



Surface water dynamics analysis based on sentinel imagery and Google Earth Engine Platform: a case study of Jayakwadi dam

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Abstract

Surface water is important for the urban and agriculture ecosystem, the accurate and very easy to detect and analysis of the surface water based on the remote sensing data and google earth engine platform. It is a very much important for irrigation and water resource management during the dry period and rabi with summer season. In this paper, we have extracted the surface water analysis from Sentinel-2A images using a new technique of Google Earth Engine (GEE) and machine learning coding. Monitoring the dynamics of surface water is a very helpful to study of the irrigation, and drinking water requirement, which climate change factors most damages on the surface water, natural environmental health and understand the impacts of global changes and human actions on the planning and development of the water resources in the semi-arid region. Currently, so much research has focused on the surface water extraction and dynamic monitoring using remote sensing imagery and softwares. But downloading a big number of remote sensing images are covering that area and then process in the remote sensing and GIS software as per the traditional method. The traditional process is much lengthy, also very time-wasting for such kind of time series dataset analysis. In this view, GEE platform has been given easier to access any satellite data within less time. The GEE is a total cloud-based platform enthusiastic to satellite image data processing based on the machine learning coding. So for many excellent remote sensing image processing coding, algorithms have been integrated in the platform of Google Earth Engine (GEE). These data do not require to save images and collection, which are very easy to doing satellite data processing and effective output capability. The results show that 2019 year has observed that there are increased water area, i.e. 202.4871 km² and for the year of 2019, water spread-out area is 410.9113 km² in dam. To compare the results of 2015–2019, there is much increase in the water area due to various reasons like pumping, heavy rain, etc. in the Jayakwadi dam. This water can use for various purposes and irrigation water management and drinking purposes during the drought condition. The developed algorithms have given better information and results of water spread-out by google earth engine. The current techniques are reliable, novel, and quick to get the maximum and minimum extent of the surface water. The results can be very useful for the surface water planning and management in the study area.

Keywords Water dynamics · GEE · Jayakwadi dam · GIS

Introduction

Sustainable development and water resources management are important to the human communities, preserve the functions of ecosystems, and ensure economic growth (Pande 2020; Moharir et al. 2020). The water surface is a primary water quality measured for development of sustainable in the semi-arid region. The climate regulation, biogeochemical cycling, surface energy balance, and many more aspects regarding the sustainable development and water resources management based on the natural resources and land cover factors and these types of parameters are so much important

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to development of water resources and agriculture development. Currently, many countries have experienced rapid urbanization, fresh water and insufficient natural resources, etc. These problems are particular found in the developing countries (Huang 2018a, b). Surface water changes have been polluted by human and climate activities, these are factors affected on the ecological parameters, such as surface temperature, soil moisture, biodiversity, and even human welfare. The monitoring of surface water dynamics is very important for environmental health and sustainable economic development with irrigation planning to various crops and drinking purpose in the drought situation (Moharir et al. 2017). The reservoirs are water bodies formed by artificial dams, spread around the world, between the rivers and lakes, particularly in areas with few natural lakes (Lin and Han 2001; Xu et al. 2019). Its earlier function is to control flooding, generate energy, irrigate and transport. However, the escalation of the contradiction between the global supply of water and demand has led to the most critical way to reduce water supply pressure by supplying reservoirs (Gorelick 2017; Han 2010; Mei et al. 2016). The construction of a reservoir is the main means for humans to regulate the distribution of natural water resources in time and space (Khadri and Pande 2016). Remote sensing and GIS technology approaches can extract the waters and monitor water body, it is very fast in monitoring the surface changes and efficient, which has macroscopic, real-time, and low-cost characteristics (Moharir et al. 2017, 2020).

Climate change is main important factor of surface water in this study because so many crops and dryland are totally dependent on the surface water if surface water is less that so much problems are faced by humans and farmers (Jiang et al. 2017). Due to its harsh natural environment, it is extremely labor-intensive and costly to conduct water resources surveys in the field and stable long-term data series are very difficult to obtain. Remote sensing satellite technology provides a successful solution in the field of water resources, earth science and irrigation planning. Following the spectral features of the water system, and many water removal indexes have developed based on the satellite bands, which allow the remote sensing images to extracted water conveniently. Several researchers and scientists have done a great deal with the work and complex monitoring on surface water mining. The important techniques are the single-band and multi-band approaches. The threshold method to remove the water from the close-infrared and medium-infrared bands of Landsat-7 is complementary to the one-band method. However, it is very difficult to remove the water signature from remote sensing images because of uncertainty between water and shadow (Feyisa et al. 2014; Rokni et al. 2014). For example, by the near-infrared and single gray band, threshold process has examined the Daleno's water body area, while has

suggested to focus on the environmental and water-related issues (Lai et al. 2020; Zhang et al. 2011). Based on the seventh band, Landsat TM image has extracted waterbody data with a single-band threshold (Mcfeeters 1996). The inter-spectral relationship method and the water body index method are part of the multi-band protocol. Analyzing the characteristic of the spectral curve of the water body and the background object, the inter-spectral relationship method establishes a logical discriminant to distinguish the details about the water body from the picture (Rover et al. 2012, Wang et al. 2018). However, it has the inconvenience of mistakenly dividing homes into water bodies. When we first download and use the software according to the traditional method, an enormous number of remote sensing images that cover a longer period, the work cycle shall be extended greatly. Ji et al. (2015) have used the NDWI and its transformed water body index to extract the discrete lake waters in the Poyang Lake area. Unni (1983) proposed a water body area extraction algorithm based on pyramid image segmentation, which is applied in high-precision automatic aerial triangulation for island and reef. Tong et al. (2017) suggested an object-oriented NDWI water body extraction method based on the OLI fusion images, which can effectively remove the effects of mountain shadows and thin clouds and avoid "scattered bodies of water". The main objective of this paper is the extraction of the water spread-out area of the Jayakwadi dam by an index called NDWI (Wang et al. 2018; Jiang et al. 2017; Zhang et al. 2014). The change of reservoir water surface or dam can effectively reflect the change of water quantity. Analysis and changing trends will help to monitor its water quantity changes and facilitate relevant departments to make scientific decisions. The water resources can be used efficiently and reasonably to ensure a stable supply of water in a nearby area, thereby increase people's understanding of the water crisis and promote a sustainable development in the Aurangabad district. Over the last century, the environment in India has been changed a lot due to increased human activities. The Aurangabad district has a large population and rapid economic development; meanwhile, frequent droughts and changeable hydrological conditions threaten the economy and ecology. Therefore, accurate and rapid monitoring of the long-term dynamics of the surface water in the dam is important to the regional economy and ecosystem. The approach of this study will provide a new perspective on surface water research, and the results of this study will assist in the Google Earth Engine based on the evaluation of water resource distribution and dynamics. Furthermore, this study also facilitates the development of appropriate water resource conservation and management strategies.

Study area

The study area is located at the site of Jayakwadi village in Paithan taluka of Aurangabad district in the Maharashtra State of India. The latitude and longitudinal coordinates of Jayakwadi dam are 19° 29' 8.7" N and 75° 22' 12" E. Jayakwadi is one of the largest earthen dams in the India. Its height is approx. 41.30 m and length of 9.998 km (10 km approx.) with total storage capacity 2909 MCM (million cubic meters) and effective live storage capacity is 2171 MCM. The total catchment area of the dam is 21,750 km². There is a total of 27 water gates for the dam. Jayakwadi Dam is called as Nathasagar Dam. Over its lifetime, it has overflowed 18 times. On 10 August 2006, the highest discharge of 250000 ft³/s was recorded. Nath Sagar Jalashay is the name of the reservoir formed by Jayakwadi Dam. Fed by the Godavari and Pravara rivers the reservoir is about 55 km long and 27 km wide and spans over 350 km² Jayakwadi project is a multipurpose project. The main purpose was to irrigate land for agriculture in the drought-prone Marathwada region of Maharashtra state. Another important purpose was to provide water for drinking and industrial usage to nearby towns and villages and the municipalities and industrial areas of Aurangabad and Jalna. 80% of the water of the dam is allocated for irrigation, 5–7% for drinking water, and the rest for industrial purposes.

Data used and methodology

Sentinel-2 is a wide-swath, high-resolution, multi-spectral imaging mission supporting Copernicus Land Monitoring studies, including the monitoring of vegetation, soil and water cover, as well as observation of inland waterways and coastal areas. The Sentinel-2 data contain 13 UINT16 spectral bands representing TOA reflectance scaled by 10000. See the Sentinel-2 User Handbook for details. Besides, three QA bands are present where one (QA60) is a bitmask band with cloud mask information. For more details, see the full explanation of how cloud masks were calculated by coding. Each Sentinel-2 product (zip archive) may contain multiple granules. Each granule becomes a separate Earth Engine asset. GEE asset ids for Sentinel-2 assets have the following format: COPERNICUS/S2/20151128T002653_20151128T102149_T56MNN. Here, the first numeric part represents the sensing date and time, the second numeric part represents the product generation date and time, and the final six-character string is a unique granule identifier indicating its UTM grid reference (see MGRS). The Level-2 data produced by ESA have been found in the collection of COPERNICUS/S2_SR. These 5-year data were obtained and accessed from google earth engine platform (Fig. 1).

Processing platform GEE

GEE is an open cloud platform developed by Google for geoscience data processing and analysis (Gorelick 2017). It supports online programming and interactive display and can process remote sensing data online without downloading images. Its powerful computing ability supports the processing of PB-level remote sensing data, making it suitable for large-scale and long-term series of research Pekel et al. (2016). Moreover, the rich API documents of GEE absorb many superior remote sensing image processing algorithms, which are very friendly to people who focus on data processing rather than programming. In the GEE platforms, different menus and its interface are shown in Fig. 2.

Data preprocessing for surface water extraction

Sentinel-2 images of years from 2015 to 2019 were declouded and radiometric calibrated. Cloud removal includes two methods: (1) cloud cover sorting method based on image: sorting by cloud cover metadata and selecting images with cloud cover less than 20% to ensure image quality; (2) GEE algorithm based on pixels: it assigns a cloud score to each pixel and selects the lowest possible range of cloud scores at each point and then computes per-band percentile values from the accepted pixels. This algorithm also selects only the least-cloudy scenes in regions where more than max depth input scenes are available. The disadvantage of this method is that there will be obvious traces around the removed cloud patches, which will have a certain impact on the subsequent water extraction. Radiometric calibration converts the digital number (DN) value of the raw image into the top of the atmosphere (TOA) value through the GEE algorithm. Sentinel 2 data are first visualized in the GEE platform for a particular year and time using code. Then, this image has pre-processed in GEE with the least cloud cover for minimum cloud cover or cloud-free image. Mosaicking of a set of images has been done after processing. Then, the water index called NDWI, i.e. Normalized difference water index was calculated using the formula and visualized it in the GEE platform. Then, this NDWI for a particular year was exported to drive using java code in GEE and further processed in Arc GIS. These raster data have been reclassified into classes to find the actual water spread-out area of the dam and converted to polygon using the Arc toolbox to calculate the area under the dam. This process is used every year from 2015 to 2019 and the area was calculated and further analysis was carried out. The adopted methodology is shown in Fig. 3.

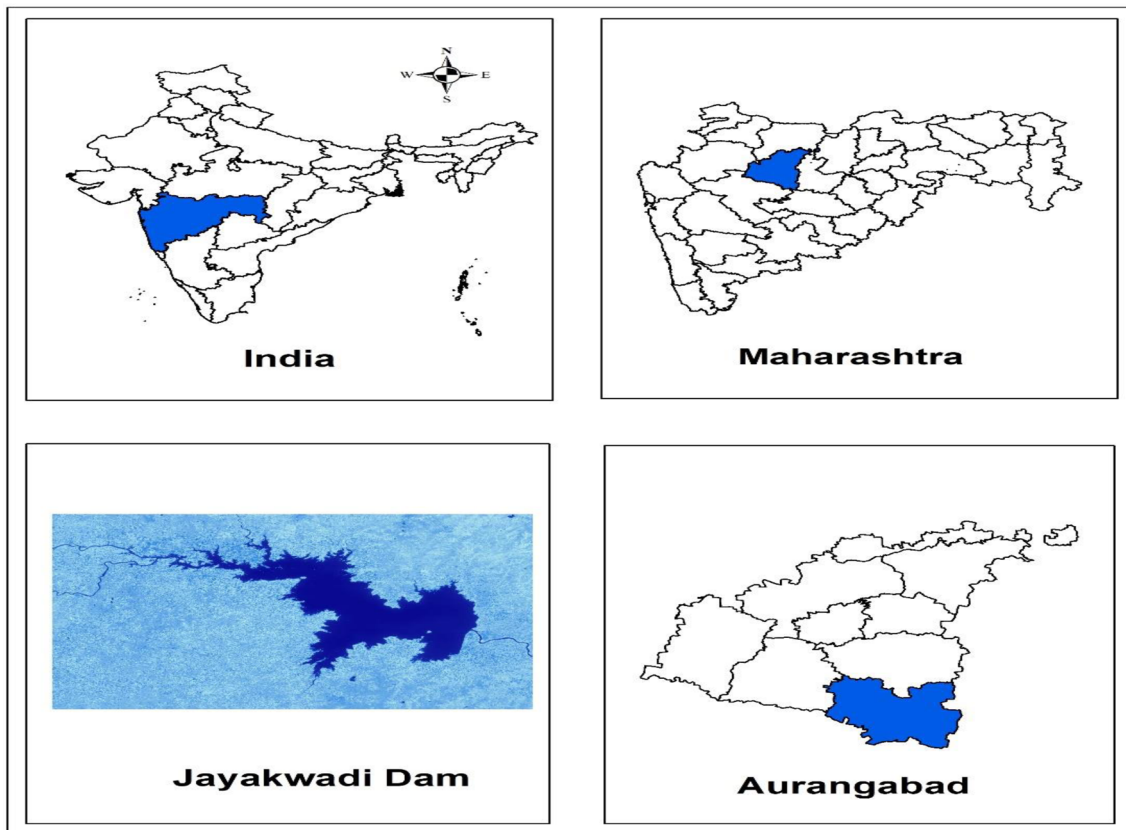


Fig. 1 Location map of study area

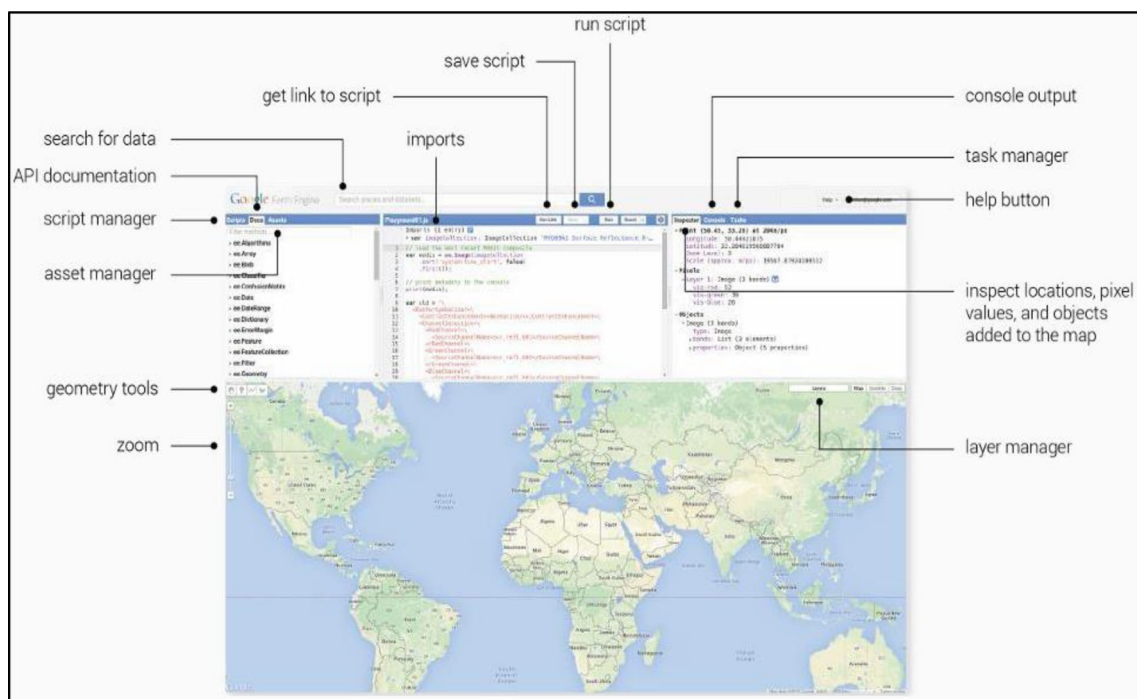


Fig. 2 Show of GEE platform

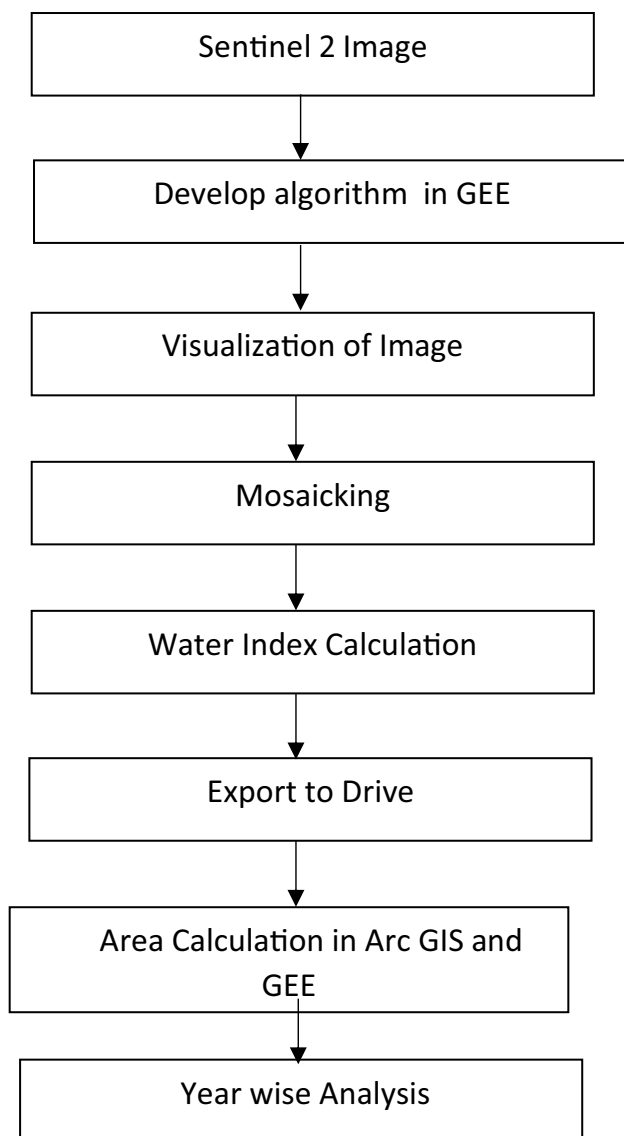


Fig. 3 Flowchart for water extraction with Sentinel images

Water Extraction Index

The construction of the water index is based on the spectral characteristics of water so that the calculated index can expand the difference between water and other objects, and then extract water according to the appropriate threshold. This method mainly enhances water body information through a multi-band combination of remote sensing images and then extracts (Eq. 1). As a result, water features have positive values and enhanced. Vegetation and soil features usually have zero negative values and are suppressed.

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)} \quad (1)$$

where NDWI = Normalized difference water index; NIR = Near Infra-Red.

For Sentinel 2 data, band 3 is the green band and band 8 is the NIR band.

Development of water extraction coding

The water extraction algorithm has developed in the GEE platforms. It very easily identified the large area of the surface water extraction. The coding is very useful for the development of water resources management and current coding is develop by VB and JavaScript Fig. 5.

Results

The Aurangabad district has a large population and rapid economic development, meanwhile frequent droughts and changeable hydrological conditions threaten the economy and ecology. Therefore, accurate and rapid monitoring of the dynamics of the surface water in the dam is important to the regional economy and ecosystem. Furthermore, this study also facilitates the development of appropriate water resource conservation and management strategies. Therefore, an image cannot completely cover certain large lakes. There are currently two or more images needed to extract the entire lakes, which are extremely burdensome traditional methods. Google Earth Engine (GEE) facilitates online remote sensing processing for photographs with many excellent remote sensing algorithms as a cloud platform for the data collection and study of geoscience. GEE not only saves the time of image downloading but also shortens the work cycle greatly because of its powerful interaction ability and computational performance, so that remote sensing science has more time to analyze rather than waste in repeated processing. Through the friendly support of GEE for remote sensing image processing, we can easily and quickly obtain the vector information of the water body, which provides a basis for further hydrological element extraction. In this paper, a 5-year analysis of the Jayakwadi dam has been done using Sentinel-2 data. The water body index method is to combine the advantages of different bands to suppress other ground information and enhance the effect of water body information. So far, many water body index methods had been proposed. At present, the commonly used methods are the normalized difference water index (NDWI). While extracting the dam, NDWI index was calculated by coding and GEE. Using the NDWI index, the water body gets directly extracted from other features and we get the only area of the dam. All data were visualized in Google Earth Engine and processed further. From the

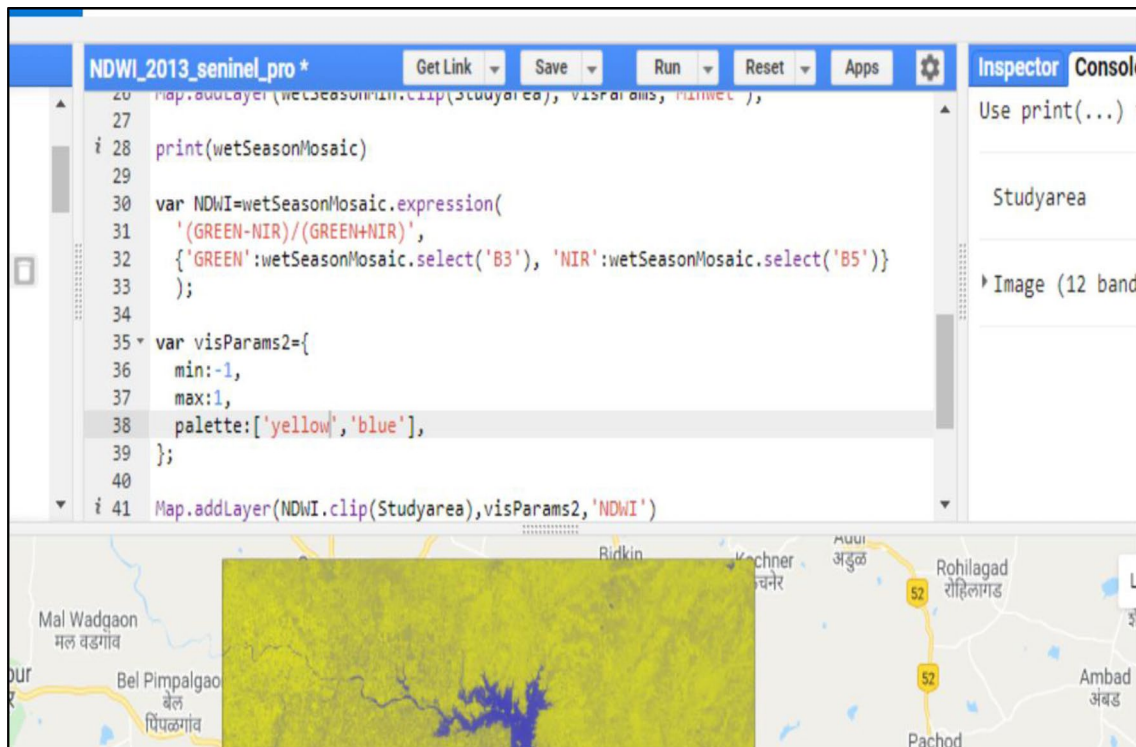


Fig. 4 Extraction of water spread-out area of the dam

year 2015 to 2019, the image collection of Sentinel-2 data for December month was used and using the NDWI formula Fig. 4, the index was calculated for every year. This NDWI index then exported to our drive using a java program and downloaded for further processing. These raster data are then reclassified using Arc GIS and then converted into polygon to calculate the water spread-out area of the dam for a particular year. Yearwise water spread-out area of the Jayakwadi dam is shown in the figure. For the year 2015, the water spread-out area of the dam was found to be 171.9684 km². Similarly, for next year, it was calculated as 335.1256 km². For the year 2017, the area underwater was found as 370.827 km². In 2018, the area gets decreased and seen to be 208.4242 km². For 2018, water spread-out area was found to be 410.9113 km². For the year 2015, the Area underwater was found to be 171.9684 km². In the year 2016, it was found as 335.1256 km² which indicates that the increase in water spread-out area is 163.1572 km². In the next year, the area increased by 35.7014 km² and found at 370.827 km² in 2017. In 2018, the water spread-out area for the dam was found as 208.4242 km² which shows a decrease in waterbody by 162.4028 km². In the year 2019, it was observed that there is much increase in water area, i.e. 202.4871 km²

Table 1 Details of water spread-out area

Year	Water Spread-out Area (km ²)
2015	171.9684
2016	335.1256
2017	370.827
2018	208.4242
2019	410.9113

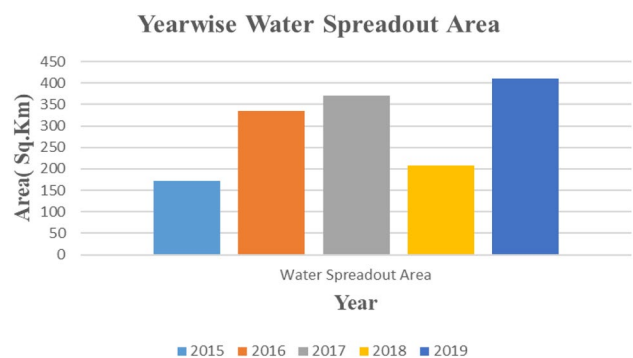


Fig. 5 Year wise water spread-out area of Jayakwadi dam

and water spread-out area under dam for 2019 was found

Fig. 6 Water spread-out area (2016)

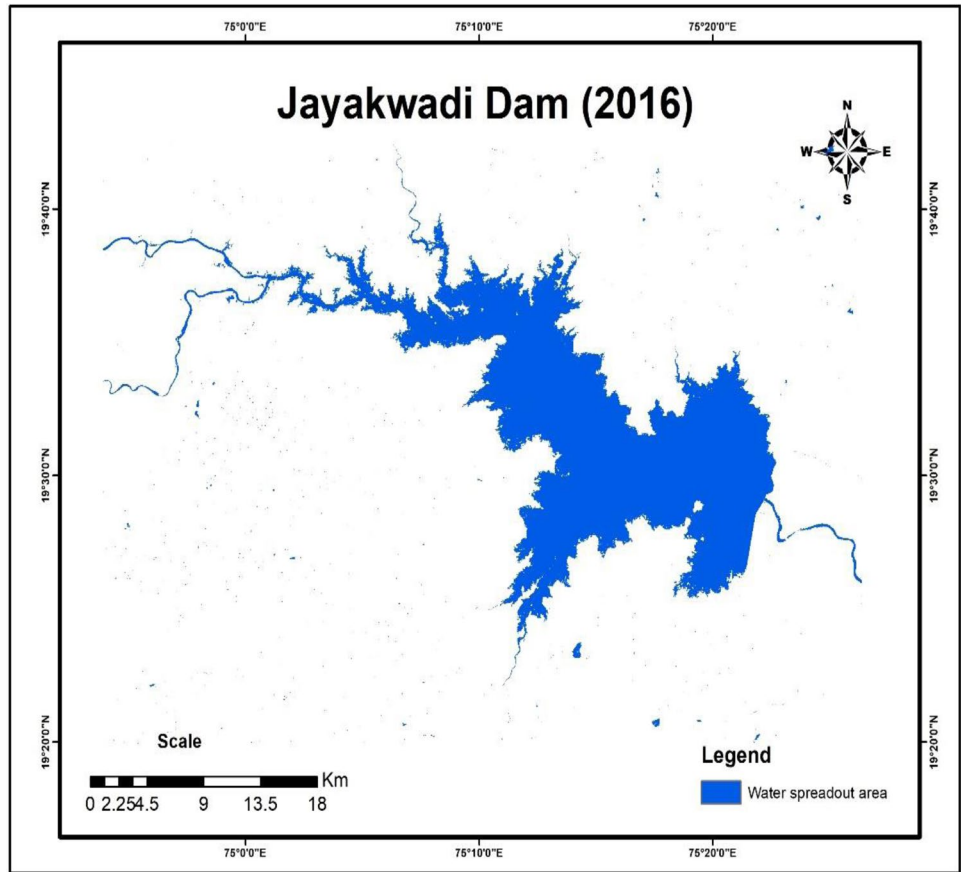


Fig. 7 Water spread-out area (2016)

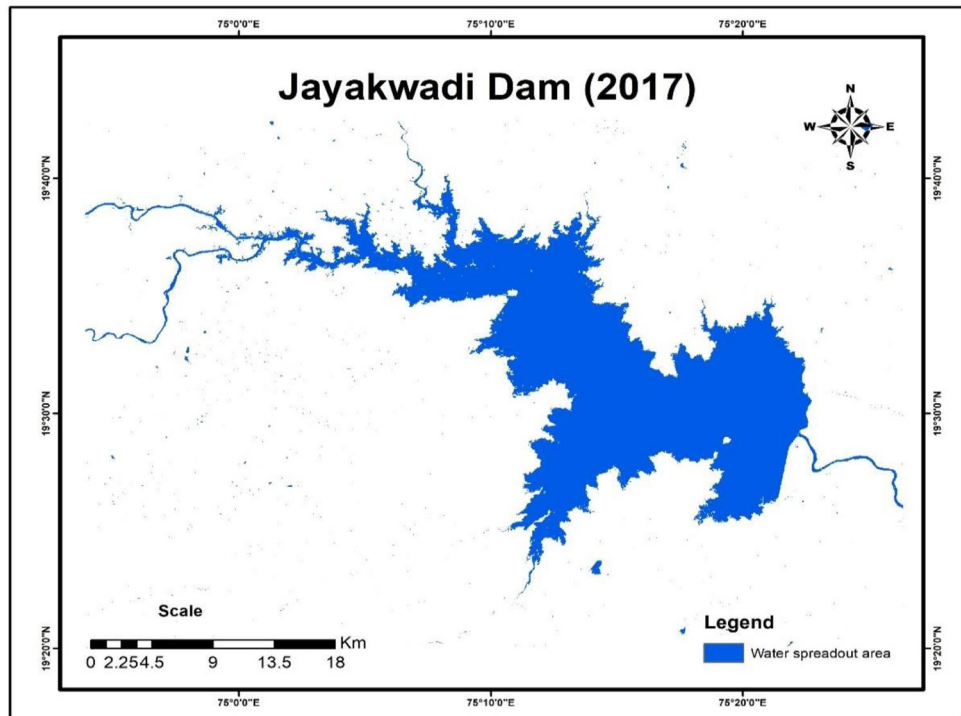


Fig. 8 Water spread-out area (2016)

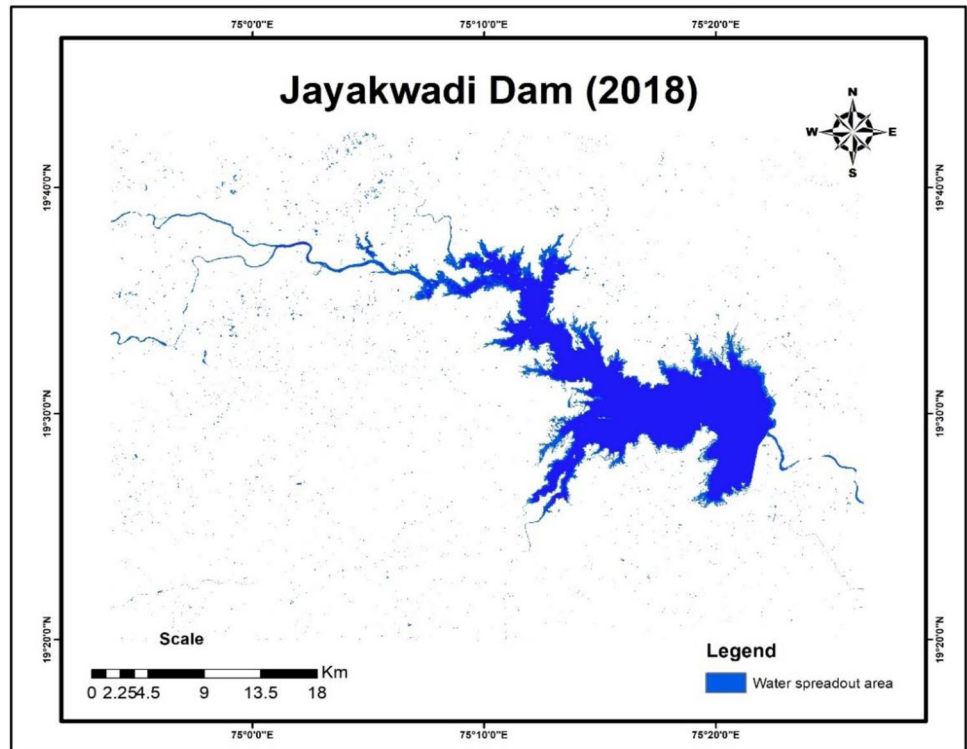
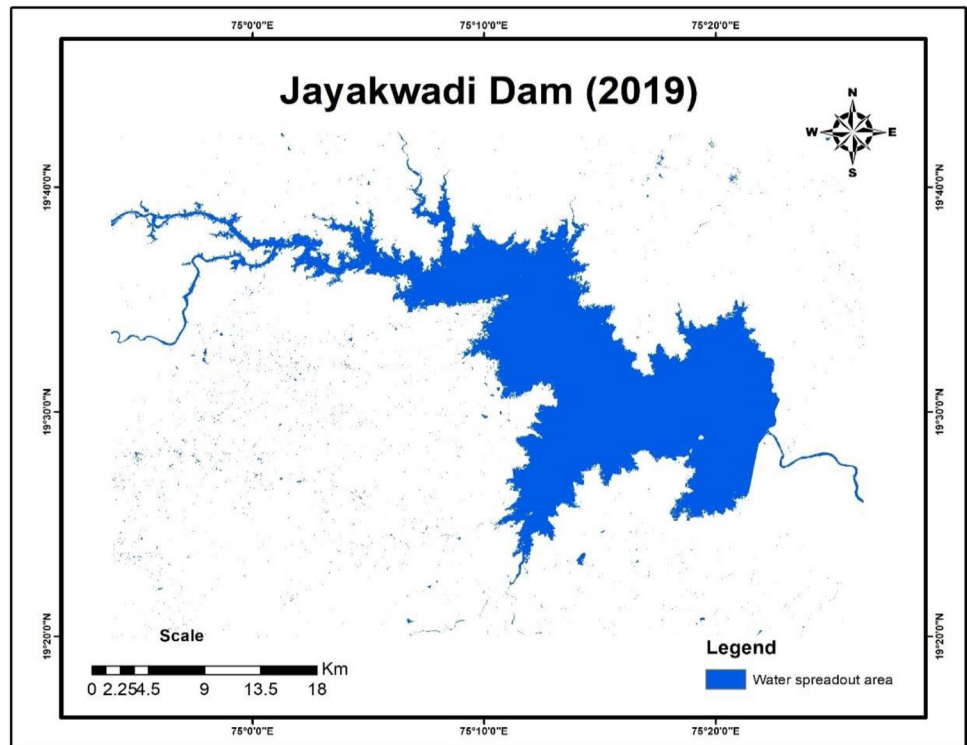


Fig. 9 Water spread-out area (2019)



as 410.9113 km² (Table 1 and Figs. 5, 6, 7, 8 and 9). So, it is seen from the results, from 2015 to 2019, there is much increase in the water area of the Jayakwadi dam due

to various reasons like pumping, heavy rain, etc. and this water can be used for various purposes and water management is very important in this manner.

Discussion

In this study, we have selected a 5-year for the analysis of the Jayakwadi dam, this study is totally based on the google earth engine and Sentinel-2 data. The underwater area was found 171.9684 km² during the year of 2015 using google earth engine. In the year 2016, under water area is 335.1256 km² which indicates that the water spread-out area increase is 163.15 km². In the next year, the area increased by 35.70 km² as compared to 2016 year. The area underwater area is 370.827 km² in 2017 Fig. 10. In 2018, the water spread-out area was identified as 208.42 km² in the dam which shows a decrease the waterbody by 162.40 km². In the year 2019, water area increased is the 202.4871 km² and water spread-out area under dam is 2019 and also found as 410.91 km². So, it has been seen from the results, from 2015 to 2019, there is much more increase in the water area in the Jayakwadi dam due to various reasons like pumping, heavy rain, and various climate change factors, etc.

This water may be used for different purposes, and water management in this way is very important. GEE not only saves image download times, but also greatly reduces the work cycle due to its strong interaction capacity and computer performance, so remote sensing science can analyze more time than waste during repeat processing. With the friendly support of GEE, we can get quick and easily vector information of the waterboard for additional hydrological element extraction. The vector information of this water body is provided.

The Jayakwadi Dam area of the water bodies on the Godavari River at the Jayakwadi village site of Paithan taluka district of Aurangabad in India's Maharashtra state is obtained from the common water body index method called NDWI, i.e. Normalized water differences index, using Sentinel-2 series data that can be found in the Google Earth Engine Data Catalog. Five years from 2015 to 2019 on Google Earth Engine platform have been calculated for the Jayakwadi

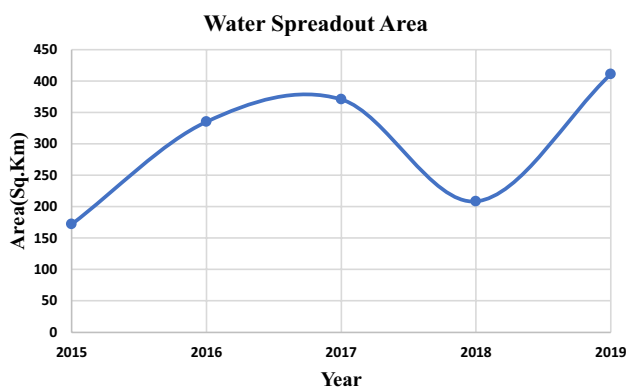


Fig. 10 Graph of year wise water spread-out area of Jayakwadi dam

dam's water distribution range. The GEE Platform is primarily visualized with Sentinel 2 data with a minimum cloud coverage for a specific year and time by coding, followed by the GEE image with the least cloud coverage with the lowest cloud coverage for minimum cloud coverage or cloud-free image.

Conclusion

The change in surface water resources is of great importance for the climate change and agriculture development in the semi-arid region. Changes in surface water have been caused by human activities, strongly affecting surface temperature, soil moisture, biological diversity, ecosystem functioning, and even human wellbeing. Therefore, monitoring the dynamics surface water is of great importance to planning of the natural environmental health and sustainable economic development. At present, many researchers have done a lot of research on the surface water extraction and dynamic monitoring by traditional method but current study is focused on the machine learning programming applied on the water extraction by google earth engine. The results of water body were extracted at the appropriate threshold by calculating NDWI index based on the Google Earth Engine. The water area expansion is 171.96, 335.12, 370.82, 208.42, and 410.91 km² during the different years of 2015, 2016, 2017, 2018 and 2019. These studies can be very useful for the monitoring of surface water in the dam and estimate the changes of water in the dam. As a cloud platform dedicated to data processing and analysis of geoscience, Google Earth Engine (GEE) supports online remote sensing image processing with many excellent remote sensing image processing algorithms. Through the friendly support of GEE for remote sensing image processing, we can easily and quickly obtain the vector information of the water body, which provides a basis for further hydrological element extraction. The change of reservoir water surface or dam can effectively reflect the change of water quantity. Analysis of its changing trends will help to monitor its water quantity changes and facilitate relevant departments to make scientific decisions. The approach will provide a new perspective on surface water research, and the results of this study will assist in the Google Earth Engine-based evaluation of water resource distribution and dynamics. Furthermore, this study also facilitates the development of appropriate water resource conservation and management strategies.

Appendix

Code for Accessing Image in GEE

```

var wetSeason = ee.ImageCollection('COPERNICUS/
S2');
print (wetSeason)
Code for Visualizing Image
var visParams = { bands: ['B4', 'B3', 'B2'], min: 0,
max:3000};
Map.setCenter (74.89, 19.75, 5);
Map.addLayer(wetSeason.clip(Studyarea), visParams,
'wetSeason');
Code for Mosaicing
var wetSeasonMosaic = wetSeason.mosaic()
var visParams = { bands: ['B4', 'B3', 'B2'], min: 0,
max:3000};
Map.setCenter(74.89, 19.75, 5);
Map.addLayer(wetSeasonMosaic.clip(Studyarea), visPar-
ams, 'Mosaicwet');
Code for Water Index Calculation
var NDWI = wetSeasonMosaic.expression(
'(GREEN-NIR)/(GREEN + NIR)',
{'GREEN':wetSeasonMosaic.select('B3'),
'NIR':wetSeasonMosaic.select('B8')
});
var visParams2 = { min:-1,
max:1,
palette:['yellow','black'],
};
Map.addLayer(NDWI.clip(Studyarea),visParams2,'ND
WI').
Export to drive
Export.image.toDrive({
image: NDWI,
description: 'NDWI_2019_10m',
scale: 10,
region: Studyarea});

```

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Feyisa GL, Meilby H, Fensholt R, Proud SR (2014) Automated Water Extraction Index: a new technique for surface water mapping using Landsat imagery. *Remote Sens Environ* 140:23–35

Gorelick N et al (2017) Google Earth Engine: planetary-scale geospatial analysis for everyone. *Remote Sens Environ* 202:18–27

Han BP (2010) Reservoir ecology and limnology in China: a retrospective comment. *J Lake Sci* 22(2):151–160

Huang Q et al (2018a) An improved approach to monitoring Brahmaputra River water levels using retracked altimetry data. *Remote Sens Environ* 211:112–128

Huang Q et al (2018b) Discharge estimation in high-mountain regions with improved methods using multisource remote sensing: a case study of the Upper Brahmaputra River. *Remote Sens Environ* 219:115–134

Ji HX, Fan XW, Wu GP, Liu YB (2015) Accuracy comparison and analysis of methods for water area extraction of discrete lakes. *J Lake Sci* 27(02):327–334

Jiang L, Nielsen K, Andersen OB, Bauer-Gottwein P (2017) Monitoring recent lake level variations on the Tibetan Plateau using CryoSat-2 SARIn mode data. *J Hydrol* 544:109–124

Khadri SFR, Pande C (2016) Ground water flow modeling for calibrating steady state using MODFLOW software: a case study of Mahesh River basin, India. *Model Earth Syst Environ* 2:39. <https://doi.org/10.1007/s40808-015-0049-7>

Lin QQ, Han BP (2001) Reservoir limnology and its application in water quality management: an overview. *Acta Ecol Sin* 21(06):1034–1040

Mcfeters SK (1996) The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *Int J Remote Sens* 17(7):1425–1432

Mei Y, Chang CC, Dong Z, Wei L (2016) Stream, lake, and reservoir management. *Water Environ Res* 88(10):1533–1563

Moharir K, Pande C, Patil S (2017) Inverse modeling of Aquifer parameters in basaltic rock with the help of pumping test method using MODFLOW software. *Geosci Front* 8(6):1385–1395

Moharir KN, Pande CB, Singh SK, Rio RAD (2020) Evaluation of analytical methods to study aquifer properties with pumping test in Deccan Basalt region of the Morna River Basin in Akola district of Maharashtra in India, groundwater hydrology. Intec open Publication

Pande CB (2020) Sustainable watershed development planning. In: Pande CB (ed) Sustainable watershed development: Springer Briefs in water science and technology. Springer, Cham. https://doi.org/10.1007/978-3-030-47244-3_4

Pekel J, Cottam A, Gorelick N, Belward AS (2016) High-resolution mapping of global surface water and its long-term changes. *Nature* 540(7633):418

Rokni K, Ahmad A, Selamat A, Hazini S (2014) Water feature extraction and change detection using multitemporal landsat imagery. *Remote Sens* 6(5):4173–4189

Rover J, Ji L, Wylie BK, Tieszen LL (2012) Establishing water body areal extent trends in interior Alaska from multitemporal landsat data. *Remote Sens Lett* 3(7):595–604

Tong LX, Yan Q, Luo CF, Du YK (2017) Water body information extraction based on NDWI segmentation and object oriented method. *Geospat Inf* 15(05):57–59

Unni NVM (1983) Forest survey and management using remote sensing. *Proc Indian Acad Sci Sect C Eng Sci* 6(3):209–232

Wang C, Jia M, Chen N, Wang W (2018) Long-term surface water dynamics analysis based on Landsat Imagery and the Google Earth Engine Platform: a case study in the middle Yangtze River Basin. *Remote Sens J* 10(10):1635

Wang X et al (2018) A robust Multi-Band Water Index (MBWI) for automated extraction of surface water from Landsat 8 OLI imagery. *Int J Appl Earth Obs Geoinf* 68:73–91

Xu RG, Qiao G, Wu YJ, Cao YJ (2019) Extraction of rivers and lakes on Tibetan Plateau Based on Google Earth Engine. *Int Arch Photogramm Remote Sens Spat Inf Sci* 42–2(W13):1797–1801

Lai Y, Zhang J, Song Y, Cao Y (2020) Comparative analysis of different methods for extracting water body area of Miyun Reservoir

and driving forces for nearly 40 years. *J Indian Soc Remote Sens* 48:451–463

Zhang BL, Jia RC, Zhang Q, Cheng G (2011) The water body area changes of Dalainur Lake based on satellite images of remote sensing. *Res Soil Water Conserv* 18(06):196–199

Zhang YF, Ai HB, Du QY, Zhang L (2014) Application of water extraction algorithm based on pyramid image segmentation in automatic aerial triangulation for island and reef. *Bull Surv Mapp* 12:70–73

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