# DEVELOPMENT OF A GOOGLE EARTH ENGINE BASED APPLICATION TO MONITOR THE SEASONAL WATER SPREAD AREA OF RIVER GANGA

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**ABSTRACT:**

The National River Ganga, home to the National aquatic animal, Gangetic dolphin along with species of critically endangered otters, gharial crocodile, turtles, waterbirds and numerous aquatic and semi aquatic life forms is of conservation importance to safeguard the biodiversity it harbors. Meanwhile, River Ganga is also the source of highly productive agricultural yield that satiates the nation's food demands. The last few years have echoed demands for 'e-flow' regulations to be formalized and regularized to maintain healthy river conditions with adequate amount of water retained in the rivers while meeting the populations demand for water supply. Though e flow estimations are a complex science in itself, the simplest way is visualization. In this context, there needs to be a transparent mechanism to picturise and depict the ground conditions of the river stretches. Remote sensing provides 'eyes in the sky'. The river receives water in the form of precipitation, snow melt and ground water recharge and the hydrological flux is evident in the surface water. Thus delineating the water spread area can provide a crude estimate of the water in the river. The Google Earth Engine platform provides a collection of satellite imageries, server side data processing and algorithms. The Landsat and Sentinel data catalogue offers good coverage of the river and its basin. Though sentinel data provides high ground resolution of 10m, Landsat provides multi temporal historic coverage at a good 30 m resolution, that works well for the main stem river. From the various available data processing methods, spectral decomposition technique of Modified Normalised Differential Water Index MNDWI was found to be most effective in delineating surface water. Data was filtered for the three major seasons of Pre monsoon, Monsoon and Post monsoon periods and MNDWI for the same was visualized. While Middle Ganga region through Uttar Pradesh shows seasonal flooding during the monsoon period, the Lower Ganga after the confluence of major tributaries of Son, Ghaghra, Gandak and Kosi flows in full bank width in the Post monsoon period. During the pre monsoon period many stretches of Ganga particularly the Upper middle stretch showed thin shallow channel and intermittent deep pools disconnected by dry sand beds. These regions result in disruption in the river flow and are priority sites to implement e flow regulations. Another key factor is the regulation of flow in the river from barrages. Sudden release of water can cause flooding resulting in disturbance to the life cycle of species that are tuned to the natural annual hydrological pulse of the river. This is because different aquatic species have different river width and depth requirements. Thus monitoring the seasonal variations in the water spread area helps to note the longitudinal and lateral connectivity of the river which is a prime characteristic for the health of a river. This study intended to create an application that offers to visualize the seasonal water spread in the Ganga river for the past years that can assist decision makers to monitor the river and make informed regulatory measures.

## 1. INTRODUCTION

### 1.1 Status of freshwater resources

Rivers have not just shaped Earth's continental landscapes but also shaped the history of human civilizations (Twidale, 2004). But still, despite all the developments of the 21st Century, providing safe drinking water to the growing population is still one of the world's greatest challenges (Oelkers, Hering, & Zhu, 2011). High human pressure on water bodies and rivers have created extreme necessity for river basin management (Campbell, 2016). In the current world scenario, the management of river basins are becoming more challenging due to change in land use, climate, and excessive water use. As per a global study, the largest basins of the world are dammed, thereby reducing the geomorphic processes, biodiversity and ecosystem services provided by free flowing rivers. These regulatory mechanisms implied on rivers have altered their natural flow regime (Grill et al., 2019).

The concept of Environmental flows attempts to understand the adequate amount of water flow in a freshwater system required to sustain the aquatic ecosystem and support human societies. E-flows are estimated by measuring water flows qualitatively and quantitatively- usually the flow discharge, flood and lean period, frequency, duration, high and low flows etc. (M C Acreman & Ferguson, 2010). Excessive water withdrawal for human use leaves very little water in the river to continue its self- regulatory and ecological functions. On the contrary, hydro-peeking or sudden release of water from reservoirs can also affect the life cycle of fresh water species downstream by increasing the water level, drowning or washing away of eggs, hatchlings etc. (Bejarano, Jansson, & Nilsson, 2018; Poff et al., 1997). Thus, knowledge of e-flows can help in RBM by providing margins for regulation of water abstraction and release of water from reservoirs based on ecologically appropriate flow.

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### 1.2 Ecohydrological requirement of Freshwater Ecosystems

Fresh water ecosystems include not just aquatic zone but also as littoral, riparian and floodplain zones and the ecological flow regimes also vary with each of these type of systems. E-flows also differ with characteristics of the basin, type of river ecosystem and the ecological demand of the aquatic and semi aquatic species. Predominantly, it is the flow, along with temperature and substratum that governs the species distribution in freshwater habitats. Water flow can play various functions during various parts or season of the year such Channel flushing, habitat maintenance, spawning or fish migration (Michael C Acreman & Dunbar, 2004)

### 1.3 Remote sensing of fresh water ecosystems

Surface water is the most accessible form of water resource and hence spatial distribution of freshwater is important. Remote sensing provides 'eyes in the sky' (Harper, 1986) for visualising Land use land cover (LULC) change, estimation of water extent, water quality, surface water inventory mapping and health monitoring etc. (Acharya, Subedi, & Lee, 2018; Kuhn, 2021). Recent advancement in remote sensing have promoted the field of detection, extracting, analysing of surface water with greater accuracy. Spectral decomposition techniques, SAR, LIDAR based inundation techniques have facilitated quantitative as well as qualitative assessment of waterbodies (Palmer, Kutser, & Hunter, 2015).

### 1.4 Google earth engine (GEE)

Creation of second generation of world wide web (WWW) in 2012 and after gaining the popularity of Big Data in 2016 (Halevi & Moed, 2012), Geo big data is now become the global attention and interest of academia, scientific community, policy makes and many organisations. Large collection of varying data especially sensors based comes with the challenge of handling the data, verifying correctness and get desired output quickly (Li et al., 2016). This problem can be addressed through high performance computing (HPC) cluster systems, where thousands of computing server networked together or cloud based infrastructure where operating system and hardware of a server in an Internet-based data centre (Ma et al., 2015). In comparison to HPC, Cloud computing system performs better and is gaining popularity, as it does not require licensing, storage in local drive and loading and processing of memory data. Multiple cloud based platforms such as Microsoft Azure cloud services, Amazon web services (AWS), Data and Information Access Services (DIAS) European commissioned, NASA Earth Exchange (NEX) etc. AWS and Azure was widely used platforms but both are paid platforms. Google Earth Engine (GEE) (https://code.earthengine.google.com), was launched in 2010 by Google and currently it is free to use in research, education, and non-profit use (Agapiou, 2016b; Gorelick et al., 2017). This cloud based geospatial processing infrastructure for earth science data analysis provides 1) An interactive developmental platform, easy to access data, scientific algorithm with vast amount of publicly available data which we does not need to store or archive in local computer. 2) User friendly way to begin exploring and analyzing data by point and click interactions for basic analysis for non-programmers and 3) fast-speed parallel processing and machine learning algorithms (Gorelick et al., 2017; Schmid, 2018). GEE provides pre-processed datasets and more than 800 functions, which users can access to efficiently handle Earth observation datasets and share in Drive, Asset and cloud storage (Gomes, Queiroz, & Ferreira, 2020). In a research (Hansen et al., 2013), 654178 images (~700 TB) from Landsat 7, with GEE it tooks only 100 hr to produce global map of forest which would have traditionally been impossible taking millions of hours. GEE webpage includes code editor section, resource directory, console area and display of map area. In code editor section users can write and execute scripts in JavaScript/Python Application programme interface (API) to develop, share and manage scripts by accessing GEE data catalog and processing workflows. To share the script and assets with other user in this platform is possible. It provides reproductibity of science by sharing code and allowing other platforms for analysis for example RGEE is an Earth Engine (EE) client library for R software (Aybar, Wu, Bautista, Yali, & Barja, 2020). EE also provided the facility to develop Apps, which are dynamic and shareable, with simpler user interface, accessible by generated URL. Publishing the App is user friendly, cost free.
We have developed a GEE based application to monitor the seasonal water spread area of River Ganga

## 2. METHOD

### 2.1 Study Area

The current study area Ganga River basin as shown in Figure 1. is a unique ecosystem, comprising of five biogeographic zones, bounded by the Himalayas on the north, by the Aravalli on the west, by the Vindhyas and Chhotanagpur plateau on the south and by the Brahmaputra Ridge on the east. The basin lies between east longitudes 73°2' to 89°5' and north latitudes 21°6' to 31°21' has maximum length and width of approx. 1,543 km and 1024 km. The Ganga is declared as the National River and is home to numerous aquatic and semi aquatic species approximately 5 species of Mammals, 177 species of aquatic birds, 27 species of reptiles, 11 species of amphibians, 378 species of fishes and more. These include the Gangetic River dolphin (*Platanista gangetica gangetica*), three species of Otters viz. the Smooth-coated otter (*Lutrogale perspicillata*), Eurasian otter (*Lutra lutra*) and the Small clawed otter (*Aonyx cinereus*), the critically endangered Gharial (*Gavialis gangeticus*), Mugger or Indian marsh crocodile (*Crocodylus palustris*), Estuarine crocodile (Crocodylus porosus) and 15 species of turtles (Sinha, 2015). Many of these freshwater species are endangered, critically endangered and vulnerable as per IUCN redlist. The principal tributaries joining the river are Yamuna, Ramganga, Ghaghra, Gandak, Burhi Gandak, Kosi, Mahananda and Sone, each with its unique set of riparian biodiversity. Chambal and Betwa are also the two other important sub-tributaries (Bhawan & Puram, 2014).

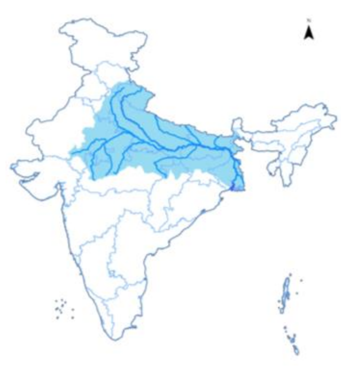

Figure 1. Study area of Ganga River Basin

Meanwhile the Ganga Basin is also the source of highly productive agricultural yield that satiates the nation's food demands. Being one of the most populous basins of the world, the basin has undergone large scale land use land cover transformations (Behera et al., 2014). Constant efforts by government in the last few decades has improved awareness and public interest in the issues faced by rivers (Hasan, 2015). Citizen science is not only gaining popularity but also proving to be effective in water quality monitoring, pollution abatement, plantation geotagging and biodiversity monitoring (Dwivedi, 2021; Kumar, Sinha, & Kanaujia, 2019; Oberoi et al., 2018). The last few years have echoed demands for 'e-flow' regulations to be formalized and regularized to maintain healthy river conditions with adequate amount of water retained in the rivers while meeting the populations demand for water supply. Though e-flow estimations are a complex science in itself, the simplest way is visualization. In this context, there needs to be a transparent mechanism to picturise and depict the ground conditions of the river stretches.
This study aims to provide a platform to visualise the seasonal hydrodynamic changes in the surface water of Ganga and its tributaries to visualise the water availability in rivers, and there by to make informed management decisions and adopt water conservation strategies to move towards an 'aviral' Ganga that flows uninterrupted.

### 2.2 Dataset

Landsat 8, launched in March 2013, provides with a 16 day revisit, data in 11 bands at a resolution of 30 m depicted in Table 1. It is efficient for monitoring water bodies (Roy et al., 2014).

| Name | Resolution (meter) | Wavelength (µm) | Description |
|---|---|---|---|
| B1 | 30 | 0.43- 0.45 | Coastal aerosol |
| B2 | 30 | 0.45- 0.51 | Blue |
| B3 | 30 | 0.53- 0.59 | Green |
| B4 | 30 | 0.64- 0.67 | Red |
| B5 | 30 | 0.85- 0.88 | Near infrared |
| B6 | 30 | 1.57-1.65 | Shortwave infrared 1 |
| B7 | 30 | 2.11-2.29 | Shortwave infrared 2 |
| B8 | 15 | 0.52-0.90 | Band 8 Panchromatic |
| B9 | 15 | 1.36-1.38 | Cirrus |
| B10 | 30 | 10.60-11.19 | Thermal infrared 1, resampled from 100m to 30m |
| B11 | 30 | 11.50-12.51 | Thermal infrared 2, resampled from 100m to 30m |

**Table 1**. Band Specifications USGS Landsat 8 Collection 1

### 2.3 Methodology

Multiple methods has been evident for extraction of waterbodies from optical satellite imagery. The near infrared radiation (NIR) band is preferred as shows dark color of surface water because of strong water absorption. Combining Red band (R) with NIR to formulate NDVI (normalized difference vegetation index), can delineate the water and non-water object (Tucker & Sellers, 1986). NDWI (normalized difference water index) enhanced this index by replacing the R band to green band (G), which aims to enhance water features using the high reflectance of water in the green band, and low reflectance in the NIR band (McFeeters, 1996). However, the NDWI cannot efficiently suppress signals from built-up areas; moreover, water features are still interspersed with noise from other features (Xu, 2006). To rectify this problem, the NDWI was altered to form the modification of normalised difference water index (MNDWI) (Xu, 2006), which utilizes shortwave infrared radiation (SWIR) that has a lower reflectance from water than NIR. MNDWI enhances the water features and gives better performance as compared to other Indices (ÖZÇELİK, Mehmet; SARP, 2020; Szabó, Gácsi, & Balázs, 2016; Zhang et al., 2018). For our study, we have applied the most widely used Modified normalized difference of water index technique for observing seasonal variation in our study area. The details of MNDWI are shown in Table 2.

| Band Index | Formula | Range value (water) | Landsat bands |
|---|---|---|---|
| MNDWI | (Green-Shortwave Infrared)/ (Green + Shortwave Infrared) | 0 to 1 | B3, B6 (Green, Shortwave infrared -1) |

Table 2. Band Specifications USGS Landsat 8 Collection 1

#### 2.3.1 Visualisation of water bodies

The Landsat 8 cloud free data from the year 2013 to 2021 was filtered from the GEE library, clipped for basin area, stacked season-wise using reducer command and band ratio was calculated using green, red and near infrared band that depicted water index (Agapiou, 2016a; Markert et al., 2018). For Landsat, the cloud score algorithm in ee.Algorithms.Landsat.simpleCloudScore() method to add a cloud score band (Mateo-Garciia, Gómez-Chova, Amorós-López, Muñoz-Mari, & Camps-Valls, 2018) was used. A mask from cloud score was created and applied to the image. A zipped shapefile of Ganga river basin was uploaded in EE assets storage, which was further used for clipping the earth engine datasets. To filter date of cloud free data, simple cloud score was applied to the selected median of least cloudy pixel using the ee.Algorithms.Landsat.simpleComposite () method provided by EE, further the dates were filtered based on season. The resultant histogram reduction was performed through Otsu threshold algorithm. Otsu's method is a type of non parametric binary thresholding that can be used for unsupervised classification based on histogram and image segmentation and extraction of water bodies using Google Earth Engine (Du et al., 2016; Otsu, 1979). After calculating Otsu's threshold value for landsat data image.reduceRegion (ee.Reducer.histogram()) function was applied and the image was clipped using the Ganga basin boundary. The Otsu threshold was further fine-tuned for accurate water extraction based on iterative trial and error method and a threshold of 0.3 in pre monsoon season and 0.25 in monsoon and post monsoon season for MNDWI gave appropriate results. The MNDWI was visualised in a colour band palette. The inundation frequency mapping (Dong, Liu, Hu, & Xu, 2019) visualises the times a pixel is classified as water within the given time frame. This analysis is very useful to understand the natural flow regime and hydrographs.

### 2.3.2 Spatial Extent

Ideally, we need to consider the Ganga river and the connected water networks. But, the entire basin is very large and consists of other water bodies, reservoirs, tanks and ponds. So, for the ease of calculation, we have considered the Ganga river's floodplain and a 2 km area around it. The changes in the spatial extent of water in this region were observed for various seasons from 2014 and 2021. Pre monsoon period was considered from January to May, Monsoon season from June to September and Post monsoon from October to December as per the rainfall trends in the Ganga Basin (Bera, 2017). The spatial extent was quantified and area statistics were calculated from pixel counts.

### 2.3.3 GEE based application

To publish an App in GEE after execution the code the Apps tab was accessed, which is above the code editor section and left to Run and Reset tabs. A panel under App tabs is Apps management where user can create new App, Remove, modify as desired. (https://developers.google.com/earth-engine/guides/apps). In the app framework we have given a split screen as per Season (pre monsoon, monsoon and post monsoon), and dropdown menu where user can select year. After selecting the desired input user, have to put the load button. A spatial view of MNDWI will come. Visual keys such as dam or barrage location, important habitats such as Protected areas, Ramsar sites, Important Bird Areas etc. are marked as monitoring sites from conservation point of view. User have the option to edit the pallet colour from choice.

## 3. RESULTS

The resultant image highlights the Ganga river and the influent tributaries. The oxbow lakes, riverine wetlands are also delineated. The variations in MNDWI can be attributed to the difference in depth and water quality parameters that can influence the reflective properties of water. Landsat 8 data was found to decently delineate river and other water bodies in the Ganga river basin shown in Figure 2..

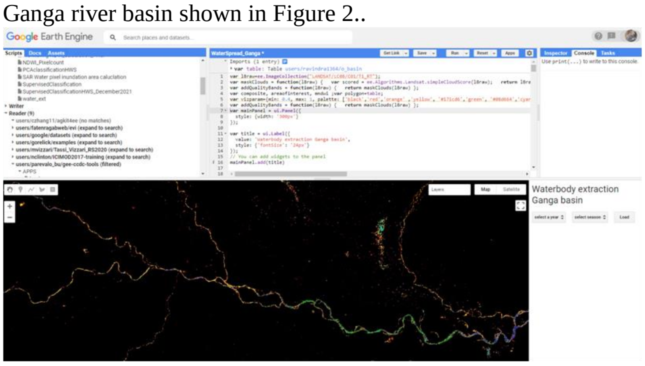


Figure 2. GEE framework

### 3.1 MNDWI visualisation

| (a) OTSU's method in MNDWI | | | |
|---|---|---|---|
| | Pre monsoon | Monsoon | Post monsoon |
| 2014 | -0.318618 | -0.277216 | -0.266647 |
| 2015 | -0.314901 | -0.283204 | -0.276625 |
| 2016 | -0.314444 | -0.267711 | -0.270715 |
| 2017 | -0.311146 | -0.276695 | -0.265572 |
| 2018 | -0.305940 | -0.264096 | -0.270319 |
| 2019 | -0.311638 | -0.278428 | -0.244462 |
| 2020 | -0.315414 | -0.255992 | -0.262264 |
| 2021 | -0.305729 | -0.252744 | -0.251555 |
| **(b) Landsat Pixel count** | | | |
| 2016 | 150301670 | 153527717 | 178447143 |

Table 3. (a) Otsu Threshold value for Landsat images of Ganga Basin. (b) Landsat pixel count value showing spatial extent

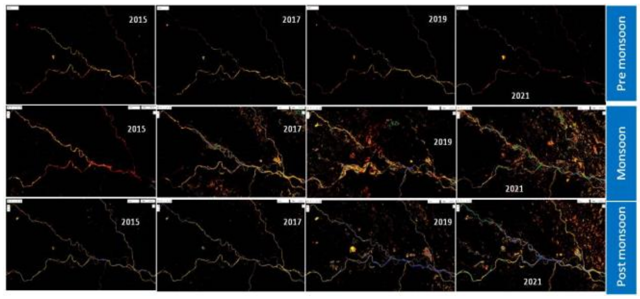


Figure 3. Temporal changes in water extent in river system

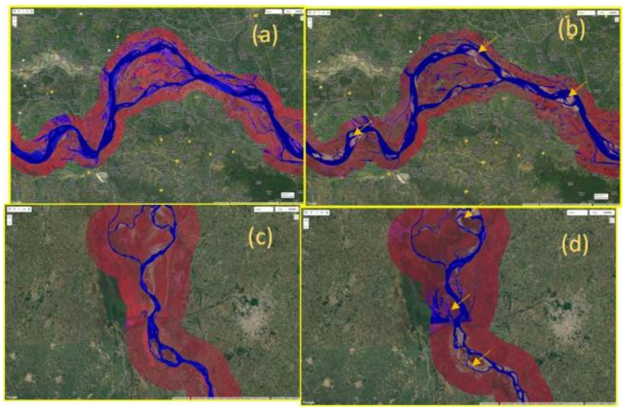


Figure 4. Frequency inundation during Monsoon and Post monsoon period near Bhagalpur, Bihar (a,b); Bijnor Barrage (c,d)

The spatio-temporal changes in stream networks is depicted in Figure3. Changes in the river course through different channels from 2015 to 2021 can be observed. The riverine wetlands are prominent in the post monsoon period. Figure 4 (a,b) depicts the seasonal change between monsoon and post monsoon period where in the latter small islands and sand bars previously inundated can be seen surfacing back. These are riparian habitat zones that are part of Important Bird Areas and also Vikramshila Gangetic Dolphin Sanctuary.

The river receives water in the form of precipitation, snow melt and ground water recharge and the hydrological flux is evident in the surface water. Thus delineating the water spread area can provide a crude estimate of the water in the river.

During the pre-monsoon period many stretches of Ganga particularly the Upper middle stretch showed thin shallow channel and intermittent deep pools disconnected by dry sand beds Figure 4 (c,d). These regions result in disruption in the river flow and are priority sites to implement e flow regulations. Another key factor is the regulation of flow in the river from barrages. Sudden release of water can cause flooding resulting in disturbance to the life cycle of species that are tuned to the natural annual hydrological pulse of the river. This is because different aquatic species have different river width and depth requirements. Thus monitoring the seasonal variations in the water spread area helps to note the longitudinal and lateral connectivity of the river, which is a prime characteristic for the health of a river.

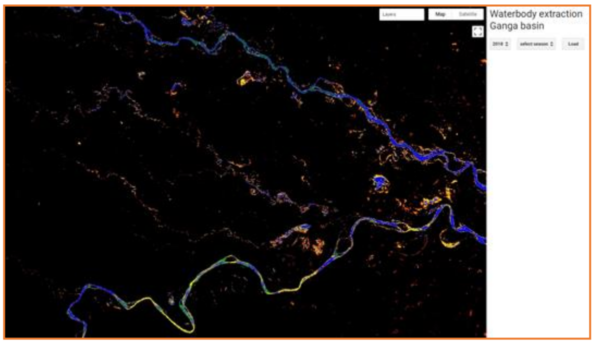


Figure 5. GEE app view

## 4. CONCLUSION

We have worked on browser-based JavaScript version of GEE. Although GEE is free to access and very interactive. The only requirement is of one google account registration. Google provide 15 GB memory in google drive and 250 GB’s for Earth Engine’s capacity per user which is very important constraint while working on heavy dataset such as training machine learning algorithms. GEE App doesn’t provide a versioning system to data in public catalog. Another challenge with this free version is processing time and storage limits. Processing occurs in two modes, while first interactive mode is fast but maximum processing time it serves is 5 minute and another is batch mode which is considerably slower and requires data exports on Google’s server which has 15 GB limit. Besides this, it is undeniable that, research in the field of image processing using GEE is a rapid prototyping tool from Google. While struggling from multiple sites to download, manage and preprocess the data traditionally, GEE provides a novel way of processing online imagery dataset which constantly updates with single framework with parallel processing approach. GEE Apps are gaining popularity not within the Remote Sensing researchers and developers but also among the different fields interested in using earth observation datasets to resolve their big data processing challenges. This application may also be used to examine the applicability of current methods in comparison with machine learning methods of surface water delineation

Landsat - 8 data is updated in every 16 days. Similarly, data of flow and water level from daily monitoring station can be incorporated and modelled within this spatial extent to stimulate real time scenario. Such an application can help administrators and decision makers monitor the situation of water spread area in the river and take appropriate measures especially in context of setting withdrawal limits and observing norms of gradual water release at reservoirs mindful of the river ecology. It strengthens the capability of users to better understand the dynamics of the Ganga basin, observe, and study changes in course and floodplain zone of Ganga river network.

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## APPENDIX

1. Link for GEE application: https://ravindra1364.users.earthengine.app/view/waterspreadgangariver
2. Link for GEE (Water inundation visualisation): https://code.earthengine.google.com/57c5693c1a07e6907ac1ad9be60f377b?hideCode=true
3. 