FLOWIDER 1.0: a web-based interface to track flood-season water levels of large rivers of India's Gangetic plains

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Abstract

Accessing and analysing flood-season water level data is crucial for monitoring riverine biodiversity and ecosystems. The Gangetic plains are among the largest river floodplains in the world. Temporal flood-season water level data for rivers of the Gangetic basin in India, though available in the public domain, are often scattered across web-based sources and recorded in non-translatable formats. We introduce 'Flow and Water Level (FLOW) Integrated Datasets (ID) for Ecological studies of Rivers (ER)', abbreviated as FLOWIDER 1.0, a web application developed using the R Shiny program. The app helps users track flood-season water level for 24 rivers and 107 gauging stations in one place, through a search filter by threatened species of wildlife. FLOWIDER presents a map view of gauging stations and graphing options to explore flood water-level time-series of up to two stations simultaneously. It features a searchable tool for users to access metadata linked with individual river stations.

Keywords

River flood water levels, Gangetic plains, dams and barrages, R Shiny, web application, data integration, endangered river wildlife conservation, risk and vulnerability

Software Availability

Software name: FLOWIDER 1.0 - Flow and Water Level (FLOW) Integrated Datasets (ID) for Ecological studies of Rivers (ER)

Developer and contact information: Riverine Ecosystems and Livelihoods programme, Wildlife Conservation Trust. Email: ramya@wctindia.org.

Hardware required: Any web-enabled computer (not suitable for mobile phone viewing)

Software Required: Internet browser

Program languages: R and CSS

Source code for FLOWIDER Shiny app: https://github.com/WCT-Riverine-Ecology-And-Livelihoods/FLOWIDER-shiny-app/tree/main, Shiny app website: https://wct-riverine-ecology-and-livelihoods.shinyapps.io/FLOWIDER_app/

Introduction

The flood-pulse of large rivers is a key determinant of biological productivity, ecosystem functions, and life-history processes of riverine biodiversity (Dudgeon et al., 2006; Humphries et al., 2014). River flood-pulses directly influence soil fertility, agricultural production, and fishery yields, and are considered as a critical regulating and supporting ecosystem service of river-floodplains (Junk et al., 1989, 2005; Junk & Wantzen, 2006; Kelkar et al. 2022a; Tockner et al., 2000). River flooding is dependent on precipitation strength and variability, geomorphological attributes across river basins, and human river flow regulation by dams and other impoundments (Kummu & Sarkkula, 2008; Trenberth, 2005; Zalewski et al., 2006). Extreme flooding can also lead to disasters and risks to society, which directly have policy implications in terms of trade-offs between the ecosystem services of flooding and disaster management (Bubeck et al., 2017; Parsons, 2019). Accessing and analysing river flood-season water level data and flood-pulses is thus critical for eco-hydrological monitoring of rivers.

Non-linear trends and increasing flood intensity are being witnessed now under the twin stressors of climate change and human water withdrawals (e.g. Trenberth, 2005; Krishnaswamy et al., 2015; Wasko et al., 2021). Flood-pulses and dry-season flows have been together described as a “River Wave” (Humphries et al., 2014), a concept that helps track trends in different attributes of the wave, such as amplitude (peak flood), wavelength (variance in flood water levels or discharge), shape (smooth rise and fall versus highly jagged), duration and timing of the wave rise, crest, and fall, and so on. Different attributes of the river wave may be directly linked to species responses and opportunities for human adaptation and livelihoods as well, for example, in case of riverine capture fisheries. There are tight linkages between fishing practices and life-history events of different fish species: spawning, recruitment, and dispersal between primary river channels and side-inlets in the adjacent floodplains (King et al., 2009; Fernandes et al., 2014), many of which track the rising and receding limbs of the flood-pulse wave. Likewise, threatened wildlife depend on flood peak and recession cues for nesting and hatching (e.g. turtles: Doody, 2011; Polisar, 1996; river dolphins: Kasuya & Haque, 1972; Martin & da Silva, 2004 and crocodilians: Champion & Downs, 2017). In recent years, there has been a global interest in developing web-based and OS-based applications that allow flood monitoring and trend analyses for different rivers (Slater et al., 2019), which mostly rely on satellite-based estimation of water levels (Crétaux et al., 2011; Papa et al., 2015) or discharge (e.g. Brakenridge et al., 2023;

Chuphal & Mishra, 2023). Other datasets and applications offer platforms to access official data on river or reservoir water levels, water area, etc. in one place (e.g. Brendel et al., 2019: SHARKS, USA; Steyaert et al., 2022). Information portals of both kinds involve data integration and/or model-based inference to assess river water level trends. Satellite-based applications to estimate discharge from SAR (microwave or RADAR) reflectance values also need ground calibration from field measurements or available data (e.g. Gaurav et al., 2015; Musa et al., 2015; Rai et al., 2021). A fruitful step forward can be the integration and compilation of publicly available official data and satellite-based discharge estimates in a single location.

In India's Gangetic plains, flood-season (June to October) river water level data are made available every year in the public domain by state government water resource departments and the Central Water Commission, a premier technical organization affiliated with the Department of Water Resources, River Development, and Ganga Rejuvenation, Government of India (www.ffs.india-water.gov.in), mainly for flood disaster risk management and warning systems (see CWC-GoI 2022). Dry-season (November to May) river flow or water level data are usually not made available. Additionally, these data are found scattered across multiple online sources, and maintained as daily bulletins which are not easy to access or utilize, due to the variable and non-translatable formats used. Recently, the FloodWatch app (https://play.google.com/store/apps/details?id=in.gov.affcwc&pli=1) was developed by the Central Water Commission (CWC), Government of India to provide real-time flood status, but it does not provide past flooding information. Many new applications for flood area mapping are also being developed (e.g. Tripathy & Malladi, 2022), but they do not provide river gauge information.

We present here FLOWIDER 1.0 - Flow and Water Level (FLOW) Integrated Datasets (ID) for Ecological studies of Rivers (ER), a web-based graphical and metadata interface developed in the R Shiny program, to observe and track flood-time water level data from 24 rivers and 107 gauging stations across six states within India's Gangetic plains. FLOWIDER synthesizes flood water level data from various information sources and presents a map view of locations of gauging sites, and time-based and graphical options to track the time-series of two stations of interest at once, for various applications. Some applications include: 1) assessment of flood level rise, recession, and seasonal to inter-annual variability in rivers, 2) planning surveys and designing studies to collect hydrological data from nearest available stations, 3) assessing the effects of the flood-pulse on variables of interest, and 4) assessing impacts of potential risks from dams or barrages, or extreme rainfall events, on flood-pulses. Additionally, we provide station-wise links to publicly accessible satellite-image based datasets such as Theia-HydroWeb (e.g. Frappart et al., 2006, Da Silva et al., 2010, Crétaux et al., 2011), DAHITI (Schwatke et al., 2015, 2019), and River Watch 4.5 (Brakenridge et al., 2023), to help track river water levels and discharge using altimetry and microwave reflectance sensing. Despite the availability of such vital information in the public domain, water researchers working in the region are often not aware, which limits the use and application of flood water level data in their work. Our painstakingly curated and designed application is an effort to provide researchers with a viewing and exploration interface with a filter on stations and selection of threatened riverine wildlife species.

Methods

Region of Interest

The Gangetic basin is among the largest and most densely populated floodplains in the world (India-WRIS, 2012). It also supports populations of many endangered riverine species such as Gharials, Ganges river dolphins and freshwater turtle species. We systematically compiled data for 107 CWC (Central Water Commission) stations belonging to 24 rivers across the Gangetic floodplains, from 2010 to 2023, with varying durations for different rivers and/or stations. A list of river sub-basins, rivers, and stations included, with the original data sources, is provided in Table 1. The chief data sources were the FMIS (Flood Management Information System) websites of three states: Uttar Pradesh, Bihar, and West Bengal.

Table 1. A list of all river water level gauging stations and data sources included in the FLOWIDER 1.0 database and R Shiny web application. Also see India-WRIS (2014a, b) for additional information on river sub-basins and stations.

Regions/states	Rivers	Stations (upstream to downstream)	Data source
Uttar Pradesh	Ganga	Garhmukteshwar, Narora, Kachlabridge, Ankinghat, Kanpur, Dalmau, Fafamau, Chhatnag (Allahabad), Mirzapur, Varanasi, Ghazipur, Ballia	https://fmiscup.in/hydromet/BlockDistrict.aspx (Irrigation and Water Resources Department, Govt. of Uttar Pradesh)
	Yamuna	Hamirpur, Chillaghat, Naini	
	Ghaghra	Katerniaghat, Elginbridge, Ayodhya, Turtipar	

	Gandak	Khadda	
	Rapti	Bhinga, Kakardhari, Rigauli, Balrampur	
	Budhi Rapti	Kakarhi	
	Ramganga	Kalagarh barrage, Bareli	
	Sharda	Banbasa barrage, Paliakalan, Shardanagar	
	Betwa	Mohana, Notghat, Sahijana	
	Ken	Banda	
	Kuano	Basti, Mukhlispur	
	Sai	Rae Bareli	
Bihar	Gandak	Valmikinagar	
Madhya Pradesh	Ken	Madla (Panna)	
	Son	Bansagar dam	
Rajasthan	Chambal	Kota barrage, Pali, Manderial, Dholpur	
Bihar	Ganga	Buxar, Dighaghat-Patna, Gandhighat-Patna, Hathidah, Munger, Bhagalpur, Kahalgaon	https://fmiscwrdbihar.gov.in/fmis/aboutus.html, https://wrd.fmiscwrdbihar.gov.in/ (Water Resources Department, Govt. of Bihar.)
	Ghaghra	Darauli, Gangpur-Siswan, Chhapra	
	Gandak	Triveni barrage (Valmikinagar), Chatia, Dumariaghat, Rewaghat, Hajipur	
	Kosi	Kosi barrage, Basua, Baltara, Kursela	
	Mahananda	Tayyabpur, Dhengraghat, Jhawa	
	Son	Indrapuri barrage, Koilwar, Maner	
Jharkhand	Ganga	Sahibganj	
West Bengal	Ganga	Farakka	
Uttar Pradesh	Gandak	Khadda	
West Bengal	Hooghly	Berhampore, Katwa, Kalna, Swarupganj	https://wbiwd.gov.in/index.php/applications/dailyreport (Irrigation and Waterways Department, Govt. of West Bengal)
	Ganga	Akherigunj, Nimtita	
	Mahananda-Fulahar	Hill Cart road, Sonapur, Teljana	
	Teesta	Coronation Bridge, Mekhliganj	
	Jaldhaka	Mansai/Matabhanga	
	Torsha	Hasimara (Alipurduar)	
	Ajoy	Budra	
	Rupnarayan	Ranichak, Gopiganj	
	Damodar	Jamalpur	

Data compilation

Daily flood-season water level data from June to October for each year were compiled from station-wise and day-wise data provided in portable document format (PDF; see Table 1). All flood-level data were manually entered from 2013 onwards, from PDF files or web pages as per availability. For some years, flood water level data were removed daily from the FMIS websites of certain states, so manual entry was required on each day when data would appear. All stations had one recorded water level value per day, and for barrage or dam sites, we manually recorded the downstream water level value corresponding to the first timestamp of the day when the data became available. No online or offline web-scraping tools were used to get these data. For certain years and stations, only graphs of flood-season water levels were available in the form of flood reports. In such cases, we used the tool Web Plot Digitizer (https://apps.automeris.io/wpd/) to directly extract data from the available graphs.

Data processing

We conducted repeated and thorough checks (n>40) of all data, filtered by station, river, day, and date, for each year to remove any erroneous entries, duplicate entries, or illogical values upon detection, until we achieved representation accuracy of 100%. We formatted all data to maintain consistency in station names and date formats. For certain CWC stations, flood-season data was available from more than one state website. In such cases, we chose the values from a single state website or took mean values between the data sources. In most cases, we used the data values directly, as provided in the source websites, except when there were obvious typos. The time duration for which data was available, was variable between the stations. In order to maintain consistency, we padded the dataset with NAs from the earliest date available (2010-06-01) to the latest data available (2023-10-31), wherever water level was not available.

Web application development and implementation

We developed FLOWIDER 1.0 - Flow and Water Level (FLOW) Integrated Datasets (ID) for Ecological studies of Rivers (ER), a web application that is targeted towards providing an interactive visual interface for accessing the above dataset. The application was developed with scientists and conservationists in mind, to help navigate flood-season water level for stations according to their species of interest. The application was developed using the package Shiny ver. 1.7.4 (Chang et al., 2022) in R ver. 4.2.2 (R Core Team, 2022). The R shiny package is increasingly being used to develop interactive dashboards for the display of hydrological data (Brendel et al., 2019; Slater et al., 2019). We converted our data file (size: 34.8 MB) into a fast storage (fst) file (size: 4.81 MB) to improve computational efficiency of the app. We deployed the FLOWIDER application online on shinyapps.io at https://wct-riverine-ecology-and-livelihoods.shinyapps.io/FLOWIDER_app/ under the 'free' hosting setting. FLOWIDER can be accessed here without installing R or using a login. After deployment, we measured loading time on a Google Chrome browser (first instance) in a Lenovo ThinkPad T480 with 24 GB RAM and approximately 200 Mbps internet speed.

App structure and design

The FLOWIDER app is composed of three main elements to filter for and visualize the flood-season time series of a station: map, graph and metadata table. The map feature is supported by the leaflet package (Cheng et al., 2022), that enables interactive viewing of stations on Ganges rivers and basin ESRI shapefile. The graph feature is supported by the interactive graphing library *plotly* (Sievert, 2020). *Plotly* graphs have several useful features in a floating menu, that appears on hovering anywhere on the graph, such as a tooltip to view the x and y axis values on hovering, options to zoom in and zoom out and to download the graph as a PNG file. This library was also our preferred choice given the ease with which dual Y-axis plots (in our case, to view the flood-season time series of two stations within the same graph) could be created. The metadata were displayed using the package DT, which is an R interface for the Javascript library DataTables (Xie et al., 2023). This package allowed for dynamic filtering, searching and sorting of the metadata table. Please refer supplementary material (Table S1) for a full list of all packages used.

Results

Web application

Our dataset compiled 100,455 values of flood-season water level data from 2010 to 2023 for 107 stations belonging to 24 rivers and six Indian states, across the Gangetic floodplain. We developed the FLOWIDER application using this dataset. The FLOWIDER application was developed with a multi-tab layout, under the titles: 'Map', 'Graph', 'Metadata' and 'About'. The loading time for each tab of the deployed app is as follows: 'Map' tab or app first page: 12-13 seconds; 'Plot' tab after time-range selection: 4-5 seconds; 'Metadata' and 'About' tab: less than a second.

Map tab

The application 'Map' tab opens with a map view of stations represented by markers. This tab contains two side panels: a right-hand side panel with a drop-down menu of rivers and a left-hand side panel with a selection of seven endangered or critically endangered riverine taxa. These include the Critically Endangered Gharial crocodile and Red-crowned roofed turtle, the Endangered Ganges river dolphin (India's National Aquatic Animal) and Indian Skimmer, and other vulnerable or near-threatened species such as Smooth-coated Otter, Marsh Crocodile, other species of freshwater softshell and hardshell turtles, and the Hilsa, a declining fish species. The distribution of river water level gauging stations in relation to species of interest for hydrological monitoring and habitat assessment relevant to their conservation, is based on the species' distributions known from the latest IUCN Red List Assessments (www.iucnredlist.org) and other key literature. This literature is summarized in Table 2. The panels on the 'map' tab can be dragged around, allowing users to move them for a more comfortable view of the map. As users select a certain river or species, the map updates dynamically to display only those stations associated with the river or species. Users can then make their selection by directly clicking the station markers on the map, the names of which will dynamically appear in the 'Selected station' input on the right-hand side panel. Users can view the flood-season time-series graph for a maximum of two stations at a time.

Table 2. Threatened species of conservation importance included in the FLOWIDER 1.0 app as a river-wise station search filter on the 'Map' tab. The impact of the flood-pulse is an important variable determining dispersal (short- and long-range movement or migration) of, physiological cues, and lagged effects on dry-season habitat availability for these species.

Species name	**IUCN Red List Status**	**References**
Ganges river dolphin *Platanista gangetica*	Endangered	Kelkar et al., 2022b
Gharial *Gavialis gangeticus*	Critically Endangered	Lang et al., 2019
Marsh crocodile *Crocodylus palustris*	Vulnerable	Choudhury & de Silva, 2013
Freshwater turtles (*Nilssonia* spp., *Batagur* spp., *Chitra* spp., *Lissemys* spp., *Hardella* sp.)	Endangered/ Vulnerable	Ahmed et al., 2021a, b; Das et al., 2021b; Praschag et al., 2019; Rahman et al., 2021
Smooth-coated Otter *Lutrogale perspicillata*	Vulnerable	Khoo et al., 2021
Indian Skimmer *Rynchops albicollis*	Endangered	BirdLife International, 2020
Hilsa *Tenualosa ilisha*	Least Concern (Population Declining)	Freyhof, 2014

Graph tab

The Graph tool of FLOWIDER 1.0 allows users to plot the flood water level data for their river gauging stations of interest, up to two stations at a time. Users can either use the date range input option provided for examining the flood water levels in a specific period, or select all years. When starting out, we recommend users to choose a single station of interest from the map interface. Two stations should be selected, ideally only when they are related to each other or influence each other in some way. For example, one station can be upstream or downstream of the other, or both could be located at the end points of a river (source and mouth), or one could be above a dam or barrage and the other below it. Another possibility is that both stations could be on different rivers but can be of relevance for a single species of interest, and hence the need to examine the flood water levels of both together could arise. The graph plots the two stations' water level data on two Y-axes. In a dual y-axis graph, users can view the y-axis values for both stations at once with the 'Compare data on hover' option in the floating menu.

Metadata tab

The 'Metadata' tab summarizes additional relevant information for all stations including details on the stations upstream and downstream of the selected reference stations, the zero reference level and danger level (for flooding risks), links to the satellite-based datasets available on river water level and discharge, and site location information. Some additional attributes such as the presence of protected areas for wildlife adjoining these stations, order of the station from upstream to downstream along the river it is located at, and related details are also presented. The metadata tab provides a search tool for the station of interest, and tabulates all the information for the user to view at a glance.

In addition, links to multi-mission satellite altimetry measurements of river water levels are also provided in the metadata. Specifically, the link to the nearest virtual station for each CWC station is provided, based on two data sources. Altimetry data from both these sources are freely accessible after a short registration process.

1. Theia-HydroWeb (https://hydroweb.theia-land.fr/) provides time-series of water level data collected on 'Virtual Stations' for lakes and rivers around the world, based on satellite altimetry data.

2. Database for Hydrological Time Series of Inland Waters (DAHITI: https://dahiti.dgfi.tum.de/en/) was developed by the Deutsches Geodätisches

Forschungsinstitut der Technischen Universität München (DGFI-TUM) in 2013 to provide water level time series of inland waters, including lakes, reservoirs, rivers, and wetlands derived from satellite data.

For a few selected sites, the metadata table also connects users to the Flood Observatory, Colorado's River and Reservoir Watch version 4.5 data repository (https://floodobservatory.colorado.edu/DischargeAccess.html; Brakenridge et al., 2023). River and Reservoir Watch provides estimates of river discharge and runoff for a few selected 'reference pixels' of 25 km x 25 km, based on the calculation of microwave reflectance from the AMSR-E, AMSR-2, and other satellite passive microwave sensors, which is used to calculate discharge based on a global runoff model.

About tab

In the ‘About’ tab, we provide a detailed description of the application, its potential use cases and the data sources. We provide information on app metadata, instructions on use, terms of use and any applicable restrictions. Importantly, we emphasize that river water level data from the dry-season are “classified” for all rivers of India’s Gangetic plains. For disaster management purposes, flood water level information is uploaded and made publicly accessible by state water resources departments and the Central Water Commission, Government of India (www.ffs.india-water.gov.in). Therefore, no data downloads are allowed in the app, nor any classified information uploaded.

We provide a video demonstrating the application with the following examples, here: https://github.com/WCT-Riverine-Ecology-And-Livelihoods/FLOWIDER-shiny-app/blob/main/FLOWIDER_demo_compressed.mp4.

Example applications of FLOWIDER

We provide two example case studies to demonstrate the use of the FLOWIDER web application for the conservation of threatened riverine fauna and in flood risk monitoring.

Impact of rising flood water levels on nesting success of Indian Skimmers

The Chambal River holds one of the most significant breeding populations of the Indian Skimmer *Rynchops albicollis*, an endangered riverine bird species. This species is known to use isolated sand islands in the river for nesting in the summer, from March to May, after which the chicks hatch by early to mid-June (Shaikh et al., 2018). Variations in water level, through sudden increases triggers flooding of nests (Nair et al., 2016) and low water levels allow access to terrestrial predators and people, therefore posing a threat to the nesting success of this species (Shaikh et al., 2018). A wildlife biology student working in the Dholpur region of the Chambal River, is interested in investigating the impact of flood water level (from previous years) on the nesting success of the Indian Skimmers (observed by mid-June) in the area from 2019-2022. The following screen grabs (Figs. 1-7) demonstrate the use of the FLOWIDER web application for this purpose.

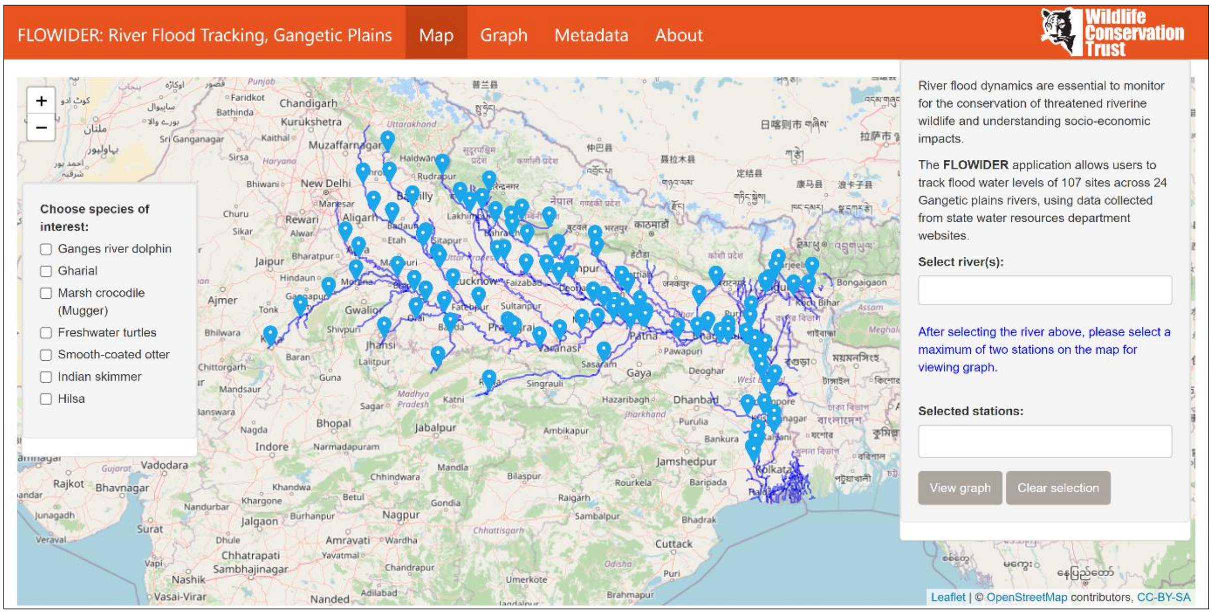


Fig. 1. The first page of the app with three main features for filtering stations of interest: drop-down menu of rivers on the right-hand side and species panel on the left-hand side. Markers in blue represent all stations prior to any user input.

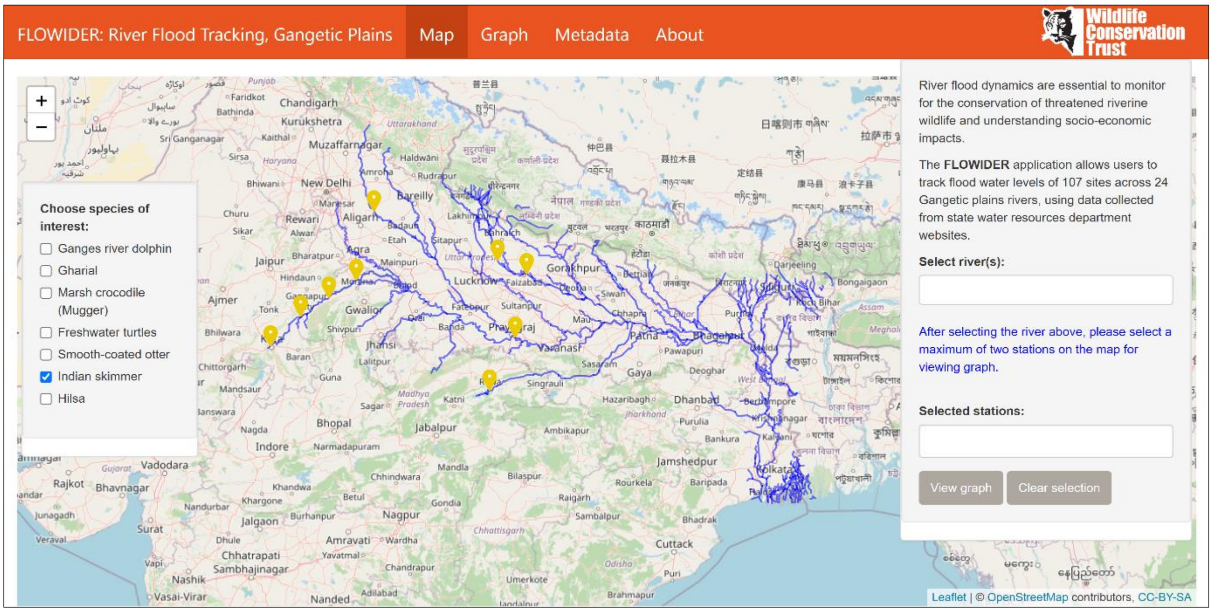


Fig. 2. The user can choose the 'Indian skimmer' option in the species panel, upon which the map view is dynamically updated to display only the stations relevant to the species selected.

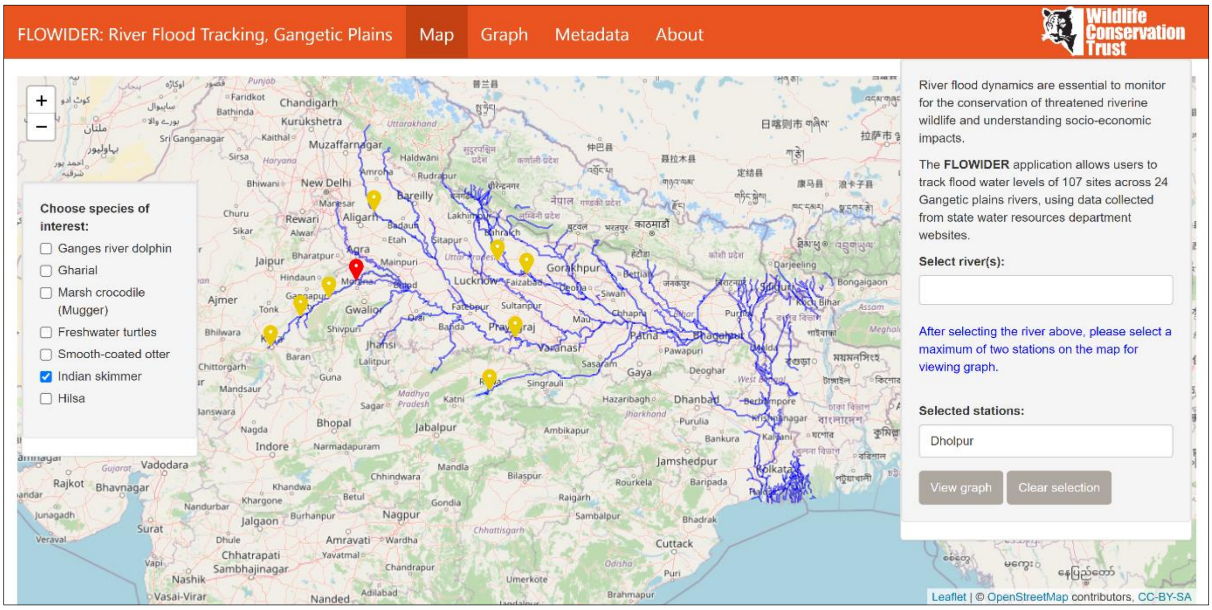


Fig. 3. The user can then click on the relevant station, for example - Dholpur, which will also simultaneously appear in the 'Selected stations:' input on the right-hand side panel. The user can then click on the 'View graph' button to move to the 'Graph' tab.

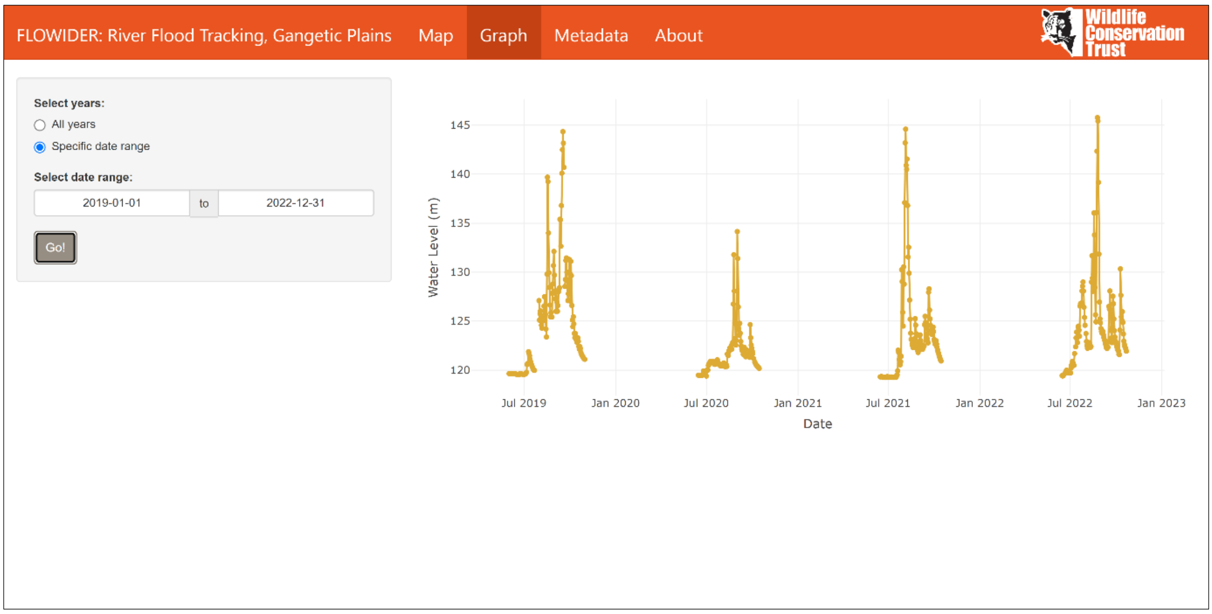
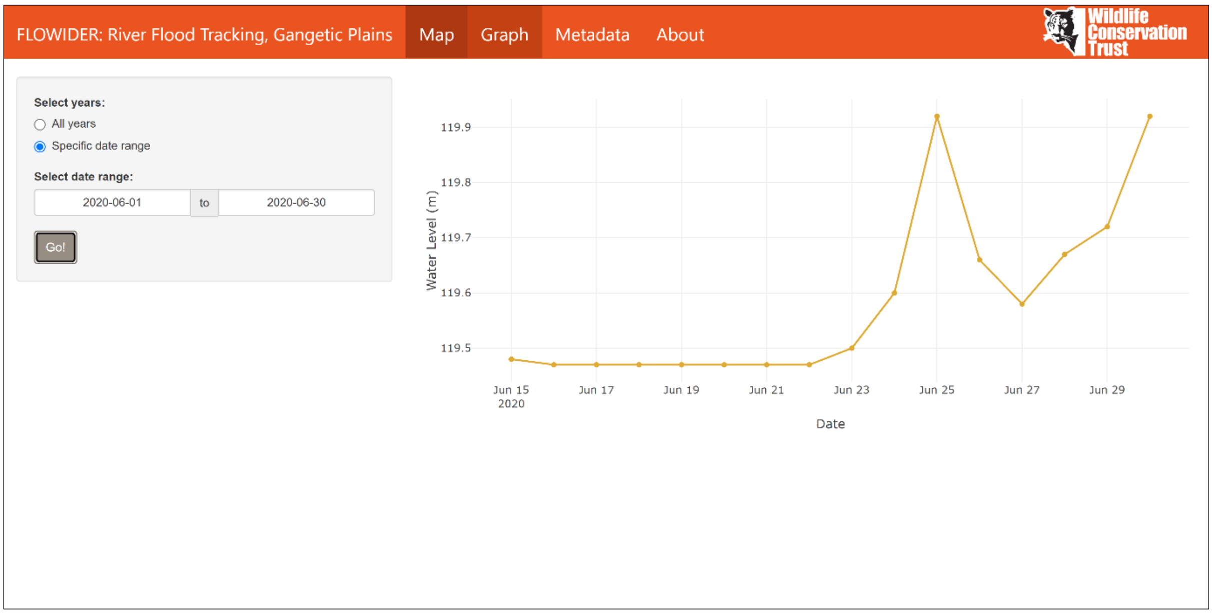


Fig. 4. In the 'Graph' tab, the user can specifically view the flood-season time series for a specific period of interest, for example, 2019 to 2022.



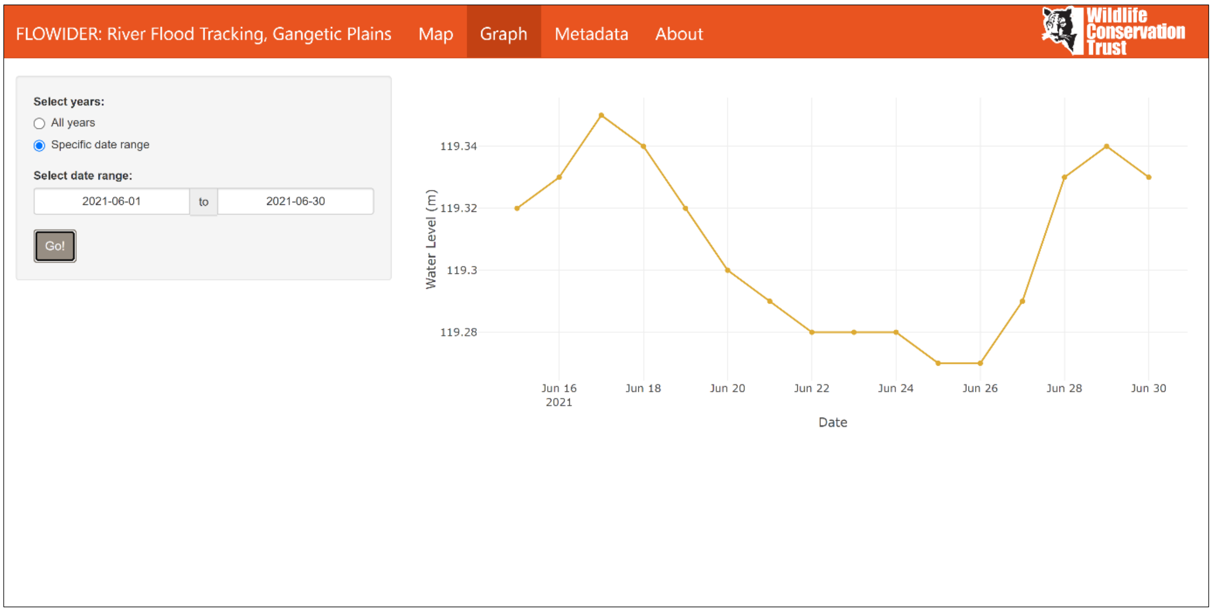
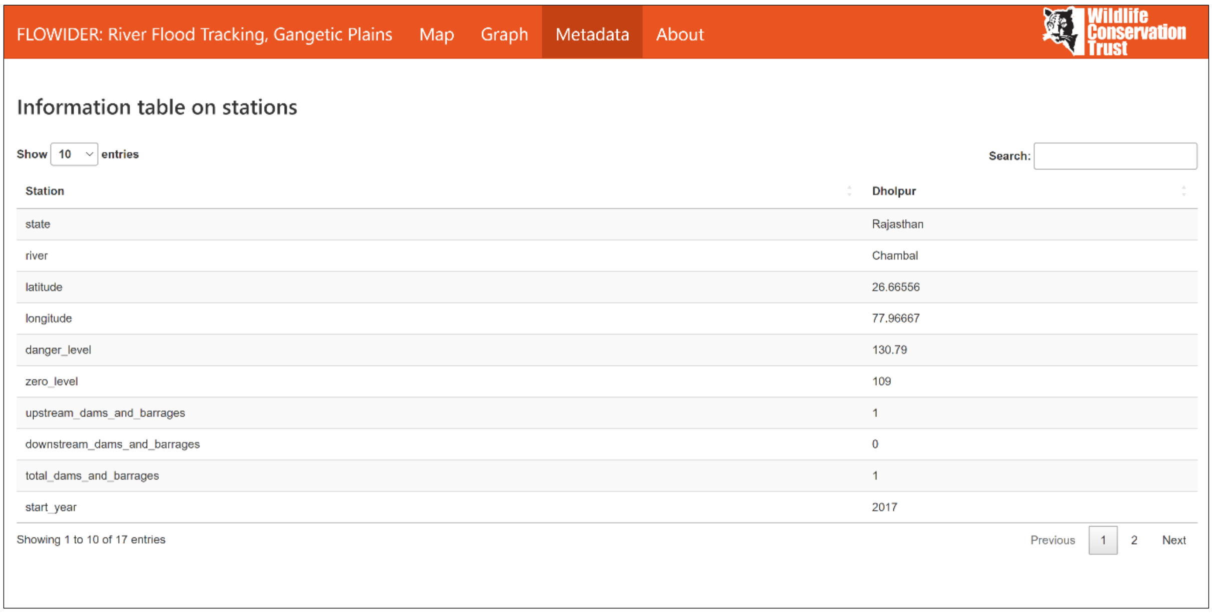
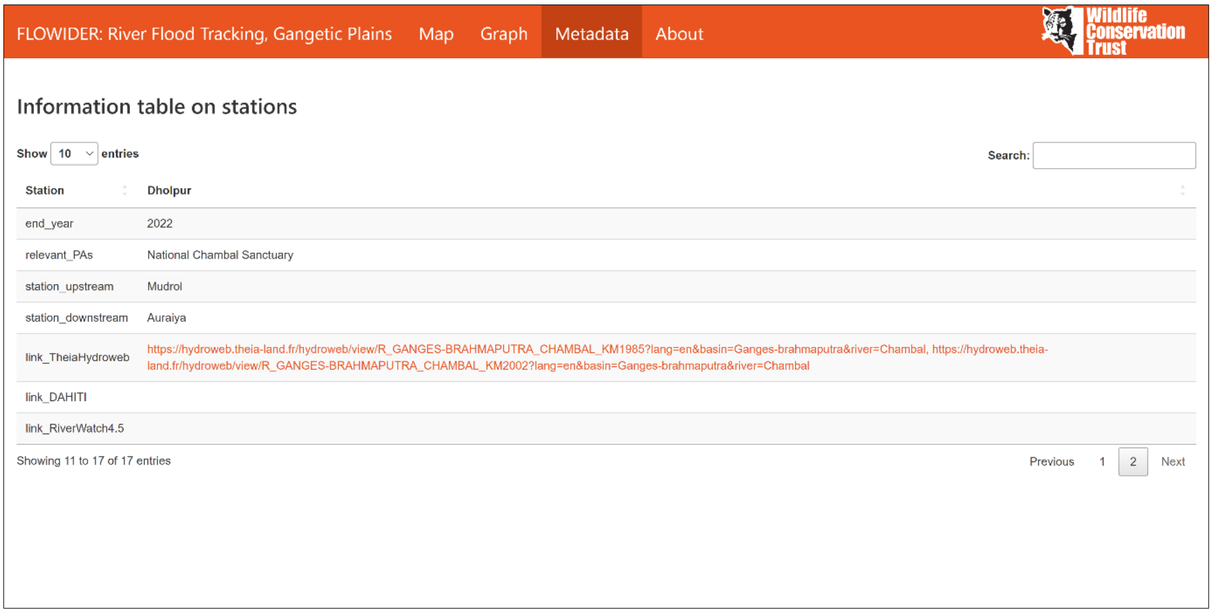


Fig. 5a (top), and 5b (bottom). The user can compare the June water levels for different years. It seems like in 2020, the rise in flood water level began post June 23, while in 2021 there was an earlier rise in mid-June. If nesting success was greater in 2020, the user can correlate it with these differences in water levels.



Station	Dholpur
state	Rajasthan
river	Chambal
latitude	26.66556
longitude	77.96667
danger_level	130.79
zero_level	109
upstream_dams_and_barrages	1
downstream_dams_and_barrages	0
total_dams_and_barrages	1
start_year	2017

Fig. 6. For further information on the selected station, the user can move to the Metadata tab, where a long table of information pertaining to that station, dams and barrages, protected areas, adjacent gauging stations, etc. will appear. Note: If no station is selected on page 1, the Metadata tab will display a wide table of all stations by default.



Station	Dholpur
end_year	2022
relevant_PAs	National Chambal Sanctuary
station_upstream	Mudrol
station_downstream	Auraiya
link_TheiaHydroweb	https://hydroweb.theia-land.fr/hydroweb/view/R_GANGES-BRAHMAPUTRA_CHAMBAL_KM1985?lang=en&basin=Ganges-brahmaputra&river=Chambal, https://hydroweb.theia-land.fr/hydroweb/view/R_GANGES-BRAHMAPUTRA_CHAMBAL_KM2002?lang=en&basin=Ganges-brahmaputra&river=Chambal
link_DAHITI	
link_RiverWatch4.5	

Fig. 7. The user can also explore publicly accessible data on satellite-based measurements of river water level (Theia-Hydroweb and Dahiti) and discharge (RiverWatch 4.5), relevant to the selected stations, using the links provided in the metadata table.

Identifying extreme flood events in the past for better dam management

In August, 2016, major river flooding affected several districts of Bihar along the Ganga. This was due in part to huge water releases from Bansagar dam on the Son River (a southern tributary of the Ganga joining the main channel near Patna, Bihar), in the state of Madhya Pradesh. In this year, Madhya Pradesh witnessed excessive rainfall, such that the Bansagar reservoir was already at close to full capacity by mid-August. Till 18th August, 2016, the dam was releasing only 1672 m^3/s of water (Thakkar, 2016). From the following day, a huge volume of nearly 15798 m^3/s was released by opening 16 of the dam's 18 gates (Thakkar, 2016; Das et al., 2021a). This resulted in excessive flooding in the Son, in turn causing flooding at downstream sites along the Ganga River. It was also proposed that an associated reason for aggravating the flood impact could be flow congestion at the Farakka barrage on the Ganga River in the state of West Bengal downstream, but the extent may not have covered a substantial part of the Ganga floodplain of Bihar (Das et al., 2021a). An environmental journalist interested in understanding extreme flood events that may have been worsened by poor dam management in the period: 2015–2017 may want to check how the water levels at two stations may be correlated with each other. For this, he can select the upstream station (Indrapuri barrage on the Son) and downstream station (Farakka barrage on the Ganga) and examine the flood-water levels in tandem. Figs. 8-11 demonstrates the use of the FLOWIDER web application for this purpose.

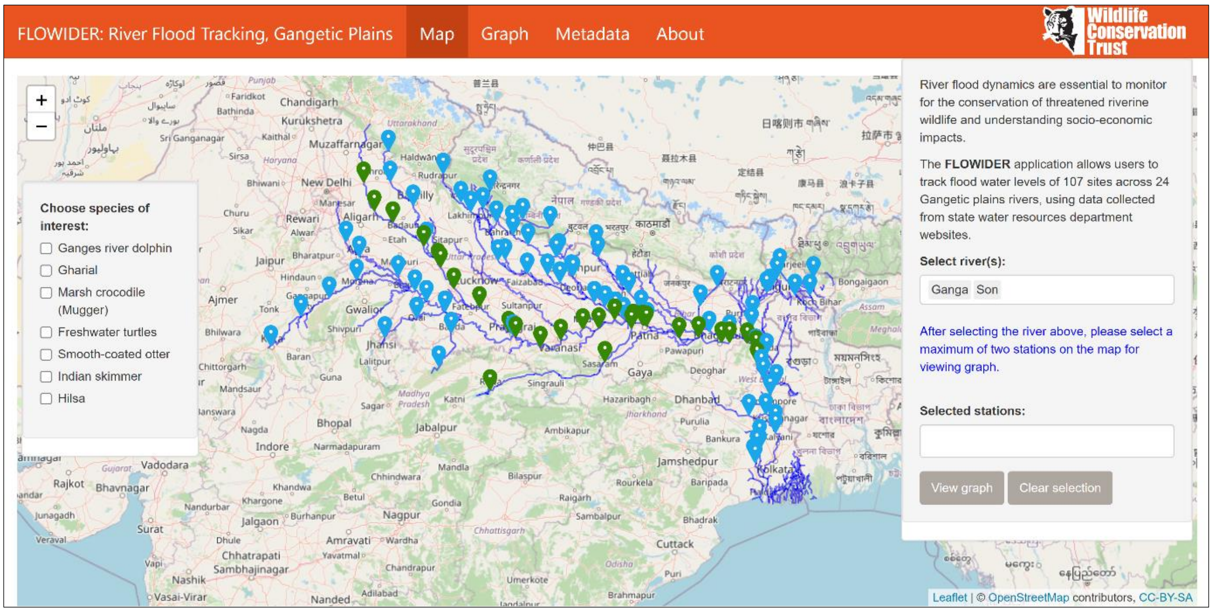


Fig. 8. The user can select both rivers of interest in the 'Select river(s)' drop-down menu, upon which the map view is dynamically updated to display the stations located on the selected rivers, in a different colour (green).

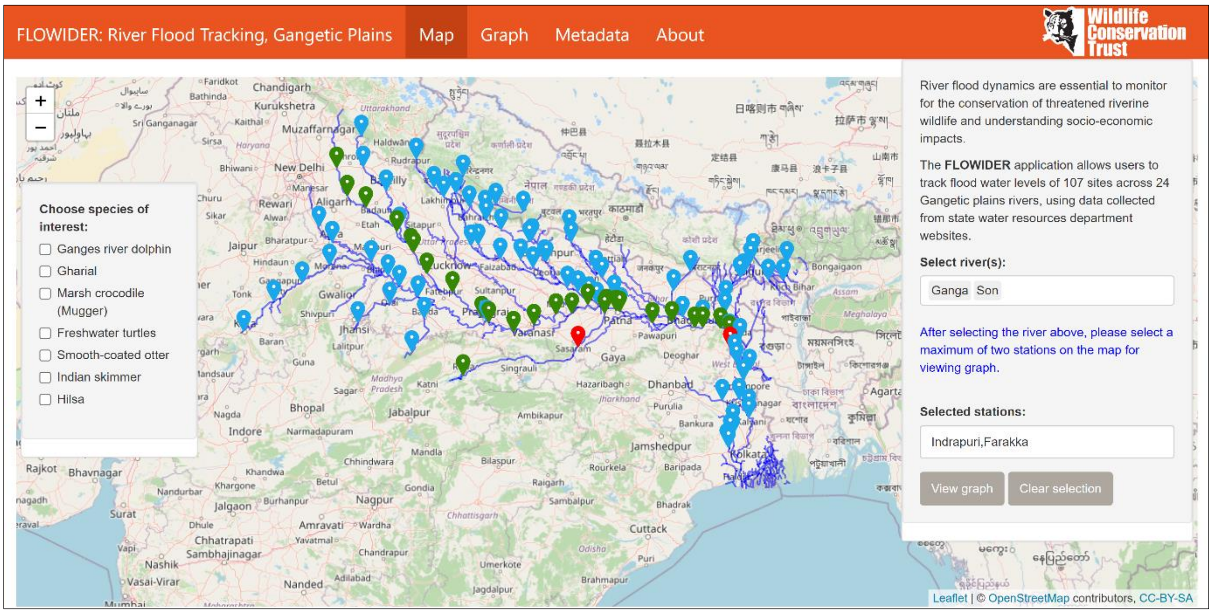
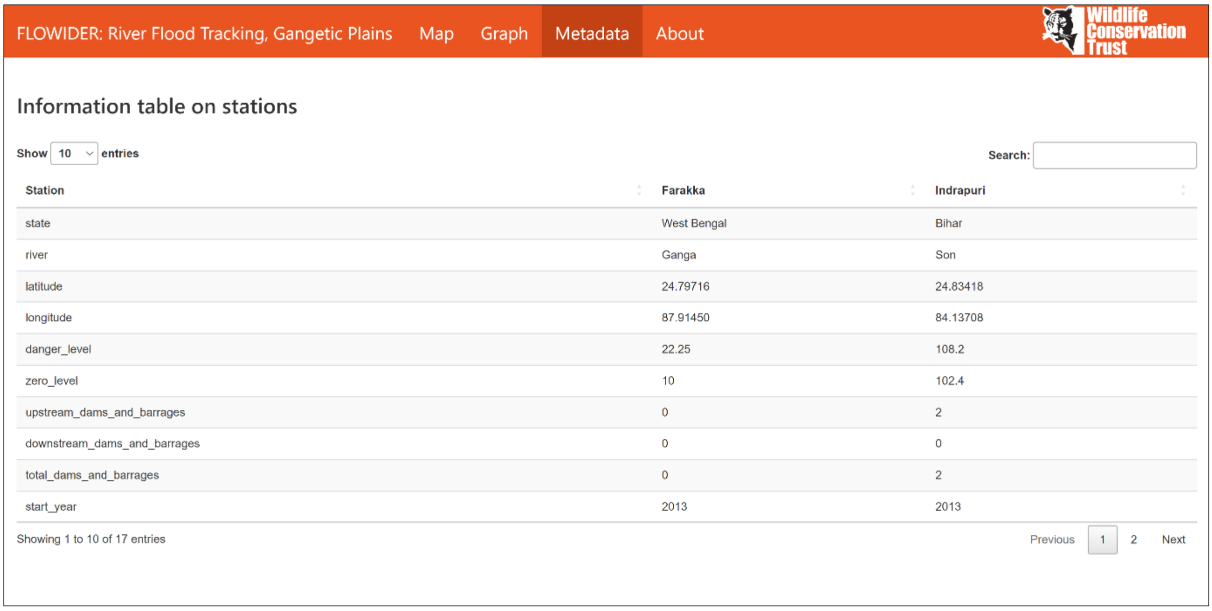


Fig. 9. The user can then select the two stations of interest (Indrapuri and Farakka) and move to the 'View graph' tab.

Fig. 10. The user can select the relevant time period and view the dual Y-axis (one Y axis each for the water level of both stations) graph. The user can toggle the 'Compare data on hover' option on the graph and check for extreme water levels/outliers and investigate potential underlying causes.

It can be noted in Figure 11 that in mid-August 2016, unlike the other years, a large jump in water level is seen at Indrapuri, due to the sudden release of water (resulting in a water level rise of 4-5 m within a few days). The water level of the Farakka barrage also peaked at this time. The graphical exploration could thus help the user narrow down to the fact that 2016 indeed witnessed unusual dam releases as compared to 2015 and 2017. It can be seen that on 20th August 2016, water level on the Son had nearly touched the danger level mark (Fig. 11).



Station	Farakka	Indrapuri
state	West Bengal	Bihar
river	Ganga	Son
latitude	24.79716	24.83418
longitude	87.91450	84.13708
danger_level	22.25	108.2
zero_level	10	102.4
upstream_dams_and_barrages	0	2
downstream_dams_and_barrages	0	0
total_dams_and_barrages	0	2
start_year	2013	2013

Showing 1 to 10 of 17 entries

Previous 1 2 Next

Fig. 11. The user can check the metadata page for important information pertaining to the stations, such as danger level, that can be used to assess the intensity of the flood event of concern.

4. Conclusion and future directions

We hope that the current version of the app, FLOWIDER 1.0, will be of interest to a diversity of users from the ecological, hydrological, and social research and practice fields. In its present form, the app's utility is mainly to provide a quick viewing of flood water level data for multiple rivers and stations in the Gangetic plains. The novelty of the app comes from the interactive searches on the data with species, river, and date filters. Future developments for the app can include 1) linking satellite altimetry and reflectance-based data on water level and discharge with ground station data through rating curves for both the flood- and dry-seasons, 2) allowing prediction of river flow from water level data downstream of barrages and dams, 3) assessing dry-season river water availability post flooding, 4) linking channel morphology attributes (depth, width, profile shape, etc.) with water level and discharge, and 5) connecting these attributes with ecological flow assessments for different threatened species and human livelihoods dependent on freshwater. Our end goal is to help diverse users get relevant information on all these variables at one place. We chose the Gangetic plains as our focal region because the Riverine Ecosystems and Livelihoods programme has been working in the area for a long time. However, as per the need and data gaps, we would be keen to extend

FLOWIDER to other ungauged or less-gauged rivers in northern and eastern India. The original motivation for this app, as indicated before, was to provide researchers and students working on riverine ecological and social issues with a direction on how to access and explore flood water level data as per their topic of interest. In India, hydrological training is quite limited among ecology and social science students, though they often may critically need that understanding. In its future iterations, FLOWIDER will seek to identify and plug such information gaps by integrating newer functionalities but keeping its core search/filter structure intact. We hope that the FLOWIDER app will be useful to all possible users and provide them with relevant insights.

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Author contributions: SRR: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing-Original Draft, Writing-Review and Editing, Visualization; NK**:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing-Original Draft, Writing-Review and Editing, Visualization, Supervision, Project Administration, Funding Acquisition.

Data Availability Statement

The FLOWIDER Shiny app is available at https://wct-riverine-ecology-and-livelihoods.shinyapps.io/FLOWIDER_app/. The source code is publicly accessible at https://github.com/WCT-Riverine-Ecology-And-Livelihoods/FLOWIDER-shiny-app/tree/main.

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Supplementary Information

Table S1. List of all R packages used in the FLOWIDER shiny app, with version and functionality

R Package	Version	Functionality in FLOWIDER shiny app
shiny	1.7.4	main package for app development
shinythemes	1.2.0	theme for the shiny application
shinycssloaders	1.0.0	adds loading animation when calculating output
shinyalert	3.0.0	creates pop-up error message when more than two stations are selected for viewing graph
plotly	4.10.1	creates interactive graphs for ‘Graph’ tab
leaflet	2.1.2	creates interactive map layer for ‘Map’ tab
sf	1.0.14	displays shapefile of Gangetic rivers on top of leaflet map layer
DT	0.27	displays interactive data table in ‘Metadata’ tab
dplyr	1.0.10	data manipulation
stringr	1.5.0	data manipulation
anytime	0.3.9	handles date objects
fst	0.9.8	conversion of data files from csv format to fast storage (fst) format