Performance Evaluation of Remote Sensing-based High Frequent Streamflow Estimation Models at the Bramhani River Basin Outlet

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Abstract

For catchment-scale streamflow estimation, recently, the preference is shifting towards the use of innovative remote sensing (RS)-based approaches at the remote gauging stations. In this context, this study evaluates the performances of three RS-based models designed with the near-infrared (NIR) bands of Landsat images at the Jenapur outlet of the Brahmani River basin in eastern India. These RS-based models are designed using the spectral behavior of land (C) and water (M) pixels in the NIR region of the electromagnetic spectrum in the presence and absence of water surrounding the streamflow gauging station. Further, the computed pixel ratio (C/M) is used as a parameter for the discharge estimation, in which four years (2009-2013) of Landsat images are used during calibration and three years (2014-2016) of these images are used during validation. Model-I uses the C/M method in which a box-matrix is conceptualized to analyze the optimal location of the land pixel (C0); and subsequently, the time series of C/M is calibrated with the in-situ discharge (Q) time series. The best pixel ratio (C0/M) time series is preprocessed with an exponential smoothing filter to derive the best filtered-pixel ratio (C0/M*) time series, which is used in the regression model to estimate the river discharge. Model-II corresponds to the multi-pixel ratio (MPR) method, where a 3×3 window is used to calculate the average reflectance of both the C and M pixels within the box-matrix, and subsequently, to obtain the best pixel (C0'/M') ratio as in the case of Model-I to develop the spectral relationship between C0'/M' and Q time series. Model-III uses both the C/M and water width-based function to estimate the streamflow. The performance evaluation of the models is carried out using the Nash-Sutcliffe efficiency, Percentage bias, and Mean absolute error, which reveals that the model performance varies in the order: Model-III > Model-II > Model-I. This proposed RS-based discharge estimation model framework has the potential to be used in many world- rivers with varying cross-sections.

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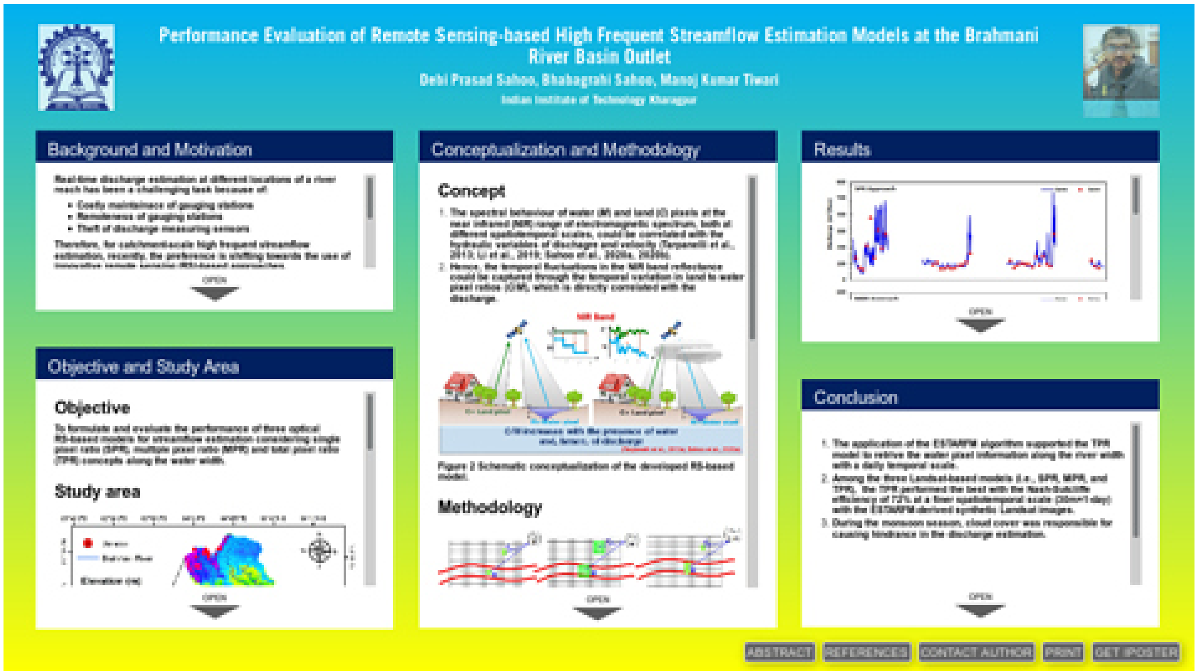

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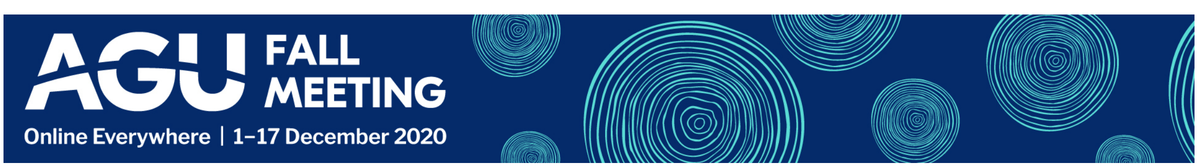


BACKGROUND AND MOTIVATION

Real-time discharge estimation at different locations of a river reach has been a challenging task because of:

- **Costly maintainace of gauging stations**
- **Remoteness of gauging stations**
- **Theft of discharge measuring sensors**

Therefore, for catchment-scale high frequent streamflow estimation, recently, the preference is shifting towards the use of innovative remote sensing (RS)-based approaches.

However, the performances of the developed approaches need to be evaluated at various spatiotemporal scales for their wide-scale application.

OBJECTIVE AND STUDY AREA

Objective

To formulate and evaluate the performance of three optical RS-based models for streamflow estimation considering single pixel ratio (SPR), multiple pixel ratio (MPR) and total pixel ratio (TPR) concepts along the water width.

Study area

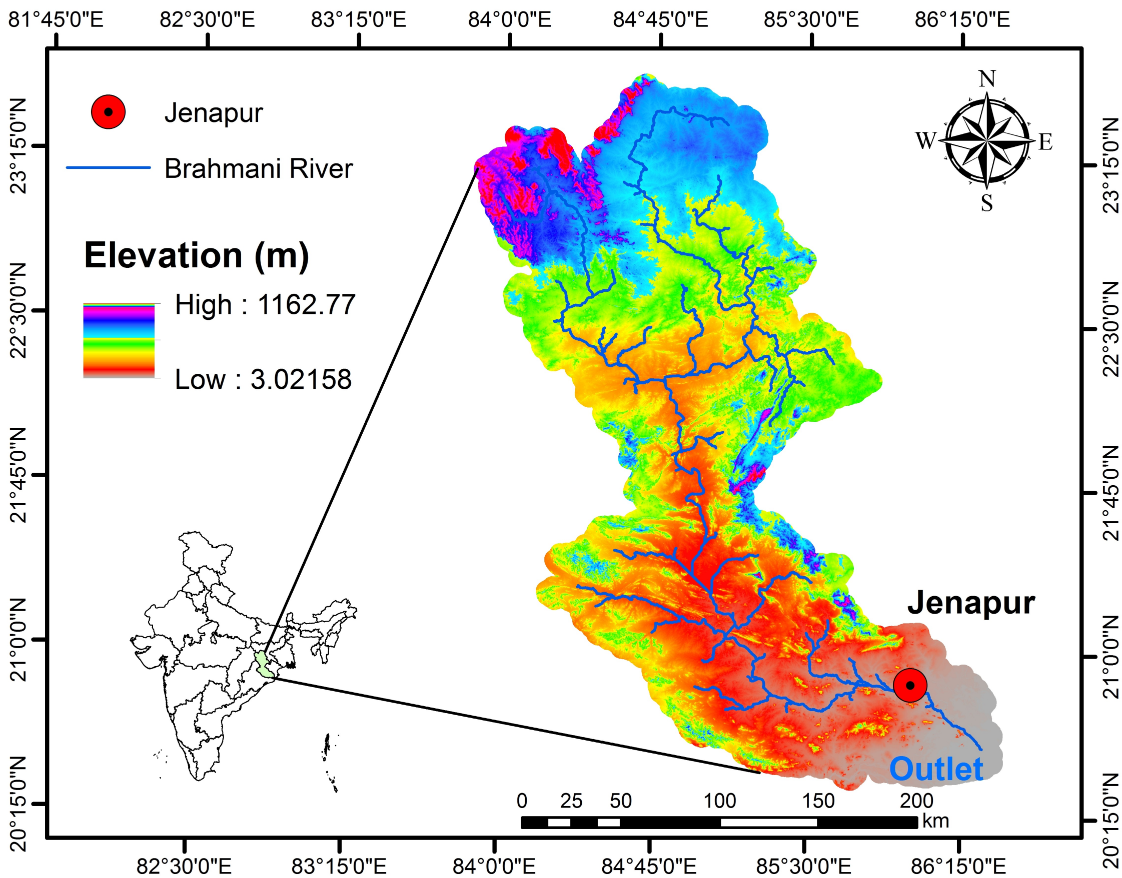


Figure 1 Elevation map of the Bramhani River basin showing the catchment outlet at the Jenapur gauging station.

Data Availability

Data Types	Calibration (2009-2013)	Validation (2014-2016)
Hourly stage discharge time series	Available	Available
Satellite Images Information		
MODIS Images (MYD09GQ) (NIR, 250 m × 1-day)	965	698
Original Landsat Images (NIR, 30 m × 16-day)	72	39
Synthetic Landsat Images	965	698
*Satellite Passage time 9:30 to 11 AM (IST)		

CONCEPTUALIZATION AND METHODOLOGY

Concept

1. **The spectral behaviour of water (*M*) and land (*C*) pixels at the near infrared (NIR) range of electromagnetic spectrum, both at different spatiotemporal scales, could be correlated with the hydraulic variables of dischagre and velocity (Tarpanelli et al., 2013; Li et al., 2019; Sahoo et al., 2020a, 2020b).**
2. **Hence, the temporal fluctuations in the NIR band reflectance could be captured through the temporal variation in land to water pixel ratios (*C*/*M*), which is directly correlated with the discharge.**

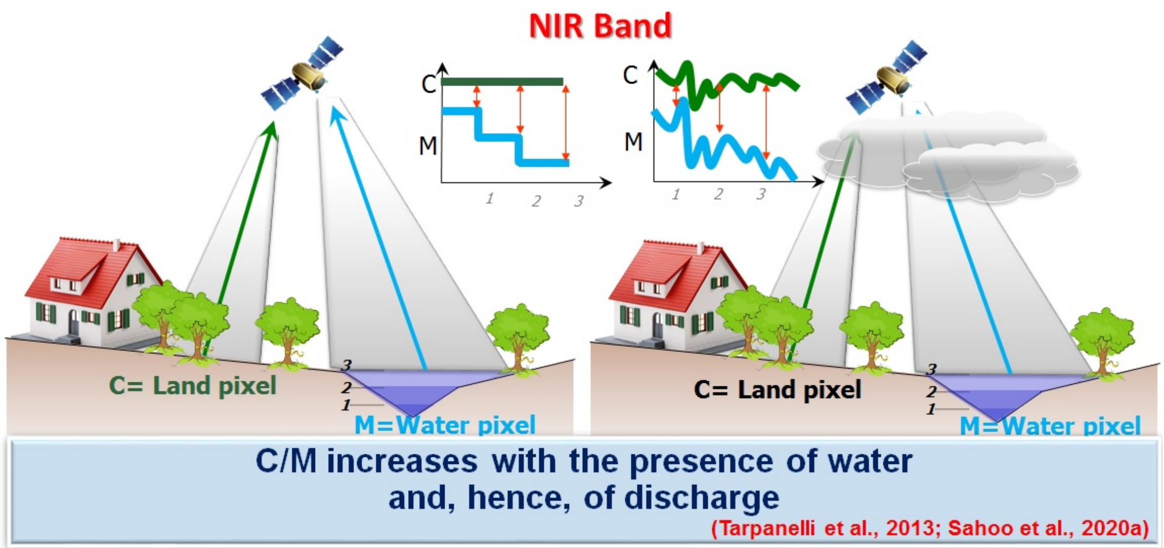


Figure 2 Schematic conceptualization of the developed RS-based model.

Methodology

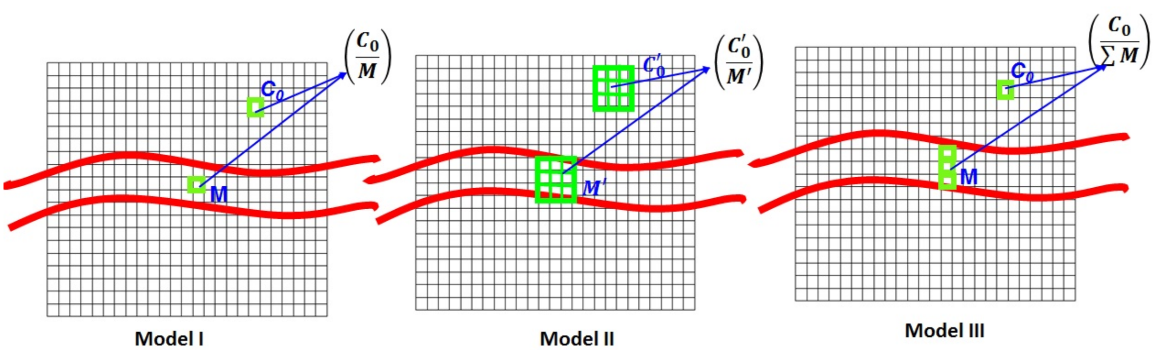


Figure 3 Schematic representations of the developed three RS-based models for their application at any river section.

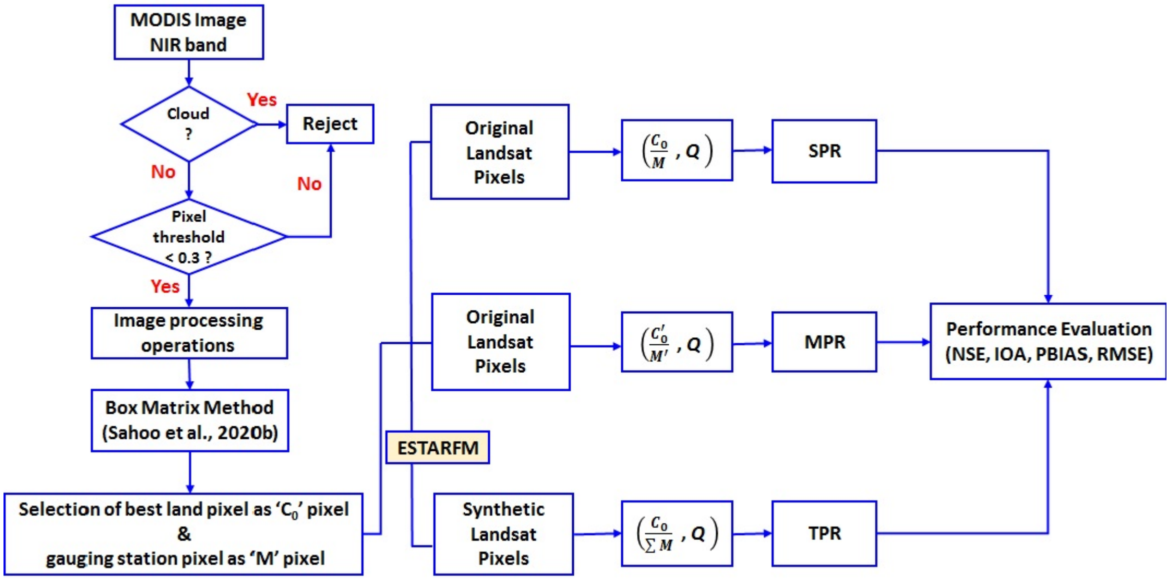
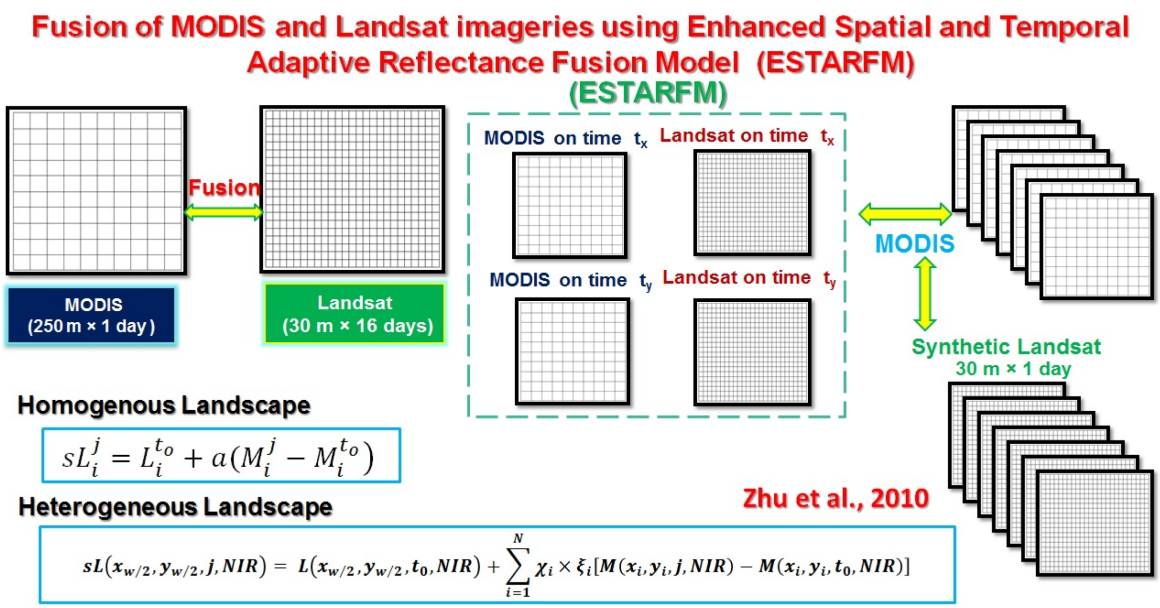


Figure 4 Methodological framework of the three developed RS-based models.

Here in this study, the Enhanced Spatial and Temporal Adaptive Reflectance Fusion Model (ESTARFM) was used to generate the synthetic Landsat (*sL*) using pair of MODIS pixels (*M*) and Landsat pixel (*L*) (Zhu et al., 2010) as presented in Fig. 5.



$$sL_i^j = L_i^{t_o} + a(M_i^j - M_i^{t_o})$$

$$sL(x_{w/2}, y_{w/2}, j, NIR) = L(x_{w/2}, y_{w/2}, t_0, NIR) + \sum_{i=1}^{N} \chi_i \times \xi_i [M(x_i, y_i, j, NIR) - M(x_i, y_i, t_0, NIR)]$$

Figure 5 Schematic representation of generation of synthetic Landsat images using ESTARFM algorithm.

RESULTS

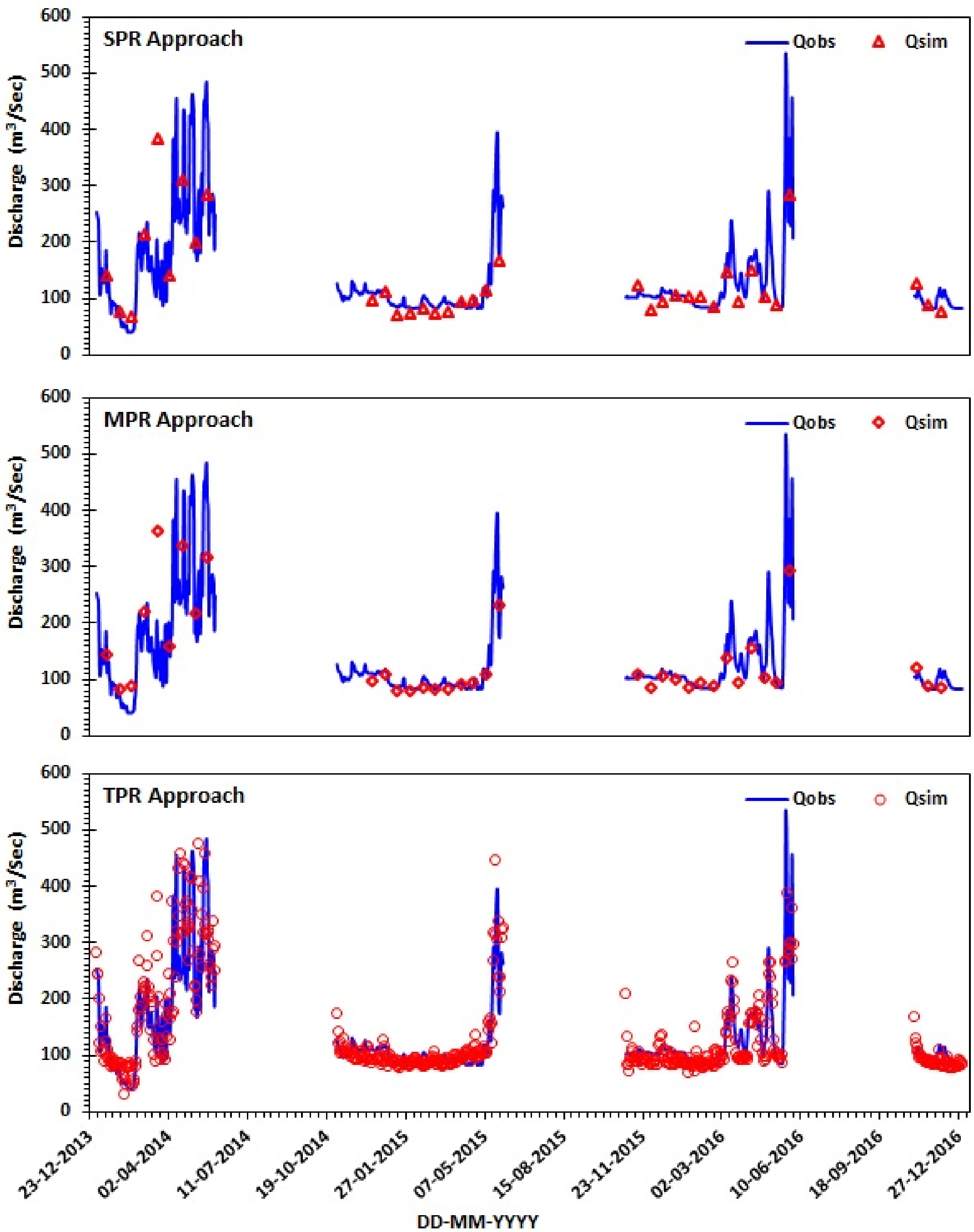


Figure 6 Performance of the a) SPR, b) MPR, and c) TPR model variants in reproducing the observed discharge time series during the validation period (2014–2016) for the Jenapur gauging station.

Table 2. Performance matrix of the three models

Model	NS	IOA	PBIAS (%)	RMSE (m^3/s)	Number of discharge prediction days (n)
SPR	0.67	0.82	-3.9	65	38
MPR	0.68	0.86	-3.7	42	38
TPR	0.72	0.91	-3.3	36	698

CONCLUSION

1. **The application of the ESTARFM algorithm supported the TPR model to retrive the water pixel information along the river width with a daily temporal scale.**
2. **Among the three Landsat-based models (i.e., SPR, MPR, and TPR), the TPR performed the best with the Nash-Sutcliffe efficiency of 72% at a finer spatiotemporal scale (30m×1-day) with the ESTARFM-derived synthetic Landsat images.**
3. **During the monsoon season, cloud cover was responsible for causing hindrance in the discharge estimation.**

ABSTRACT

For catchment-scale streamflow estimation, recently, the preference is shifting towards the use of innovative remote sensing (RS)-based approaches at the remote gauging stations. In this context, this study evaluates the performances of three RS-based models designed with the near-infrared (NIR) bands of Landsat images at the Jenapur outlet of the Brahmani River basin in eastern India. These RS-based models are designed using the spectral behavior of land (C) and water (M) pixels in the NIR region of the electromagnetic spectrum in the presence and absence of water surrounding the streamflow gauging station. Further, the computed pixel ratio (C/M) is used as a parameter for the discharge estimation, in which four years (2009-2013) of Landsat images are used during calibration and three years (2014-2016) of these images are used during validation. Model-I uses the C/M method in which a box-matrix is conceptualized to analyze the optimal location of the land pixel (C_0); and subsequently, the time series of C/M is calibrated with the *in-situ* discharge (Q) time series. The best pixel ratio (C_0/M) time series is preprocessed with an exponential smoothing filter to derive the best filtered-pixel ratio (C_0/M^*) time series, which is used in the regression model to estimate the river discharge. Model-II corresponds to the multi-pixel ratio (MPR) method, where a 3×3 window is used to calculate the average reflectance of both the C and M pixels within the box-matrix, and subsequently, to obtain the best pixel (C_0'/M') ratio as in the case of Model-I to develop the spectral relationship between C_0'/M' and Q time series. Model-III uses both the C/M and water width-based function to estimate the streamflow. The performance evaluation of the models is carried out using the Nash-Sutcliffe efficiency, Percentage bias, and Mean absolute error, which reveals that the model performance varies in the order: Model-III > Model-II > Model-I. This proposed RS-based discharge estimation model framework has the potential to be used in many world- rivers with varying cross-sections.

REFERENCES

Li, Haojie, Li, Hongyi, Wang, J., Hao, X., 2019. Extending the Ability of Near-Infrared Images to Monitor Small River Discharge on the Northeastern Tibetan Plateau. Water Resour. Res. 55, 8404–8421. doi.org/10.1029/2018WR023808

Sahoo, B, Sahoo, D.P., Tiwari, M.K. 2020a. A hydrodynamics and remote sensing based framework for establishing virtual streamflow measurement stations in scantily-gauged river reaches, EGU General Assembly 2020, Vienna, Austria, EGU2020-18311, May 4-8, 2020. doi: 10.5194/egusphere-egu2020-18311

Sahoo, D.P., Sahoo, B., Tiwari, M.K., 2020b. Copula-based probabilistic spectral algorithms for high-frequent streamflow estimation. Remote Sens. Environ. 251, 112092. doi.org/10.1016/j.rse.2020.112092

Tarpanelli, A., Brocca, L., Lacava, T., Melone, F., Moramarco, T., Faruolo, M., Pergola, N., Tramutoli, V., 2013. Remote Sensing of Environment Toward the estimation of river discharge variations using MODIS data in ungauged basins. Remote Sens. Environ. 136, 47–55. doi.org/10.1016/j.rse.2013.04.010

Zhu, X., Chen, J., Gao, F., Chen, X., Masek, J.G., 2010. An enhanced spatial and temporal adaptive reflectance fusion model for complex heterogeneous regions. Remote Sens. Environ.114, 2610-2623