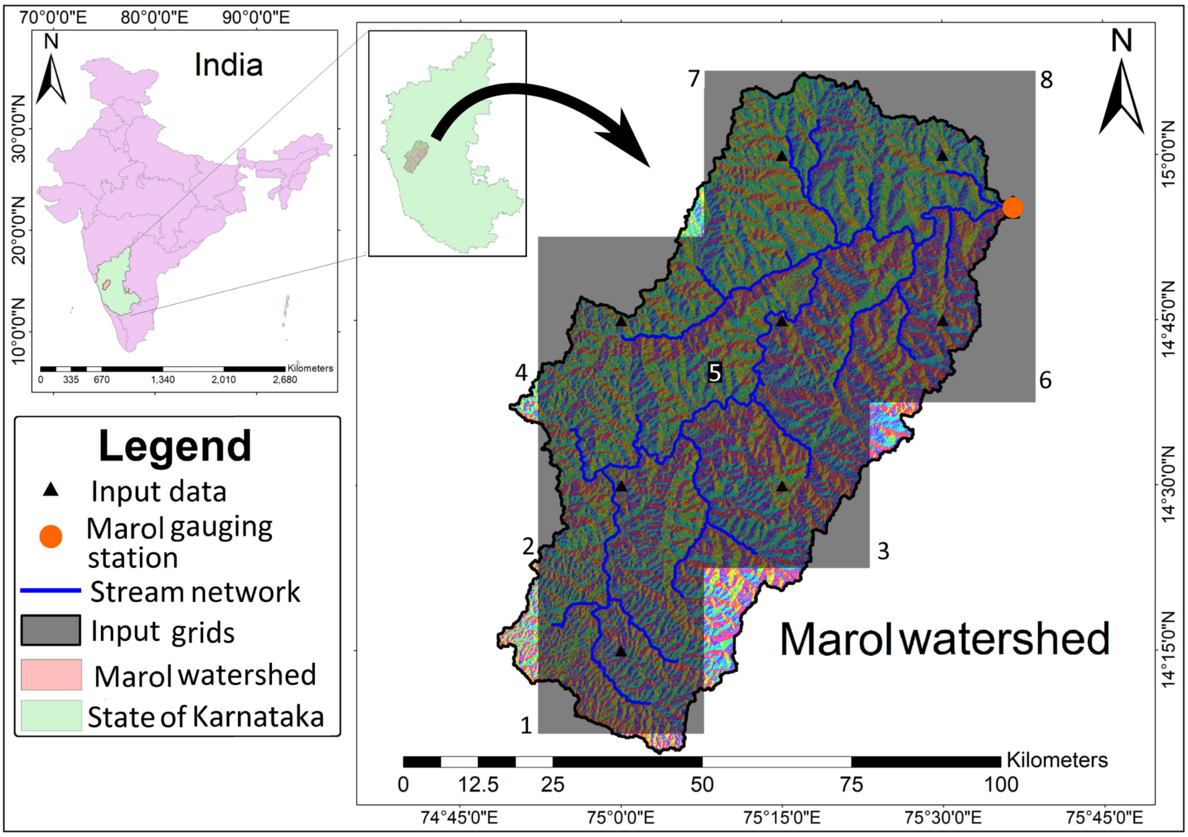


Figure 1: Study area map showing the location of input observation points, stream gauging station, and stream networks of the Marol watershed

Marol watershed is chosen as the study area, which lies in the western part of the Krishna river basin, India.

## Dataset:

Table 1: Description of the datasets used for the current study

| Variable(s) | Reason | Spatial resolution | Unit | Source | Remarks |
|---|---|---|---|---|---|
| Relative humidity, wind speed, and solar radiation | Model forcings | 0.25 ° × 0.25 ° | (-), (m/s) and (°C) | (NCEP-CFSR) https://rda.ucar.edu/datasets/ | Interpolated using gauge observations |
| Rainfall amount | | | mm | (IMD) https://imdpune.gov.in/cmpg/Griddata/ | |
| ASCAT Surface soil moisture | Assimilation | 0.125° | Relative percentage | (EU METSAT) https://archive.eumetsat.int/ | Passive microwave retrievals |
| Streamflow | Calibration, and Validation | Point | Cumecs | (CWC) https://indiawris.gov.in/wris/ | Observed gauge observations |

Note: Temporal resolution is at daily scale for all the data and data duration extends from January 2000 to December

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# METHODOLOGY

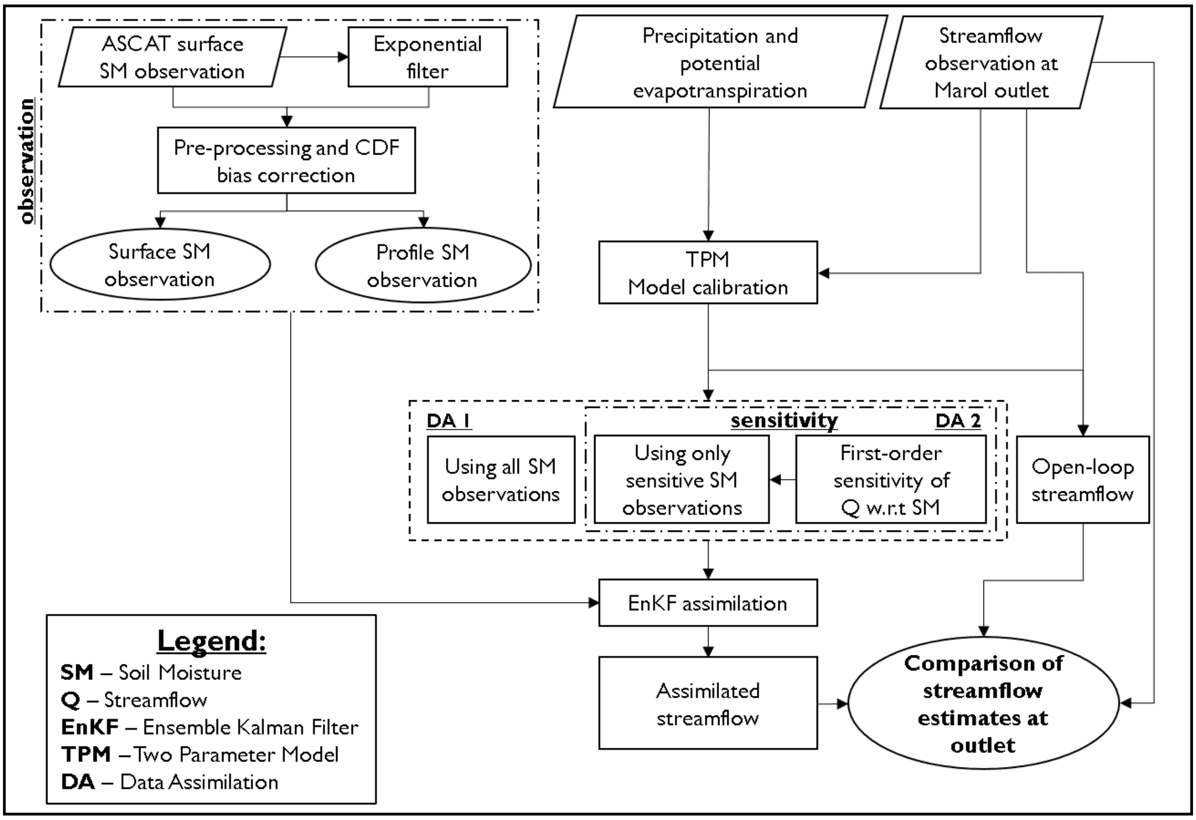


Figure 2: Schematic illustration of the study framework

## Sensitivity formulation

Step 1: The sensitivity of the dynamically varying SM is evaluated by determining the first-order derivative of the target variable (streamflow) with respect to the assimilating variable (soil moisture), i.e.

$$U(t) = \frac{\partial Q(t)}{\partial SM(t)}$$

In this way, the evolution of SM sensitivity to the model output (streamflow) can be established. with the obtained sensitivity values over the assimilation period (June 2007 to June 2012), a threshold is identified that differentiates the SM observation to be sensitive or not. Therefore, at those time steps when the value of the *U(t)* is greater than the threshold value (*th*), the observation is treated as a sensitive observation

Step 2: EnKF assimilation is performed only at those time steps when the SM observations are considered sensitive (i.e. $U(t) \geq th$). Whereas, the model is run at a deterministic open-loop mode for non-sensitive periods ($U(t) < th$).

$$th = \sum_{t=1}^{N} \frac{U(t)}{N}$$

# RESULTS

Table : performance evaluation of TPM RR models for open-loop and assimilation scenarios

| Scenarios | RMSE | PBIAS | KGE | $R^2$ | EFF |
|---|---|---|---|---|---|
| (Units) | (Cumecs) | (%) | (-) | (-) | (-) |
| OL | 121.078 | 18.312 | 0.709 | 0.618 | 0 |
| DA 1 | 103.51 | 3.259 | 0.797 | 0.73 | 0.221 |
| DA 2 | 110.591 | 1.327 | 0.791 | 0.719 | 0.215 |

Note: EFF = 0 for OL runs as there is no assimilation performed in those scenarios

Out of 2030 observations (between June 2007 and December 2012), just 793 observations (i.e., **39.064**%) were identified as sensitive. Still, sensitivity-based assimilation showed **similar model performance** as compared to assimilating all the SM observations.

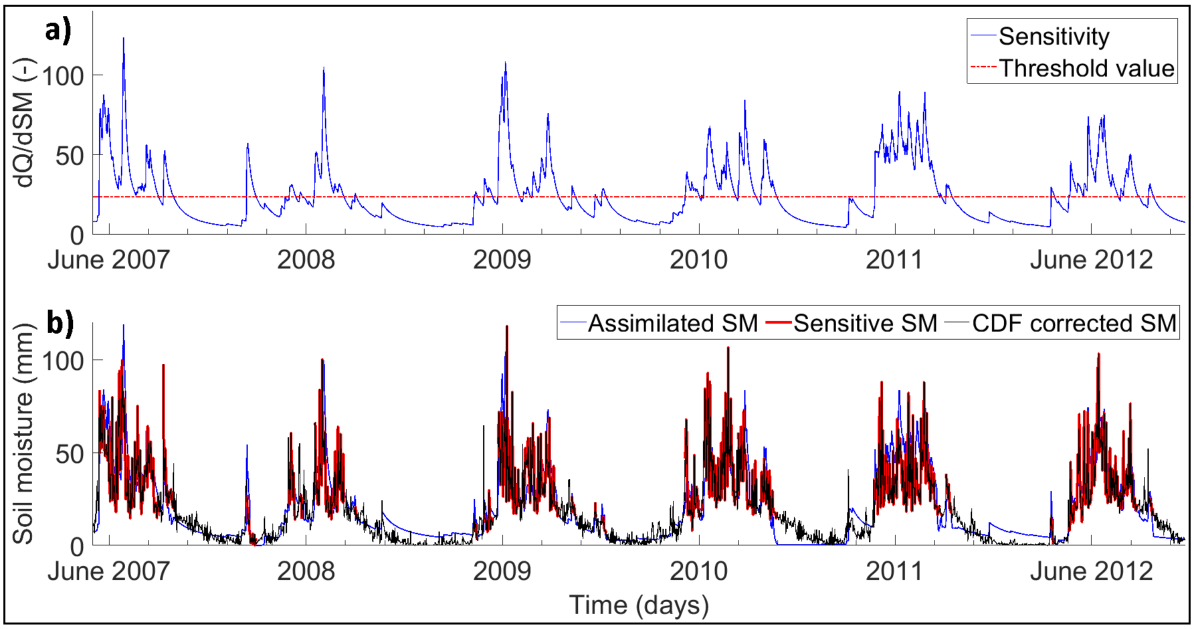


Figure 3: Line plot representing a) temporal sensitivity obtained by determining first order derivative of streamflow w.r.t. soil moisture and b) identification of sensitive SM observations

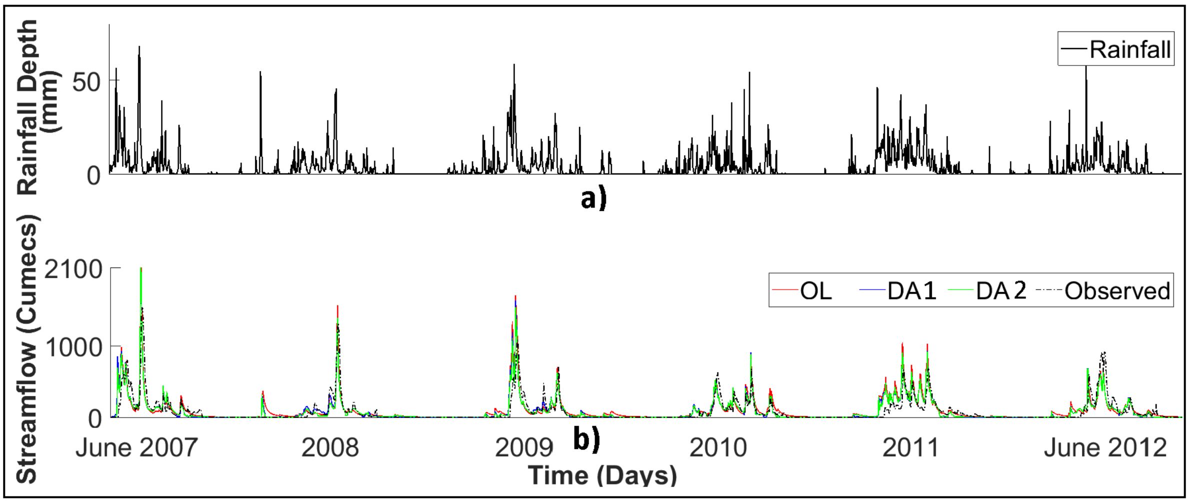


Figure 4: Time series plot showing the a) Rainfall and b) streamflow during the normal SMDA case, and sensitivity SMDA case

# CONCLUSIONS

1. Results from the sensitivity-based EnKF assimilation showed that, at those temporal locations when the model showed **weak sensitivity** towards the soil moisture, assimilation was **not essential**.

2. The model **still showed a comparable result** while using only a subset of observations when compared against the normal SMDA experiment

3. A notable thing is that similar model performance is achieved with **less than 40%** of observations, with most of the sensitive observations being identified from the **non-monsoon period** of the year.

4. To the best of the author's knowledge, **sensitivity-based sequential assimilation** of this type has never been tested before in this field, making this a **novel** experiment.

# REFERENCES

Khaki, Mehdi. (2020). Satellite Remote Sensing in Hydrological Data Assimilation. Satellite Remote Sensing in Hydrological Data Assimilation. https://doi.org/10.1007/978-3-030-37375-7

Visweshwaran, R., Ramsankaran, R. A. A. J., Eldho, T. I., & Lakshmivarahan, S. (2022). Sensitivity-Based Soil Moisture Assimilation for Improved Streamflow Forecast Using a Novel Forward Sensitivity Method (FSM) Approach. Water Resources Research, 58(1), 1–23. https://doi.org/10.1029/2021WR031092

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# ABSTRACT

The use of accurate streamflow estimates is widely recognized in the hydrological field. However, due to the model's structural error, they often yield suboptimal streamflow estimates. Past studies have shown that soil moisture assimilation improves the performance of the hydrological model which often results in enhanced model estimates. Due to this reason, it is widely studied in the hydrological field. However, the efficiency of the assimilation largely relies on the correct placement of the observation into the model. Ingesting futile observations often results in the degradation of model performance. On the contrary, performing assimilation only at those time steps when the assimilating variable is sensitive to the model output may yield desirable output. Further, it will avoid the assimilation of spurious observations. In this view, this study proposes a new approach where sensitivity-based sequential assimilation is performed on a conceptual Two Parameter Model (TPM). To demonstrate this approach, ASCAT soil moisture observations are assimilated into TPM using Ensemble Kalman Filter (EnKF) sequential approach. At first, the temporal evolution of the soil moisture sensitivity with respect to streamflow is established. Later, at those time steps when the soil moisture is sensitive, EnKF assimilation is performed. For this purpose, a moderately sized catchment in the Krishna basin, India is selected as the study area. Model calibration and validation are performed between 2000 to 2006 and 2007 to 2011 respectively. Model run without assimilation is considered as open-loop simulation. Streamflow simulation after assimilation showed a significant improvement when compared against the open-loop simulation. KGE value increased from 0.70 to 0.79 and PBIAS value reduced from 18.31 to 1.80. The highlighting factor is that only 39% of the total observations were used during the assimilation process. The initial results are encouraging and looks that the proposed approach shall be highly useful at those locations where data availability for assimilation purpose is a serious concern.