Integrating Remotely Sensed Observations of Surface Water Storage with Climate Forecast for Freshwater Management

Report of Senior Researcher Exchange April-May 2018

March 2020

INDIA-UK
Water Centre
भारत-यूके
जल केन्द्र

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India-UK Water Centre

www.iukwc.org

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CITATION

Mishra, V. & Sembhi, H. (2020). Integrating remotely sensed observations of surface water storage with climate forecast for freshwater management. Report of Senior Research Exchange March 2020. The India-UK Water Centre. UK Centre for Ecology & Hydrology, Wallingford and Indian Institute of Tropical Meteorology, Pune.

Version 2.0 20/09/19

Natural Environment Research Council

Ministry of Earth Sciences
Government of India

The India-UK Water Centre promotes cooperation and collaboration between the complementary priorities of NERC-MoES water security research.

भारत-ब्रिटेन जल कें द्र एमओईएस-एनईसीआरसी (यूके) जल सुरक्षा अनुसंधान के पूरक प्राथमिकताओ के बीच सहयोग और सहयोग को बढ़ावा देने के लिए करना है

Front cover image: Krishna River (Pixabay)

Contents

Executive Summary

This report presents an overview of research exchange undertaken by Dr Vimal Mishra (IIT, Gandhinagar) at Dr Harjinder Sembhi's lab at University of Leicester, UK. The exchange focussed largely on developing a methodology to estimate freshwater storage of lakes in India using the Multi Spectral Instrument (MSI) on European Space Agency's Sentinel 2 mission.

Remote sensing has successfully provided the solutions for monitoring water storage in large water bodies, however monitoring changes in storage in smaller water bodies (less than 100,000 m^2) remains a challenge. This is mainly because of the coarser resolution achieved by many space-borne sensors. Tracking of storage changes in smaller water bodies can help to understand the risks of water availability, particularly in vulnerable regions, and provide critical information for stakeholders in decision making for freshwater management. This exchange visit aimed to develop a remote sensing based framework to monitor changes in water storage during the dry season in India in a selection of diverse climatic regions located in semi-arid areas of Gujarat and West Bengal. The exchange aimed to utilise long-term climate data records of land surface temperature, developed at the University of Leicester, as well as, novel high-spatial resolution observations from the Sentinel 2 mission.

1. Activity Leads

The Junior Research Exchange was convened by the India-UK Water Centre (IUKWC) and involved Activity Leads:

Dr Vimal Mishra

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The exchange was held at the Earth Observation Science Group, Department of Physics and Astronomy, University of Leicester, UK from 19th June to 29th June 2018

2. Exchange Aims

The India-UK Water Centre is based around five key cross-sectoral themes and aims to deliver a portfolio of activities across these themes.

This Senior Research Exchange focused on the themes:

- Using new scientific knowledge to help stakeholders set objectives for freshwater management; and
- Improving freshwater monitoring frameworks and data for research and management.

The Exchange focussed largely on developing a methodology to estimate freshwater storage of lakes in India using the Multi Spectral Instrument (MSI) on European Space Agency's Sentinel 2 mission. The specific objectives of the exchange were:

- To develop a remote sensing based framework to monitor changes in water storage during the dry season in India (science objective);
- Use of Earth Observation to map variation in surface water extent and to utilise the outputs to determine water storage (volume) using depth-area relationship (science objective); and
- To transfer knowledge and information about Earth Observation and *in situ* datasets and co-develop methodology for surface monitoring applications (knowledge exchange objective).

3. Exchange Structure and Research

The exchange visit took place from Tuesday 19th June to Friday 29th June 2018 with the Earth Observation Science Group based at the Department of Physics and Astronomy, University of Leicester, UK. During this period, the lead, Dr Vimal Mishra, delivered a research seminar on drought monitoring to the Earth Observation Science and Centre for Climate and Landscape Research Groups. The visit also consisted of regular networking and knowledge exchange meetings with colleagues from the University of Leicester, as well as, Kings College London and Imperial College London.

3.1. Data sources and research design

Earth observation satellites

The investigation focussed on utilising high-resolution observations made by the Multi-Spectral Imager (MSI) through the European Space Agency (ESA) Sentinel 2 mission. The mission was developed as part of the European Copernicus program for the purpose of supporting operational services related to monitoring changes in land cover and managing natural disasters; two satellites were launched in June 2015 and March 2017 under this mission (Table 1).

Table 1: Sentinel 2 bands along with its central wavelength, resolution and bandwidth

Sentinel-2 Bands	Central Wavelength (µm)	Resolution (m)	Bandwidth (nm)
Band 1 – Coastal aerosol	0.443	60	27/45 (2A/2B)
Band 2 – Blue	0.490	10	98
Band 3 – Green	0.560	10	45/46 (2A/2B)
Band 4 – Red	0.665	10	38/39 (2A/2B)
Band 5 – Vegetation Red Edge	0.705	20	19/20 (2A/2B)
Band 6 – Vegetation Red Edge	0.740	20	18
Band 7 – Vegetation Red Edge	0.783	20	28
Band 8 – NIR	0.842	10	115
Band 8A – Narrow NIR	0.865	20	20
Band 9 – Water vapour	0.945	60	20
Band 10 – SWIR – Cirrus	1.375	60	20
Band 11 – SWIR	1.610	20	90
Band 12 – SWIR	2.190	20	180

Data Source: https://www.sentinel-hub.com/develop/documentation/eo_products/Sentinel2EOproducts

Case study

Ghataprabha River is a tributary of River Krishna and is one of the major sources of water supply to Belgaum city and adjoining areas in Karnataka (Purandara *et al*. 2011). The Ghataprabha/ Hidkul Lake has a surface area of 73.0233 km^2 and is a result of the construction of dams under the Ghata Prabha irrigation project in 1897. The lake is located at 74.64°E, 16.148°N and stretches across Karnataka and Maharashtra states (Karnataka Water Resources Department accessed online).

Data sourcing and research design

Eight-day composite MODIS EVI images obtained from Tiwari & Mishra (2018) were used to create a mask for a reservoir considering pixels with EVI less than 0.1 as 'water pixel'. To estimate the surface area of a reservoir covered with water on a particular day, the number of pixels (classified as water) were multiplied by the area of a single pixel (250x250 m^2). However, this approach to estimate the reservoir's surface area has errors and inconsistencies as reported in the previous studies (Gao *et al*., 2012; Zhang *et al*., 2014). To overcome this, a nonparametric unsupervised K-means clustering approach was adopted. In this approach the masked area was further classified into three classes: water, non-water dry surface, and non-water wet surface as described in Zhang *et al*. (2014). The enhanced image classification technique was also used to improve the classification of water surface area as described in Zhang *et al*. (2014).

The reservoir surface elevation data was extracted from ICESat/GLAS dataset obtained from National Snow and Ice Data Center (NSIDC: https://nsidc.org/data/icesat/data.html). The datasets are available from January 2003 to February 2010 (Shuman *et al.*, 2006; Wang *et al.*, 2013; Zhang *et al*., 2011). The vertical precision of the ICESat/GLAS data is higher than 10 cm (Zwally *et al.*, 2008) with a horizontal spacing of 172 m (Kwok *et al*., 2004). Further, the ICESat/ GLA14 Release-34 elevation data was also obtained from the National Snow and Ice Data Center. Using water surface area and water surface elevation, a linear surface area-elevation relationship was assumed to be as per equation 1.

$$E = a \times A + b \qquad (1)$$

Where E is the water surface elevation from mean sea level, A is the reservoir surface area, and a and b are constants; obtained from the best fit relationship between water surface area and water surface elevation.

Due to the limited availability of ICESat/GLAS elevation, reservoir storage from the ICESat/GLAS and MODIS data cannot be obtained directly. Using elevation data from area-elevation relationship, reservoir storage was estimated using equation 2, and as mentioned in Gao *et al.* (2012) and Zhang *et al.* (2014).

$$V_{RS}=V_C-(h_C-h_{RS})(A_C+A_{RS})/2 \quad (2)$$

Where Vc, hc, and Ac represent storage, area, and water elevation at capacity (maximum storage), and VRS, HRS and ARS are the estimated storage, area, and water elevation using remote sensing.

The observed storage, area, and water elevation at capacity for each reservoir were obtained from Water Resources Information System of India (http://tamcnhp.com/wris/#/).

General methodology

- Sentinel 2 multi-spectral images were selected from June 2016 to June 2018 using the Copernicus browsing platform (https://www.sentinel-hub.com/)
- Sentinel 2A tiles were selected over GhatPrabha/Hidkul Lake, which was selected as a test case from the lake database generated by IIT Gandhinagar (Table 2).
- Individual scenes were traced through to extract clear-sky scenes; these were used to calculate the Normalised Differential Vegetation Index (NDVI[1]) using an ESA Sentinel Application Platform (SNAP). This toolbox allows EO processing and analysis directly on raw satellite imagery or channel data.

Table 2: Location and characteristics of some small reservoirs in India

S. No.	Dam	x	y	Full reservoir level (m)	Storage (BCM) at Capacity	Area (km²)
18	GhatPrabha/Hidkul	74.642	16.148	662.95	1.391	73.0233
72	Sholayar	76.744	10.309	1002.79	0.143	5.723
17	Gerusoppa	74.6749	14.25164	55	0.13	5.98
1	Aliyar	76.981	10.488	320.04	0.095	6.5
9	Bhandardara	73.767	19.534	744.91	0.304	7.4318
30	Jhakham	74.032	23.982	359.5	0.132	10.148
37	Khadakwasla	73.7681	18.4417	582.47	0.056	14.8
33	Kakki	77.15	9.326	981.46	0.447	17.51
50	Manikdoh	73.816	19.239	711.25	0.288	18.434
22	Harangi	75.9056	12.4917	871.42	0.22	19.08096

[1]The Normalized Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.

Pettorelli, N., 2013. The normalized difference vegetation index. Oxford University Press.

4. Data Analysis and Outputs

4.1. Performance of remotely sensed reservoir storage

Comparison of 8-day composite satellite-based reservoir storage and 8-day mean observed storage for 9 selected reservoirs (Almatti, Bargi, Bhadra, Hirakud, Lower Manair, Malaprabha,

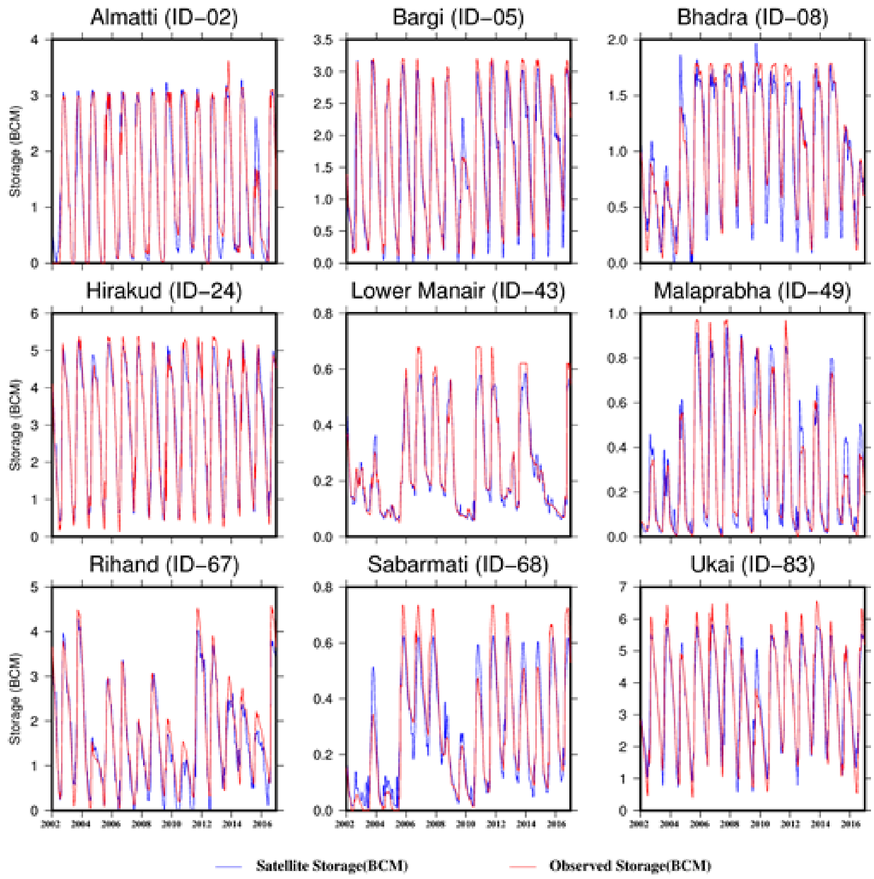


Figure 1: Comparison of satellite storage using MODIS data and Observed storage for selected 9 reservoirs

Rihand, Sabarmati, and Ukai) is presented. Comparison from the year 2002 to the year 2016 is presented in Figure 1.

Performance of satellite-based 8-day reservoir storage was evaluated against the observed storage using the coefficient of determination (R2), normalized root mean squared error (NRMSE %) and bias (%). Median R2, NRMSE, and bias for remotely sensed reservoir storage were 0.47, 50.90%, and 15.04%, respectively (Fig. 2). Here R2 is evaluated after removing seasonality from the observed and satellite reservoir storage data. We find that the performance of the remotely sensed reservoir storage was low in the western coastal region, which can be attributed to complex topography and high cloud cover (Fig. 2).

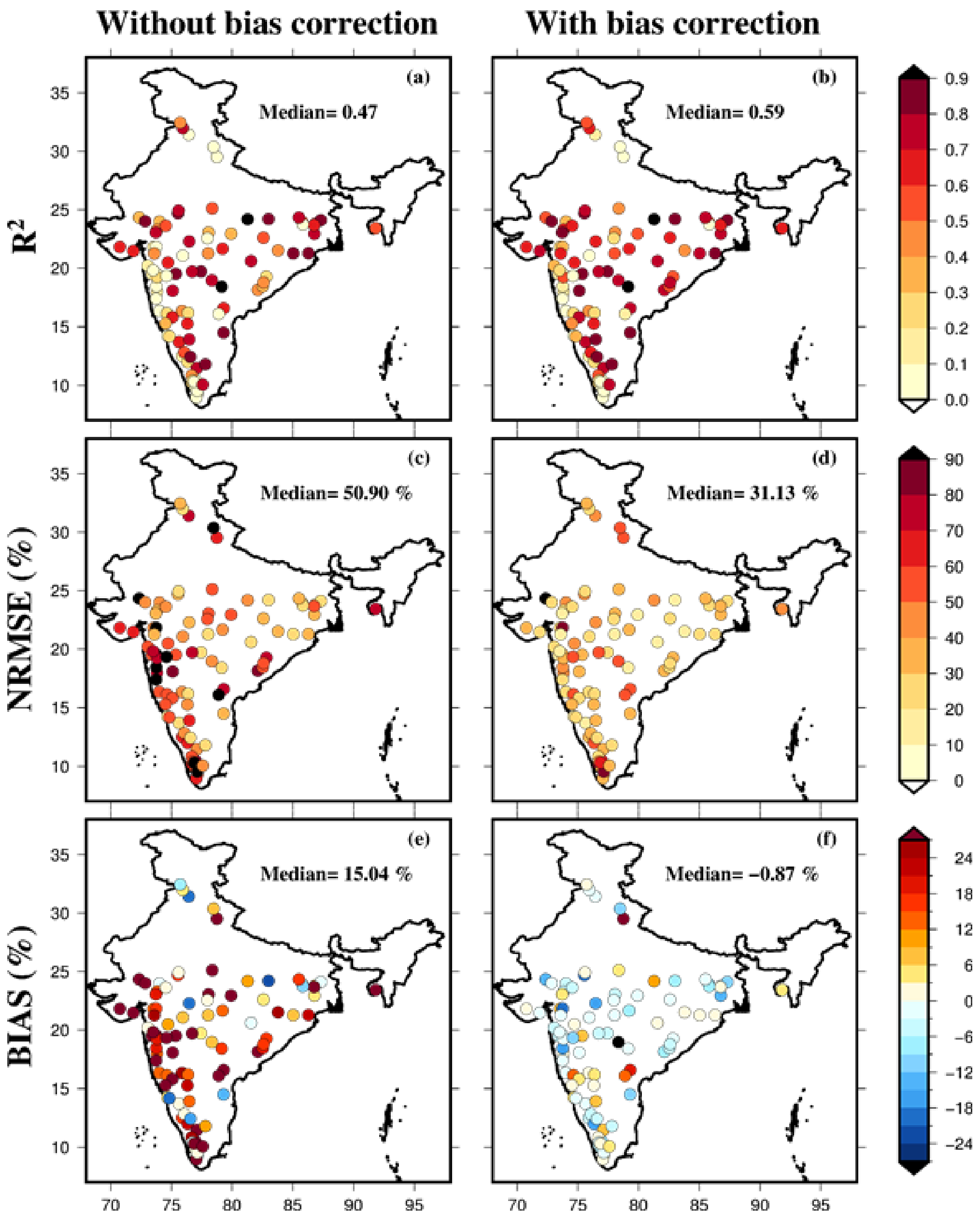


Figure 2: Skill between satellite reservoir storage and observed storage for 91 major reservoirs in India before and after bias correction.

The same area elevation relationship was used for Ghat Prabha reservoir to evaluate the reservoir storage from December 2016 to April 2018 (Table 3 and Fig. 3). The storage obtained from Sentinel was compared with MODIS storage and observed storage as well. It was found that for the year 2017, storage obtained from MODIS data shows better result than storage obtained from Sentinel data for the Ghat Prabha reservoir (Fig. 6).

Table 3: Comparison of Satellite storage using Sentinel and MODIS and Observed storage for Ghat Prabha reservoir

Date	Storage (Sentinel)	Storage (MODIS)	Storage (Observed)
31-Dec-16	0.6423	0.8110	0.77
20-Jan-17	0.4166	0.5848	0.58
09-Feb-17	0.3025	0.5160	0.50
21-Mar-17	0.0235	0.2440	0.24
10-Apr-17	0.0009	0.2099	0.20
30-Apr-17	0.0000	0.0708	0.05
16-Nov-17	1.2556	1.1360	1.25
15-Jan-18	0.7188	-	0.75
14-Feb-18	0.5261	-	0.63

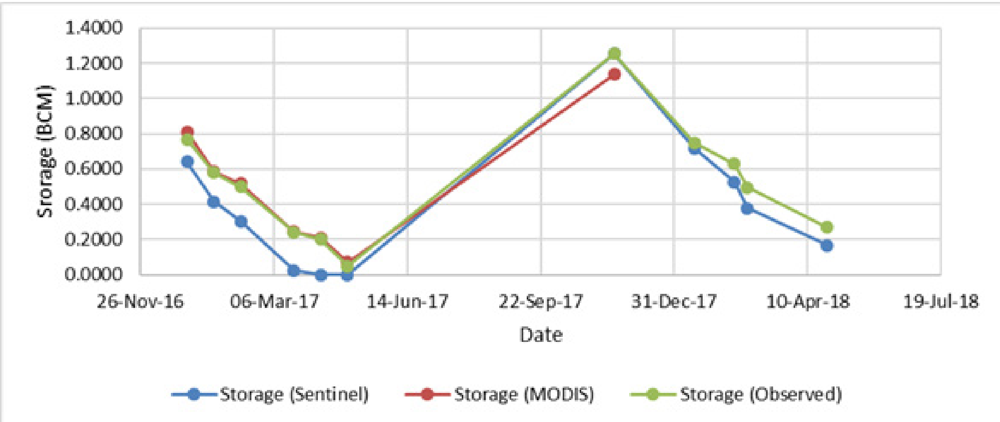
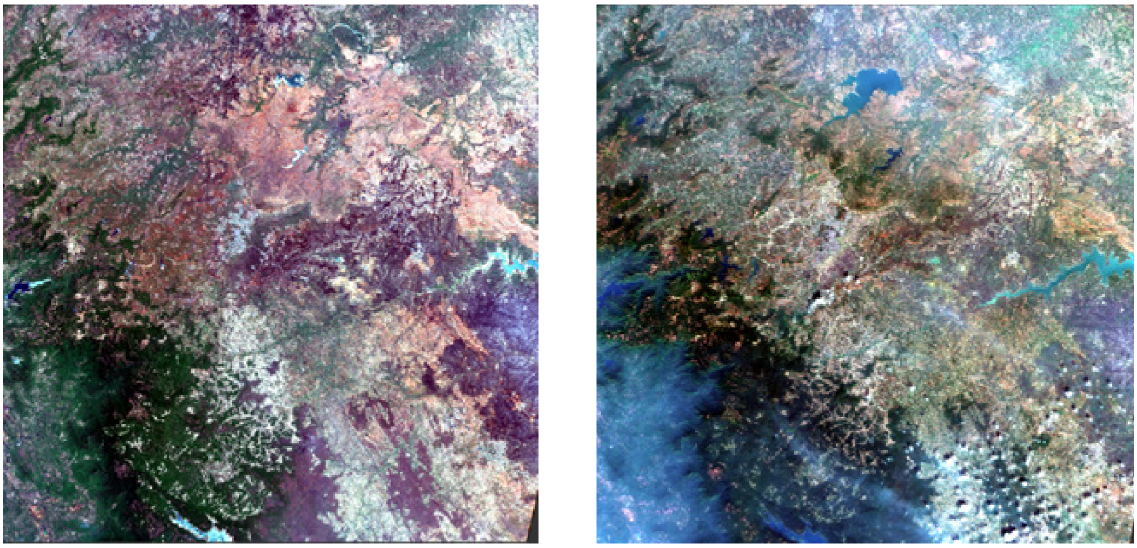


Figure 3: Comparison of satellite storage using Sentinel and MODIS and observed storage for Ghat Prabha reservoir

24-Feb-18	0.3782	-	0.50
25-Apr-18	0.1661	-	0.27



(a) 30th April 2017 *(b) 16th November, 2017*

Figure 4: Red-Green-Blue (RGB) image generated from S2A Level 1C tile covering GhatPrabha Lake on (a) 30th April 2017 and (b) 16th November 2017

4.2. Image processing

Sentinel 2 multi-spectral images were used (Fig. 4) to create a mask for Ghat Prabha reservoir considering pixels with NDVI less than 0.1 as 'water pixel'.

An approach similar to the calculation of surface water area from MODIS EVI was applied to calculate the reservoir surface water area. The images were classified into three classes: water (green), non-water dry surface (red), and non-water wet surface (blue) using K-means clustering

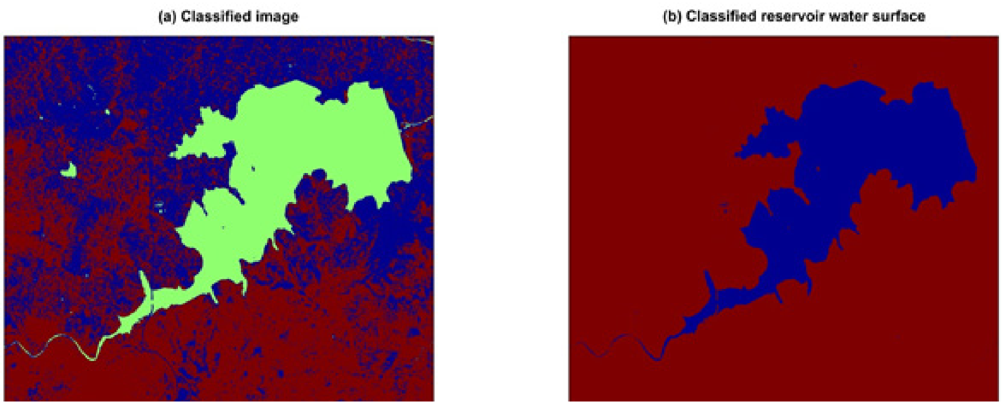


Figure 5: (a) Classified image in 3 classification parts as water (green), non-water dry surface (red), and non-water wet surface (blue) and (b) classified Ghat Prabha reservoir water surface (blue) on 16th November 2017

classification (Fig. 5a),. The classification was further enhanced using the MODIS EVI image classification and enhancement approach. The number of pixels obtained in the classified area (derived through above image processing) was multiplied with the area of 1 pixel (10mx10 m) to determine the reservoir surface water area (Fig. 5b).

To validate the results for each reservoir, gauge observations were obtained from Water Resources Information System of India (India-WRIS). This dataset has been available from January 01, 2002 for all reservoirs; the dataset exhibits daily repeat cycles (although with some missing dates) until 2016. Post-2016 the temporal resolution of this data has been 7 days, with 25 days of latency period. The precision of this dataset for reservoir storage is 0.001 BCM.

4.3. Estimating reservoir storage of Ghat Prabha

The same area elevation relationship for Ghat Prabha reservoir was established to evaluate the reservoir storage from December 2016 to April 2018 (Table 3 and Fig. 3).

5. Conclusions

For this study the storage data was derived from Sentinel and MODIS and compared with Gauge observed dataset for validation. The key conclusion is that for the year 2017, storage obtained from MODIS data shows better results than storage obtained from Sentinel data for the Ghat Prabha reservoir.

6. Annexes

Annex A: References

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