Development of a Cloud-Based Application for the Assessment and Monitoring of Water-Bodies in Haryana

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Abstract

Remote sensing data sets provide temporal information about the ponds, and water bodies however a large data size and processing efforts are required for this making the constraints on the temporal information extraction. An online platform is developed using the Google Earth Engine (GEE) to visualize and analyze ponds and water bodies in the Haryana region. Sentinel-2 satellite images which provide multi-spectral data for land and water analysis were used as an input. The application performs various tasks including selection of Region of Interest (ROI), calculation, selection, and visualization of water mask based on Normalized Difference Water Index (NDWI), Interaction with User Interface (UI), and Charting and Data Visualization. A total of 40657 ponds and water bodies including government ponds, private ponds, waterworks, and other water bodies can be analyzed using the current application along with 15163 historical ponds and water bodies. This application can be used and expanded for other regions to analyse and monitor the water bodies and ponds that may support water resource management and its sustainability.

Key Words: Google Earth Engine (GEE), NDWI, Historical Ponds, Haryana, Satellite Image

Introduction

Land surface water bodies such as rivers, lakes, and ponds are significant for the global ecosystem and climate system. The availability of fresh water is highly seasonal since the country's weather is mainly governed by a monsoon climate. This seasonality is reflected in its abundance during the monsoon followed by its scarcity in early summer (Chowdhury, 2010). Conservation of rainwater and scientific management of water bodies in the country is the only way to overcome the early summer droughts. Water conservation to prevent rainwater wastage through sloped areas, rivers, and rivulets is essential for sustainable water management, and various techniques are being used to check this wastage which involves rainwater harvesting through gully plugs, contour bunds, gabion structure, percolation tanks, check dams, recharge shaft, dug well recharge and groundwater dams/ subsurface dyke (Pala et al., 2021).

The government of India has implemented several policies and laws to address water-related issues, such as The National Water Policy, National River Conservation Plan, and the National Water Mission (Siddiqui et.al 2008). Surveying land surface water bodies and their spatial distribution has great significance in understanding hydrology processes and managing water resources (MacKay et.al 2009). Surveying water bodies provides an integrated evaluation of water systems' physical and biological characteristics in relation to, ecological conditions, and designated uses (Hadjimitsis et.al 2010). Monitoring of existing aquatic reservoirs helps in planning water management, early determination of localized floods, water budgeting, etc. (Trysnyuk et. al., 2021). However, the monitoring and evaluation of these waterbodies in situ involves challenges that can be very expensive and time-consuming. These challenges have been tackled by remote sensing and satellite imagery in recent days (Yigit Avdan et al., 2019).

In the past few decades, remote sensing techniques and capabilities have been studied for monitoring several water quality parameters (Su et al., 2003). Remote sensing is an effective tool for water and water level monitoring (Crétaux et al., 2011), water demand modeling (Ines et al., 2006), groundwater management, flood mapping (Feng et al., 2015), and water quality monitoring (Andres et al., 2018). It has been found that remote sensing is a valuable tool for providing complete and synoptic geographical coverage of water status in freshwater systems (Weiqi et al., 2008). The Moderate Resolution Imaging Spectroradiometer (MODIS) image is widely used for monitoring water surface variation in time series (Özelkan et.al 2020). European Space Agency (ESA) launched a new Optical fine spatial resolution satellite, namely Sentinel-2 that is dedicated to supplying data for Copernicus services, Sentinel-2 carries a multi-spectral image with a swath of 290 km (Caballero et.al 2019). The image provides a versatile set of 13 spectral bands spanning from the visible and near-infrared to the shortwave infrared, featuring four spectral bands at 10 m, six bands at 20 m, and three bands at 60 m spatial resolution.

Various methods have been developed, including single-band density slicing, unsupervised and supervised learning classification, and spectral water index to extract water bodies using the geospatial approach. Normalized Difference Water Index (NDWI) is used to monitor changes related to water content in water bodies. As water bodies strongly absorb light in the visible to infrared electromagnetic spectrum, NDWI uses green and near-infrared bands to highlight water bodies. It is sensitive to built-up land and can result in overestimation of water bodies. The index was proposed by McFeeters, 1996. NDWI uses sentinel-2 image two Bands which are Green Band(B03) and Near Infrared Band (B08) over the Region of Interest (ROI) which is the Haryana state. Hence, to monitor and manage water-related issues, remote sensing and geospatial approaches can be employed.

Since other studies like McFeeters (1996), and Özelkan (2020) has tested and suggested the NDWI as a potential indicator for the water applications and it is less explored in the context of Haryana, the same must be explored for a soft real-time automated water extent monitoring. Present study is focused mainly, for the development of a cloud-based system to monitor the water extent in the waterbodies of Haryana automatically. It has potential to be applied for the other regions as well. Among all the existing methods, the Normalized Difference Water Index (Singh et.al 2021) using green and near-infrared bands (NIR) is used for the extraction of water bodies of Haryana state by utilizing Google Earth Engine (GEE) which can be expended to SAR-based thresholding during cloudy days.

Study Area

Geographically Haryana state is located northwest of India. It is bounded on the northwest by the state of Punjab and the union territory of Chandigarh, on the north and northeast by the states of Himachal Pradesh and Uttarakhand, on the east by the state of Uttar Pradesh and the union territory of Delhi, and on the south and southwest by the state of Rajasthan.

The Haryana state covers an area of 44,212 sq. Km. The coordinates of Haryana are between 27°39' and 30°35' north latitudes and 74°28' and 77°36' longitude (Singh et al., 2022). The location map of the study area on satellite image is shown in Figure 1. Shapefile or GeoJSON within the area of interest are uploaded on the earth engine as an asset in Google Earth Engine (GEE) (Rana et.al 2022).

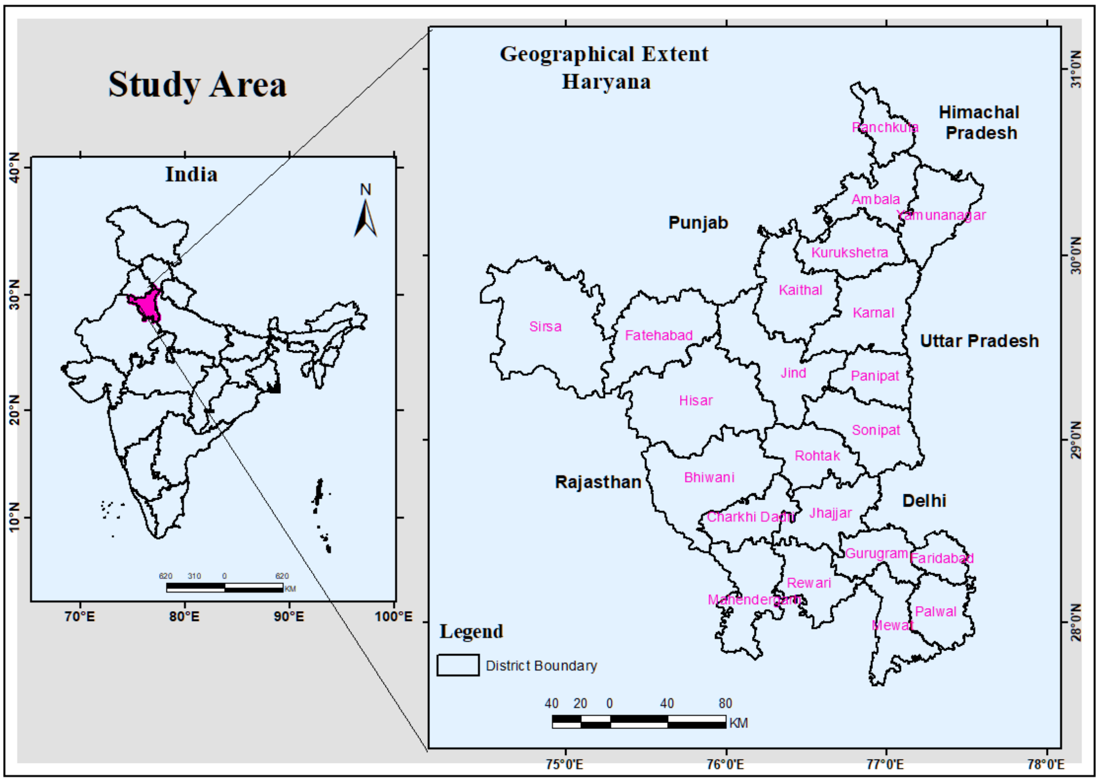

Fig. 1 The geographic location of the area of study. **(Source:** https://hsac.org.in/pond_acreage/)

Materials and Methods

The datasets utilized for the experiment encompasses water body polygons representing currently available Government Ponds, Private Ponds, and other waterbodies in the Haryana state. Along with this another set of databases representing Historical Ponds are also provided. The remote sensing data is provided from https://scihub.copernicus.eu/ with a spatial resolution of 10m. The specifications of the satellite data used in the current facility are given in Table 1. The imagery was subset through the GEE of the concern area of interest i.e. ponds and waterbodies of Haryana state for the analysis. The layers of water bodies were collected from the HARSAC. The flow chart regarding the methodology carried out is depicted in Figure 2. In the given methodology, Normalized Difference Water Index (NDWI) was used for the extraction of water bodies, and a graphical user interface (GUI) was used for the visualization in GEE platform. The NDWI changes dynamically, according to the change in the threshold values, date ranges and datasets.

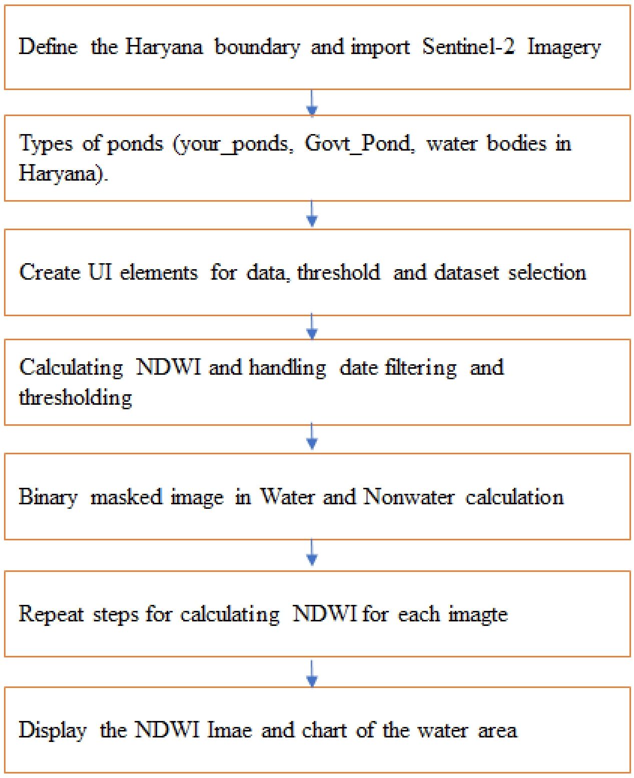

Fig. 2 Work flow of methodology.

Table 1: Specification of satellite data used for the experiment.

Sentinel-2 Band	Wavelength(µm)	Resolution(m)
B03- Green Band	0.560	10
B08- Near Infrared Band	0.842	10

Normalized Difference Water Index (NDWI): The NDWI is a spectral index used to identify water bodies in satellite imagery (szabo et al., 2016). It is particularly sensitive to the presence of water and has been widely employed for water body detection (McFeeters, 1996). The NDWI is calculated using the following formula:

$$NDWI = NIR + Green/NIR - Green$$

The NIR band of the satellite image represents the Near-Infrared band, and green represents the green band. The range of NDWI varies from -1 to 1, where higher values indicate the presence of water. A threshold value for NDWI was established to discriminate water and non-water areas. The threshold value was chosen based on the characteristics of the study area and the satellite data. To represent water mask on the GEE platform the value above threshold is represented as 1. Value 0 represents areas where the NDWI value does not exceed the threshold. These areas are identified as non-water areas. The resulting binary image represents water and non-water areas, with water pixels set to 1 and non-water pixels set to 0.

For each pond in the datasets, the water area was computed using the masked NDWI images. The masked NDWI images were multiplied by the pixel area and divided by a factor to convert the area from square meters to hectares. The sum of water pixel areas within the polygonal boundary estimates the water area for each pond. The processed binary images and water area calculations were visualized using interactive maps in the GEE interface. Users shall be able to click on specific ponds to view the water area and corresponding charts comparing the selected pond's area with its water area over time. As a part of the methodology, a sensitivity analysis was conducted to assess the impact of changing the threshold value and date change for water detection however results are not shown here.

Graphical User Interface: JavaScript was employed to create graphical user interfaces (GUIs) for the analysis, visualization, and calculation of water bodies in the Haryana region. One layer of the water body is placed on the Google Earth Engine (GEE) and one layer is of NDWI. Here, two date pickers one is for start date selection and the other one is for end date selection was given. The NDWI would dynamically update by clicking on the 'select date' which will select the data from the start-date and end-date within that date range. One text box was programmed to select the NDWI threshold value and one drop-down window which was used to select different datasets from the GEE Cloud. Whenever changes are made in variables like threshold value, or date range selection then the real-time update on the map can be visualized using GUI. A drop control panel was given on the left side of the website to select the date, threshold value and data set selection.

Every water body in the datasets is considered as area of interest and while clicking on any water body, binary classification would give the water area. For each and every click, one layer is uploaded on the map which includes the Masked water body and a column graph of the water body, so that the water area will be generated automatically to visualize and analyse the changes whenever changes happen in the date range and threshold value.

Results and Discussion

The application of the NDWI from Sentinel-2 satellite imagery to extract water extent is combined with the datasets of ponds/waterbodies of the Haryana region have been explored. The results of the experiment are explained in forthcoming sections.

The initial step in the study was to set the threshold value in order to differentiate the water body and non-water body. From the analysis it is was found that the threshold value of a waterbody is 0.01 for an optimum condition and thus default value is set to be the same. Figure 3 shows the screenshot of the cloud-based tool developed to identify the water bodies in the state of Haryana and to analyze its water extent. The desired water body can be selected from the search option and the water area can be obtained by filling up the information in the control panel which is provided at the upper corner of the GUI. From the figure, it was proven that the tool had successfully identified all the water bodies in the Haryana state.

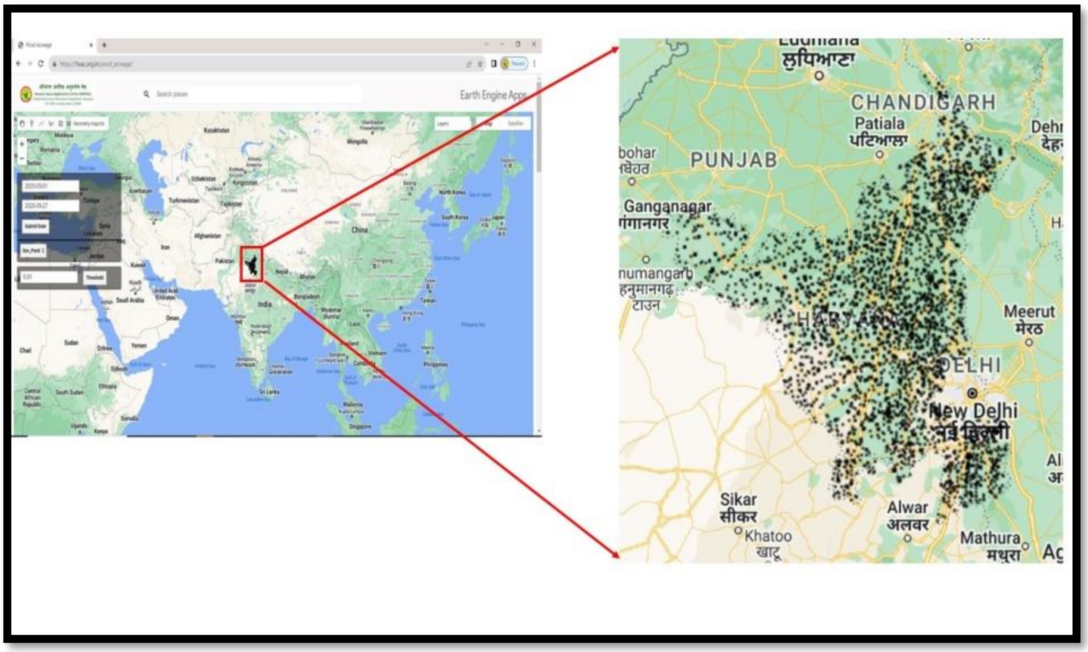

Fig. 3 Cloud-based tool for identifying water bodies in Haryana. (Source: https://hsac.org.in/pond_acreage)

Here, Figure 4 shows the water area in a selected ponds/waterbody during four periods i.e., 2019 (Figure 4a), 2020 (Figure 4b) 2021 (Figure 4c), and 2022 (Figure 4d). The date is in year-month-day format. Threshold-based water detection produced binary images, and water pixels were assigned a value of 1, and non-water pixels were assigned a value of 0 (Figure 4a to 4d). These binary images were allowed for the mapping of water bodies across the study area. This was generated by masking the image after setting the threshold value by changing the date using the 'date picker' and observing for different time ranges within the same water body. The image shows that all water bodies showed accurate water areas such that water area tends to increase during the monsoon season. From the Figures, it was understood that water area calculated during different years i.e., 2019, 2020, 2021, and 2022, was gradually increasing with respect to year probably due to meteorological events or some water conservation practices. The same needs a ground verification.

Figure 5 shows the water area of the same water body in a bar chart for the time period between 2020-05-01 and 2020-05-27 by using a threshold value of 0.01. This chart was obtained by clicking on the waterbody on the GEE cloud platform. The first column of the chart represents the total area of the waterbody and second column represent the water are in the waterbody. The water pixel area was combined to get the second column of the chart presented in Figure 5.

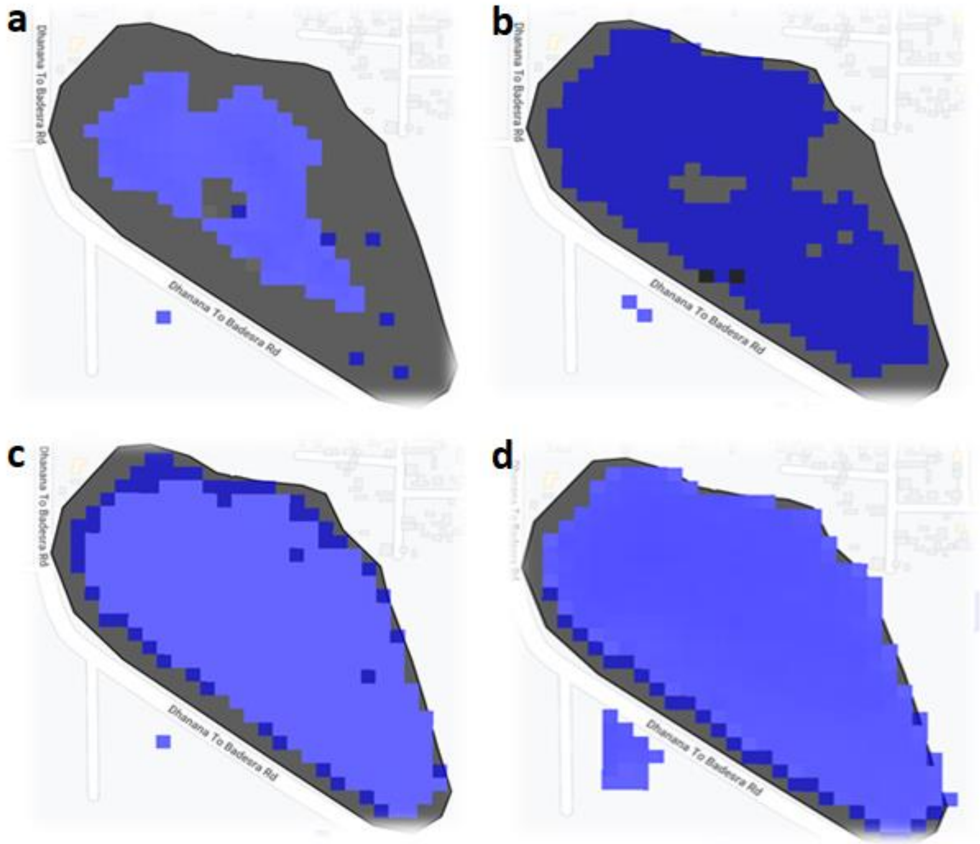

Fig. 4 Water area in the water body during four years. **(a)** 2019-05-01 - 2019-05-27. **(b)** 2020-05-01 - 2020-05-27. **(c)** 2021-05-01 - 2021-05-27. **(d)** 2022-05-01 - 2022-05-27.

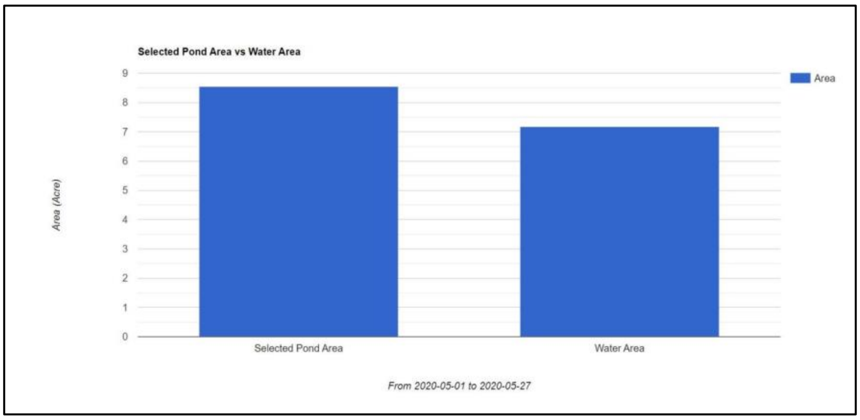

Fig. 5 Chart showing Waterbody area Vs. Water area.

Conclusion

The cloud-based tool performed well in detecting the water bodies and water extent of Haryana state and also showed that it can estimate the water area on a soft-real time basis based on the NDWI values. It also detected the variations in water area during the monsoon periods over past years i.e. since the data availability. Therefore, this cloud-based tool can be used for surveying and periodical monitoring of water bodies which reduces the time, manpower and efforts required for the field-based survey methods or satellite-based analysis methods done in the workstations. This interface will reduce the requirement of hardware storage also as all the analysis is done on cloud-bases computing. This tool can be improved further by adding historical data sets and can be used for research and development activities as well. The facility can also be expanded for other part of the globe.

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