West Bengal Drinking Water Sector Improvement Project, India

Final Report

Support requested by:
Asian Development Bank (ADB)

Reference: EOC0015_REP_v1_r1.0
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EXECUTIVE SUMMARY

This document compiles the objectives and achievements of the West Bengal Drinking Water Sector Improvement Project together with the conclusions and findings. It presents how to support a larger service over other regions, countries and indicators. The methodology applied during the project is described, but also its limitations, for the Asian Development Bank (ADB) and other stakeholders to be aware of the working flow and its possibilities. It is also intended for dissemination purposes, and provision of potential of using EO for rapid assessment of suitable Nature-Based Solutions (NBS) for fresh water storage sites.

The driving objective of the project presented in this paper is to provide support to ADB by means of a rapid preliminary assessment of suitable NBS water storage sites in an area of interest (AOI) of Purba Medinipur, obtained with satellite remote sensing techniques.

Starting from the selection of the appropriate satellite sources, image types, dates and resolutions, the methodology used is described in detail, which is itself part of the intended deliverables. It can serve as a reference to be used by other EO studies for future replication of this kind of study to other areas. This methodology goes through a series of intermediate steps necessary to get to know the AOI better and to narrow down the most suitable water storage sites, based on various criteria:

- The waterbodies within the AOI are identified and mapped. These maps are the basis for further analysis.
- The waterbodies dynamics along the seasons and the effect of the monsoon/dry season is analysed, this allows to classify waterbodies presenting similar flooding patterns.
- Up-to-date Land Use / Land Cover (LU/LC) maps are generated, and are used to derive factors that contribute to choose most suitable water storage sites.
- An index of the siltation risk or siltation potential of the area is produced and mapped showing the frequently submerged areas favourable for clear water storage, this also will guide the correct choice of better sites according to water quality
- Multicriteria Expert knowledge and a multi criteria decision analysis (MCDA), based on previous steps, i.e. the flooding recurrence, site dynamics, land cover, and water quality is used for the selection of suitable sites for water storage.
- Finally an analysis of the potential connectivity between the inland water-storage sites is also considered as a positive factor in the site selection procedure, taking into account the vulnerability of the small and scattered inland waterbodies.

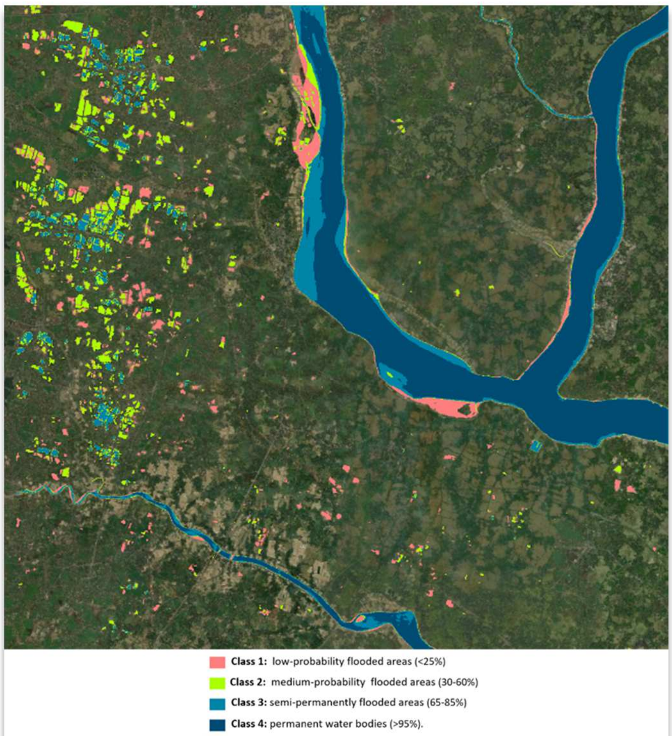


Fig. i. Waterbodies dynamics

With the results obtained with this process, two potential kinds of NBS are proposed:

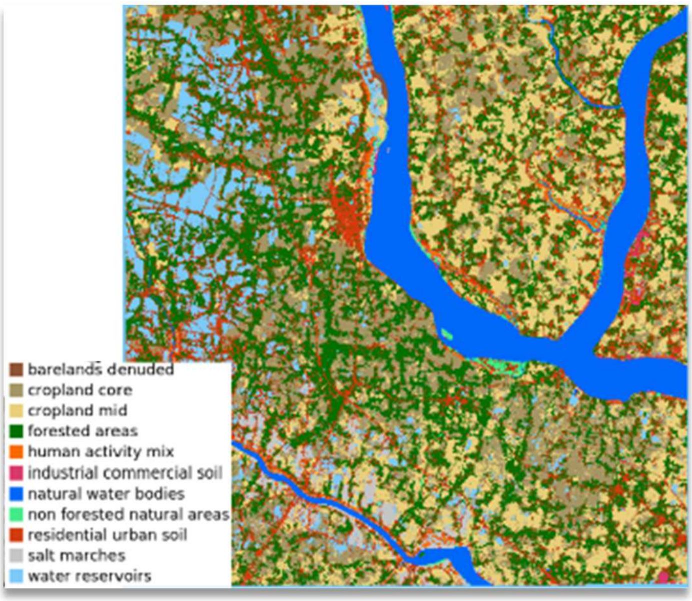


Fig. ii. LU/LC map

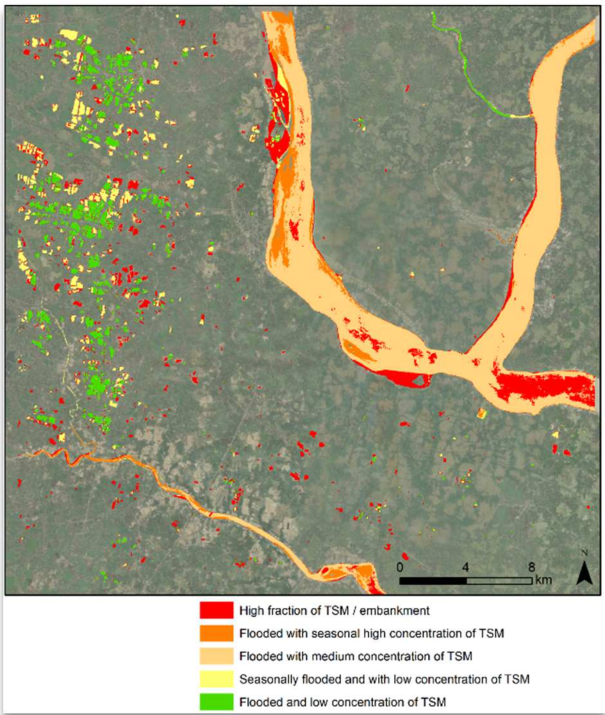


Fig. iii. Siltation

- Near bank water areas to be reclaimed as reservoirs: along the distributary river banks. Most of these areas are subject to moderate and seasonally variable suspended sediment concentrations. These areas could periodically supply neighboring settling basins. In this active part of the AOI, seasonality is an important factor in conditioning water use, e.g. due to saline marine intrusion in the dry season and excess of turbidity induced by floods during the monsoons.
- Inland, a large part of the detected parcels is frequently flooded with clear water with very low density of suspended matter. By adding the seasonally flooded areas, the usable area for surface water extraction increases considerably.

Non-stationary events (e.g. as observed with cyclone Yass) can be decisive in the dimensioning and decision-making when identifying the freshwater supply corridors,

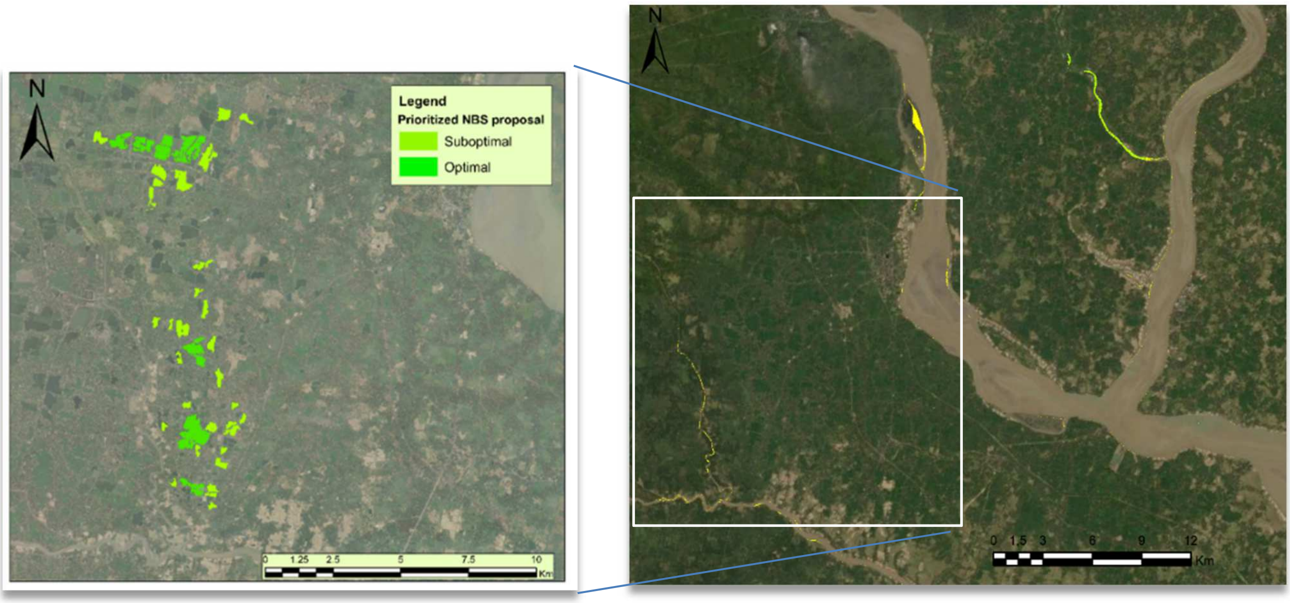


Fig. iv. Proposed NBS freshwater storage sites

1 DEVELOPMENT CONTEXT AND BACKGROUND

1.1 Introduction

Services based on Earth Observation (EO) are useful tools for providing a wide range of past and present environmental information through the analysis and processing of historical information, present status and analytical data available.

Technology has now achieved the capacity of processing large amounts of data within a time frame and inside an affordable budget.

The particular advantages of EO in this context are the non-intrusive, objective and globally consistent nature of the information and the use of satellite mapping services provides many opportunities for the management and verification of the environmental practices associated with the development projects.

Through unique EO products, it is possible to map agriculture, land use and environment, water quality, energy availability, food security, coastal subsidence and forest state among other equally important data, which EO can gather effectively in areas with little ground information.

ESA's Copernicus programme is aimed to make environmental monitoring a reality, delivering near-real-time data on a global level which can also be used for local and regional needs.

Through its own dedicated Sentinel satellites, various contributing missions and on-ground stations that collects information from in situ systems such as ground stations, which deliver data acquired by a multitude of sensors on the ground, at sea or in the air, Copernicus programme allows to create value-added information by processing, comparing and analysing data that stretches back for years, and from this monitor changes, create forecasts, analyse patterns and generate maps that identify anomalies and features.

Over this, ESA has been collaborating with Banks and International Financial Institutions for a long time on monitoring development projects and its impact on the environment.

This collaboration has demonstrated the relevance of EO for Development projects, and has proven that it is a valuable tool for make cost effective, quick and incontrovertible assessments, that help to manage urban growth, protect forest, monitor water quality and broadly provides evidence of progress or baselines for remediate actions whenever an environmental transformation occurs as result of a development project.

Although larger initiatives and programmes are currently on execution (like EO4SD, an ESA initiative to support the uptake of EO-derived information in sustainable development), <u>there is a need to cover small-scale and exploratory uses of EO products as a response to short-term, ad-hoc requests</u> from Banks and international institutions. These requests demand an innovative approach and capacity to deliver within a short time frame, a solution that goes beyond standard product generation and that links the EO data with underlying statistical and geographic information in a creative way.

To achieve this, ESA is funding a Framework Contract (named: EO-Clinic) scheme to which this project belongs to.

Under this Framework Contract, several "Request for Proposal" are being issued to the contractors from different end users (banks and International Finance Institutions). These Requests can vary largely on its purposes and will address any or several of the following Thematic Groups: Agriculture, Climate Change, Coastal Zone Management, Disaster Risk Management, Energy and Natural Resources, Forestry, Marine Environment Management, Transport, Urban, Water Resources Management and Non-EO Information and Analytics.

1.2 Request for proposal 015: West Bengal Drinking Water Sector Improvement Project, India

This chapter summarises the objectives and approach of the requested EO support referred in the Request for Proposal RFP015 of the EO-clinic Frame Contract, requested by the Asian Development Bank (ADB).

The **main initial objective of this Request for Proposal number 015 (RFP015) is to support the ADB providing a rapid assessment of suitable Nature Based Solutions (NBS) water storage sites in Purba Medinipur based on remote sensing.**

ADB is working with the Government of India to provide safe, sustainable, and inclusive drinking water service to about 1.65 million people in three districts of West Bengal state, India, affected by arsenic, fluoride, and salinity. With about 85% of water in India's rural areas coming from groundwater, some 27 million people are at risk from arsenic and fluoride contamination. Arsenic in drinking water can lead to a range of problems including cancer, while high exposure to fluoride can cause dental or skeletal fluorosis and bone diseases.

Several options had been explored, and a Nature-Based Solution (NBS) to improve storage of flood water has been shortlisted.

Nature-based solutions (NBS) are actions inspired by, supported by, or copied from nature, which deploy various natural features and processes, are resource efficient and adapted to systems in diverse spatial areas, facing social, environmental, and economic challenges. The main goals of NBS are the enhancement of sustainable development, the restoration of degraded ecosystems, the development of climate change adaptation and mitigation, and the improvement of risk management and resilience. Moreover, NBS address global challenges, directly connected to the Sustainable Development Goals (SDG). NBS provide multiple benefits and have been identified as critical for the regeneration and improvement of wellbeing in urban areas, coastal resilience, multifunctional watershed management, and ecosystem restoration. They also increase the sustainability of matter and energy use, enhance the insurance value of ecosystems, and increase carbon sequestration.

Considering the water demands in the West Bengal districts, the adoption of and design of NBS is an urgent matter. Therefore, the identification of non-permanent water bodies within the area as potential storage sites is, in this sense, of paramount relevance.

The NBS for surface storage is, for instance, to develop abandoned river channels, as storages, along the river Rupnarayan. These can be identified by mapping inundation before and after the monsoon. Channels that were dry during pre-monsoon, but with water during post-monsoon, are potential NBS sites of storage. Another possibility is to reclaim near bank water areas as reservoirs.

1.3 Initial request: Objectives, Work Logic and Expected Outputs

1.3.1 Problems to be Addressed and Geospatial Information Gaps

As part of the assessment of the history and availability of surface water resources, ADB and its partners have no comprehensive overview of potential surface storage sites in the three aforementioned districts of West Bengal state. The objective of the study presented in this technical note is to provide a rapid assessment of suitable Nature-Based Solutions for fresh water storage sites in the Purba Medinipur district (Indian state of West Bengal), by an initial screening based on remote sensing. Output will be a prioritised inventory of suitable sites which will serve as background for further detailed investigations. The requested services will help by providing an inventory and detailed characterisation of potential additional water storage sites by focussing on the non-permanent water bodies in the area.

1.3.2 Information services to be delivered: Identification of NBS water storage sites

In order to reach the objective, some intermediate steps are requested:

Service 1: Waterbody Inventory and Dynamics, will outline which of the factors in the Cascade Suitability Matrix can be reliably classified using EO and GIS analysis. It will then perform the classifications of the factors identified, assigning the scores outlined in the matrix. The output is a map per factor containing the applied scores (score layers).

Service 2: Land Use and Land Cover, shall provide the latest status of land use and land cover (LU/LC) for the surroundings of the identified seasonal water areas. The classification shall consider at least the following classes: agricultural/vegetated, bare soil, permanent water, forest and urban. The use of Sentinel-2 enhanced by very high resolution (VHR) imagery in priority areas is encouraged, to add detail on the following: residential vs. industrial built-up areas, critical infrastructure (roads, aquaculture, and, possibly, power lines and larger groundwater wells), etc.

Service 3: Potential Surface Storage Site Inventory, shall provide an inventory of sites potentially suitable for NBS-based surface storage based on rapid assessment (from remote sensing), by combining the results and insights of services 1 and 2 with a relative suitability score for prioritising the sites for further investigation at subsequent stages.

The criteria used to define suitability shall be clearly documented (e.g. flood recurrence, LU/LC characterisation, etc.). Apart from providing detailed maps, the characteristics of the identified sites shall be described in tabular form in the WOR, including area, distance to proposed intake location, existing road access, etc.

The service shall be delivered on an area near the Rupnarayan river, up to 25 km around the proposed intake location (see Figure 1), to minimise pumping distances and costs of pipe networks.

The analysis shall be based primarily on free and open optical and radar data, e.g. ERS, Envisat, Sentinel-1/2, Landsat, exploiting the feasibility limits in what regards the levels of spatial detail of the resulting mapping products

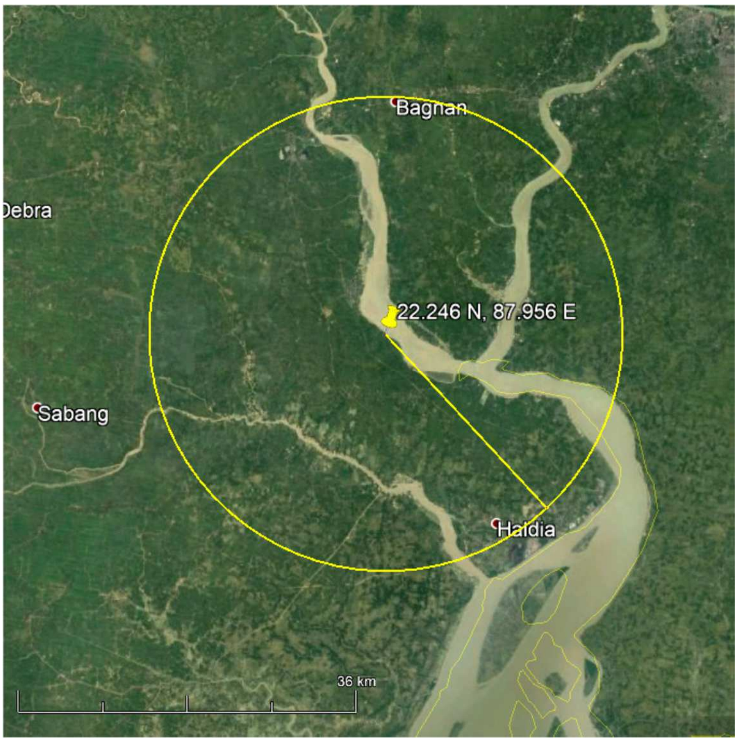


Figure 1. Area of Interest. [Background image: Google Earth].

2 WHAT WAS PROPOSED TO BE PERFORMED

2.1 Understanding of the requirements and proposed approach

The following requirements were identified within the RFP and our compliance statement is also summarised herein:

Table 1. Requirements understanding and proposed approach

Requirement	Fulfil-ment	Comments
map of surface waterbodies and their associated dynamics, including the seasonal changes in waterbody extent for the period from the early 1990's and up to present, focussing on the short-term variability between wet and dry sea-sons as well as long term changes in terms of erosion or siltation over the years	Yes	*The short-term changes are analysed using EO images of relevant dates of the pre- and post-monsoon period for each of the year under analysis. The long-term changes are analysed using comparable images from the same period in different years.*
describe and build on existing relevant datasets and initiatives, at global, regional and local level, such as the Copernicus Global Surface Water Explorer	Yes	*Copernicus Surface Water Explorer datasets are considered in order to supplement the results achieved directly from EO data. Other geoportals related to water resources including but not limited to Bhuvan (ISRO's Geoportal) and India-WRIS project are taken into account.*
service delivered on an area near the Rupnarayan river, up to 25 km around the proposed intake location (see Figure 1), to minimise pumping distances and costs of pipe networks	Yes	*The analysis is performed over a square shaped area covering most of the encircled geographical area proposed in the RFP.*
Base the analysis primarily on free and open optical and radar data, exploiting the feasibility limits in what regards the levels of spatial detail of the resulting mapping products	Yes	*The analysis is mainly based on Sentinel-1 and Sentinel-2 data for recent years. ERS-1 and Envisat data are used to perform the analysis before 2014. Landsat 7/8 and VHR imagery included in Google Earth and ArcGIS Basemap is also considered.*
provide the latest status of land use and land cover (LU/LC) for the surroundings of the identified seasonal water areas	Yes	*The LU/LC map status of the area under study is provided for year 2020*
at least the following classes: agricultural/vegetated, bare soil, permanent water, forest and urban. (the use of Sentinel-2 enhanced by very high resolution (VHR) imagery in priority areas is encouraged, to add details	Yes	*Agricultural/vegetated, bare soil, permanent water, forest and urban are mapped using Sentinel-2. Additional classes can be envisaged to support Service 3. Also, based on VHR imagery, details are provided in order to highlight all LU/LC types related to "small" and "large" water cycles but also critical infrastructure for ever people, economy and/or defence.*
provide an inventory of sites potentially suitable for NBS-based surface storage based on rapid assessment (from remote sensing)	Yes	*An inventory of sites potentially suitable for NBS-based surface storage is provided as the result of the pooled analysis of the outputs generated in Service 1 and Service 2 with non-cartographic data.*
Document the criteria used to define suitability	Yes	*Criteria are documented.*

apart from providing detailed maps, provide the characteristics of the identified sites in tabular form in the WOR, including area, distance to proposed in-take location, existing road access, etc.	Yes	*In order to fulfil the WOR, spatial analysis is done using the critical infrastructures extracted from Pléiades VHR images.*

2.2 The partners

The overall EO-Clinic frame contract consortium is composed by thirteen companies. Twelve EO service providers, expert in a specific thematic group, but also, with expertise in most of them. And the prime contractor, everis Aerospace and Defense, an entity which primary expertise in management of challenging international development projects. This way, the key of the success lies on a well-structured and collaborative team, which members supporting each other in order to achieve outstanding results.

It is a **well-balanced team** formed by **one multinational entity** leading the consortia, expert in managing international projects, **two research organization** which provides state of the art techniques in term of EO solutions and **10 SMEs** entities highly dynamic and specialized on EO solutions.

The main principles of the consortium are:

- **Highly reactive and dynamic structure** – for accommodating short-term, small and exploratory request from the end user.
- **Deep understanding and expertise on thematic EO products** – providing a wide coverage of range of skills and capabilities in terms of different EO study areas and products generation.
- **Client-oriented solutions** – always keeping in mind the scope and the necessities of the end-users. Their business activity and aiming to provide the best suited EO solutions for them.
- **Time-oriented project** execution – It is essential in this environment to deliver EO information on time against deadlines. This is the only approach for achieving what it is called “rapid-response” capability to the Bank users.
- **High quality assistance for end users** – usually, final users are not familiar EO technologies, even less, when innovative methodologies and techniques are applied. It is essential to provide assistance on final information for its correct exploitation.
- **Expand the knowledge through Europe** – thirteen companies, nine different countries. The consortium aims to promote European missions, generate value-adding services, and take European EO capabilities to the next step.

The complete thematic groups required by ESA for different Request for Proposals are fully addressed by the consortium members.

This project in particular is performed by the following partners providing the best expertise for the specific purpose of the project:

everis Aeroespacial y Defensa, S.LU.	Prime Contractor: EO-clinic Frame Contract and project management and technical Coordination
everis is a multinational group that offers to its clients services and solutions that add high value covering all the value chain areas of a company, from defining the strategy, to design, development, integration, implementation and maintenance of technological solutions. **everis Aerospace and Defence**, the **everis** Group’s Aerospace and Defence Division, offers global solutions for implementing critical systems in aerospace, defence, security and simulation sectors, integrating reliable and innovative technologies though proprietary development and through the SMEs with which the Group has strategic alliances as leading partners.	

i-Sea SAS	Subcontractor: Thematic Group TG10- Water Resources Management Leader

i-Sea demonstrates a significant experience for LU/LC. In the framework of Biocoast project (grants from BPIfrance/Programme Investissement d'Avenir, 2016-2018), i-Sea developed a semi-automated approach for habitat mapping serving Natura 2000 habitat directive. The approach was designed and validated over 5 individual natural sites and, since then, Biocoast operational service was deployed over 10 additional areas. Biocoast initially focussed vegetation and habitats of community interest of coastal wetlands. Progressively, it addressed most types of open and then closed environments from lowlands (including flood plains) to semi-mountainous environments. Originally based on the use of VHR imagery, to derive very fine and precise phytosociological typologies, it was adapted to the use of yearly Sentinel-2 image time-series over large catchment areas (several tens of thousands km²) to monitor wetlands of one of the French National Water Agency (Agence de l'Eau Seine Normandie). In order to achieve this latter challenge, Biocoast was adapted to LU/LC in order to demonstrate the impact of urbanization, industrialisation, and intensive agriculture on wetlands space distribution.

i-Sea developed tools for riverine and coastal water turbidity monitoring. Based on MR to HR optical imagery, tools are based on water optics to derive for each pixel surface water turbidity for 1-1000 FNU ranges. Tools are also adapted to suspended matter concentrations. i-Sea's tools are particularly adapted to generate long time series exploiting Landsat and Sentinel-2 free databases (e.g. a 35-year database was produced for the Adour Garonne Water Agency in order to contribute to the understanding of the maxi-mum turbidity dynamics in Gironde-Garonne-Dordogne rivers and estuaries).

Fundación Instituto de Hidráulica Ambiental de Cantabria (FIHAC) (Research institution)	Subcontractor: Thematic Group TG3- Coastal Zone Management Leader

FIHAC has extensive experience in managing projects co-financed by the EU and other international bodies. It has led 3 Interreg Atlantic over the last 10 years - SPRES on discharge management at sea, PORTONOVO on water quality in ports and ALICE, a project led by the Continental Ecosystems group which seeks to promote sustainable investments in NBSs through integrated modelling of ecosystem services.

In H2020, it has participated as a partner in 12 projects since 2014 and the Continental Ecosystems group is leading one of them, ITN-EUROFLOW. FIHAC has also led 3 LIFE proposals in the last 4 years: DIVAQUA, CONVIVE and ADAPTA BLUES.

It also participates as a partner in a project of the ECHO call and at an international level it participates in projects financed by entities of great relevance such as the WB, the IDB or the UN.

Added to these, FIHAC is carrying out different research projects in different geographical areas of the Iberian Peninsula, Asia, and South America on topics related to hydrology, geomorphology, vegetation and landscape, biodiversity and ecosystem functioning and services.

The institution also develops a large amount of applied work and consultancy to transfer the advances of research to the management and conservation of continental, aquatic and terrestrial ecosystems. The team works at different spatial-temporal scales using different data collection systems ranging from the scale of the vegetation polygon or river section to the scale of large river basins or networks. The application and development of remote sensing and spatial modelling techniques for the cartography of the different continental, littoral and coastal systems, as well as the evaluation of their environmental patterns and processes, constitutes an-other of FIHAC interests.

Within this line of work, the following areas of specialisation have been developed: 1) Monitoring of aquatic ecosystems (e.g., morphodynamics, water quality, etc.) and analysis of trends; 2) Modelling and mapping of vegetation and change in soil use; 3) Management and conservation of ecosystems (e.g., vulnerability, ecosystem services, etc.); and 4) Development of Spectral Libraries (surface radiance and reflectance) of different environments (terrestrial and aquatic).

2.3 Work Logic proposed

The work logic of this particular Work Order has been defined to ensure the provision of an efficient service to ADB and ESA, maximizing added value outputs, delivered on time and in the required format. Indeed, the work for this RFP is organized around five work packages (WP).

- **WP0**: This work package contains the overall management and the successful implementation of the work as well as the delivery of the results.
- **WP1**: Waterbody inventory and dynamics
- **WP2**: Land use / Land Cover
- **WP4 (ADDED)[1]:** Siltation rate qualification as a function of riverine turbidity
- **WP3:** Potential surface storage site Inventory
- **WP5**: This work package contains the final report, recommendations, and quality assurance of the results of WP 1 and 2.

The high-level work logic is described in the following Figure:

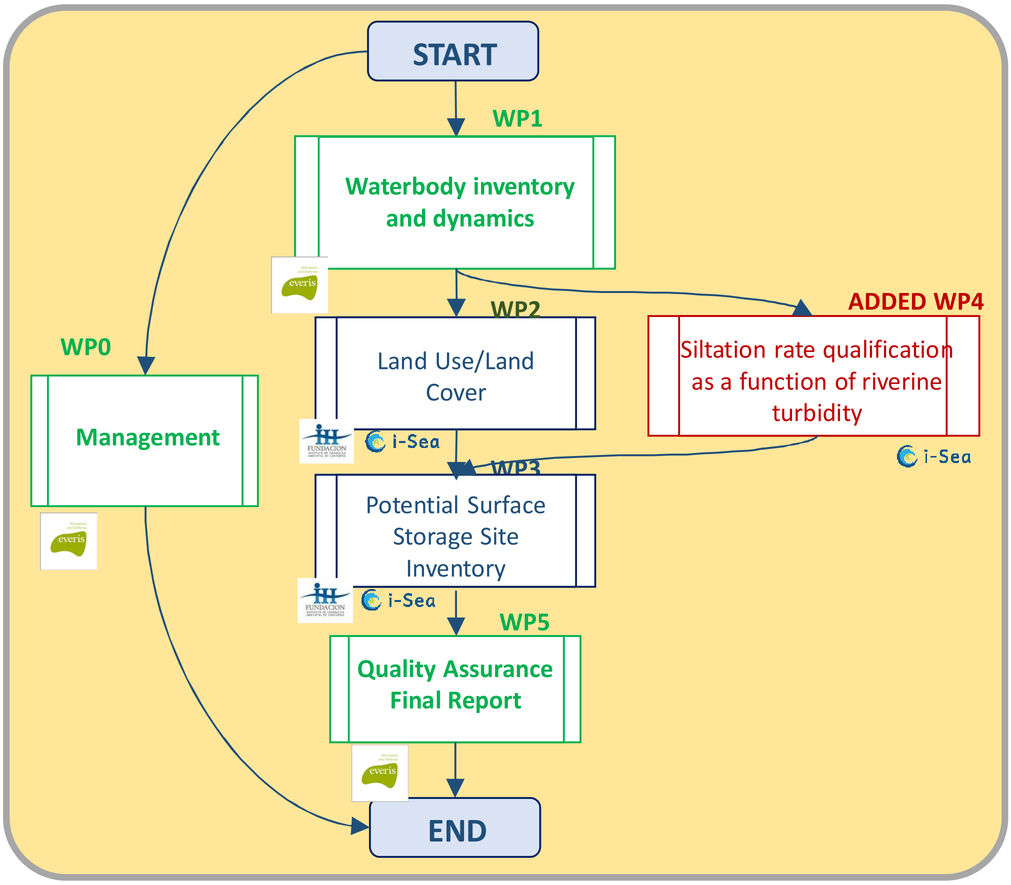


Figure 2.Work Logic

[1] WP numbering keeps the one in the contract Proposal, not coherent wit the study logic, i.e. added WP4 is to be developed logically before WP3

2.4 Methodology

2.4.1 WP0 – Management

Management processes follow the ones described in reference Management Proposal. In this proposal, only specific management aspects for this RFP are described. In order to control the progress of the work order with respect to cost, schedule and technical objectives, the following milestones are set up:

Table 2. Milestones management.

Milestones		Date
Kick-off Meeting (KOM)	Once the Work Order (WO) is launched, a KOM held by ESA, ADB, and the contractors to review schedule, scope of the work and deliverables. Agree the additional available data sources to support for the execution of WO.	T0
Mid-term review	discussion of the draft map and WOR delivered	T0+5 weeks
Progress meetings	Bi-weekly progress meetings to meet the customer and stakeholder and present the progress of the project	Bi-weekly
Acceptance Review (AR)	A final meeting with ESA, ADB, and the contractors performed to review and accept the work done along the work order.	T0+10w

Other management-related tasks such as cost control procedures, progress reporting, meetings management, actions management and so on are carried out as stated in the Management Proposal. Moreover, the proposal manager contributes to the final report with the conclusions obtained during the Work Order, and related to the estimation of feasibility, conditions, and cost of an extended service.

2.4.2 WP1- Waterbody inventory and Dynamics

2.4.2.1 Objectives and tasks

The main objective of Work Package 1 (WP1) is to map surface waterbodies in the proposed AOI, using pre- and during monsoon SAR images as main input data for each of the years considered in the analysis. Optical imagery, global DEMs and geospatial data for hydrology also use as ancillary information to process and refine the delineation of the waterbodies extent. Relaying on this cartographic basis, variability short-term and long-term analysis is performed.

The main tasks that are necessary for this work are:

1. Data collection and image processing
2. Delineation of waterbodies extent
3. Analysis and interpretation of the mapped dynamics.

Task 1.1 – Data collection and image processing

This data collection and image processing task is planned to be performed following several steps, being:

a) To gather information related to Monsoon occurrence and dry season dates that enables the selection of images acquired pre- and during monsoon months to be used in the delineation of changes in waterbodies extent. Monsoon schedules, rainfall trends, and measures carried out in the hydrographic stations of West Bengal are consulted from the website of the Indian Meteorological Department

(Ministry of Earth Science[1]). As a tentative proposal, last 10 years (2011-2020) are considered to map surface waterbodies and dynamics. An extra period of 3 years in early 1990's are also considered as reference data.

b) To carry out an extensive search of archived SAR images acquired close to the dates chosen in the first step of this task, are used as main input data to perform the water extent delineation. Four SAR images, two within the dry season (e.g. tentatively January and February) and two within the wet season (e.g. tentatively July and August, but determined by the analysis of the available hydrographic stations), are processed for every year within the period of analysis. Sentinel-1, Envisat, and ERS-1 images are used. Sentinel-2, Landsat, SRTM DEM and imagery included in Google Earth and ArcGIS/QGIS Basemaps are also considered as ancillary data.
Sentinel-1&-2 products are downloaded from the Copernicus Open Access Hub[2] (previously known as Sentinels Scientific Data Hub), Envisat ASAR and ERS-1 products are acquired through the dissemination services included in the ESA Earth Online[3] and SRTM DEM and Landsat data are consulted in the USGS Earth Explorer[4]

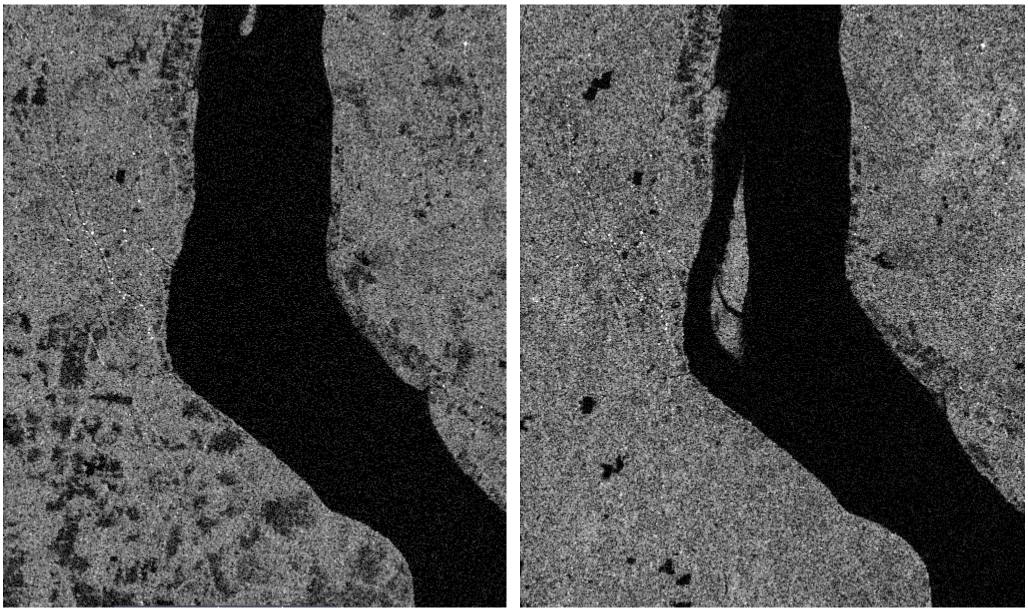


Figure 3. Different extent of the course of the Rupnarayan River within the AOI in two different dates. Images acquired by Sentinel-1, 28th of February 2020 (left) and 30th of November 2020 (right)

c) Moreover, this task includes the processing of SAR images required to perform the Task 1.2 and the pre-processing of Sentinel-2 images required to perform WP2. In the case of Sentinel-2 data, subsetting, subsampling and mosaicking processes are performed on a set of cloud free Level-2A products acquired during 2020. The processing phase of SAR data involve the absolute calibration, orthorectification and subsetting of each image before applying a speckle noise filter. All the described steps are performed with the SNAP (Sentinel Application Platform) software[5]. SNAP is an open source common architecture for ESA Toolboxes, ideal for the exploitation of Earth Observation data that supports the scientific exploitation for the ERS-ENVISAT missions and the Sentinels 1/2/3 missions.

SAR Processing methodology:

[1] Indian Meteorological Department (Ministry of Earth Science). http://imdpune.gov.in/hydrology/
[2] https://scihub.copernicus.eu/
[3] https://earth.esa.int/eogateway/
[4] https://earthexplorer.usgs.gov/
[5] https://step.esa.int/main/toolboxes/snap/

The objective of SAR data calibration is to provide an image in which the pixel values can be directly related to the radar backscatter. Though uncalibrated radar data is sufficient for qualitative uses, calibrated radar images are basic to make a quantitative use of SAR data. Level-1 image as in this case, does not include radiometric corrections. Thus, it is necessary to apply the radiometric correction to radar images so that the pixel values of the radar images represent the radar backscatter of the reflecting surface. The radiometric correction is recommended for the comparison of either radar data acquired with different sensors or acquired from the same sensor but at different times, in different modes, as is in the scope of the present project.

Furthermore, terrain corrections are intended to compensate for the distortions introduced by topographical variations of a scene and the oblique angle of the radar signal distances. The Range Doppler Terrain Correction operator implements the Range Doppler orthorectification method for geocoding radar images from single 2D raster radar geometry. It uses available precise orbit vector information in the metadata, the radar timing annotations, the slant to ground range conversion parameters together with the reference Digital Elevation Model (DEM) data to derive the precise geolocation information.

The third step proposed above aims to reduce the characteristic speckle noise of a radar image. Speckle is the coherent interference of waves scattered from ground surface elements which is seen as a grainy salt and pepper pattern in radar imagery. Speckle filtering improves discrimination of scene targets. Adaptive filters, such as the Refined Lee or Gamma Map, accommodate changes in local properties of the backscatters on the surface.

Only the data acquired in VH polarization are processed due to being more appropriate than VV for the intended purpose, the reason is that VV is highly influenced by surface roughness conditions[1].
It was proved that HH polarisation provided a more suitable discrimination of waterbodies or flooded areas than VH or VV (Henry et al., 2006). However, Sentinel-1 sensor commonly acquired images in VV+VH dual polarization.

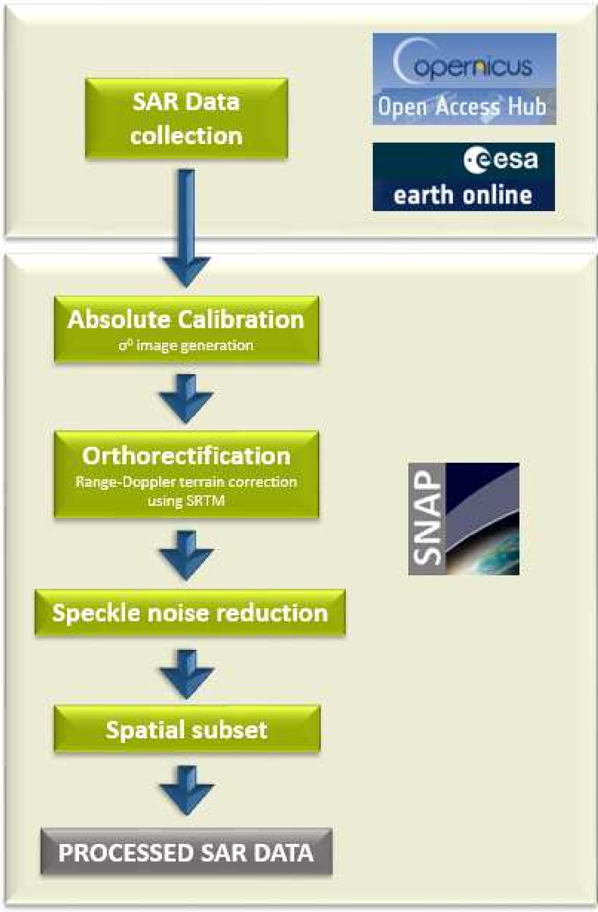


Figure 4. SAR image processing workflow

Task 1.2 – Delineation of waterbodies extent

The goal of this task is to map waterbodies for every SAR image processed in Task 1.1 in order to represent the dynamics of the waterbodies extent along the period of analysis.

Waterbodies extent are derived mainly from SAR backscatter intensity images by means of an automatic extraction followed by manual refinement. Trimble eCognition[2] tool is proposed to carry out a supervised classification. Optical imagery and SRTM DEM are used to discard areas not susceptible to floods or incorrect

[1] https://earth.esa.int/download/eoedu/Earthnet-website-material/to-access-from-Earthnet/2009_ROSA-ESA-DLR-Radar-Remote-Sensing-Course/Flood_detection_principles_TSX.pdf
[2] eCognition is trademark of Trimble

assignments that might be encountered in areas where radar hill shade effect occur or in very flat surfaces that may show a response similar to water surfaces.

Waterbodies extraction methodology

The extraction of waterbodies involve the data analysis and the creation of a water mask. Thresholding is a frequently used technique to delineate waterbodies in a radar image (Sanyal and Lu, 2003). To establish a threshold value is a subjective action, and the choice of the cut-off value (water and non-water) analysing the histogram is not always clear. For these reasons an objectively supervised and object-based classification is proposed for a semi-automatic extraction of the waterbodies extent.

The first step is a selection of training datasets for water detection, i.e., waterbodies, and then the parameters on which the model is based on are defined. The selection of the training data is based on SAR images with the support of optical imagery.

The second step is the extraction of the water mask, which is a time consuming process. Different parameters in which the model is based on have to be adjusted and the final result is obtained by a trial and error process applied over all the SAR processed images. To minimise the workload when performing this step, a minimum area that the object that we are classifying is expected to have is defined in order to avoid the representation of non-relevant areas.

The final output is a stack of water masks, in vector and raster format to be used as inputs to the analysis described in the task 1.3

Trimble eCognition is the commercial tool chosen to carry out this task. It is a software designed for the interpretation of remote sensing and geospatial data, combining object-based analysis techniques with state-of-the-art Deep Learning, fuse raster, point cloud and vector data.

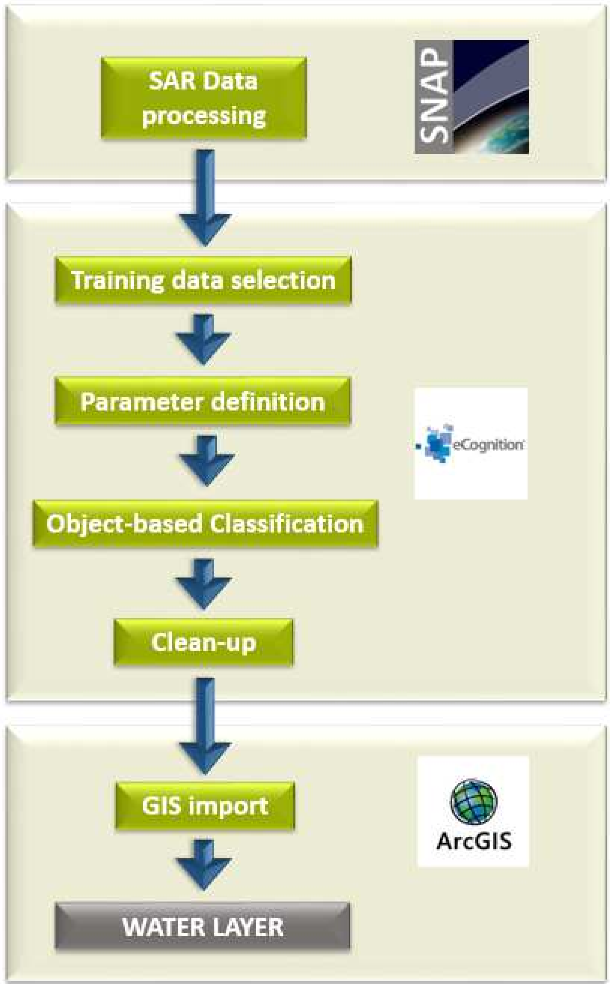


Figure 5. Water extraction workflow.

Task 1.3 – Analysis and interpretation of the mapped dynamics

The goals of this task are to: (i) examine the spatio-temporal patterns of satellite-derived floods, using the waterbodies maps obtained within Task 1.2 for the West Bengal region, (ii) identify the abandoned river channels most affected by the monsoon floods, and (iii) determine the environmental drivers related to large-scale climate indices.

In order to achieve these objectives, the collection of waterbodies maps obtained within Task 1.2 for the West Bengal region at different dates (comprising two time periods of 3 and 10 years, from the early 1990's and the one collected between 2010 and 2020), are used to sustain the analysis. Moreover, data derived from Copernicus Global Surface Water are also used in case of need to fulfil potential gaps in the water dynamics.

This collection of satellite-derived variables (images or maps) for the same region at different dates (SITS) can be seen as a stack of images (one layer per date) or as a grid of time series: each pixel is associated with a time series. Historical data from remote sensing is often valuable because it may provide only long-term data for a large extent of geography. These data can improve our understanding of global dynamics and processes occurring on the surface. In this particular case, the purpose of analysing the temporal series of data derived from remote sensors would be to identify the hydrological pulses (frequency, intensity, amplitude, seasonality, etc), both for regular years as for those ones marked by the presence of climatic phenomena (i.e. el Niño, la Niña).

2.4.2.2 Processing methodology and elaboration

The proposed methodology to analyse long-term dynamics of the satellite-derived floods has two main steps illustrated in Figure 6:

- The **characterisation of annual profiles** from a set of annual SITS of a set of variables derived from Task 1.2 outputs. This step leads to the construction of typical annual images that characterize the behaviour of a pixel location along a specific year. Ideally, these annual profiles should be produced with the most complete monthly dataset, to nicely trace the dynamics. Instead, due to time and budgetary limitations, it is envisaged to use 4 monthly images per year, from the dry months and the wet season (during the monsoon).
- The **characterisation of the sequence of annual images**. This step leads to the construction of a single image that sum up the behaviour of a pixel location along the long-term period. In this sense, the longer the period covered by the SITS, the better.

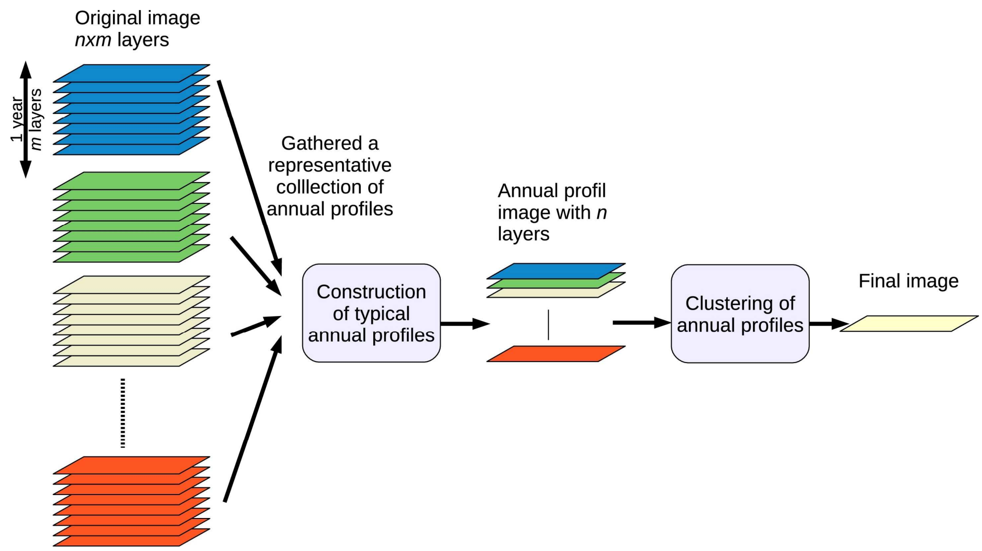


Figure 6. Methodology scheme. The same methodology is applied for the detection of seasonal changes

For an absolute multi-temporal analysis (*i.e.*, detected changes have to attribute solely to variation on target`s signal), all monthly/seasonal water masks are summed up to obtain an image product depicting how many times an area was covered with water during the respective rainy season within each year. This enables an understanding of flood length for different areas. Furthermore, all sum products for the individual years are added to retrieve a satellite-based long time series of flood occurrence, distinguishing between water covered (flooded) versus non-flooded areas. In this sense, we identify the spatial distribution of flooding frequency and the annual initiation date and duration to describe the dynamic characteristics of the flood pulses. Based on further classification (year and month), the monthly and annual flooding frequencies of each pixel are calculated as:

$$F_{i,j} = \frac{C_{i,j}}{TC_j}$$

where $F_{i,j}$ is the flood frequency of pixel i over j days/months, $C_{i,j}$ is the bloom occurrence count, and TC_j is the total count of satellite-derived water masks.

Furthermore, anomalies are calculated by subtracting the climatological mean (*i.e.*, the mean of all years for a given month, considered as a representation of the system state across the different years) from the value for the selected month of that year. Anomaly data are presented as the number of standard deviations about the mean, *i.e.*, standardized anomalies, by dividing the monthly anomaly value by the climatological standard deviation for that month:

$$Y.Norm_t = \frac{Y_t - Y.Clim_t}{Y.Clim.sd_t}$$

being Y the variable under study, t the time (month number), $Y.Clim_t$ each month long-term mean, and $Y.Clim.sd_t$ standard deviation.

This procedure ensures seasonal amplitudes to be comparable. As previously mentioned, this seasonal amplitude should be ideally retrieved based on all of the months.

The strength of an anomaly is defined as follows:

- below −2.0 = strong
- −2.0 – −1.0 = moderate
- −1.0 – 1.0 =weak
- – 2.0 = moderate
- above 2.0 = strong

Hereafter, and unless specified otherwise, a positive anomaly for each variable means that the value was higher relative to the climatological mean, whereas a negative anomaly means that the value was lower relative to the climatological mean.

Added to the identification of those flood-prone areas present in the area of study, there are also an assessment of riverbank erosion-accretion and identification of bank line shifting pattern of the river, based on the observed river planform changes. The identification of such sectors is relevant for the later water-storage site selection procedure that is carried out in WP3. From all these identified areas of interest, AOIs, their surface extension is obtained, as well as relevant statistics from the above-mentioned variables. This leads to a time-series decomposition and the retrieval of the different components to determine the intra-, inter-annual variability as well as the overall trend.

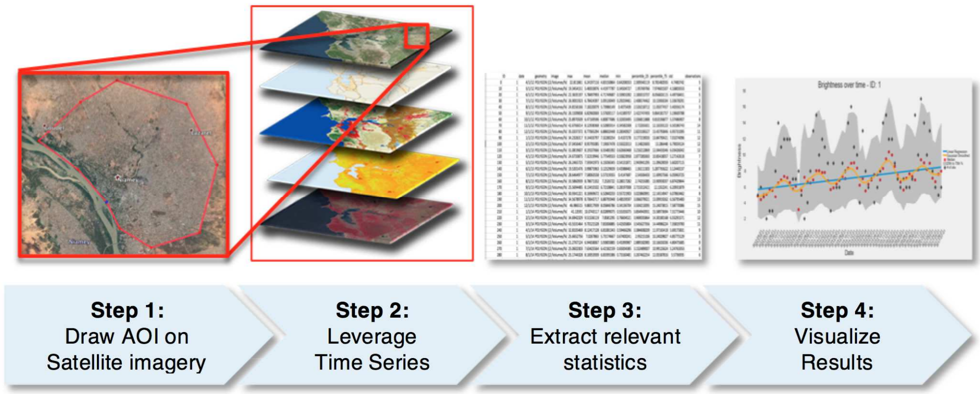


Figure 7: Proposed scheme for the site-specific temporal series analysis

2.4.2.3 Outputs of WP1

- Water mask representing the extent of waterbodies in different dates. (GeoTiff format and ESRI shapefile format)
- Sentinel-2 pre-processed images. (GeoTiff format)
- Seasonal (dry and wet periods) climatological means and annual flooding profiles. (GeoTiff format)
- Seasonal anomalies images. (GeoTiff format)

- Frequency flooding map. (GeoTiff format)
- Erosion-accretion map obtained from the SITS analysis. (GeoTiff format

2.4.3 WP2- Land use / Land Cover

2.4.3.1 Objectives and tasks

The objective of Work Package 2 (WP2) is to provide the most actual LU/LC map status based on the use of remote sensing and AI techniques. Therefore, the main tasks that are necessary for this work are:

1. Training sets definition
2. Image classification and LU/LC map generation
3. LU/LC map improvement using VHR images

Task 2.1 – Training sets definition

The objective of this task is to define the training sets for all classes in the LU/LC legend from EO and Non-EO data if available.

Supervised classification systems used for land cover mapping require accurate reference databases. These reference data come generally from different sources such as field measurements, thematic maps, or aerial photographs. The reference dataset is crucial in order to train classification systems and to evaluate the produced land cover maps. Accordingly, it is generally split into two sets in supervised classification schemes: one for training, and the other one for validation, i.e., for assessing land cover algorithm quality. Obtaining well-labelled data is an important challenge. For this study, the strategy to obtain an accurate labelled dataset consists in using interpreted data from very high spatial resolution satellite images, Google Earth imagery, available existing maps or specific existing databases from the West Bengal districts.

For the model training, it is necessary to have a minimum number of training polygons (points of occurrence) for each of the land cover to be modelled, without environmental or geographical bias, which reflect all the spatial variability of the land cover class in the study area.

Some formations may occupy large areas, while in other cases, mostly formations linked to aquatic environments, show a stenotic and localized distribution, drawing tesserae of small surface areas and elongated and narrow shapes. These characteristics of distribution, size and shape of the vegetation patches condition the possibility of modelling based on data from remote sensors, therefore, the selection of optimal points for modelling is carried out using the following criteria:

1. Those polygons in which the coverage of the main land cover class is greater than 90% are selected, in order to ensure the data purity and the reliability of the set of training points. The selection of mixed tesserae increases the probability of defining erroneous points since the content of each typology is not defined in a spatially explicit way within the tessera.
2. In order to guarantee a spatial resolution compatible with the spatial resolution of the modeling database, a selection criterion related to the surface of the polygons is applied, so that only those with an area greater than (or equal to) 1 Ha are selected.
3. The following criterion is related to the shape of the tessera, so that tessera with a width greater than 20m are selected, in order to avoid the edge effect in the selection of the training points of the models.
4. Once these criteria is applied, only the map tesserae corresponding to the selected land cover classes are selected.

For each of the land cover classes, a selection of 10-30 polygons are extracted for training the image classification model, and a similar amount are also selected for validation purposes.

Task 2.2 – Image classification and LU/LC map generation

This task aims to generate an automatic classification of a selection of optical images (previously collected in WP1) in order to create a map that provides the latest status of LU/LC for the AOI.

This task aims to generate an automatic classification of a selection of optical images (previously collected in WP1) in order to create a map that provides the latest status of LU/LC for the AOI.

Our objective is to produce LU/LC map based on 2020 imagery. With this aim, we select a complete set of Sentinel-2 cloud-free imagery acquired in 2020 collected in Task 1.2. Then, RandomForest classifier algorithms are used. The prediction model is adjusted based on the Sentinel-2 image time series (10 m resolution) and the training data set elaborated in Task 2.1. The model predicts, for each pixel, the typology specifically elaborated to perform the analysis in WP3. The prediction is performed for the whole AOI. The derived map and confidence index are examined. If necessary, improvements are proposed. In that case, either the LU/LC typology is adapted and/or the training dataset revised and/or enhanced. This operation can be repeated two or three times in order to obtain the best and most appropriate result.

A shapefile is exported from the raster with a space resolution of 10 m is exported and delivered

As an example, a couple of maps realised for the Seine Normandie Water Agency, are presented on Figure 8. The typology was elaborated in order to analyse wetland change in relation to regional water policy.

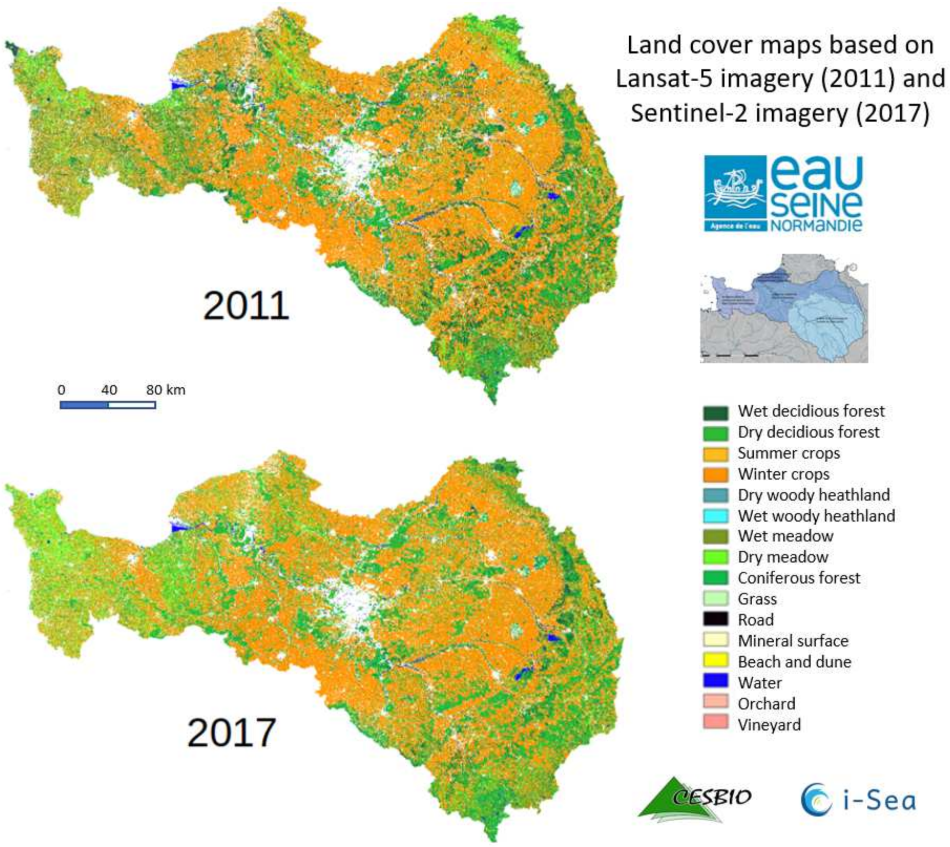


Figure 8: Example of and cover maps carried out to analyse wetlands space and time evolution

Task 2.3 – LU/LC map improvement using VHR images

The objectives of this task is to refine the LU/LC urban class (and natural areas) introducing a higher spatial detail using VHR image, and to delineate critical infrastructures (and sensitive habitats).

Same operations and strategy as described in above task 2.2 are applied, on a Pléiades short times series, recorded in 2020. Acquisitions are frequent to the South of the AOI (Figure 9), and appropriate to obtaining LU/LC maps with higher resolution, and with the typology defined in Task 2.1. A shapefile is exported from the raster with a space resolution of 50 cm and delivered. Objects with a critical size lower than Pléiades space resolution (50 cm), are photo-interpreted on VHR airborne pictures (e.g. Google Earth, Figure 10) and, then, inlayed in the final shapefile.

Figure 9 : Pleaides image recorded on November 22nd, 2020, in Haldia region

Figure 10. VHR airborne image in Google Earth (20/11/2020).

2.4.3.2 Processing methodology and elaboration

In order to address any problem and typology related to LU/LC, a previously developed full mapping process based on the exploitation of High and Very High Resolution satellite images (such as Pléiades, Sentinel 2, etc.) and latest machine learning approaches such as Deep Learning in order to produce different levels of land use mapping. Our process is neither sensor/source dependent nor thematic dependant, and it could be applied for many mapping tasks, integrating temporal analysis or multi-source abilities.

The core of our mapping process is the articulation of two main pillars:

- First, an iterative discussion with the final end-users and thematic specialists allows us to define and fine tune the targeted typology according to the potential of available data and image constraints. This leads to the elaboration of a pertinent and accurate database (see Task 2.1. - Definition of a training data set).
- Second, we adapt our image analysis and machine learning strategies to the problem, from a pixel wise classification of time series image features with RandomForest when mapping of various classes is required to convolutional neural network architectures for very high precision mapping of specific objects. Depending of the problematic, we focus more on temporal analysis or on spatial analysis (such as shapes and textures), which allows investigating and optimizing the exploitation of the image potential.

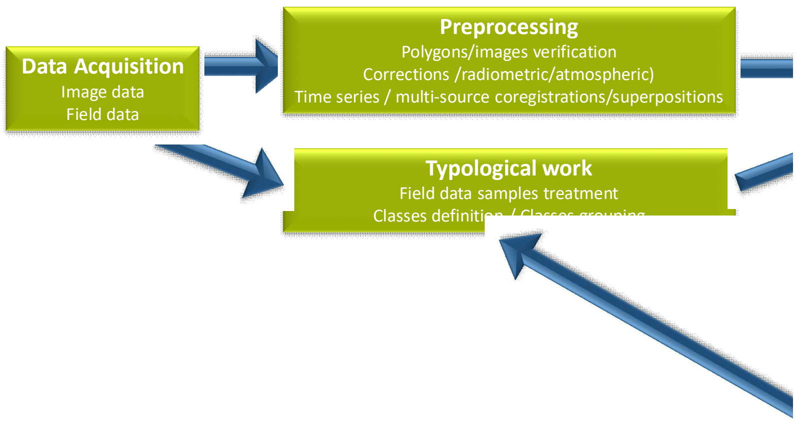


Figure 11: Overview of supervised mapping approach

The automatic processing chain is presented Figure 11. Starting from image and field data acquisition, a work-around typology is needed, based on a cognitive process between thematic experts and image analysis and machine learning experts. This step is very important as it designs the problem and its limits according to the objectives to be achieved. Images are pre-processed and field data polygons are carefully checked. Images (or image time series) are then used to compute new information such as radiometric or textural indexes (depending on the nature of the problem and the image spectral and spatial resolution) and a reference database is built. The next step consists in testing and optimizing the machine learning process, looking for the best configuration of images features, sampling strategies and classifiers. RandomForest classifier is usually used as a reference, but we also work continuously on DeepLearning architectures and compare performances. We select the best configuration and then apply our modelling to the whole image. A confidence index of the classifier is produced and a spatial regularization is applied to the classification output (in order to reduce some noise and isolated pixels). Coherence of the permanent waterbodies location in LU/LC are compared with the results from Task 1.3. If necessary, LU/LC is corrected accordingly.

2.4.3.3 Outputs of WP2

Geodatabase: Individual vector files (shapefiles) based on Sentinel-2 and Pleiades imagery. Each polygon is labelled following the typology. Metadata are provided to trace the source of the shapefiles.

2.4.4 WP4 Siltation rate qualification as a function of riverine turbidity

2.4.4.1 Objectives and tasks

This is an added work package not requested in the RFP.

The objective of Work Package 4 (WP4) is to help the interpretation of the results and to guide the decision maker in WP3, we propose a cartographic reading grid which combines a set of observations derived from Task 1.2. in a form of hierarchical and spatial classification of the siltation potential in the study area.

The main objective is to build an index of siltation risk (or potential) by combining two parameters: a per-pixel temporal percentage of water recurrence and a per-pixel temporal percentage of high turbidity occurrence.

The main tasks that are necessary for this work are:

1) Extraction of water bodies turbidity
2) Siltation potential retrieval per water body.

Task 4.1 – Extraction of water bodies turbidity

The per-pixel temporal percentage of high turbidity occurrence is computed for each water pixel in the area of interest using a large satellite image database of 10 years long (2011-2020). This database includes Landsat-5 (2011-2013), Landsat-8 (2014-2015) and Sentinel-2 images (2016-2020). These image data are collected at an atmospherically corrected level using L2A products (Bottom-of-Atmosphere (BOA) reflectance) delivered by USGS for Landsat-5/8 sensors and ESA for Sentinel-2 sensors. Each collected image is then processed using the following steps:

- cropping of the image to the area of interest using a predefined geographical extent,
- retrieval of valid water by masking land, cloud and cloud shadow pixels using the water body extent provided in Task 1.2 and cloud masks provided by USGS and ESA with L2A products,
- conversion of water pixels' reflectance to turbidity using a multi-conditional algorithm based on the red and near-infrared bands (Han et al., 2016 ; Novoa et al., 2017). This type of algorithm is adapted to the estimation of high turbidity with a range of 10 to 1.000 FNU.

Task 4.2 Siltation potential retrieval per water body

We propose to synthesize the information derived from tasks 1.2 and 1.4.1 to:

1) simplify the reading, and

2) extract the entire substance from the results obtained.

This additional exercise is based on 3 steps:

A. Discretize and map the results of water body recurrence and turbidity recurrence

a) Water bodies recurrence: For each pixel analysed, the percentage of submersion recurrence (water occurrence among the set of dates analysed) is calculated to define the frequency with which water is detected in the pixel (water floods the zone) from year to year.

   Here is the discretization of the classes proposed for each pixel of the image:

   - [0 – 10 %] = No/almost no date with observed water (i.e. Dry land surface)
   -] 10 – 30 %] = Few dates (10 – 30 % among the set of images analysed) with water (pixel flooded occasionally)
   -] 30 – 60 %] = Moderate/Medium frequency of water recurrence (e.g. seasonal immersion)
   -] 60 – 90 %] = High/very high proportion of dates/images analyzed with water
   -] 90 – 100 %] = All / almost all images analyzed with water (active river channel, permanent water bodies)

b) Turbidity recurrence: For each pixel analyzed, the percentage of high turbidity recurrence (frequency of occurrence of high turbidity threshold reached among the set of dates analyzed) is calculated to define the frequency with which high turbidity is detected in the pixel from year to year. The high turbidity threshold is determined according to the turbidity gradient obtained over all the dates of the study period. This threshold corresponds to the value of the third quartile of the series of extracted turbidity values.

Here is the discretization of the classes proposed for each pixel of the image:

- [0 – 10 %] = No/almost no date with observed high turbidity
-] 10 – 30 %] = Few dates (10 – 30 % among the set of images analysed) with high turbidity (occasional)
-] 30 – 60 %] = Moderate/Medium frequency of high turbidity recurrence (e.g. seasonal)
-] 60 – 100 %] = High/very high proportion of dates/images analyzed with high turbidity, or even permanent

B. Definition of an index of siltation potential

We overlay the two maps produced in step A above, according to the following ranked levels (0 to 3) of siltation potential:

		Water body recurrence			
		[0 – 10%] /] 90 – 100 %]	] 10 – 30 %]	] 30 – 60 %]	] 60 – 90 %]
Turbidity recurrence	[0 – 10%]	0	0	0	0
	] 10 – 30 %]	0	1	1	1
	] 30 – 60 %]	0	2	2	1
	] 60 – 100 %]	0	3	3	2

Where

0 = Pixel/area not affected by siltation issues (permanent water or permanent dry land, and/or almost never turbid)
1 = Pixel/area rarely/occasionally favourable to siltation (too often submerged of not turbid enough)
2 = Pixel/area conducive to siltation
3 = Imminent/frequent siltation

Depending on the results, a seasonal distinction (wet period/dry period) may be considered.

C. Zoning mapping according to siltation potential criteria

The final results are represented in the form of a map ranking the sectors from the most favorable to the least favorable to siltation.

2.4.4.2 Outputs of WP4

Geodatabase : one vector file (shapefile) labelled to locate sites most and least favourable to siltation.

2.4.5 WP3- Potential surface storage site Inventory

2.4.5.1 Objectives and tasks

The main aim of this WP3 is to produce a map-format list of potential storage sites adequate to be considered for the implementation of the envisaged nature-based solutions for the water quality improvement.

To achieve such goal, the following tasks have been identified, and are agreed with ESA and ADB:

1. Selection criteria definition, data integration and identification of all potentiality-selectable sites

2. Connectivity study between sites and vulnerability analysis
3. List of potential storage sites according to the selected criteria

Task 3.1 - Selection criteria definition, data integration and identification of all potentiality-selectable sites.

Expert knowledge and a multi criteria decision analysis (MCDA), based on the flooding recurrence, site dynamics and stability (non-erosion prone), riverine land cover, and isolation degree of the channels subject of study, are used for selection of suitable sites for water storage. The methodology is completed in four main steps:

- Collection of data.
- Selection of factors and constraints.
- Giving percentage influence to each criterion.
- Performing weighted overlay.

Among the variables that are considered for the site selection process, there is an especial consideration to the following aspects:

- The drainage density, which should be low for the potentially selectable sites.
- The sediment load of the stream, which should be low so that the site has more capacity to store water.
- The evaporation rate in the area should be low.
- If the source is not adequately protected, the supply shall be adequately protected by treatment, frequent sanitary surveys should be made to identify health hazards.
- Further the adequate capacity to meet the peak demands without development of low pressure should exist. Then the water treatment plant near such source should be located.
- Selected sites should not have any effect on natural aquifers.
- The sites should have gravity forces in such a way to transport water where it may be treated.

These parameters are in part retrieved from the outcomes produced by WP1 and WP2, but also derived from some other variables. In this sense, the slope is derived from the DEM, reclassified into a number of classes and then put into the weighted overlay (Stemn et al., 2016). Settlements are identified and mapped in WP2, and so are the existing roads. Moreover, considering that the site selection is solely dependent on availability of water to recharge the reservoir, the flooding extension and recurrence (obtained in WP1) are paramount. Flow direction is based on DEM and carried out as the foundation of flow accumulation.

Euclidean distance is calculated for the river, roads and settlements of the study area and finally put it into the weighted overlay on the different weighted on the basis of the requirement of the storage site. The factors and constraints are the central part of MCDA for site suitability. The factors indicate where a site is suitable or not suitable for the particular purpose relative to others features. Based on available data and study area knowledge the research adopted factors like slope, distance from settlements, proximity to roads and closeness to water treatment plants, as the farther the site, the less suitable would be. Further, Boolean algebra is used for suitability analysis; this is a technique that is used for consideration of areas suitability. The Boolean algebra exclude the area which are unsuitable and give code “0” and consider all those area with code “01” which are suitable (Stemn et al.,2016). Using Boolean algebra, based on factors; a site is assigned 1 when it was considered suitable and 0 when unsuitable. The factors are classified in 4 four classes, ranked as high suitable, suitable, least suitable and unsuitable in descending order.

Task 3.2 – Connectivity study between sites and vulnerability analysis.

A set of new connectivity indices (integral index of connectivity, probability of connectivity) that have been shown to present an improved performance compared to other existing indices are estimated, as they are particularly suited for landscape planning and change monitoring applications (Pascual-Hortal & Saura 2006, Saura & Pascual-Hortal 2007, Saura & Rubio 2010, Saura et al. 2011). These indices are based on spatial graphs (networks) and on the concept of measuring habitat (in this particular case, the water bodies) availability (reachability) at the landscape scale. This concept consists in considering that an habitat/water body patch is connected to itself, measuring the connected habitat resources existing within the patches (intrapatch connectivity) jointly with the resources made available by (or reachable through) the connections with other habitat patches (interpatch connectivity). In this way, connectivity is conceived (and measured) as the property of the landscape that determines the amount of reachable habitat in the landscape, no matter if such reachable habitat comes from big and/or high quality habitat patches themselves (intrapatch connectivity), from strong connections between different patches (interpatch connectivity) or, more frequently, from a combination of both. For this particular study, the idea is to analyze the potential connectivity between the potential water-storage sites, as a negative factor in the site selection procedure.

By ingesting WP1 and WP2 outputs, developed at various spatial/temporal resolutions across the area of interest, there is an integration of the results from terrestrial/aquatic domains in a common product. This integration is used for developing vulnerability-resilience analysis of the system. The analysis that is carried out of the system dynamics and associated anomalies of selected indicators of riparian areas and river reaches serve as a proxy of the system's vulnerability (characterized by recurrence period and phenomenon intensity) and resilience. This activity accomplishes spatio-temporal analyses to determine potential impacts and resilience capabilities of the target system. Through the use of the data produced in WP1 and WP2, there are identified periods of change, of recurrence and their duration to inform the system capacity for recovery at the local level (study site).

Task 3.3 - List of potential storage sites according to the selected criteria

A list of potential water-storage sites is produced based on the integration of the results obtained in Task 3.1 and 3.2.

2.4.5.2 Outputs of WP3

The outputs of this working package include:

- the list of potential water-storage sites in a geo-located map format,
- the conclusions and findings of the performed services in a technical note
- guidelines and limitations of the services, and results from innovative experiments defined in WP1 and 2 (part of the same technical note).

2.4.6 WP5 -Quality Assurance, and Final Report Creation

2.4.6.1 Objectives and tasks.

Main objectives of the WP5 are dedicated to ensure the overall quality of the service and report findings and conclusions acquired during the WO execution. Quality assurance principles approved are followed. Those procedures are tailored to fit into the 8-week time frame, and then ensuring that a minimum quality is reached.

The second objective of WP5 is the creation of a final report that states the success of the project, conclusions and findings are compiled in this report, and then well support a larger service over other regions. The potential of the platform applied during the WO is described, but also its limitations. Then, ADB and other stakeholders will be perfectly aware of the working flow and its potential.

To achieve the objectives, following tasks are identified and agreed with ESA and ADB:

- Task 5.1 - Independent Quality Check of the output products.
- Task 5.2 - Final Report, which includes conclusions and guidelines to an extended project over a larger area.

2.4.6.2 Outputs of WP5

The outputs of this working package are compiled into the Work Order Final Report (this document). It includes the verification and quality assurance metrics, but also the conclusions and findings of the performed services. It also includes guidelines and limitations of the services, and results from innovative experiments defined in WP1, 2, 4 and 3.

2.5 Input dataset required

The input imagery needed in order to execute proposed tasks is primarily collected (in Task 1.1) from the online platforms and data stores of the European Space Agency (ESA), which provides full, free and open access to data to serve general public. Sentinel-1/2 images are collected from the Copernicus Sentinel Data Hub, and ERS-1 and Envisat imagery are collected via Earth Online. The Pléiades VHR data to be used as improvement of the results in WP2 are purchased from Airbus Geostore[1]. More specifically, the acquisition of the following images within the AOI is proposed:

- Period from January 2020 to December 2020:
    - Sentinel-2 Level 2A (BOA reflectance) product, GSD: 10m: all the available cloud-free scenes.
    - Pléiades Pan-Sharpened product, GSD: 0,5m: subsets of the scenes acquired on 11/02/2020, 02/06/2020 and 22/11/2020.
- Period from January 2011 to December 2020:
    - Sentinel-1 IW GRD Level 1C product, GSD: 10m: four images per year (when available).
    - Envisat ASAR Level 1 IM Precision product, GSD: 30m: four images per year (when available).
- Period of 3 years on early 90´s:
    - ERS-1 SAR Level 1 IM Precision product, GSD 12,5m: four images per year (when available).

Secondly, as ancillary information to complete the proposed task, a list of imagery and raster products are collected or consulted on viewers. Apart from Sentinel-2 archive, VHR images available in Google Earth and ArcGIS/QGIS Basemaps, the following data available in the USGS Earth Explorer is taken into account:

- Shuttle Radar Topography Mission. SRTMv3 1 ArcSec, GSD: 30m
- Landsat 5/7/8 imagery.

Concerning hydrological data, Datasets from Copernicus Global Water Explorer are used to support the dynamics analysis.

Table 3. List of the input data.

Input Data	WorkPackage	Purpose	Source
Imagery Data			
Sentinel-1 Level-1C IW GRD product, GSD:10m 4 images per year from the period 2014-2020 when available)	1	Water extent mapping.	Copernicus Open Access Hub https://scihub.copernicus.eu/
Envisat ASAR Level 1 IM Precision, GSD: 30m (4 images per year from the period 2010-2012 when available)	1	Water extent mapping.	ESA online dissemination https://esar-ds.eo.esa.int/oads/access/
ERS-1 Level 1 IM Precision Product, GSD 12,5m	1	Water extent mapping.	ESA online dissemination

[1] https://www.intelligence-airbusds.com/

(4 images per year in a 3-years period on early 90's)			https://esar-ds.eo.esa.int/oads/access/
Sentinel-2 Level 2A BOA reflectance product, GSD: 10m (A selection of images acquired close to the Sentinel-1 images)	1	Ancillary data for water extent mapping.	Copernicus Open Access Hub https://scihub.copernicus.eu/
(A selection of images from 2016 to 2020)	4	Extraction of water bodies turbidity	
(All cloud free scenes available on 2020)	2	LU/LC Classification	
Pléiades Pansharpened product, GSD:0,5m Acquired on 11/02/2020, 02/06/2020 and 22/11/2020	2	LU/LC classification improvement	Airbus Geostore https://www.intelligence-airbusds.com/geostore/
Landsat 5/8 products (A selection of images from 2011 to 2015)	4	Extraction of water bodies turbidity	USGS EarthExplorer https://earthexplorer.usgs.gov/
Thematic Raster Data			
Global Surface Water data Occurrence, Occurrence change intensity, Seasonality, Recurrence, Transitions, Maximum water extent layers.	1	Support dynamics analysis Ancillary data for water extent mapping.	Copernicus Global Surface Water Explorer https://global-surface-water.appspot.com/download
DEMs			
Shuttle Radar Topography Mission. SRTMv3 1 ArcSec (30 m)	1	SAR images orthorectification. Ancillary data for the clean-up process of the water layer generation.	USGS EarthExplorer https://earthexplorer.usgs.gov/
Vector Data			
-	-	-	-
Non – Cartographic Data			
Monsoon schedules, rainfall trends, and measures carried of hydrographic stations.	1	Support the selection of the optimal mages.	Indian Meteorological Department (Ministry of Earth Science) http://imdpune.gov.in/hydrology/

2.6 Schedule

Schedule for the delivery of the services, counting from the release of the Work Order:

WP	Description	Leader	Start	End	Duration
WP0	Managemet and Procurement of Satellite Images	everis	T0	T0+10	50 days
WP1	Waterbody inventory and Dynamics	everis	T0	T0+3	15 days
Task 1.1	Data collection and image processing	everis	T0	T0+2	10
Task 1.2	Delineation of waterbodies extent	everis	T0	T0+2	10
Task 1.3	Analysis and interpretation of the mapped dynamics	FIHAC–IH Cantab	T0+2	T0+3	5 days
WP2	Land Use/Land Cover	FIHAC–IH Cantabria	T0+3	T0+6	15 days
Task 2.1	Training sets definition	FIHAC–IH Cantab	T0+3	T0+6	15 days
Task 2.2	Image classification and LU/LC map generation	i-SEA	T0+3	T0+6	15 days
Task 2.3	LU/LC map improvement using VHR images	i-SEA	T0+3	T0+6	15 days
WP3	Potential Surface Storage Site Inventory	FIHAC–IH Cantabria	T0+6	T0+9	15 days
Task 3.1	Selection criteria definition, data integration and identif	FIHAC–IH Cantab	T0+6	T0+7	5 days
Task 3.2	Connectivity study between sites and vulnerability analis	FIHAC–IH Cantab	T0+7	T0+8	5 days
Task 3.3	LU/LC map improvement using VHR images	FIHAC–IH Cantab	T0+8	T0+9	5 days
WP4 (ADDED)	Water turbidity and resulting siltation	i-SEA	T0+3	T0+6	15 days
WP5	WP5 Quality Assurance and Final report	everis	T0+2	To+10	40 days

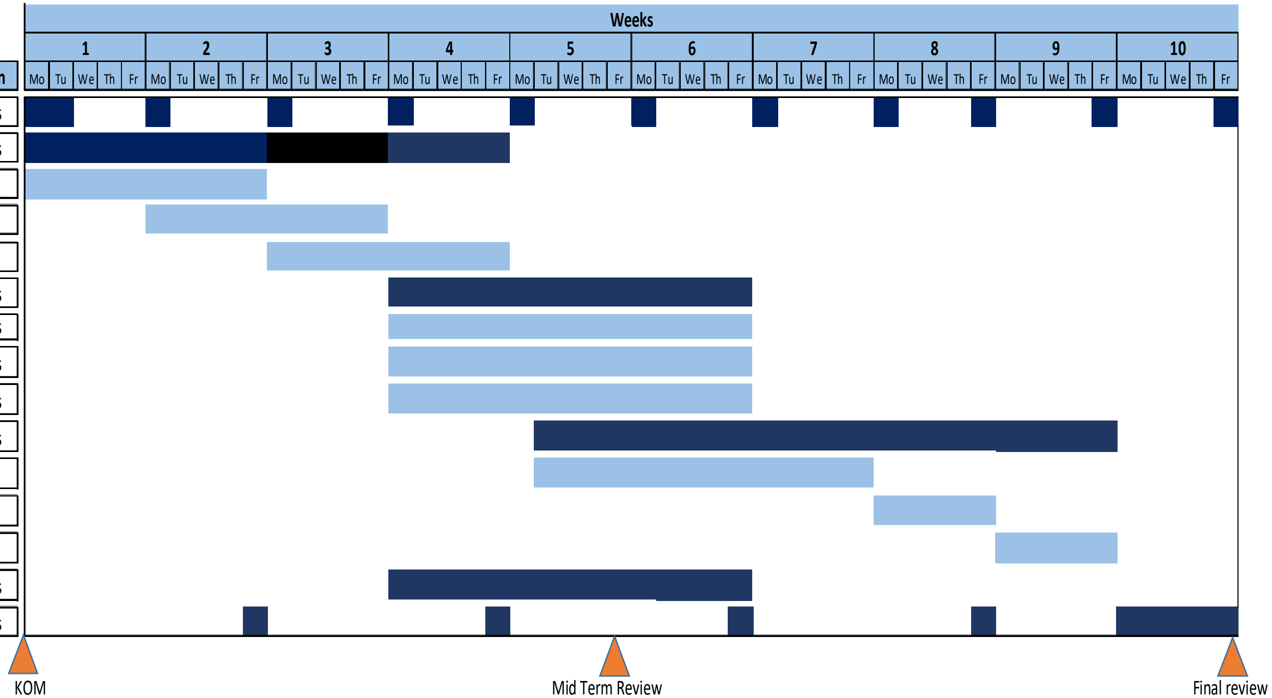


Figure 12. Schedule

3 RESULTS AND CONCLUSIONS

3.1 WP0 – Management Conclusions

The project was initially managed following the initially planned schedule. However some additional tasks were requested by ADB and agreed by the contractor team, specifically an ad-hoc study of immediate effects of cyclone Yaas, the presentation of the project in an internal session of and the preparation of some extra dissemination material.

The initial Kick-off meeting plus bi-weekly progress meetings were held, sending all Minutes of meeting by email to all participants just after the meeting. A Mid Tern Review was performed one week after the planned date, mostly due to schedule clash due to Easter period. Later progress meeting was replaced by the participation in an internal knowledge sharing session organised by ADB in which the project was presented as an example of use of EO technologies.

A final acceptance review and close out meeting was also held 2 weeks after the initially planned end of the project. However new considerations on the possibility of water reservoirs near the river banks were raised and the contract team agreed to perform some extra work to include this option.

Eventually, the final delivery suffered a noticeable delay, because the extra effort was beyond the planned margins and the project team was already allocated for other task.

3.2 WP rationale

In order to create the inventory of potential NBS freshwater surface storage sites in the AOI with the use of satellite EO imagery and methods, some preliminary steps are carried out: first the waterbodies are delineated and their dynamics characterised (WP1); then a LU/LC map is constructed (W2); and finally the turbidity and siltation rate are studied (WP4). The intermediary results obtained with these steps are the used to propose the most promising waterbodies for the purpose of the study

3.3 WP1 results: Waterbody inventory and dynamics

The main objective of Work Package 1 (WP1) is to map surface waterbodies and their associated dynamics, including the seasonal changes in waterbody extent for the period from the early 1990's and up to present, focussing on the short-term variability between wet and dry seasons as well as long term changes in terms of erosion or siltation over the years.

This WP1 has the following tasks, presented in sections below:

- Task 1.1 Data collection and image processing
- Task 1.2 Delineation of waterbodies extent
- Task 1.3 Analysis and interpretation of the mapped dynamics

3.3.1 Task1.1 Data collection and image processing

An area of interest (AOI) has been defined establishing a common extent for the project in which the results of the different task and WP have to be performed. A more convenient square-shape area have been chosen in order to ease the imagery processing. The resulting geometry covers most of the encircled area, see Figure 13), proposed in the Request From Proposal (RFP) document and has an area of 1,250km^2.

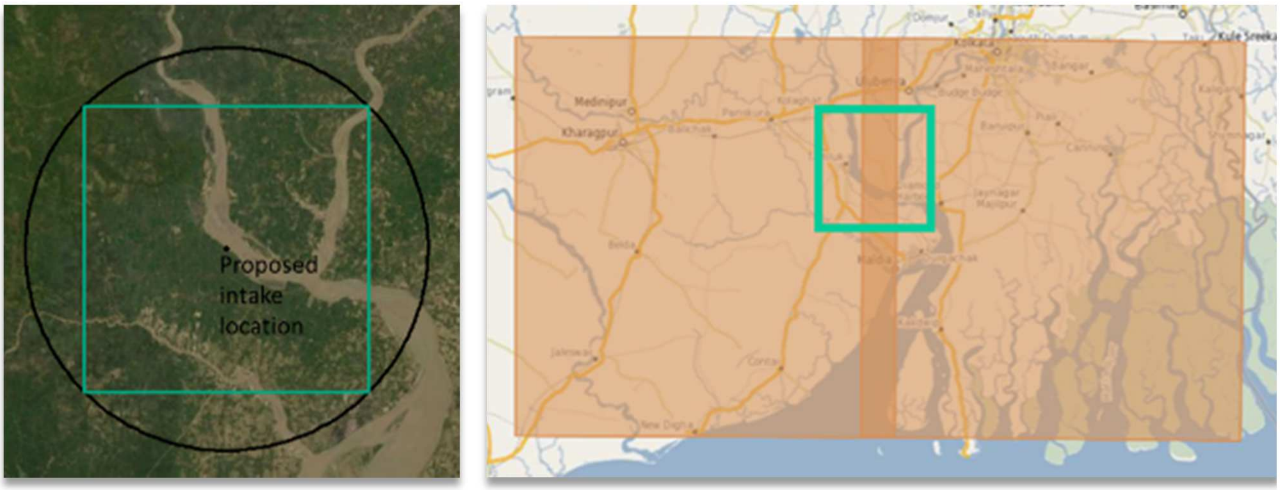


Figure 13. Location of the AOI (in green) respect to the proposed intake location in the RFP (left). Location of the AOI respect the granules T45QWE and T45QXE of the fixed tiled grid of Sentinel-2 products (right).

The next subtask has been focused on the search and pre-process of all the available cloud-free [optical] Sentinel-2 images acquired in the AOI during 2020. The resulting dataset was used in WP2 for creating the land use and land cover (LU/LC) map.

Table 4. Acquisition schedule of cloud-free Sentinel-2 images during 2020

	2020											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1st - 15th		04/02/2020			09/05/2020						05/11/2020	05/12/2020
	15/01/2020	14/02/2020	10/03/2020	09/04/2020	14/05/2020						15/11/2020	15/12/2020
16th - 31st												20/12/2020
	25/01/2020	29/02/2020	30/03/2020							26/10/2020	30/11/2020	30/12/2020

A collection of data related to Monsoon occurrence and dry season dates, obtained from different public sources. They were analysed. Allowing the identification of the Monsoon period and the other seasons in each of the year under analysis. Task 1.2 Delineation of waterbodies extent

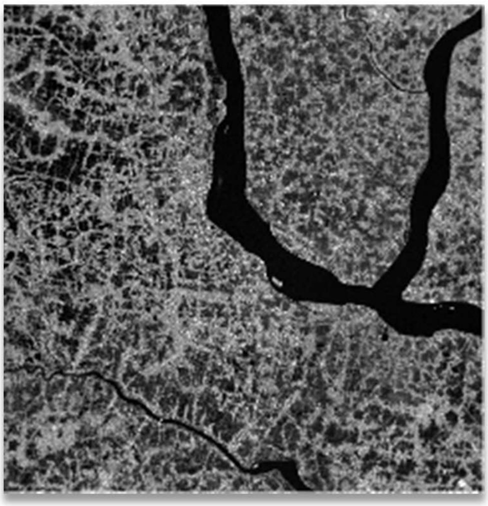
The Sentinel-1 images for the monsoon period have been searched during and after the peak of rainfall, selecting the image in which the river presents the maximum extent of all of the available images on these dates, i.e., the SAR image in which the observed water layer covers the largest area. Nevertheless, it is important to note that not all the data is available for all the years. For older dates ERS and Envisat images were used. However, the selection of the dates was strongly conditioned by the lack of enough acquisitions in the AOI.

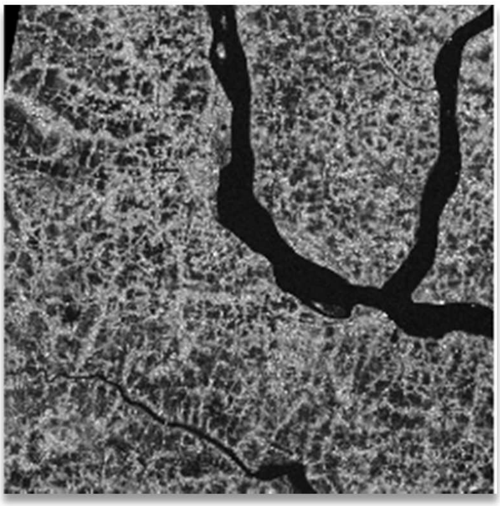
The following table includes all the selected SAR images. Finally, 35 images from 1992 to nowadays were processed.

Table 5. Temporal distribution of the processed images

Sensor	Image Mode	Polarization	Year	Winter Jan - Feb	Pre-Monsoon Mar-Apr-May	Monsoon Jun-Jul-Aug-Sep	Post-Monsoon Oct-Nov-Dec
NO SENSOR			1990	NO SENSOR	NO SENSOR	NO SENSOR	NO SENSOR
ERS (AMI/SAR)			1991	NO SENSOR	NO SENSOR	NO DATA	NO DATA
ERS (AMI/SAR)	IMP_1P	VV	1992	NO DATA	28/04/1992	15/09/1992	20/10/1992
ERS (AMI/SAR)	IMP_1P	VV	1993	02/02/1993	NO DATA	31/08/1993	05/10/1993
ERS (AMI/SAR)			1994	NO DATA	NO DATA	NO DATA	NO DATA
Envisat (ASAR)	IMP_1P	VV	2005	NO DATA	NO DATA	26/08/2005	25/11/2005
Envisat (ASAR)	APP_1P, IMP_1P	HH, VV	2006	NO DATA	NO DATA	08/08/2006	10/11/2006
Envisat (ASAR)			2007	NO DATA	NO DATA	NO DATA	NO DATA
Envisat (ASAR)			2008	NO DATA	NO DATA	NO DATA	NO DATA
Envisat (ASAR)			2009	NO DATA	NO DATA	NO DATA	NO DATA
Envisat (ASAR)			2010	NO DATA	NO DATA	NO DATA	NO DATA
Envisat (ASAR)	IMP_1P	HH	2011	NO DATA	NO DATA	30/07/2011	NO DATA
Envisat (ASAR)			2012	NO DATA	NO SENSOR	NO SENSOR	NO SENSOR
NO SENSOR			2013	NO SENSOR	NO SENSOR	NO SENSOR	NO SENSOR
Sentinel-1	IW GRD	VV/VH	2014	NO SENSOR	NO DATA	NO DATA	Partial coverage
Sentinel-1	IW GRD	VV/VH	2015	Partial coverage	Partial coverage	24/07/2015	28/10/2015
Sentinel-1	IW GRD	VV/VH	2016	01/02/2016	13/04/2016	11/08/2016	03/11/2016
Sentinel-1	IW GRD	VV/VH	2017	19/02/2017	17/04/2017	25/07/2017	10/11/2017
Sentinel-1	IW GRD	VV/VH	2018	23/02/2018	24/04/2018	05/07/2018	17/11/2018
Sentinel-1	IW GRD	VV/VH	2019	21/02/2019	10/04/2019	08/08/2019	30/11/2019
Sentinel-1	IW GRD	VV/VH	2020	04/02/2020	13/04/2020	26/08/2020	06/11/2020
Sentinel-1	IW GRD	VV/VH	2021	19/02/2021	18/03/2021	NO DATA	NO DATA

The SAR-based method applied to delineate the waterbodies extent facilitates the generation of large sets of georeferenced, reliable and comparable water layers in a semi-automated mode. SAR sensors are not affected by cloud cover or a lack of illumination and can generate data over huge areas under all weather conditions. Particularly, the consistent long-term archive of Sentinel-1 allows for precise and reproducible results by using more automated processes. In addition, Sentinel-1 works in a pre-programmed operation mode making it ideal for planning flood monitoring, e.g. during the early warning stage of an upcoming crisis event.





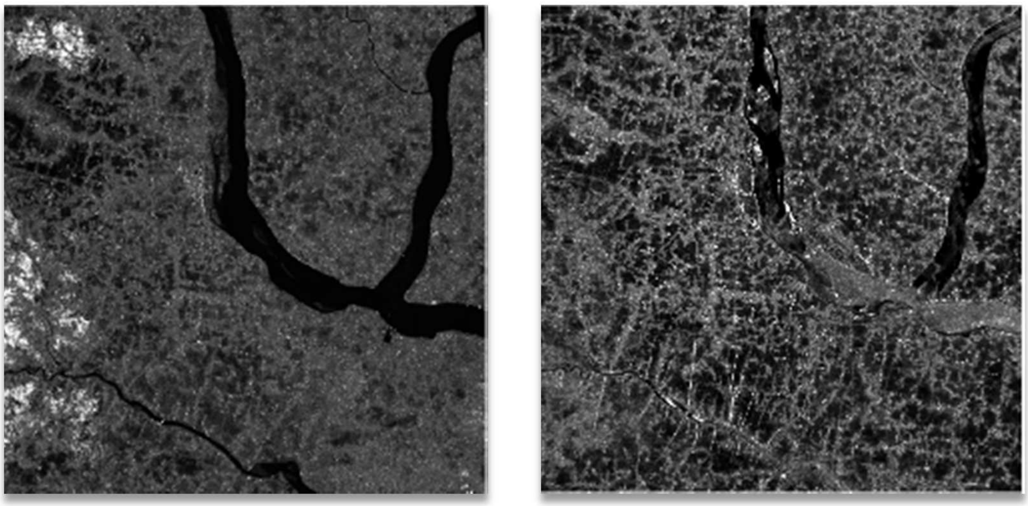


Figure 14. Examples of SAR processed images collected during monsoon season. From left to right and from top to bottom: Sentinel-1 IW mode VH polarization, Envisat ASAR AP mode HH polarization, Envisat ASAR IM mode VV polarization and ERS SAR IM mode VV polarization.

3.3.2 Task 1.2 Delineation of waterbodies extent

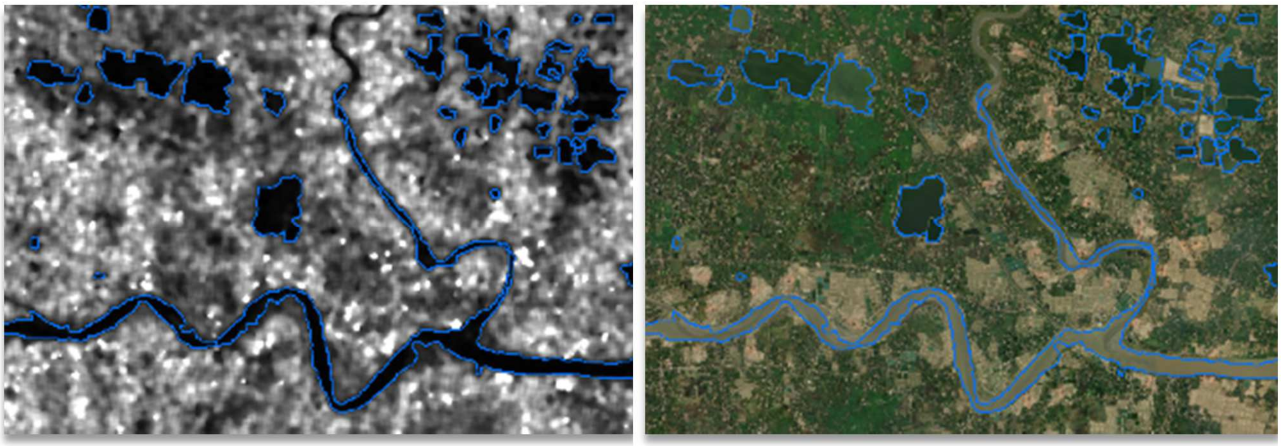
Waterbodies extent was derived from SAR backscatter intensity images by means of an automatic feature extraction process followed by manual refinement.

ERS SAR image (main source)

Landsat 4/5 image (ancillary data)

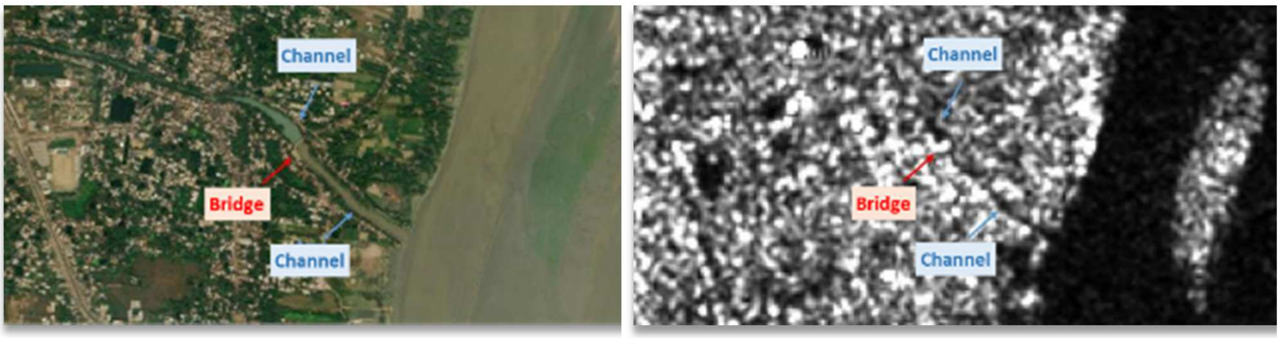
Water layer

Figure 15. Example of the combination of ERS and Landsat data and the resulting water mask.



Sentinel -1 21/02/2019 (GSD:10m) WorldView-3 20/02/2019 (GSD: 0.3 m)

Figure 16. Water layer represented over the Sentinel-1 image used to extract it (left). The same water layer represented over a VHR image (right).



WorldView-3 20/02/2019 (GSD: 0.3 m) Sentinel -1 21/02/2019 (GSD:10m)

Figure 17. Limitations of medium resolution SAR images on representing narrow channels respect to VHR optical images.

The delineation and the positional accuracy of the waterbodies is good taken into account that they are extracted from medium resolution images. The main limitation in this task, is that narrow channels (about 10 or 20 meters wide) are partially or completely missed in the water layers. Narrow waterbodies are not visible in the SAR image and therefore they are not extracted in the water mask.

The final output is a set of waterbodies masks in GeoTIFF format spatially that have been co-registered to Sentinel-2 data to serve as input in the analysis performed in the task 1.3

3.3.3 Task 1.3 Analysis and interpretation of the mapped dynamics

The main objective of this task is to discern the actual flooding dynamics pattern based on the water masks derived from radar data obtained in Task 1.2 at different dates.

The extent of water covered areas fluctuates with different flooding frequencies: daily (high- and low tide water), fortnightly (spring tide), seasonal (monsoon, dry season), years interval (larger flood events or drought events) or secular (climate change). In this task we intend to characterise the seasonal behaviour, since for this particular project, the purpose is to identify areas, which can be used to store excess freshwater during the monsoon for later extraction during the dry season. Four flooding seasons were discerned: Winter (from January to February); Pre-Monsoon (from March to May); Monsoon (from June to September), and Post-Monsoon (from October up to December).

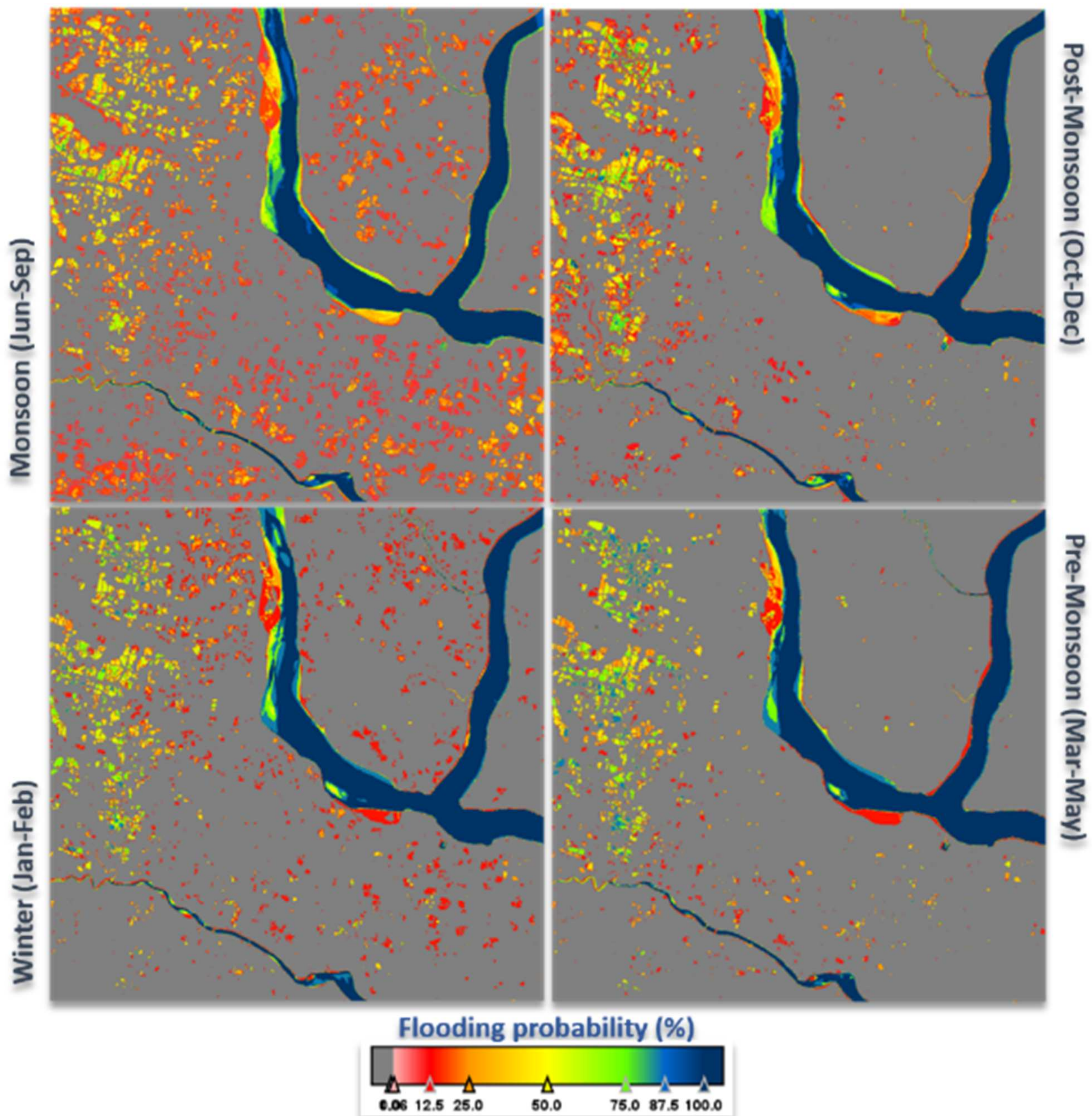


Figure 18: Averaged seasonal flooding probabilities.

The obtained results per season are quite distinct, with the monsoon period unsurprisingly dominating the flooding extent, and a minimum flooded area reached during the pre-monsoon. In terms of geographical distribution, the Western part of the AOI seems to present the highest flooding probabilities, whereas the Eastern side seems to be more stable. This may be due to the presence of water reservoirs/fishponds in the Western area, which may facilitate the flooding. This is not the case for the Eastern area. This also seems in agreement with the presence of low flooding probability (<25%) in the Southern part of the AOI, corresponding to punctual flooding events, non-re-incident.

With respect to the river banks, in Southern end (right bank) of Rupnarayan just before reaching Hooghly confluence, there is a large yellow spot (50% flooding) during monsoon which changes to red (12% flooding) during dry season, which seem easy to explain. Interestingly, this is opposite from the green/blue spot 20 km North of this near Tamluk, where flooding is less frequent (75%) in monsoon, than during dry season (85%).

This could have a natural explanation (like bed level changes between seasons), but data uncertainty cannot be discarded, this would require further analysis.

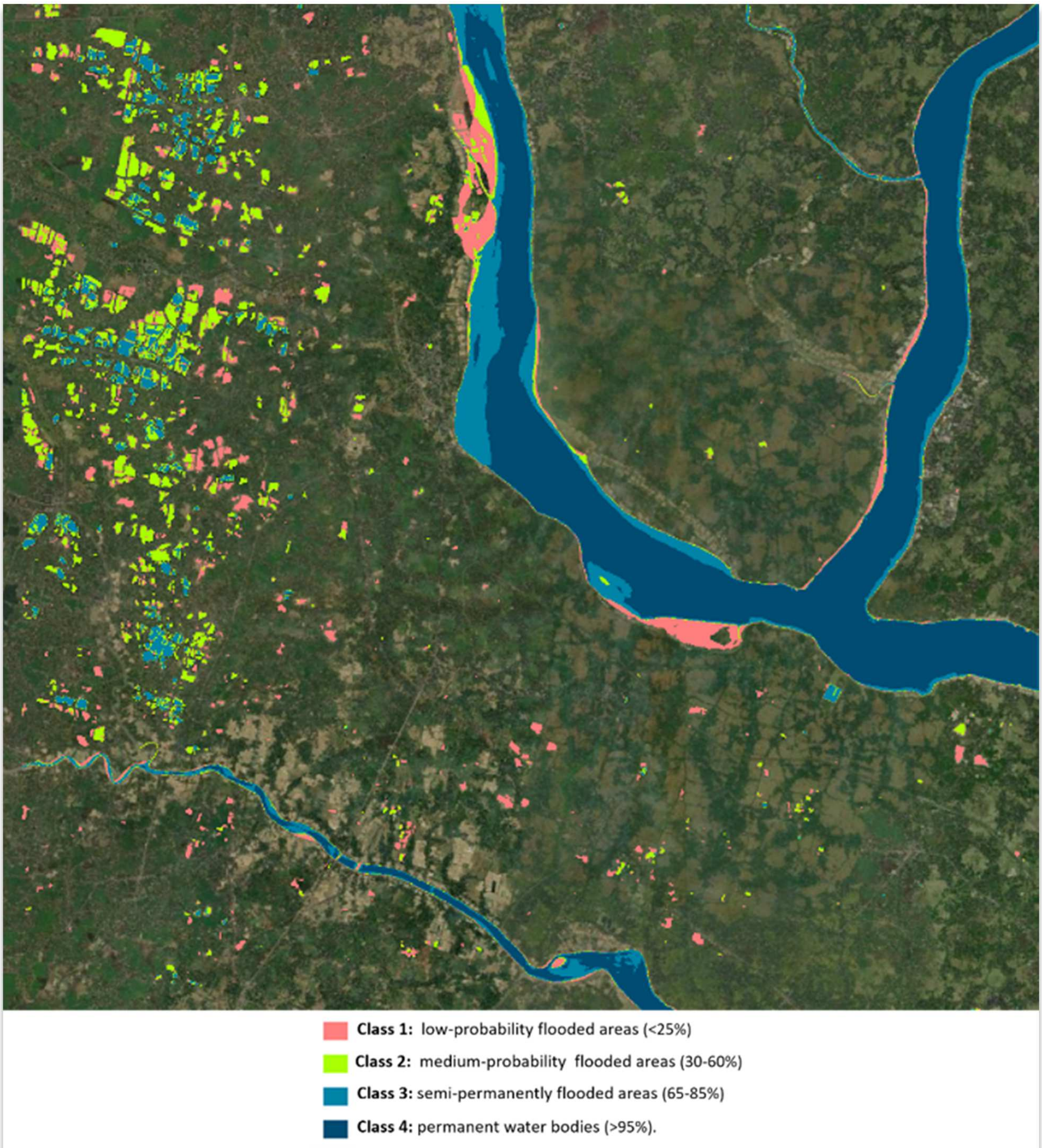


Figure 19. Annual flooding profiles (different shades of blue represent the areas flooded along the year).

These results have been used for the identification of water bodies presenting similar flooding patterns. Such identification has been done through an unsupervised clustering analysis (ISO clustering). Four classes were identified to highlight water bodies presenting similar flooding patterns, from low-flooding probability, medium, semi-permanently flooded areas and permanent water bodies (Figure 19. *Annual flooding profiles (different shades of blue represent the areas flooded along the year).*). The percentages shown correspond to class averages, being the assignation to one or other class based on Euclidian distances from the centroids, estimated from the average % for each of the seasons.

Eliminating those low-probability flooded areas, the attention has been focussed on those flooding areas more highly influenced by the monsoon and post-monsoon. These have been key for the further identification of potential water reservoirs in WP3. It would be useful to verify if the flooded areas in the Western part is actually aquaculture fish ponds, i.e. it looks as the flood cells are regular in shape like artificial fish ponds. Unfortunately we cannot discern if they are water reservoirs or fishponds with the available information from the images, further analysis with VHR images could be considered.

3.4 WP2 results: Land Use / Land Cover

Land cover data sets distinguish between characteristics of the land surface observable by satellite data. Classes are typically divided into tree cover, shrubs, grasslands, croplands, water, soil and built-up areas, a slightly deeper and better suited set of classes has been produced for this study.

The main tasks that are addressed for this WP are:

- Task 2.1 Training sets definition
- Task 2.2 Image classification and LU/LC map generation
- Task 2.3 LU/LC map improvement using VHR images

3.4.1 Task 2.1 Training sets definition

The purpose of this task is double, first to define a LU/LC legend (classes) for characterizing the area under study, and secondly, to obtain a reliable labelled dataset, essential for an accurate LU/LC map.

The classes that have been addressed are:

- Water. Within this main category, we have identified the following sub-categories:
  - Natural water bodies. This category includes all the observed lotic water bodies, including rivers and river channels.
  - Water reservoirs. Within this category are both lentic water bodies (ponds and lakes) and aquaculture ponds (fishponds). For further analysis in the future, it would be recommended to have an extra class, exclusively dedicated to “fishponds”.
  - Salt marshes.
- Forest and Other Natural areas:
  - Forested natural areas. This category is referred to those areas covered by trees.
  - Non-forested natural areas. This category includes all of those vegetated natural areas characterized by the presence of shrubs and grasslands, or even wetlands, but not trees.
  - Barelands/denuded. This class refers to non-vegetated areas.
- Agriculture. For this main class, considering the water-availability issue, we have differentiated between rain fed and irrigated croplands:
  - Rain fed croplands (“Croplands_mid”). These croplands only depend of rainwater to grow.
  - Irrigated croplands (“Croplands_core”). This type of croplands need an added water supply, aside from rain.
- Urban:
  - Residential urban soil.
  - Industrial/Commercial soil.
  - Human activity mix. This category includes all those areas in which we have detected alterations due to an anthropic activity, but we lack further information to specify the type.

For the model training, it was necessary to have a minimum number of training polygons (points of occurrence) for each of the identified land cover classes to be modelled, without environmental or geographical bias, which reflected all the spatial variability of the land cover classes within the study area.

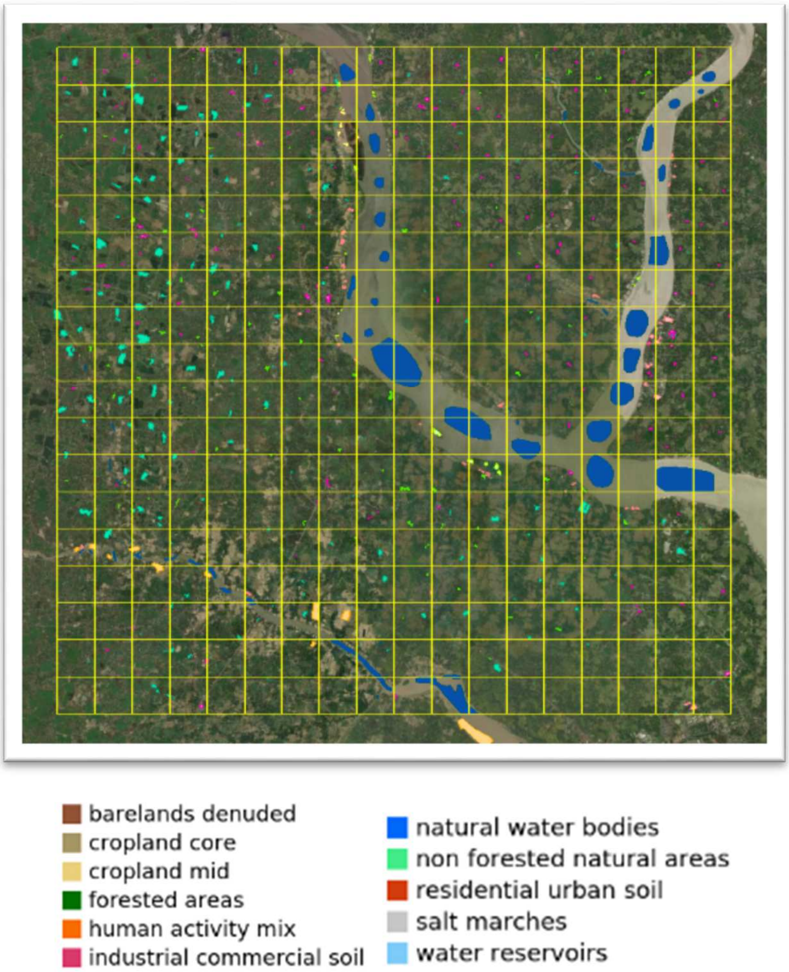


Figure 20: Training (and validation) polygons for Sentinel-2 imagery.

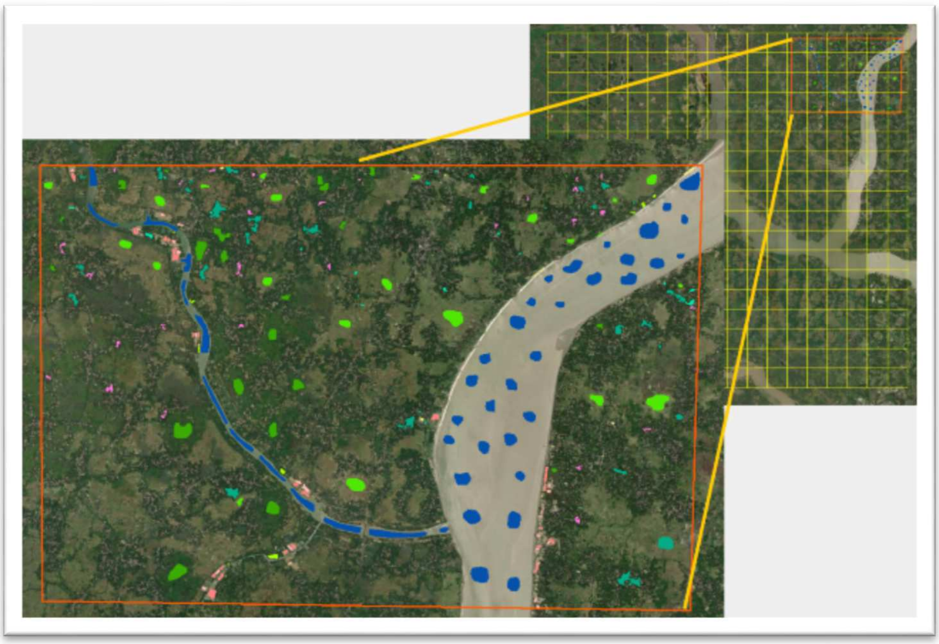


Figure 21: Training (and validation) polygons for Pléiades imagery.

3.4.2 Task 2.2 Image classification and LU/LC map generation

This task aims to generate an automatic classification of a selection of optical Sentinel-2 images in order to create up-to-date LU/LC maps, based on an image time series acquired during 2020 for Sentinel-2 and 2018 for Pléiades. These maps are used as an input to contribute to the identification of potential water storage sites.

The results achieved are very satisfactory, reaching an overall accuracy of 93%. The precision per class varies from 83% for the "Residential Urban Soil" to 99% for "Water reservoirs".

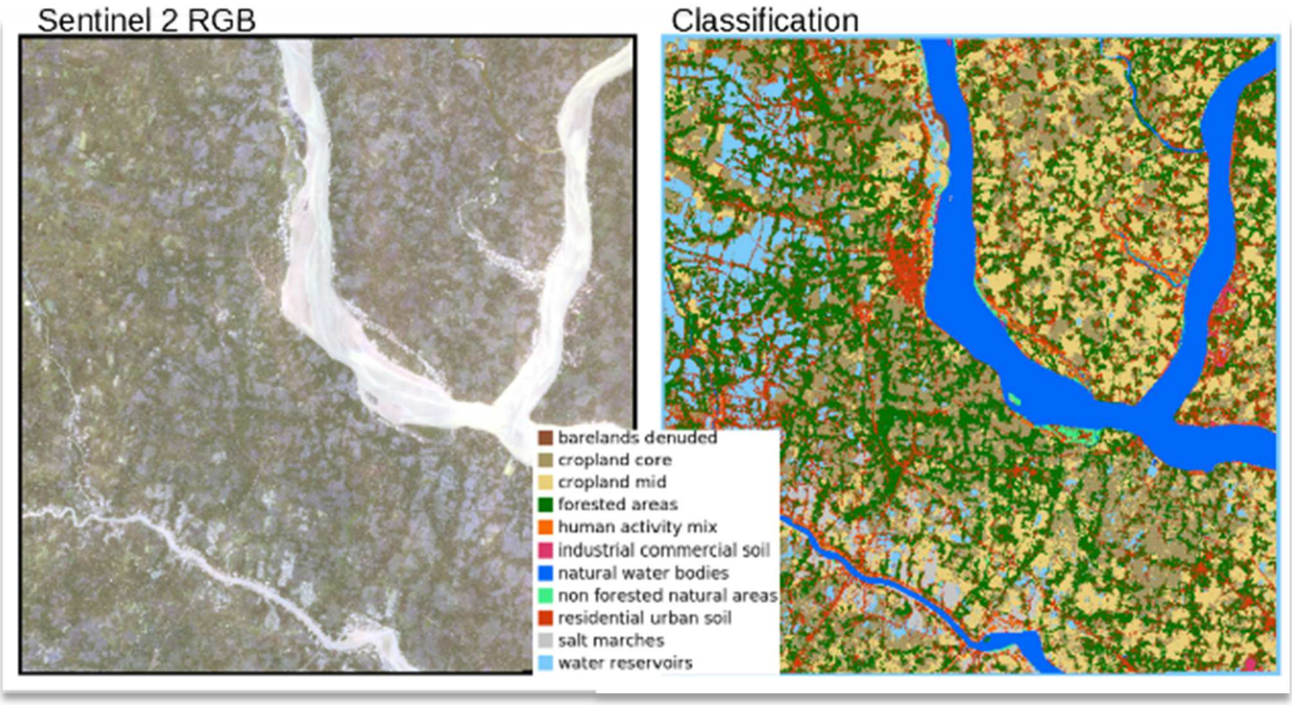


Figure 22. Classification results obtained with Sentinel-2 time series and RandomForest classifier

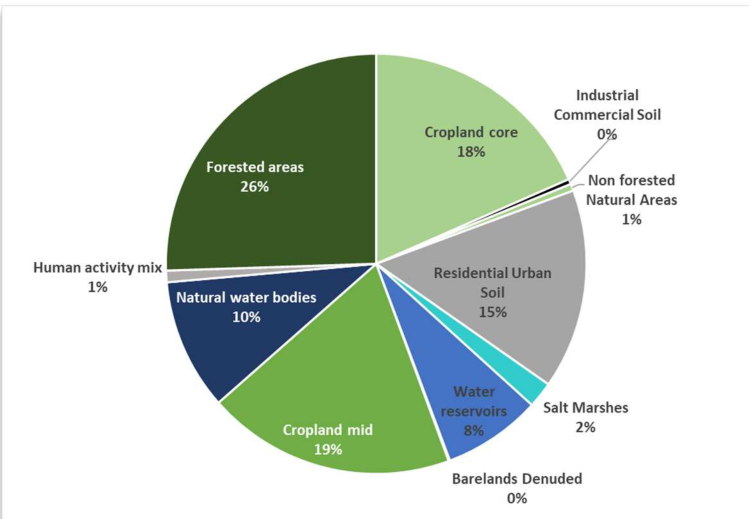


Figure 23. Percentage distribution of each LU/LC type displayed in the Sentinel-2 map covering the whole study area (1265 km²).

3.4.3 Task 2.3 LU/LC map improvement using VHR images

The objectives of this task is to refine the LU/LC classes introducing a higher spatial detail using Very High Resolution (VHR) images. Our objective is to demonstrate the capacity of VHR imagery to improve (i) the spatial delineation (or the shape) of surfaces in the map, (ii) the detection of the classes of interest by comparing results achieved with Sentinel-2 and VHR resolution images. Pléaides satellites have been selected for this experimentation.

Figure 24. Location of Pléiades images within the study area

The obtained results are very satisfying, reaching an overall accuracy of 86%. The precision per class ranges from 74% for the "Cropland mid" to 99% for "Natural water bodies". The precision of the "Water reservoirs" class is of 97%.

Figure 25 demonstrates that VHR Pleaides images allow to produce a better and more precise delineation of the LU/LC types. The VHR could also allow to go further into the typology, as small land surfaces are recognisable, we should be able to refine the typology and better serve the objectives of the project while preserving the robustness and the precision of the classification results.

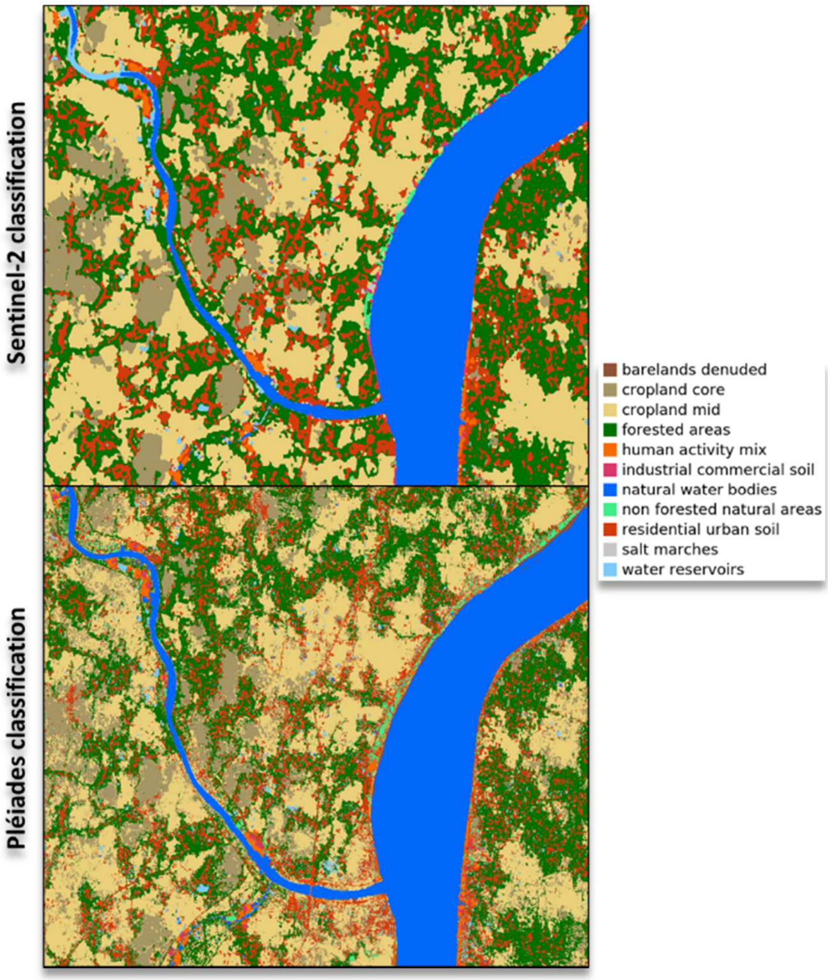


Figure 25. Comparison between Sentinel-2 classification and Pléiades classification

3.5 WP4 results: Siltation rate qualification as a function of riverine turbidity

For this analysis, the results of the occurrence frequency of water determined in WP1 are combined with results from an analysis of the occurrence frequency of the Total Suspended Matter (TSM). The objective is to define proxies of preferential areas of relatively clear water. This WP was not originally requested but it is believed it can show additional considerations that can be studied when looking for NBS for clean water storage. The proposed approach makes it possible on the one hand to identify the inland reservoirs, on the other hand to define areas favourable to water bodies reclaiming along the Rupnarayan River, where the concentration of suspended sediment is higher during certain flood events.

- Task 4.1 Data collection and selection
- Task 4.2 Extraction of water bodies turbidity
- Task 4.3 Siltation potential retrieval per water body

3.5.1 Task 4.1 Data collection and selection

To constitute the dataset used to analyse the TSM in the area of interest, a Sentinel-2 satellite image was downloaded for each month from January 2016 to December 2020 (Table 6). The time series is not complete due to heavy cloudiness over some periods. Several months are therefore under-represented, which may induce a bias in our analysis of the occurrence frequency of high levels of turbidity. Furthermore, between June 2015 and March 2017, only one of the two Sentinel-2 satellites was in operation. Later, the second satellite was launched allowing more frequent acquisitions. This explains the underrepresented months in 2016.

Table 6. Dates of the Sentinel-2 images used for the turbidity analysis.

2016	2017	2018	2019	2020
01/01	01/15	01/30	01/30	01/15
07/29	02/24	02/14	02/14	02/14
11/16	03/16	03/11	03/21	03/15
12/16	04/25	04/15	04/20	04/09
	06/04	05/15	05/10	05/14
	07/14	06/29	06/14	06/03
	10/22	10/22	09/17	10/26
	11/06	11/16	10/27	11/25
	12/26	12/21	11/21	12/05
			12/06	

3.5.2 Task 4.2 Extraction of water bodies turbidity

Sentinel-2 images are converted into Total Suspended Matter (TSM) products using a generic algorithm calibrated and validated using a large database of in-situ measurements (Nechad, Ruddick and Park, 2010).

This algorithm is represented by the following equation:

$$TSM = \frac{A_R \rho_R}{1-(\rho_R/C_R)}$$

$where:$

ρ_R is the reflectance of the red band

A_R, C_R are the parameters of the Nechad model calibrated for the red band

3.5.3 Task 4.3 Siltation potential retrieval per water body.

Analysing the frequency of the water occurrence on each pixel allows to determine 3 distinct classes of flooding for all seasons:

- Less than 25% of the time series,
- Between 30 and 60% of the period,
- Quasi-permanent to permanent flooding.

The pixels flooded less than 25% of the time are systematically excluded from the dataset for the next steps because we estimate that they are too frequently emerged areas to be considered as potential areas clear water storage.

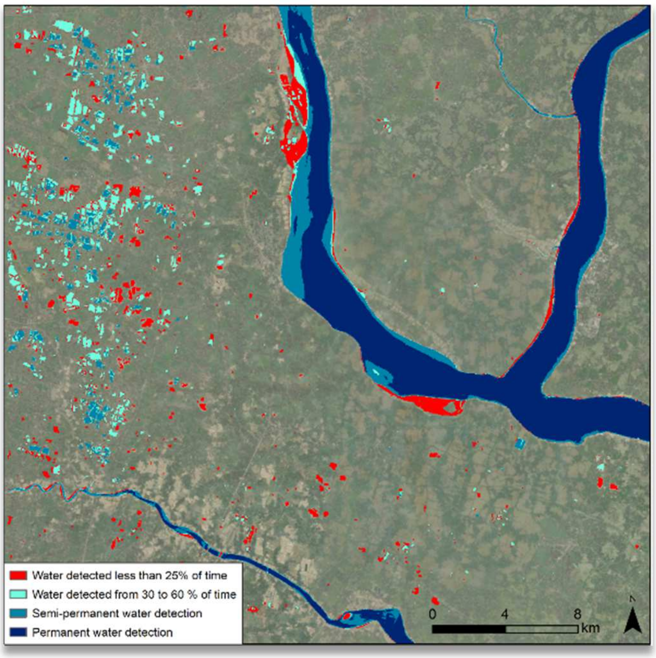


Figure 26. Frequency of water occurrence over the dataset period (1992-1993 ERS data, and 2015 – 2021 Sentinel-1 images).

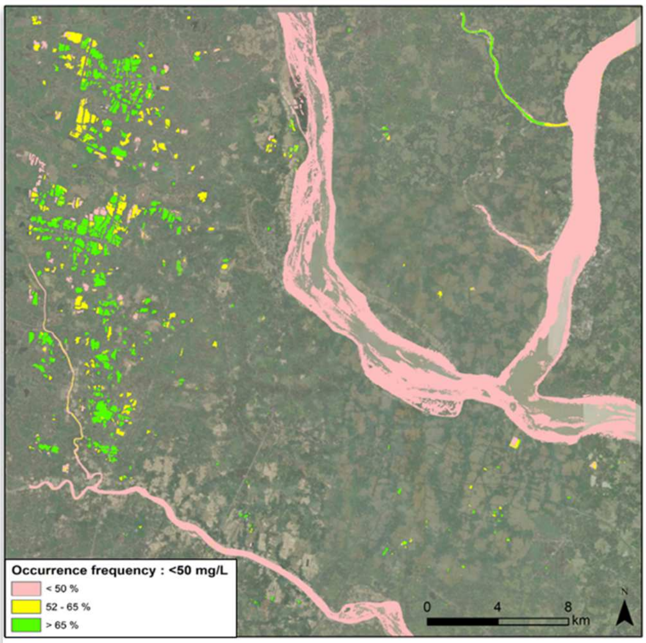


Figure 27. Spatial distribution of the occurrence frequency of TSM lower than 50 mg/L. In green, the areas are subject to low TSM more than 65 % of the period analysed. In red, the areas are subject to low TSM less than half of time.

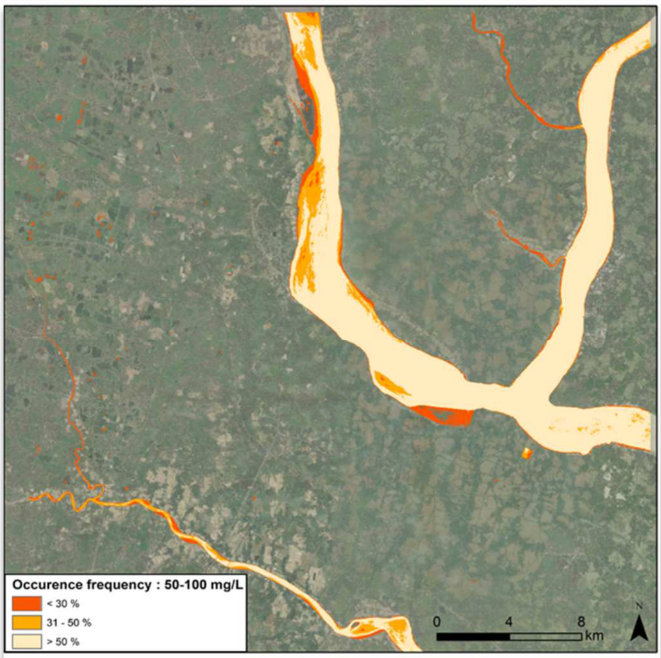


Figure 28- Spatial distribution of the occurrence frequency of TSM varying between 50 mg/L and 100 mg/L. We con-sider this TSM range as intermediate/medium magnitude. In green, the areas are subject to low TSM more than 65 % of the period analysed. In red, the areas are subject to low TSM less than half of time. This class mainly concerns the zone of active channels of the river.

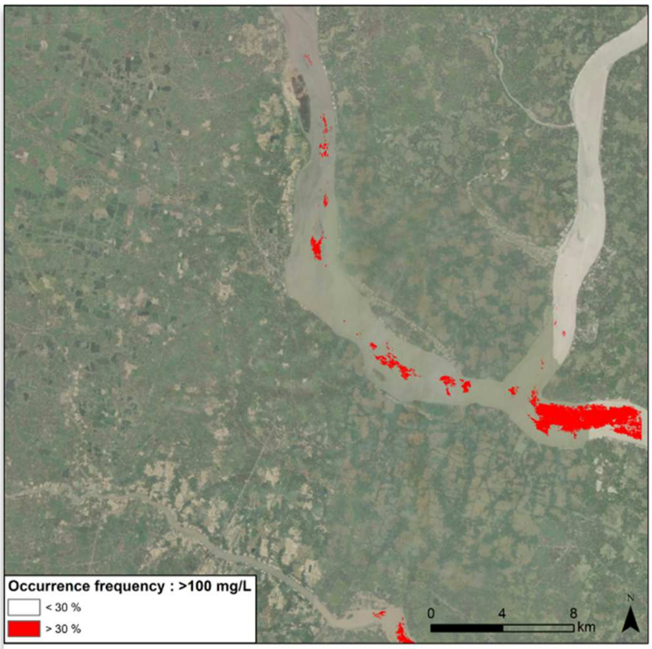


Figure 29. Occurrence frequency of the highest levels of turbidity expressed through the TSM upper than 100 mg/L. In red, the areas are subject to high TSM more than 30% of time. This class only concerns the central zone of active channels of the river

The occurrence frequency of TSM has also been discretized. First, the TSM concentrations were classified into three ranks: low TSM for magnitudes below 50 mg/l, moderate TSM for those between 50 and 100 mg/l, and high TSM for pixels over 100 mg/l. According to our monthly sampling database, we produced synthetic maps that show the occurrence frequency of the each of these levels of TSM.

Table 7. Criteria for ranking potential of clear water storage.

<table>
<tr><th colspan="2" rowspan="2"></th><th rowspan="2">Flooding frequency</th><th rowspan="2"></th><th colspan="2">Occurrence of TSM conditions</th></tr>
<tr><th>Frequency</th><th>Intensity</th></tr>
<tr><td colspan="2">Negligible potential of clear water storage</td><td>< 25 %</td><td>and/or</td><td>> 40 %</td><td>> 100 mg/l</td></tr>
<tr><td>Low potential of water storage</td><td rowspan="2">(within the dynamic river channels)</td><td rowspan="2">> 65 %</td><td rowspan="2">and</td><td>30 - 50 %</td><td rowspan="2">50 – 100 mg/l</td></tr>
<tr><td>Moderate potential of water storage</td><td>> 50 %</td></tr>
<tr><td colspan="2">Seasonal potential of clear water storage</td><td>> 30 - 60 %</td><td>and/or</td><td>50 - 65 %</td><td>< 50 mg/l</td></tr>
<tr><td colspan="2">Very high confidence for clear water storage potential</td><td>> 65 %</td><td>And</td><td>> 65 %</td><td>< 50 mg/l</td></tr>
</table>

3.5.4 Application to the area of interest

The final map shows the frequently submerged areas favourable for clear water storage (Figure 30). Within the active river channels, the TSM is locally frequently high on portions of the side banks and downstream (Figure 30, red on the map). The rest of the channels are continuously flooded with moderated to seasonally high TSM values. Inland, the results distinguish ponds with a very low probability of use for the storage of clear water (Figure 30, areas in red), given a high frequency of drying, from those with higher possibilities of clear water storage (Figure 30, areas in green). The recorded TSM is nowhere frequently high. However, part (about half) of the parcels are only periodically flooded (seasonally or even more often). These could be irrigated crops. Comparing these results with land cover and land use is necessary to reach reliable conclusions.

In West Bengal, along the Hooghly River and Rupnarayan River, NBS reservoirs directly connected to the river flood are used. In these near-bank settling basins, the surface water is pumped when the salinity is low. In the case of low turbidity, with a TSM lower than 50 mg/l, the suspended sediments may settle completely over about twice a day (e.g. water gets in during ebb-tide, suspended sediment settling while close during flood-tide). Considering a consolidated sediment density of about 1500 mg/m^3, for a depth of 3 m, then accretion of the reservoir bed would be 0.2 mm/day, or 7 cm/year.

However, in the settling basins in West Bengal along Hooghly and Rupnarayan rivers when using surface water intakes, very high turbidity with a TSM above 500 mg/l is not uncommon. The work of this WP4 opens the way to the possibility of refining the analysis on the spatial and temporal variability of suspended sediments to optimize the location, timing, and operation of surface water pumping, while monitoring salinity

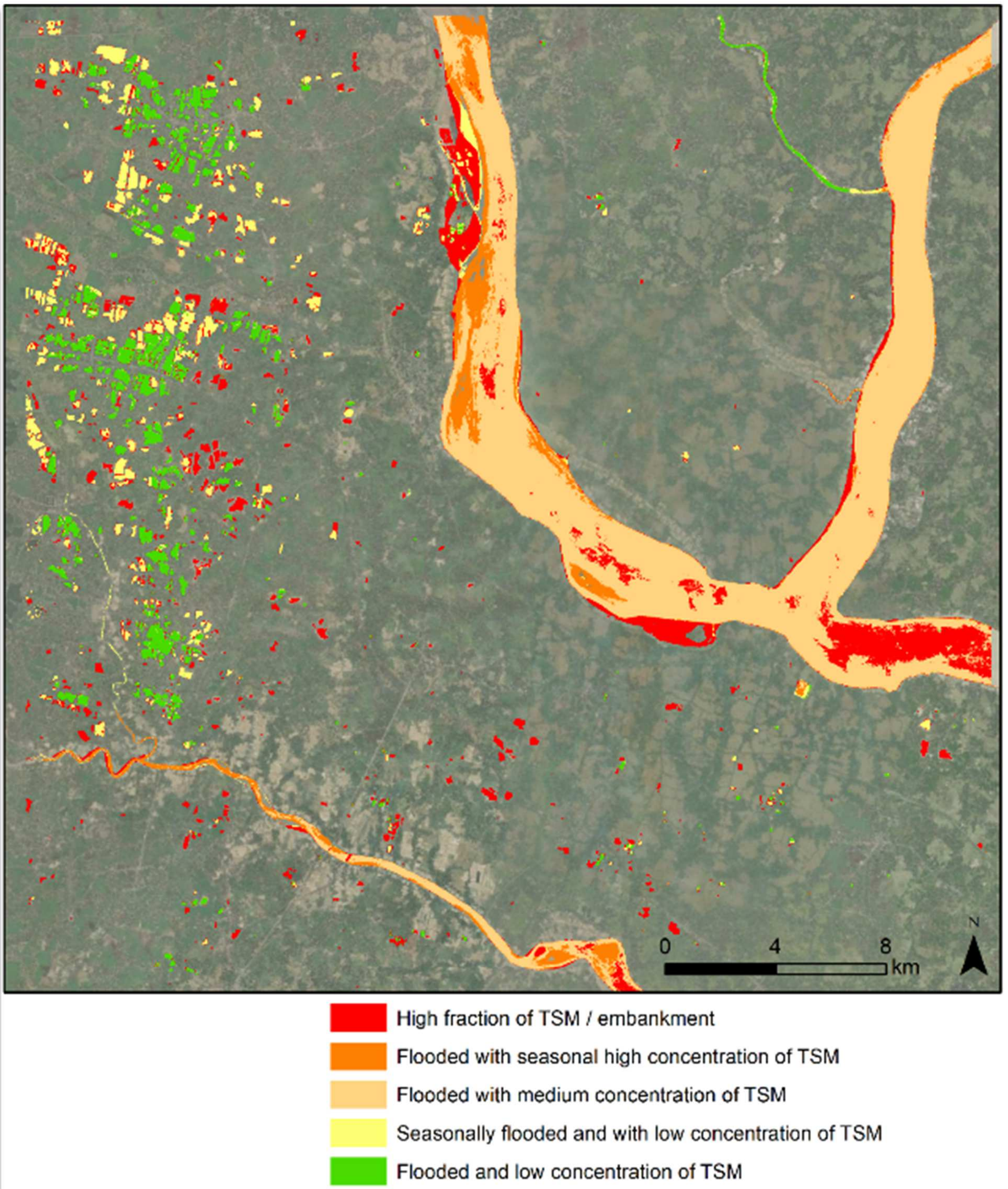


Figure 30. Levels of potential of clear water storage over the area of interest according to the magnitude of flooding and turbidity conditions analysed monthly between 2015 and 2020.

3.6 WP3 results: Potential surface storage site Inventory

The main aim of this WP3 is to produce a map-format list of potential storage sites adequate to be considered for the implementation of the envisaged nature-based solutions for the water quality improvement.

- Task 3.1 Selection criteria definition, data integration and identification of all potentiality-selectable sites

- Task 3.2 Connectivity study between sites and vulnerability analysis
- Task 3.3 List of potential storage sites according to the selected criteria

3.6.1 Task 3.1 Selection criteria definition, data integration and identification of all potentiality-selectable sites

Expert knowledge and a multi criteria decision analysis (MCDA), based on the flooding recurrence, site dynamics, land cover, water quality and degree of connectivity between potential sites, has been used for the selection of suitable sites for water storage. The methodology has been completed in four main steps:

- Collection of data.
- Selection of factors and constraints.
- Giving percentage influence to each criterion.
- Performing weighted overlay.

Among the variables that are considered for the site selection process, there is special consideration to the following aspects:

- The drainage density (e.g., defined as the total length of channels per unit area, and it describes the spacing and distribution of the drainage ways in a catchment).
- The sediment load of the stream, which should be low so that the site will not lose storage capacity over time due to rapid siltation.
- If the source is not adequately protected, the supply shall be adequately protected by treatment; frequent sanitary surveys should be made to identify health hazards.
- Selected sites should not have any detrimental effect on natural aquifers (although recharge of groundwater through infiltration is not necessarily a bad thing, as long as the surface water is of proper quality, i.e. not saline).
- Natural gravity forces should be utilized to the extent possible to hydraulically to transport water to its intended destination.

Notice that avoidance of high salinity concentration can be managed to some extent with pumping strategies: variation in salinity occurs in space and in time. E.g. at a water intake in the estuary, it is not a problem to have saline during some hours a day, and freshwater the remaining hours (due to the tide), as the pumping will just be stopped during the time of high salinity. Similarly, flow into a NBS freshwater reservoir near the estuary can be allowed during freshwater in the estuary and stopped (through a gate) during saline water. Existing artificial reservoirs are currently used in this manner, i.e. the Geonkhali water treatment plant near the Rupnararyan/Hooghly confluence. This opens the possibility to consider NBS near the river banks.

Figure 31 shows the spatial distribution of the sites selected based on the Multi-criteria analysis, addressed to be reviewed and improved. It shows the two fundamental different NBS reservoirs to be considered:

- Reclaim water bodies along the shallow water areas (e.g. along the right bank of the Rupnarayan estuary) by separating the reclaimed water area from the estuary with embankment, and connected via gates which are opened during ebb tide and/or season when the salinity is low enough. There is no further extensive and detailed analysis about this option in this document, but it should not be ruled out because of salinity issues, which can be managed with appropriate pumping strategies as explained before.
- Inland reservoirs scattered far from the estuary. These are subject to a connectivity study between sites and vulnerability analysis in next section.

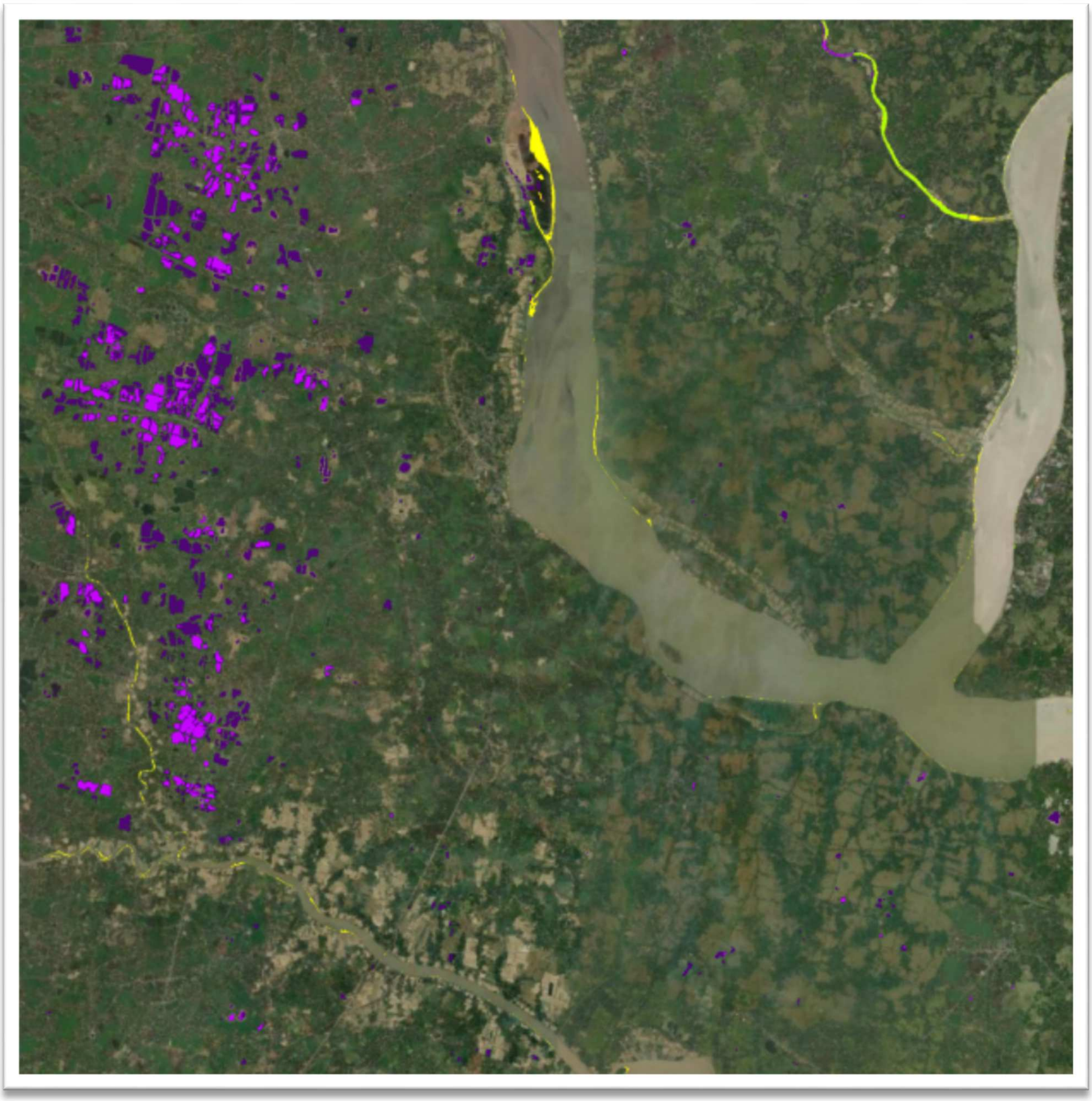


Figure 31. Spatial distribution of the sites selected based on the Multi-criteria analysis, distinguishing between inland water reservoirs (in magenta those ones considered to be optimum, and purple, those sub-optimum ones), and natural river banks water bodies (in green, those optimum areas, and in yellow, the sub-optimum ones).

3.6.2 Task 3.2 Connectivity study between sites and vulnerability analysis

Due to the size and location of the potential reservoirs (small and scattered in the territory), we consider that the optimum approach for sustainable management of water resources is distributed storage network, promoting the pooled management of water use. Based on this, the idea has been to analyse the potential connectivity between the potential inland water-storage sites, as a positive factor in the site selection procedure. This analysis is not required for the potential water-storage sites located along the river reaches or small channels, due to their size and freshwater availability.

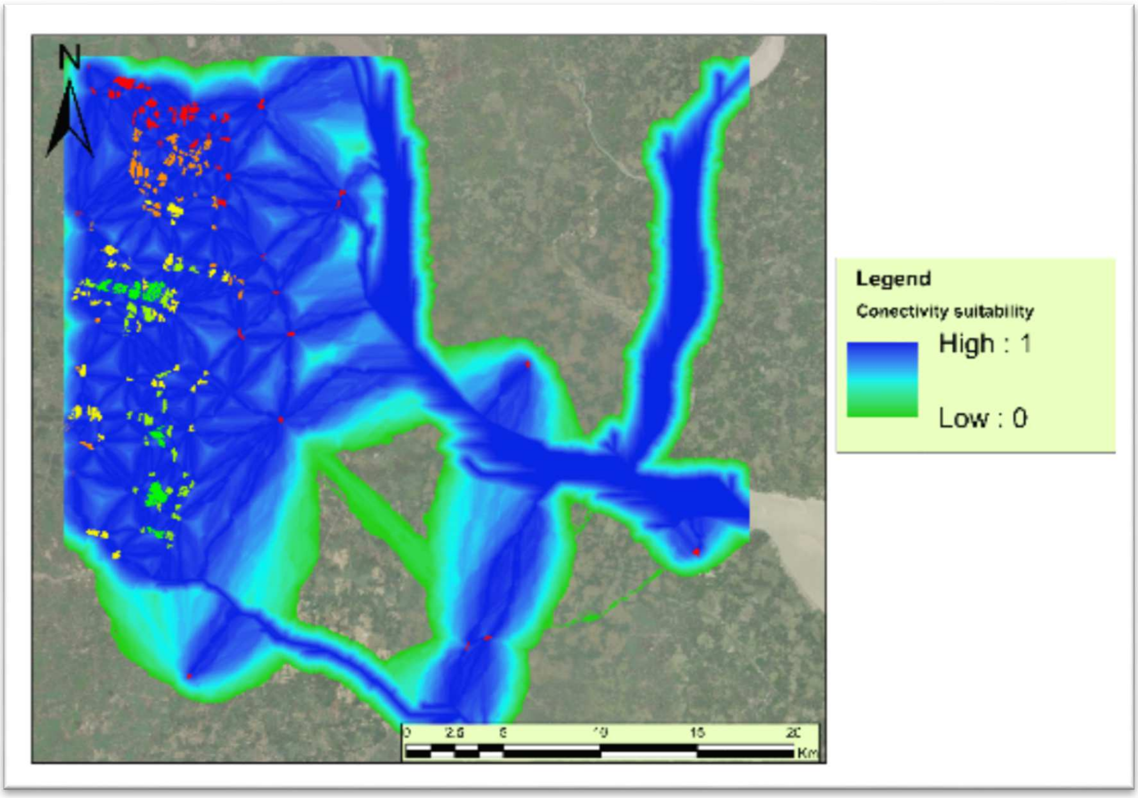


Figure 32. Results of the connectivity suitability, from the lowest (0) to the highest (1).

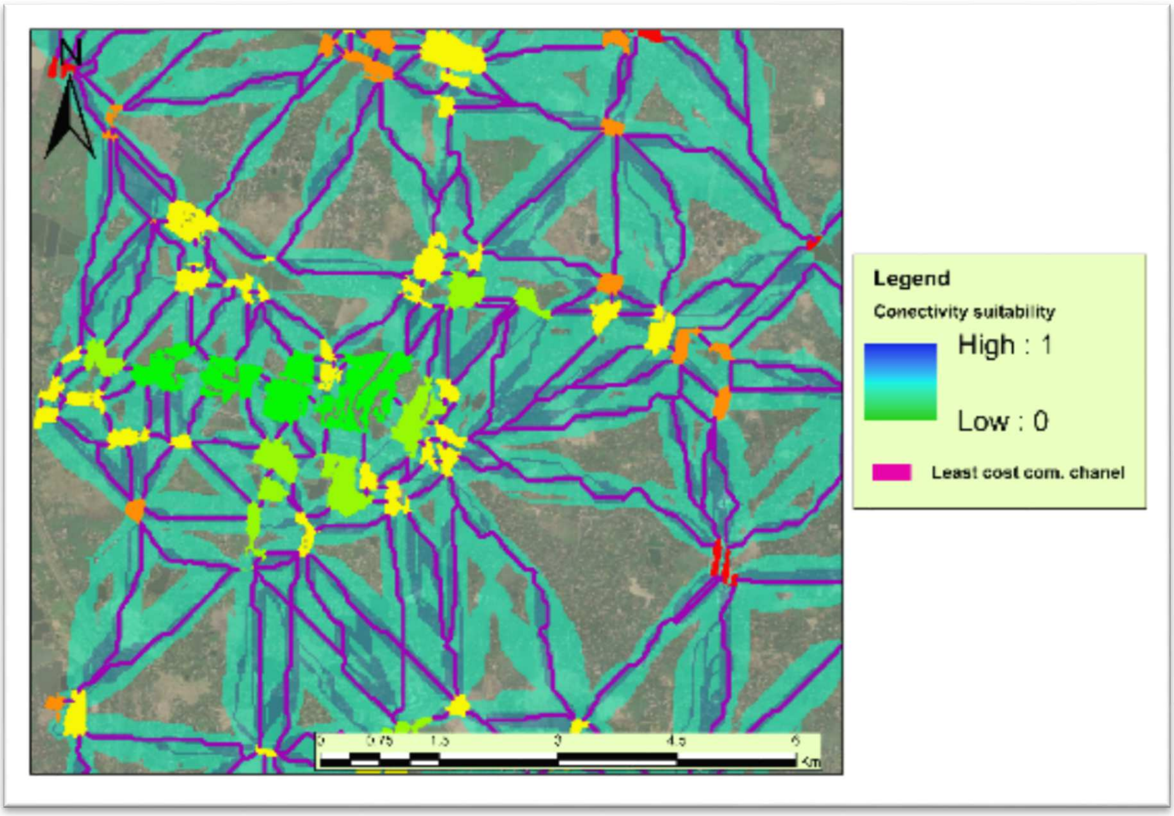


Figure 33. Example of the potential "water ways" connecting different reservoirs.

3.6.3 Task 3.3 Potential storage sites according to the selected criteria

After the integration of the results obtained from the Multi-criteria analysis (Task 3.1) and the subsequent connectivity analysis (Task 3.2), a set of potential sites for water reservoirs was selected. Figure 34 represents which are the optimal and sub-optimal areas suitable to become potential water-storage sites. The square image west of the AOI illustrates those potential sites that could conform a distributed storage network of small water reservoirs, whereas the full AOI figure focusses on those "running water" sites (lotic water bodies) that are the most suitable for the implementation of NBS solutions (i.e. it is derived from Figure 31, after taking into account the connectivity and vulnerability analysis).

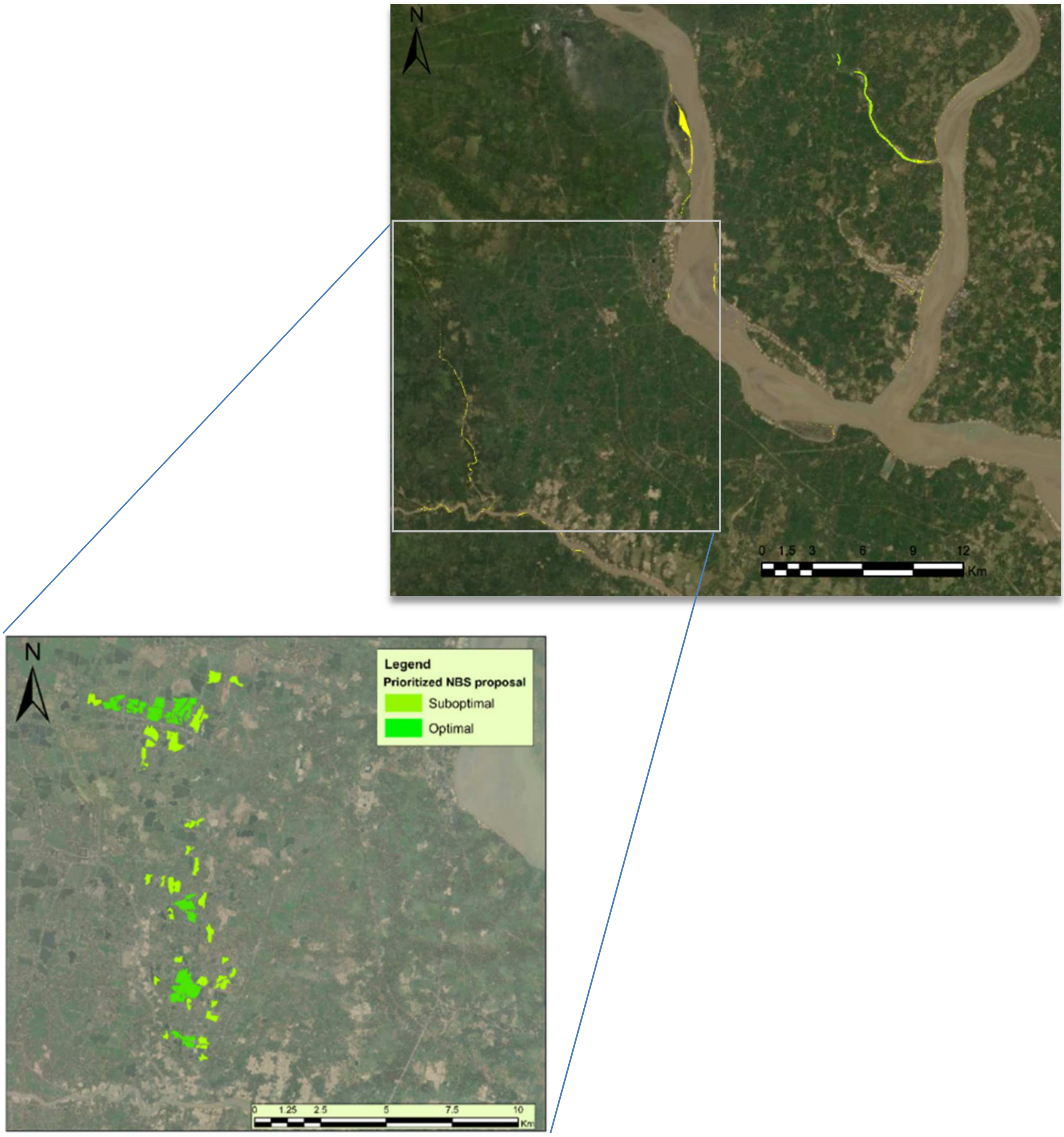


Figure 34. Proposed NBS freshwater storage sites. Inland and Potential lotic (running waters) water-storage sites selected after the integration of multiple analysis (in darker green optimal sites; light green and yellow, sub-optimal)

4 SUMMARY AND FUTURE ACTIONS

4.1 Results

Along the process of producing a recommended NBS inventory of potential freshwater storage sites, intermediate results are also very relevant.

Waterbody delineation, is a stack of water masks which has been produced as input for subsequent studies. It can be used with other geographical data in a GIS environment in both raster and vector format. In all cases, the delineation and the positional accuracy of the waterbodies is good taken into account that they are extracted from medium resolution images.

The analysis of the temporal series and interpretation of the mapped dynamics has allowed a first approximation to discern the flooding dynamics and the identification of those flooding-prone areas within the AOI. The results evidence a geographical division between the Western and the Eastern parts, being the first one more flooding prone. This may be due to the presence of water reservoirs/fishponds located all over the Western zone. The annual profiles evidence a progressive increase in the area flooded, but this output has to be carefully considered, as it may be biased by the limited amount of images available for the study, or caused by human activity (e.g. development of aquaculture).

LU/LC maps have been obtained. By using image time series and cautiously selected training datasets over the whole AOI the maps presents good overall accuracies as shown by the evaluation tests performed. Results presented here are indicative: the maps can integrate additional and/or alternative LU/LC types.

Siltation preliminary results highlight the ability of identifying the areas with high clear water storage capacity, in a comprehensive and synthetic way.

The results achieved through the thresholds applied to flooding frequency, LU/LC maps, and water quality show potential surface storage sites which guarantee a good water quality and a good geographic location if we are talking about urban proximity. Two potential kind of NBS are proposed:

- Near bank water areas to be reclaimed as reservoirs (North of Tamluk, and in Southern part close to confluence). Along the distributary river banks, most of areas are subject to moderate and seasonally variable suspended sediment concentrations. These areas could periodically supply neighboring settling basins (high probability in the branch upstream of Silampur). In this active part of the AOI, seasonality is an important factor in conditioning water use. For example, the surroundings of Narayanpur should be suitable for the diversion of river water, for part of the year, to settling basins. However, it is highly likely that the middle of the dry and wet seasons is constraining, respectively by the saline marine intrusion and an excess of turbidity induced by floods.
- Inland, a large part of the detected parcels is frequently flooded with clear water with very low density of suspended matter. By adding the seasonally flooded areas, the usable area for surface water extraction increases considerably.

In terms of overall cost, the characteristics of both are quite different. The former may have higher costs (embankments) but will consist of available free land (mudflats), the later may have bigger impact for people already using the land.

Specific events of a non-stationary nature are decisive in the dimensioning and decision-making when identifying the freshwater supply corridors, as experience with cyclone Yass has shown during the generation of this report.

4.2 Limitations

In the context of this EO Clinic project, with the purpose of just providing an initial screening, only a limited number of images was processed. Moreover they are mostly free of charge, and VHR images are used just for comparison purposes in a limited area. Even if this represents a constraint for the analysis of the time series and the flooding dynamics of the area, it provides an overall idea of the flooding dynamics and patterns affecting the AOI.

For old images, the more experimental satellite sensors, predecessors of Sentinel-1, Envisat ASAR and ERS SAR, provide quite continuous global measurements but not always in precision mode, i.e. the mode that collects images with a spatial resolution comparable to Sentinel-1 images, therefore there are “gaps” in some years. This lack of appropriate acquisitions hinders long-term studies and may provide a biased perspective of flood dynamics.

The SAR images used for the delineation of waterbodies are especially useful in cloud prone areas, like the AOI. In contrast, narrow waterbodies (e.g. channels) are not always visible in medium resolution SAR images and therefore they are not extracted in the water masks. If these particular waterbodies are potential sites for embankment, an alternative or complementary VHR image should be used.

LU/LC would benefit much from VHR images. However, VHR imagery is still expensive and only was used for checking purposed in this study. Moreover, despite the high revisit period of Sentinel-2 constellation, it should be noted that all the available [optical] cloud-free images are distributed out of the monsoon and pre-monsoon period, which may difficult the typologies identification. In addition, human activity changing the land use could produce inaccurate results, keeping in mind that we use a time series to create a unique map corresponding to the considered period.

Similarly for siltation analysis, the main limit lies in the climate seasonality of the area: the monsoon strongly constraining the use of optical images during the period. One could expect that turbidity levels are higher during the monsoon, because of sediment runoff from the upstream catchments. The dataset therefore over-represents the dry period. In addition, 1 processed image reflects the turbidity per month, which is therefore not significantly representative of the dynamics of the entire month.

The obtained inventory of selected sites is considered just a first attempt but further study needs to be done. Verification has to be performed and other considerations taken into account, e.g. by means of ground truth and local feedback.

4.3 Further Work / Recommendations towards Full-fledged Prefeasibility Study

Beyond the specific context of this EO Clinic, the applied methodologies could be enhanced to avoid some of the limitations encountered during the project or to broaden the results achieved.

Extend AOI

The processing methodology used in this project could be applied globally for waterbodies mapping and flood mapping using radar data in extended areas of interest. E.g. the analysis of the dynamics could be extended upstream and downstream, up to the end of the estuary which may allow for more complete studies.

LU/LC maps could be derived over much larger areas, at the scale of individual watersheds for instance, or even full hydrologic regions. The map legend could also be refined (see below).

More EO imagery

A better representation of the complex dynamics of the Rupnarayan River, especially its short-term fluctuation, could be achieved enlarging the input SAR dataset e.g. up to 60 images per year exploiting the revisit capabilities of the Sentinel-1 constellation (12 days revisit period) and also exploiting all the possibilities offered by their dual-polarimetric acquisition mode (VV+VH). The resulting stack of water mask could avoid a possible biased perspective. In fact, an increase of the number of radar images, combined with the use of optical imagery from Landsat and Sentinel-2 constellations, will complete the robustness of the time series analysis allowing:

- More realistic statistical metrics to be obtained (unbiased perspective).
- The identification of inter-annual anomalies.

- The coupling between flooding dynamics and climate drivers.

Moreover, commercial higher resolution SAR and VHR optical sensors could be used in specific areas to achieve finer details (e.g. of narrow channels, relevant infrastructure, etc.) in the water masks or LU/LC. However, very high-resolution imagery is expensive and it is recommended to use it only to map specific issues.

We therefore recommend to largely enrich the source imagery dataset.

Integration

It is relevant to mention the possibility of closely integrating satellite EO imagery processing with other complementary information, e.g.:

- LU/LC, salinity occurrence, sediment composition, soil maps, demographic maps, aquifers location, bathymetry
- other different sources of remote sensing (e.g. drones) imageries including optical and radar
- data from real-time *in situ* sensors of water levels, salinity, turbidity… collected simultaneously to the imageries
- use of hydrological and hydraulic modelling (sometimes termed "virtual sensors" to fill out gaps in measurements).

In this manner, the combined use of the full potential of each methodology could be utilised to the maximum possible extent, which would be extremely beneficial to improve the accuracy and the robustness of the results.

LU/LC

LU/LC classes are typically divided into tree cover, shrubs, grasslands, croplands, water, soil and built-up areas. A slightly deeper and better suited set of classes has been produced for this study, however it can be further detailed and improved, for instance:

- Water reservoirs. Within this category are both lentic water bodies (ponds and lakes) and fishponds. In a more comprehensive EO study, it would be recommended to have an extra class, exclusively dedicated to "fishponds" or aquaculture. To achieve this the use of VHR imagery could be considered, e.g. the presence of visible infrastructures will obviously ease the detection of such activities.
- Identification of freshwater wetland class, i.e. areas too dry to be called natural water bodies and too wet to be called grassland or cropland. Differentiate "Salt Marsh" from a freshwater wetland area
- Get into deeper detail customised to the particular stakeholders needs, e.g. some of the classes may also generate some discussions, such as the interpretation of "non forested natural areas"

Turbidity / Siltation

The analysis of turbidity and siltation can add great value to subsequent studies. Some recommendations could be:

- Siltation analysis could be enhanced by enlarging the Sentinel-2 input database and by improving class discretization.
- Siltation analysis can be improved by distinguishing wet, dry, and intermediate seasons, especially for near riverbank areas.
- Siltation analysis can separate the two types of water reservoirs defined (inland and near the active distributary channels) for more adapted conclusions.
- The turbidity quantification is based on a standardized method, therefore the analysis could be performed at the scale of hydrographic regions.
- Discrimination of terrigenous from algal turbidity, and even point out water ponds that show frequent harmful algal bloom events would be interesting.
- A hydrogeological analysis of the area would be highly interesting, drawing a link between the lithology and the type of the sediments. They can provide a lot of information on hydraulic environment connectivity.

- A connection between the surface runoff analysis and the movement of groundwater would be interesting. The aim is to identify the real nature of the water distribution, where the aquifers are relevant.

Near Bank Salinity

Considering that the objective of this study is to identify the areas of the active channels, which may be are suitable for use to supply clear fresh water towards reservoirs on the side banks, it would be important to have the information about when the saltwater intrusion rises further upstream (i.e. during the dry period). To determine this period, we would need to use time series of salinity information. In this sense, the saline wedge processes could be analysed from an operational point of view, in order to ensure the best management of water resources. For this purpose, the following tasks would be carried out, which would work together to obtain the evolution and position of the salt wedge at all times.

i. On the one hand, a Logistic Equilibrium Model (LEM) would be implemented to obtain the rainfall-river flow transferring (e.g. from hydrological and hydraulic models).

ii. On the other hand, a process-based model would be applied and calibrated with field data to analyse the hydrodynamics and the evolution of salinity under certain river flow and tides characteristics[1]..

Once models are mobilised, their coupled working with EO data as shown in this note, would allow to work in operational mode and provide forecasts of the position of the wedge or to carry out long-term analyses, analysis of different management scenarios, more precise favourable period calendar, possibly highlighting the inter-season period etc.

[1] Public Health Engineering Department West Bengal already has operational hydrodynamic and salinity models, which simulates scenarios and forecasts in real-time the flow, flood and what the extent of salinity intrusion is. It has been established as part of the West Bengal Drinking Water Sector Improvement Project financed via ADB

APPENDIX A: REFERENCES

Table 8. References

Company		
everis	General cartographic repository of Unnamed Traffic Management Demostrator for SESAR JSU (DOMUS)	Spain, 2019
	Small Infrastructure Study, associated with public transport services and urban and rural terminals	Regional Government of La Araucanía, Chile, 2018
	Technological specialized consultancy about Corporative GIS of the Metropolitan Transport of Barcelona	Barcelona, Spain, 2018
	Madrid Digital, GIS applications maintenance: urban planning, official street name, property and real estate valuation system	Madrid, Spain, 2018
	Framework GIS of Autonomous Community of Madrid	Madrid, Spain, 2018
	Spatial Data Infrastructure (IDE) of the Spanish Directorate General of Cadastre of National Institute of Statistics	Madrid, Spain, 2018
Other experience from everis' proposed personnel	Design methodologies for flood mapping generation and validation. Optical/SAR VHR and Sentinel-1/2 data processing for flood mapping in emergency context for several Rapid Mapping and Risk and Recovery Copernicus EMS activations.	Copernicus EMS - Mapping Validation Service, 2014-2019
	Creation of LU/LC maps by means of supervised (object-based) classification using multispectral optical imagery (Landsat-8, Sentinel-2, Rapid-Eye, Pléiades, WorldView-2) with the aim of generate reference information to validate Risk and Recovery Copernicus EMS products. Thematic validation of LU/LC maps. Harmonization of Corine Land Cover classes with other land cover classifications	Copernicus EMS - Mapping Validation Service, 2014-2019
i-Sea	Mapping wild oysters and farms using Deep learning approaches (2019 – 2020: Agence Française pour la Biodiversité)	Development of Deep Learning approach to characterize the wild oysters and oysters' cultures at large scale, based on very-high resolution imagery.
	Vegetation and/or Land Use / Land Cover mapping over various sites in France (15 commercial contracts over the past 5 years + 2 R&D projects)	Mapping of natural and non-natural coastal/estuarine/lagoon/terrestrial habitats and ecosystems, specific species (including estimation of vegetation cover), of LU/LC based on Deep and Multi-temporal Machine learning techniques.
	Estuarine & Coastal Water quality monitoring (11 commercial contracts over the past five years + 1 R&D project + 1 EO CLINIC 2020 "Characterisation of Waste Sites Along the Lim River in Serbia")	Mapping turbidity from medium to high resolution optical data. Provision long-term database and expert analysis on time and space evolution of the turbidity at short, medium and long-time scales. Objectives: scientific description of the turbid climates and evaluation of potential impact of works on vulnerable ecosystems.

Company		
FIHAC	Habitat Mapping within Special Areas of Conservation (SACs) using Deep learning approaches (2016 – 2021: General Directorate for the Natural Environment of the Government of Cantabria)	Development of Machine Learning approach to characterize habitats presence and ecological status, based on medium resolution imagery.
	Vegetation and/or Land Use/Land Cover mapping over several country sites in Europe (10 contracts over the past 5 years)	Mapping of natural and non-natural coastal/estuarine/inland/terrestrial ecosystems, and LU/LC based on Multi-temporal Supervised Machine learning techniques.
	Implementation of the Water Framework Directive (2000/60/CE) in Cantabria (2004-2010: funded by Regional Government of Cantabria, Spain)	Elaboration of the River Basin Management Plan (region of Cantabria), according to the requirements of the Water Framework Directive. The tasks developed comprise, among other things, the characterization of water bodies, the identification and risk assessment of pressures, the assessment of ecological status of water bodies and the proposal of specific programs of measures.
	Design and development of the Monitoring Network in transitional and coastal waters of Cantabria (2005-2020: funded by Regional Government of Cantabria, Spain)	Establishment of a monitoring network for the estuarine and coastal waters of the region of Cantabria. Both surveillance and operational monitoring are implemented. The network comprise the study of all physicochemical and biological elements required for the evaluation of ecological status according to the Water Framework Directive (water column, sediments, phytoplankton, fish fauna, macrophytes, seaweeds and benthic macroinvertebrates).
	Improving the management of Atlantic landscapes: accounting for biodiversity and ecosystem services. (2017-2021: Intereg Atlantic project)	The main goal is to promote sustainable investments in Blue-Green Infrastructure Networks (BGINs) through identification of the benefits of Ecosystem Services delivered at the terrestrial-aquatic and land-sea interface in the Atlantic Region. The activities are developed by: 1. combining a range of satellite images, GIS data and modelling frameworks to map aquatic and terrestrial vegetation formations and ecological processes; 2. enhancing the predictive capacity by using a multi-model platform; 3. participatory learning approaches to engage local stakeholders. ALICE has also identified economic and social barriers to the implementation of Blue-Green Infrastructure Networks in each of the four case studies of the project, providing robust scientific, socioeconomic and environmental policy support for the effective implementation of future BGINs.

Company		
	A European training and research network for environmental flow management in river basins (EUROFLOWS; 2018-2021: EU H2020 program – DG Research).	EUROFLOW has trained a cohort of researchers to be future leaders in the science, business and policy of this field. EUROFLOW addresses the need to develop novel scientific understanding for the field of e-flows via 4 inter-related scientific work-packages: (i) abiotic environment dynamics, (ii) aquatic biodiversity, (iii) ecosystem processes and (iv) developing models to underpin socio-economic and policy decision making, integrating information from i-iii.

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APPENDIX C: LIST OF ACRONYMS

Table 9. List of Acronyms

Acronym	Meaning
ADB	Asian Development Bank
AOI	Area of interest
BI	Brightness Index
BOA	Bottom-Of-Atmosphere
dPC	Probability of connectivity
dPCintra	Probability of intra-patch connectivity
dPCflux	Probability of connectivity by dispersal flow or inter-patch
dPCconnect	Assessment of contribution as a connector
EO	Earth Observation
ESA	European Space Agency
GIS	Geographic information system
HYSOG	Global Hydrologic Soil Groups
LU/LC	Land Use /Land Cover
MMU	Minimum Mapping Unit
MSI	MultiSpectral Instrument
NBS	Nature-based solutions
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
RI	Redness Index
RVI	Ratio Vegetation Index
SAVI	Soil Adjust Vegetation Index
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goals
SITS	Satellite Images Time Series
TSM	Total Suspended Matter
VHR	Very High Resolution
VNIR	Visible /Near Infrared
WP	Work Packages

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