
eo clinic
the walk-in satellite support
esa
West Bengal Drinking Water Sector Im-provement Project, India
In support to the Asian Development Bank (ADB)
EO CLINIC
Final Presentation
9 June 2021
Rapid-Response Satellite Earth Observation Solutions for International Development Projects
Aerospace and Defense
everis
FUNDACION
INSTITUTO DE HIDRÁULICA AMBIENTAL DE CANTABRIA
i-Sea

Contents

OBJECTIVES

01

DEVELOPMENT CONTEXT

- 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.
- Nature-Based Solution (NBS) for surface storage is the chosen solution in order to improve storage of flood water by using abandoned river channels, along the river Rupnarayan.
- The objective of the study is to provide a rapid assessment of suitable NBS water storage sites in Purba Medinipur based on EO. Target output is a prioritised inventory of suitable sites which will serve as background for further detailed investigations.

REQUIREMENTS and PROPOSAL

Service 1: Waterbody Inventory and Dynamics

Map surface waterbodies and their associated dynamics, including seasonal changes in waterbody extent for the period from the early 1990's, 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.

Service 2: Land Use and Land Cover

This service shall provide the latest status of land use and land cover (LU/LC) for the surroundings of the identified seasonal water areas.

Service 3: Potential Surface Storage Site Inventory

This service shall provide an inventory of sites potentially suitable for NBS-based surface storage based on rapid assessment (from EO), 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.

Service 4: ADDED Siltation rate qualification as a function of riverine turbidity

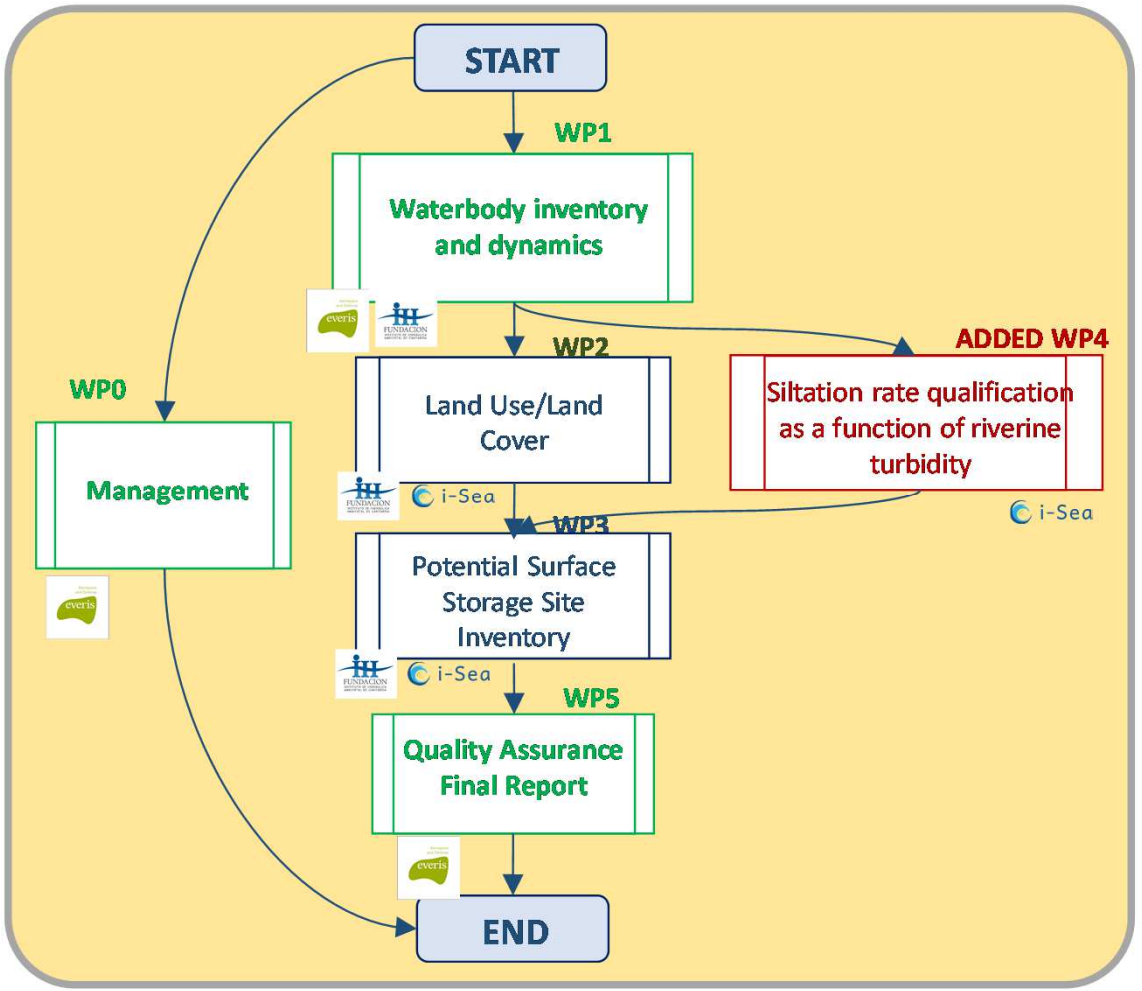
The objective of this Service is to help the interpretation of the results and to guide the decision maker creating a hierarchical and spatial classification of the siltation potential in the study area.

PROPOSED WPS AND PARTNERS

02

Work Packages

WORK LOGIC



Team Composition

- Dr. Patricia Rodríguez (PM)
- Mr. J. Enrique González (PM)
- Mr. Agustín Tamés (SA)
- Mr. Daniel Corbacho (DA)

- Dr. Ana Silió (TL)
- Dr. Jose Manuel Álvarez (SA)
- Dr. César Álvarez (SA)
- Dr. Javier García (SA)
- Mr. Gonzalo Hernández (DA)

- Dr. Virginie Lafon (TL)
- Mr. Benoît Beguet (SA)
- Mrs. Manon Besset (SA)

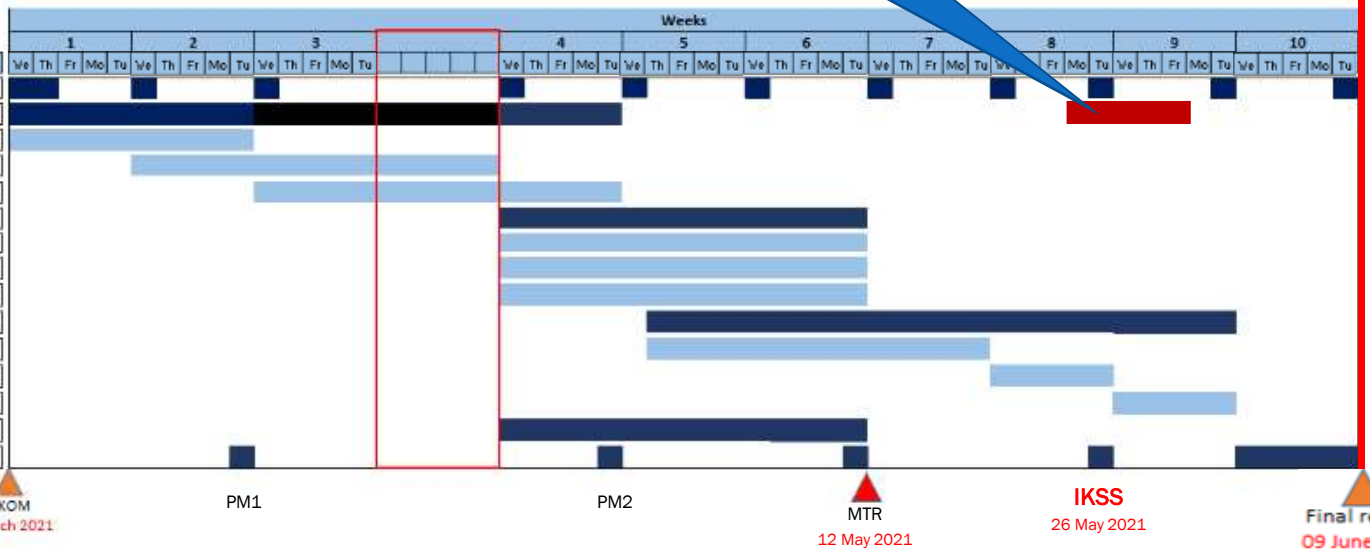
Legend:

PM: Project Manager TL: Technical Leader SA: Senior Analyst DA: Data Analyst

Schedule

✓Cyclone Yaas Opportunity task

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 dynamic	FIHAC-IH Cantabr	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 Cantabr	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 id	FIHAC-IH Cantabr	T0+6	T0+7	5 days
Task 3.2	Connectivity study between sites and vulnerability a	FIHAC-IH Cantabr	T0+7	T0+8	5 days
Task 3.3	LU/LC map improvement using VHR images	FIHAC-IH Cantabr	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



- The project has one (negotiated) week delay due to Easter holidays, with respect to the 10 weeks foreseen
- WP 4 was not requested in the RFP, it was added in the Proposal
- An internal ADB's IKSS event was celebrated on May 26th. With contribution of the project team
- An extra WP1 task was dedicated to rapid assessment of flooding caused by Cyclone Yass

- Overall a sizeable extra effort was dedicated to the project.

Deliverables

- Deliverables at End of Project are:
  - Final Review summary presentation (this one)
  - TN1: technical note with all the details an methods of the study: a final draft is already available, it will be closed with this comments and contributions form the FR
  - Data Set: all the images and graphs used or produced in the study, at usable resolution: already available
  - Final Report: comprehensive report of the management and results of the project: to be delivered within 1w after the approval of the FR

Asian Development Bank

European Space Agency

RESULTS

03

WP1. Waterbody inventory and Dynamics

- **INPUTS**

  Sentinel-1, Sentinel-2 and other SAR satellites images

  Monsoon and meteorological ancillary information

- **TASKS.**

  Task 1.1. Data collection and image processing

  Task 1.2. Delineation of waterbodies extent

  Task 1.X. Cyclone Yaas flooding fast evaluation

  Task 1.3. Analysis and interpretation of the mapped dynamics

- OUTPUTS

  1) Water mask representing the extent of waterbodies in different dates.
  2) Seasonal climatological means, annual flooding profiles, anomalies (Yaas!)
  3) Frequency flooding map
  4) Erosion-accretion map obtained from the SITS analysis

WP1 Data collection and image processing

❑ Selection of the Area of Interest (AOI)

- A 50 x 50km square shaped area covering most of the encircled geographical area proposed in the RFP.

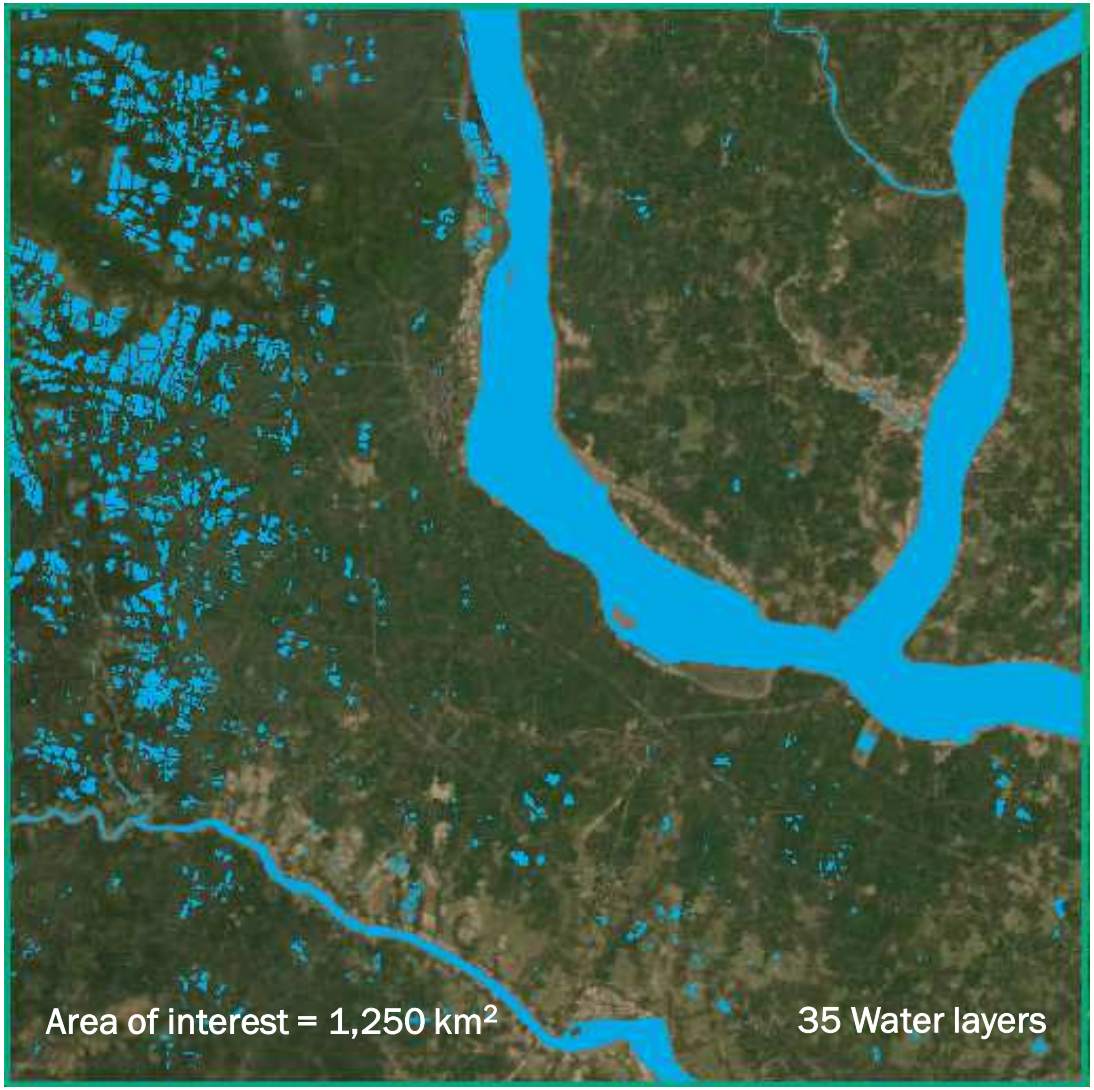
An area of 1250 km2 has been analysed for every processed image (optical or SAR)

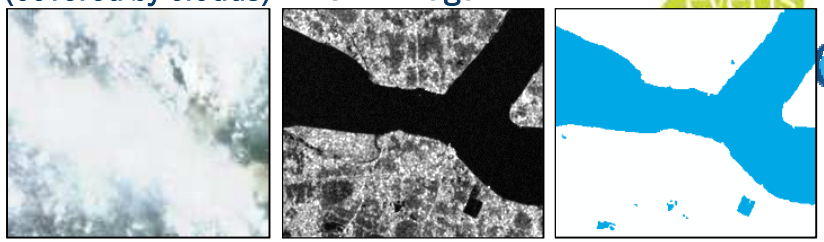
❑ Selection of cloud-free S2 images

- 60 products has been checked. Aiming to select the products with no clouds in the AOI, all the Level-2A products acquired with less than 30% of cloud cover in 2020 have been searched and checked.
- 36 products has been processed. All the products without cloud cover in the AOI will be processed in order to serve as **input in WP2 and WP4**

S-2 footprints (orange) and AOI (green).
A mosaic of two products, acquired at the same time, is needed to cover the complete AOI.

WP1 Delineation of waterbodies extent





Challenge

- Map surface waterbodies under all-weather conditions

Solution

- Semi-automated method: Synthetic Aperture Radar (SAR) + supervised object-based classification.

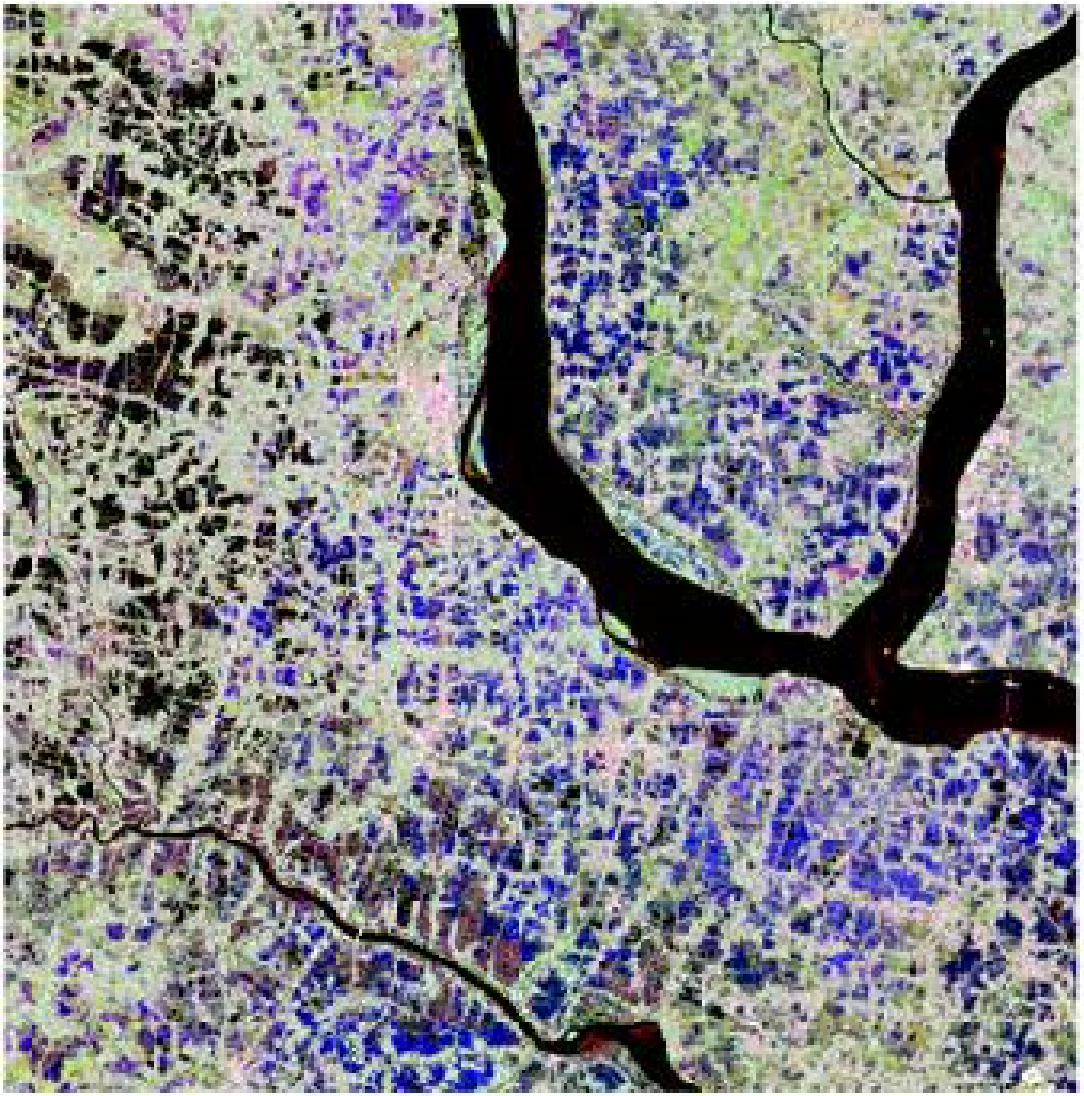
Results

- Geo-referenced, reliable and comparable water masks from 35 dates between 1992 and 2021.
- Dataset ready to use with other geographical data in a GIS environment (raster and vector format).

Possible continuation studies

- Enlarge the input dataset e.g.up to 60 images/yr with Sentinel-1
- Finer definition with commercial higher resolution SAR images

Cyclone Yaas flooding fast evaluation



Challenge

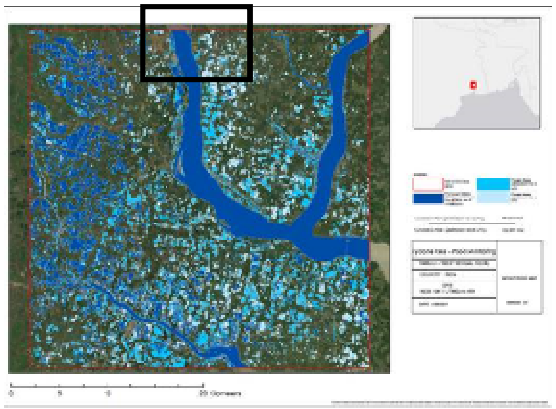
- Generate flood maps in a few hours after the crisis event.

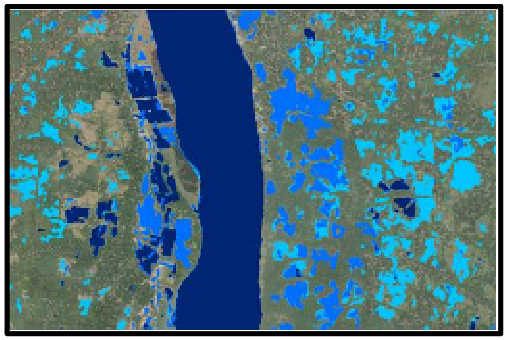
Solution

- Semi-automated method: dual polarimetric SAR data + supervised pixel-based classification.

Results

- False colour flood maps (raster) to be used in rapid response.
- Waterbodies areas (vector) distinguishing between permanent waterbodies and flooded areas.
- Monitoring maps (PDF) based on pre-, co- and post-event images.





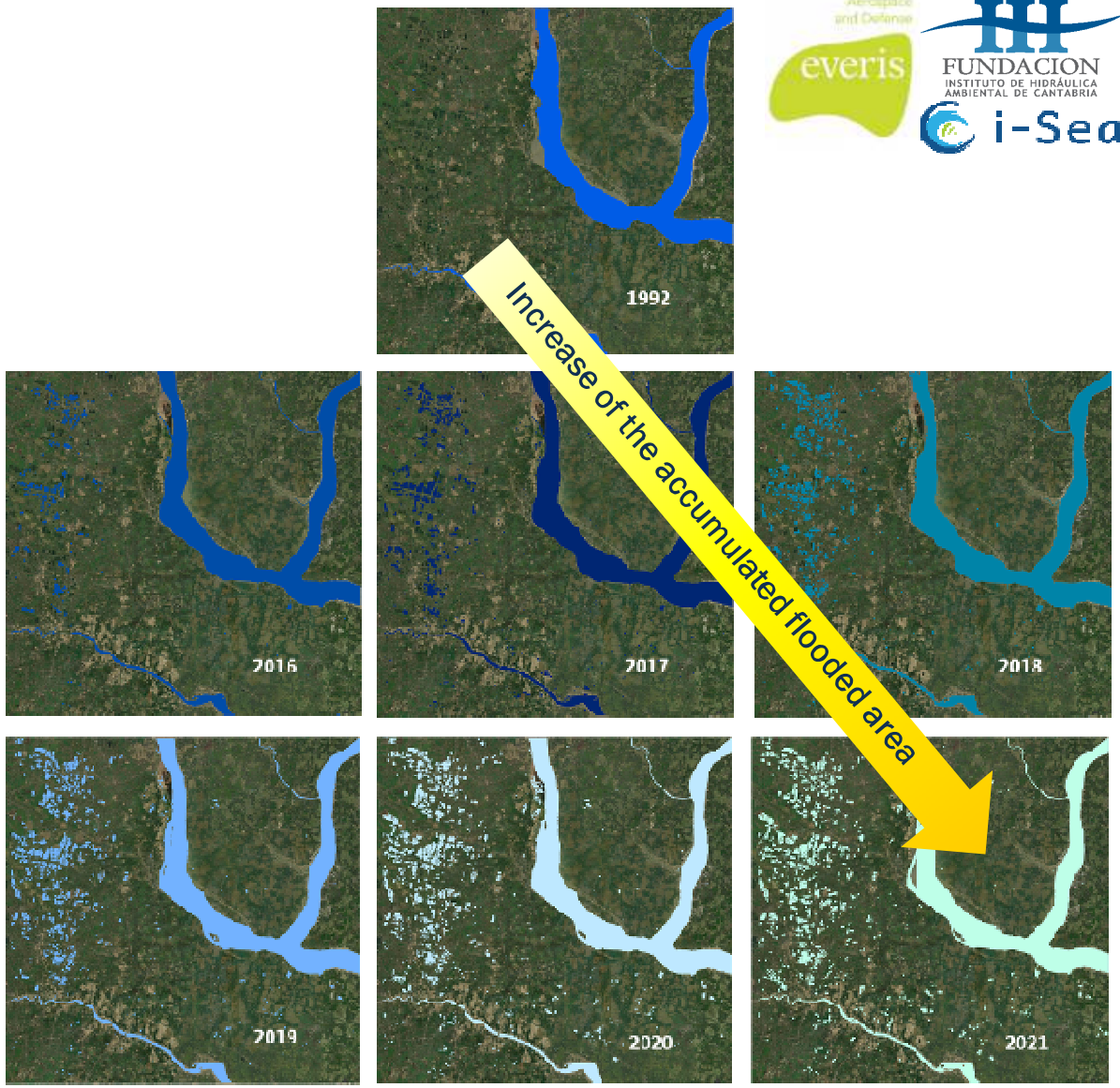
Flooding Dynamics

Challenge

- Identification to seasonal and yearly flooding patterns that will contribute to decision-making about potential NBS by locating flooding hot spots & providing information relevant for the clear water ponds identification.

Solution

- Statistical analysis of flooding frequency based on water masks derived from radar data.



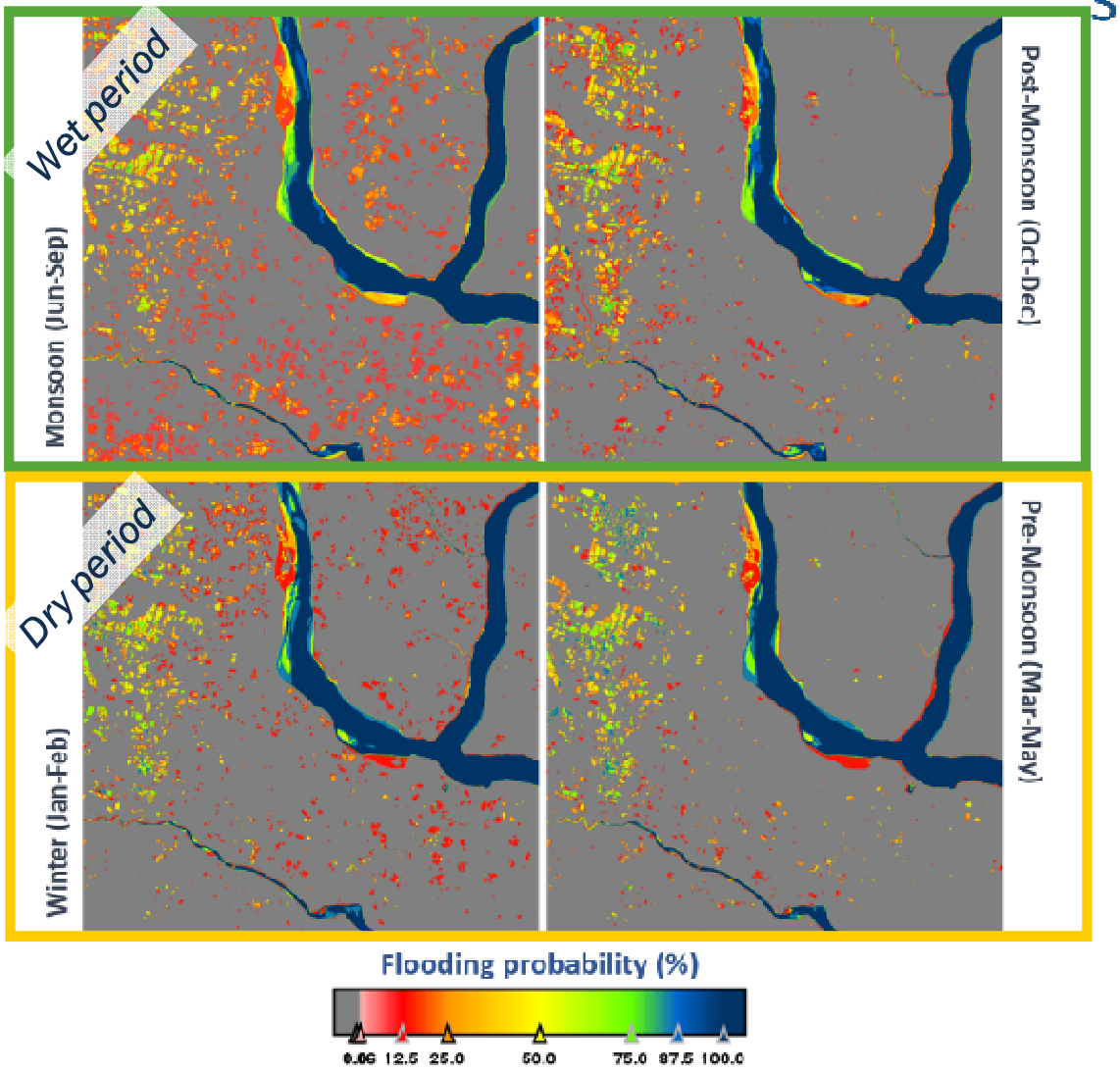
Estimation of the annual flooding profiles.

Flooding Dynamics

Estimation of the seasonal flooding probability based on the available seasonal water mask time series:

Results

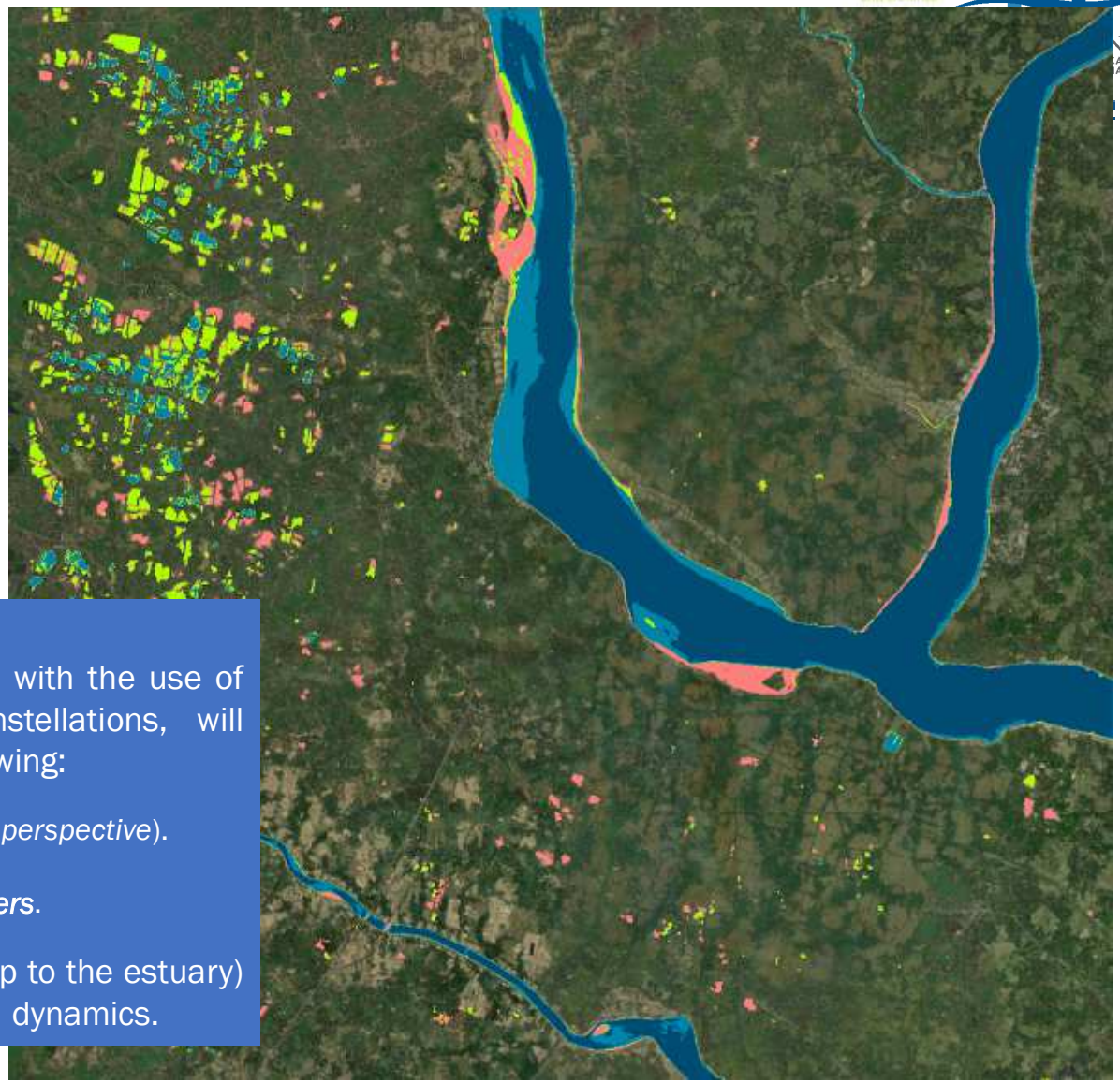
- Seasonal and yearly climatic flooding probability estimates.
- 4 classes to highlight water bodies presenting similar flooding patterns.



Flooding Dynamics

Identification of water bodies presenting similar flooding patterns.

- **Class 1:** low-probability flooded areas (<25%)
- **Class 2:** medium-probability flooded areas (30-60%)
- **Class 3:** semi-permanently flooded areas (65-85%)
- **Class 4:** permanent water bodies (>95%).



Possible continuation studies

- 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***.
- Extending the study area (upstream and downstream, up to the estuary) will also be of great benefit in accurately assessing flood dynamics.

WP2. Land Use / Land Cover

- **INPUTS**

  Land cover reference dataset

  WP1 outputs, Sentinel-2 & Pleiades sample images

- **TASKS.**

  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

- OUTPUTS

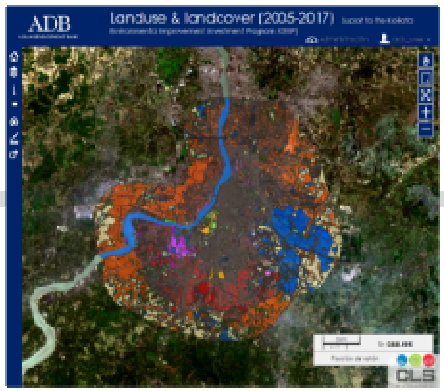
  1) Geodatabase: Individual vector files (shapefiles) based on Sentinel-2 and Pleiades imagery. Each polygon will be labelled following the typology. Metadata will be provided to trace the source of the shapefiles.

WP2 Training sets definition: LU/LC map legend

The legend was produced after a detailed revision, and interpretation of Google Earth's very high spatial resolution imagery, and the available ADB LULC map from the Calcutta surroundings. The outcome has been an adaptation of the existing ADB LULC map legend:

ADB LULC MAP LEGEND

- Natural Water Bodies
- Trees
- Other Natural and Semi-natural Areas
- Urban / Artificial Areas
- Formal High Density Residential (Sealing Level: 50%-80%)
- Formal Low Density Residential (Sealing Level: 10%-50%)
- Informal Settlement (Sealing Level: More than 80%)
- Village Settlement (Sealing Level: Less than 10%)
- Commercial and Industrial Units
- Non-residential Urban Fabric
- Roads and Associated Land
- Railways and Associated Land
- Port Areas
- Airports
- Waste Sites
- Construction Sites
- Vacant Land Not Obviously Being Prepared For Construction
- Urban Greenery
- Sports And Leisure Facilities
- Bare Lands
- Agriculture



PROPOSED LEGEND

- Natural Water Bodies
- Water Reservoirs / Fish Ponds
- Salt Marshes
- Forested Natural Areas
- Non-forested Natural Areas
- Residential Urban Soil
- Industrial and Commercial Soil
- Human Activity Mix
- Bare Lands / Disturbed
- Rainfed Croplands (grasslands mix)
- Irrigated Croplands (grasslands mix)

WP2 LU/LC Training sets definition

Challenge

- Obtaining well-labelled training sets for all classes in the LU/LC legend from EO data.

Solution

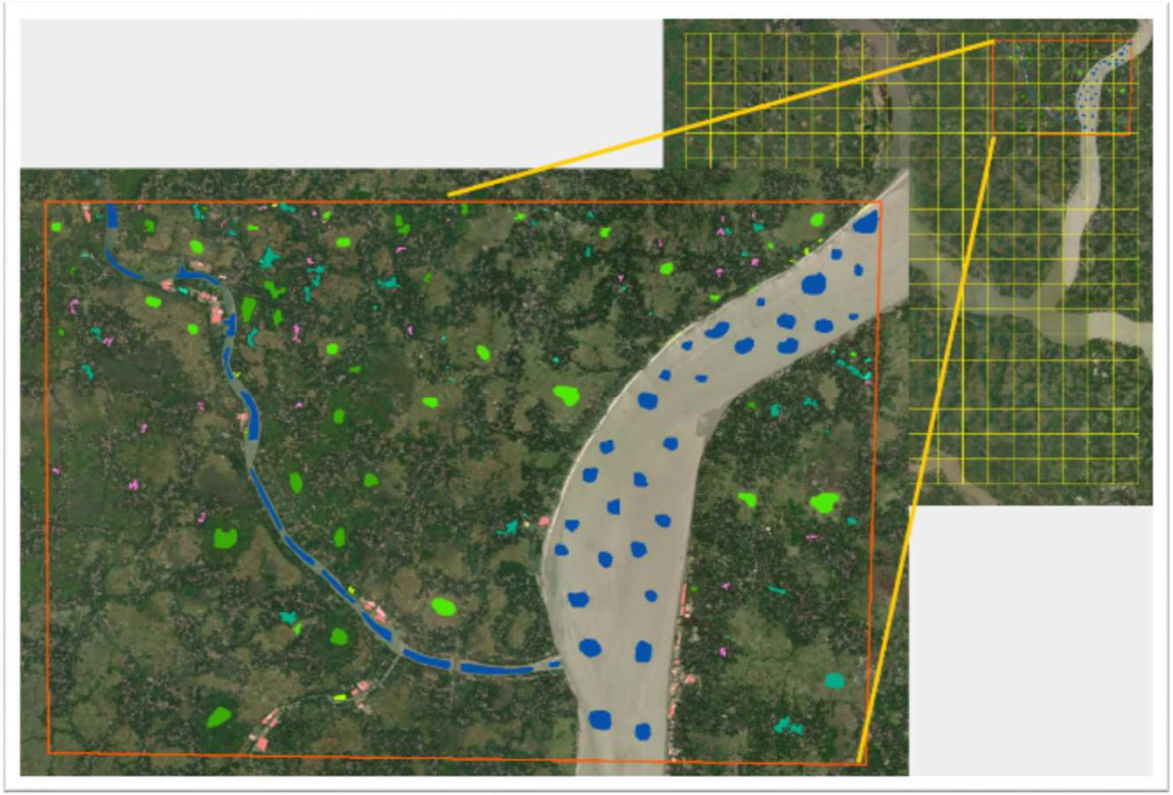
- Interpretation of data from very high spatial resolution satellite images, Google Earth imagery, and available existing maps from the West Bengal districts.
- Only those polygons in which the **coverage** of the main land cover class is **greater than 90%** were selected to ensure the data purity and the reliability of the set of training points.

Polygons digitalized for training LULC map derived from **Sentinel-2 imagery**:

- barelands denuded
- cropland core
- cropland mid
- forested areas
- human activity mix
- industrial commercial soil
- natural water bodies
- non forested natural areas
- residential urban soil
- salt marches
- water reservoirs

WP2 LU/LC Training sets definition

Polygons digitalized for training LULC map derived from **Pléiades imagery:**

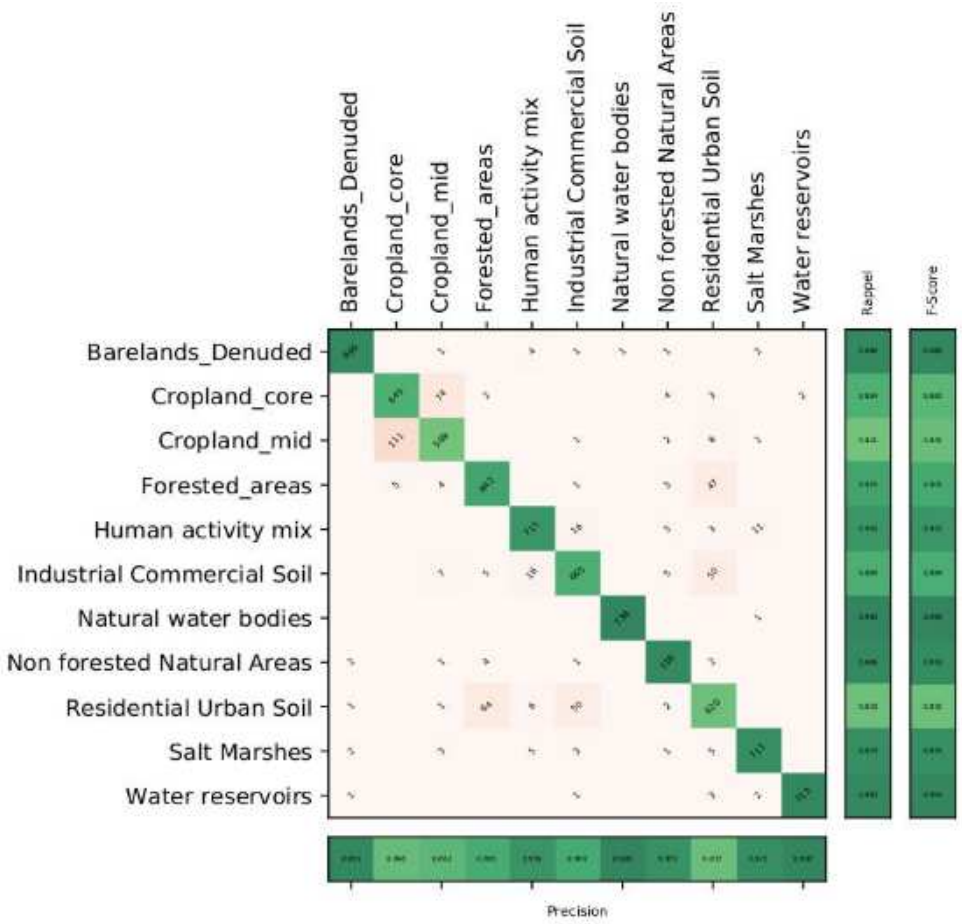


Results

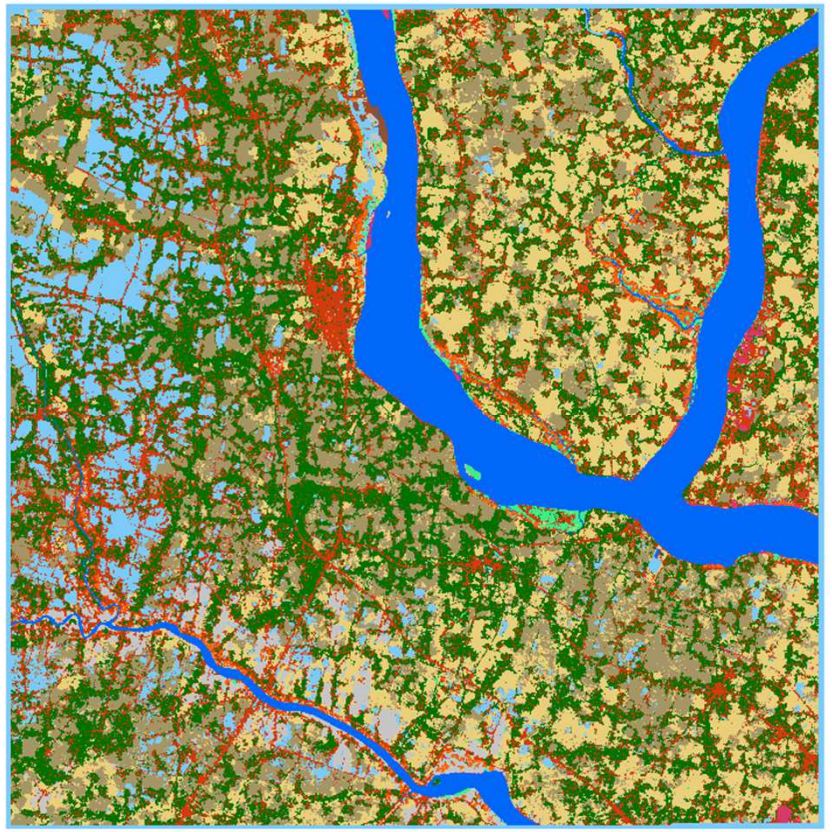
- **An specifically defined LULC legend.**
- **A database of 866 labelled polygones covering 48 km² for Sentinel-2 imagery.**
- A database of 299 labelled polygones covering the Pléiades image.

Class Name	NB Polygons S2	NB Polygons PL
Barelands_Denuded	10	15
Cropland_core	154	31
Cropland_mid	165	43
Forested_areas	80	37
Human activity mix	29	22
Industrial Commercial Soil	14	23
Natural water bodies	59	39
Non forested Natural Areas	18	12
Residential Urban Soil	138	45
Salt Marshes	9	0
Water reservoirs	190	32
Sum	866	299

WP2 Image classification and LU/LC map generation

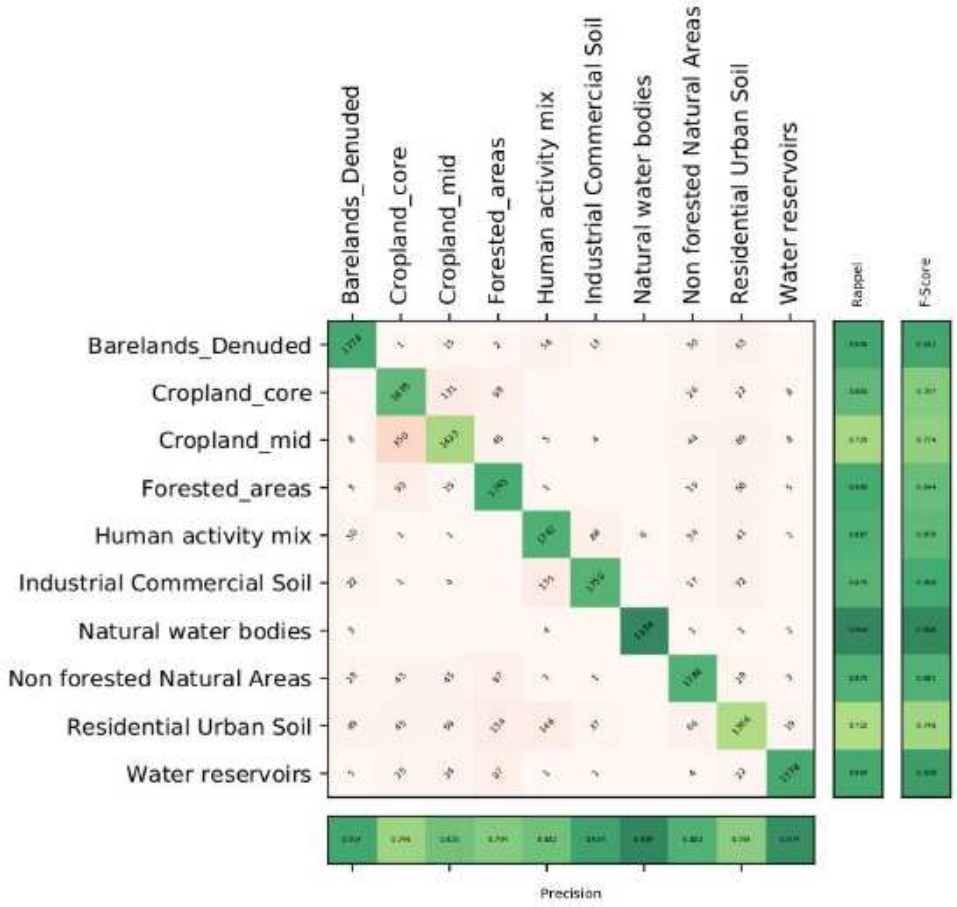


Confusion matrix Sentinel 2, **Overall Accuracy = 93%.**

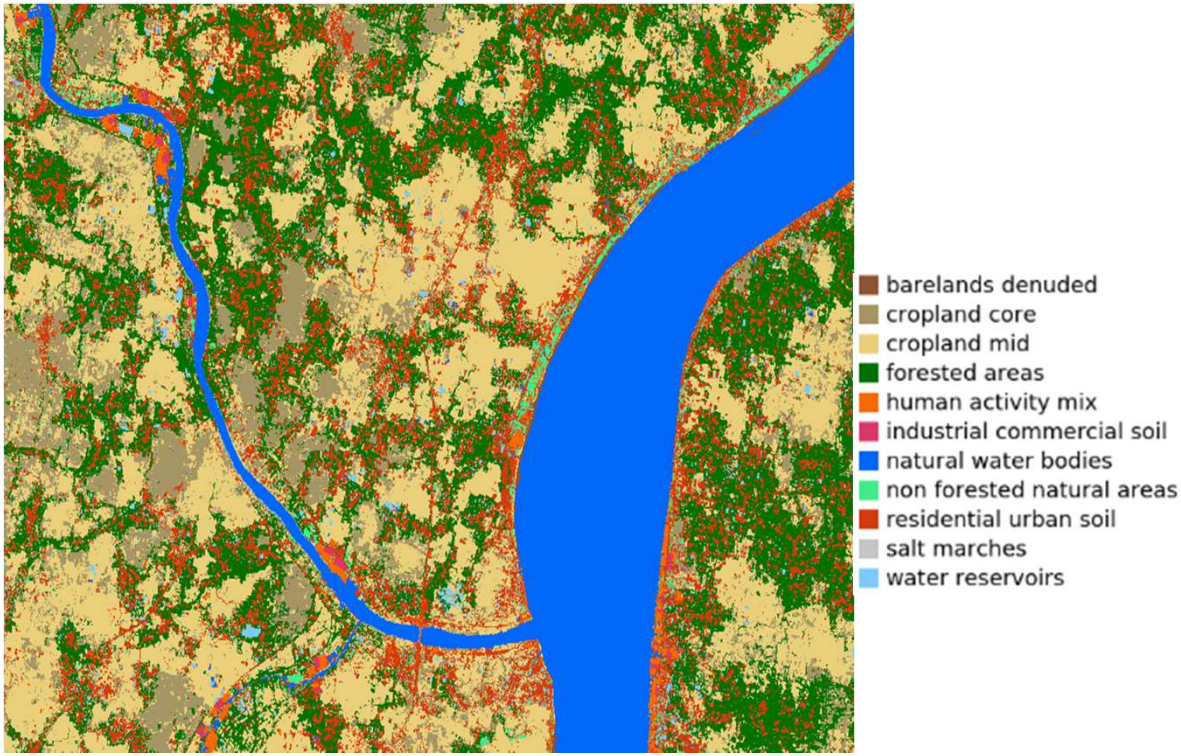


RandomForest Classification : Sentinel 2 (full area)

WP2 LU/LC map improvement using VHR images



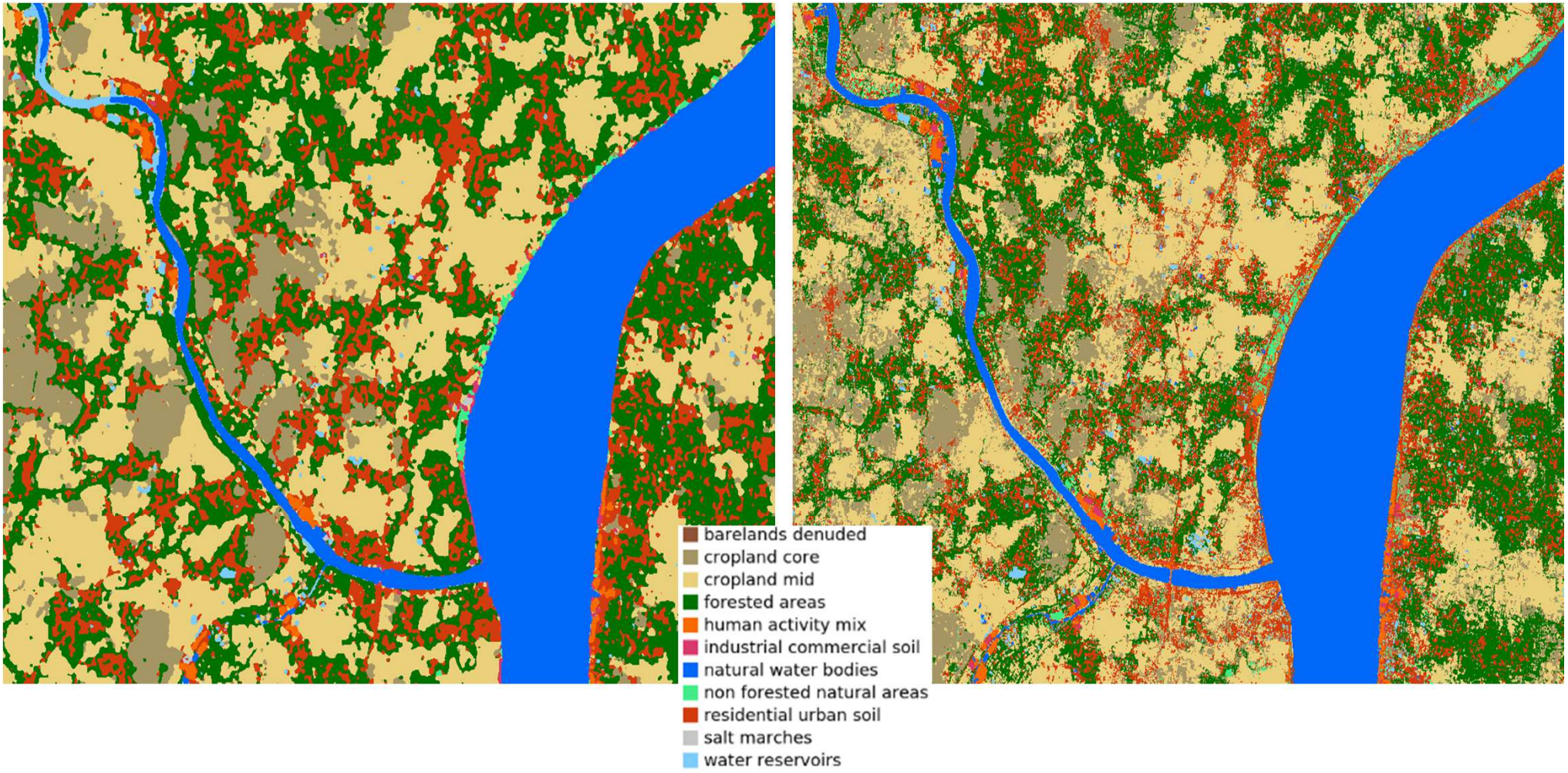
Confusion matrix Pléiades, **Overall Accuracy = 86%.**



RandomForest Classification : Pléiades (ROI)

WP2 LU/LC map improvement using VHR images

RandomForest Classification : Comparison between Sentinel 2 (10m) and Pléiades (2m)



WP4. Siltation rate qualification

- **INPUTS**

  Large temporal satellite image database (10 years), Landsat & Sentinel-2

  Outputs of WP1

- **TASKS.**

  Task 4.1 Data collection and selection

  Task 4.1. Extraction of water bodies turbidity

  Task 4.2 Siltation potential retrieval per water body.

- OUTPUTS

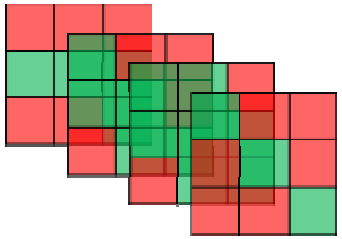
  1) map ranking the sectors from the most favorable to the least favorable to siltation.

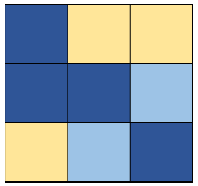
Siltation potential indicator - WP4

Objective: Define areas of potential clear water storage

1 Frequency of flooding per pixel per satellite image

Based on WP1 & linked to WP3



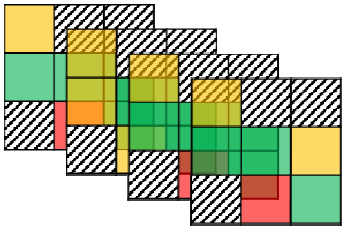


Water pixel
No water pixel

0-25%	Permanent land, frequently emerged
30-60%	Seasonal land/water alternation
65-100%	Permanent water, frequently submerged

Pixels retained for step 2

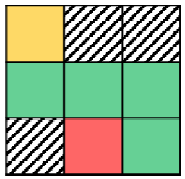
2 Monthly TSM occurence per Sentinel-2 satellite image



< 50 mg/L
50 – 100 mg/L
> 100 mg/L

Low suspended matter
Moderated TSM
High TSM

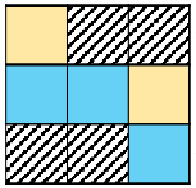
3 Frequency of total suspended matter conditions during the period



> 50 % at < 50 mg/L
50-100% at 50-100 mg/L
> 40 % at > 100 mg/L

Frequent low TSM
Seasonal to frequent medium TSM
Frequent high TSM

4 Ranking of pixels in terms of clear water storage potential



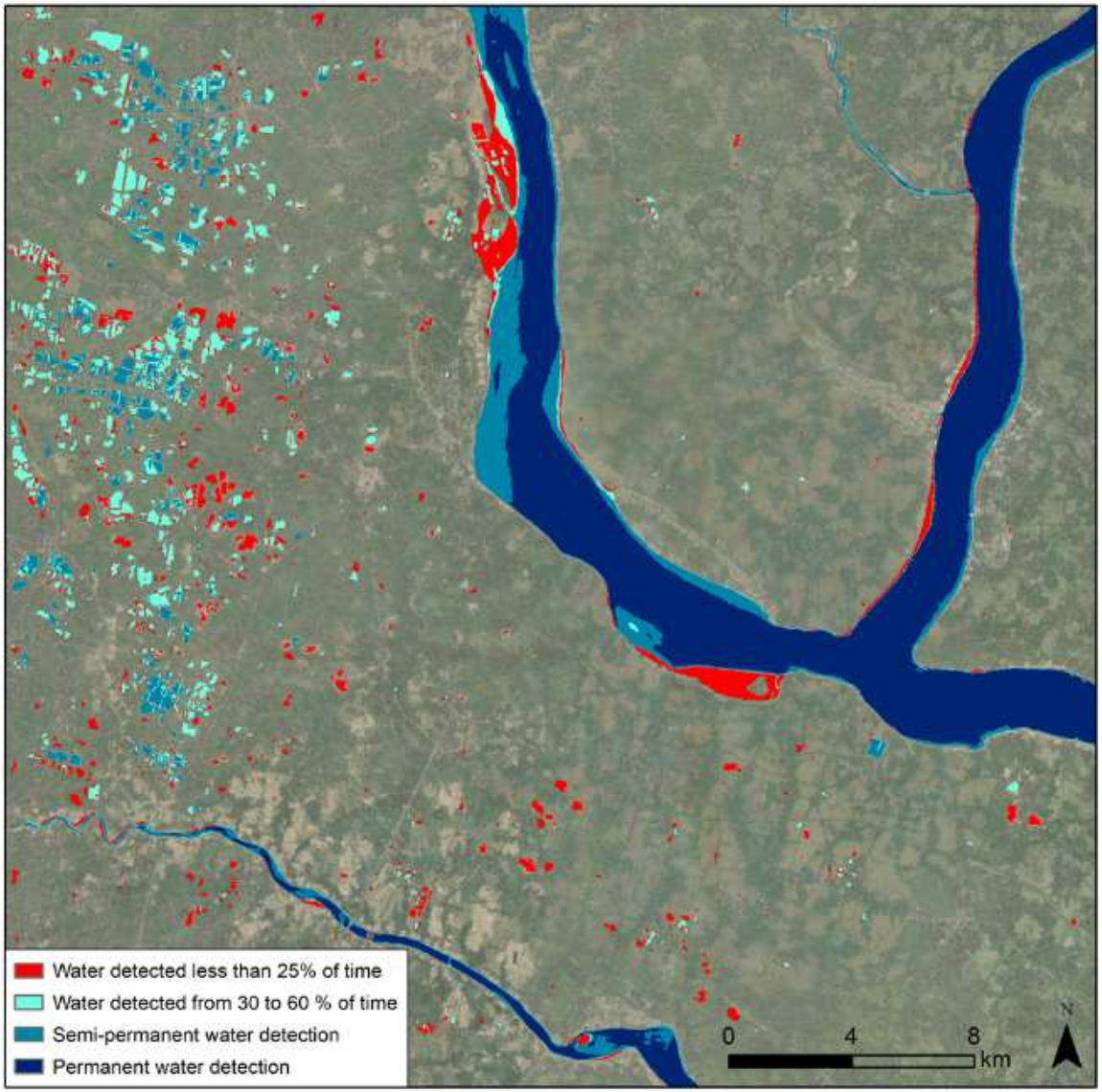
		Flooding frequency		Occurrence of TSM conditions	
				Frequency	Intensity
Negligible potential of clear water storage		< 25 %	and /or	> 40 %	> 100 mg/L
Low potential	Within the dynamic river channels	> 65 %	and	30 - 50 %	50 – 100 mg/L
Moderate potential				> 50 %	
Seasonal potential		30 – 60 %	and /or	50 – 65 %	< 50 mg/L
High potential of clear water storage		> 65 %	and	> 50 %	< 50 mg/L

Dataset used for total suspended matter analysis

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	1						29				16	16
2017	15	24	16	25		4	14			22	6	26
2018	30	14	11	15	15	29				22	16	21
2019	30	14	21	20	10	14			17	27	21	6
2020	15	14	15	9	14	3				26	25	5

WP4. Results

WATERBODIES
ANALYSIS ACCHIEVED

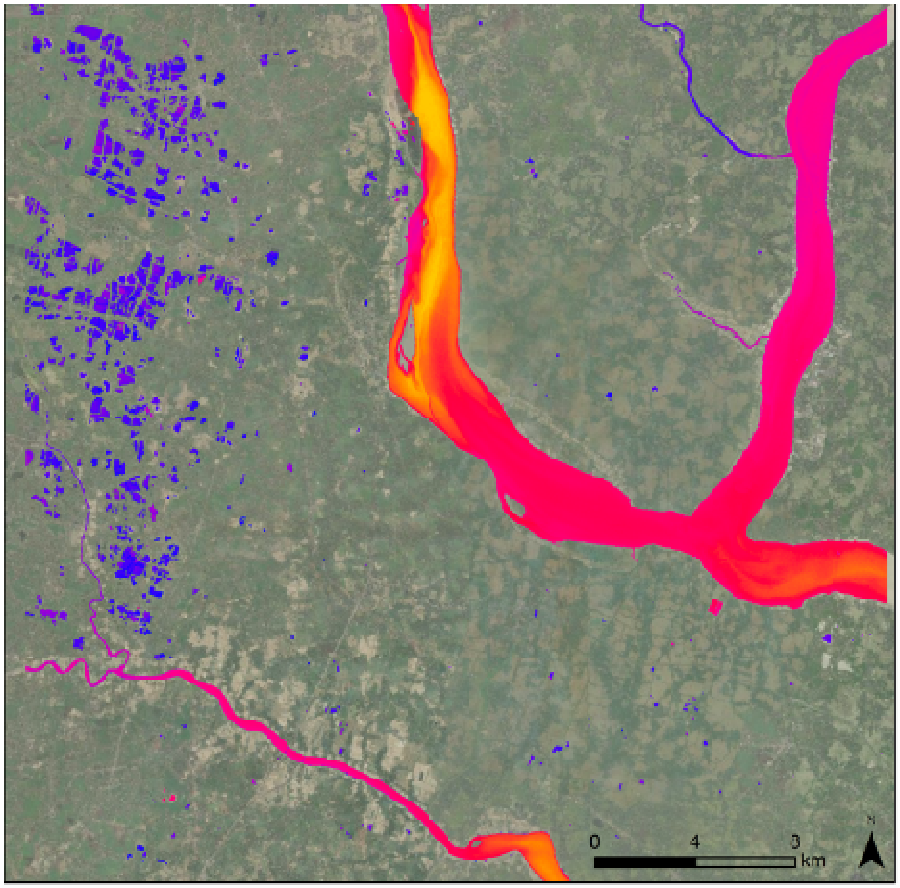


Preliminary results

WP4. Results

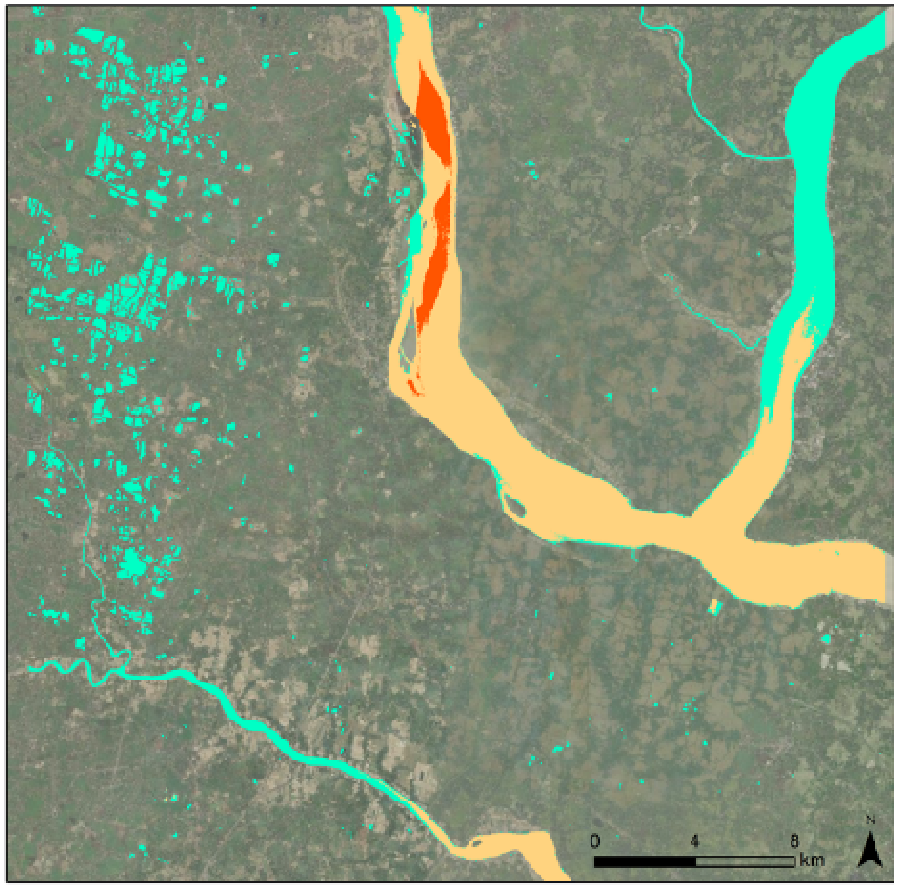
TOTAL SUSPENDED MATTER EXTRACTED MONTHLY FROM 2016 TO 2020

Example for TSM analysis (Case of 10/26/2020)



High TSM: 119.5 mg/L

Low TSM: 5.9 mg/L



< 50 mg/L

50 – 100 mg/L

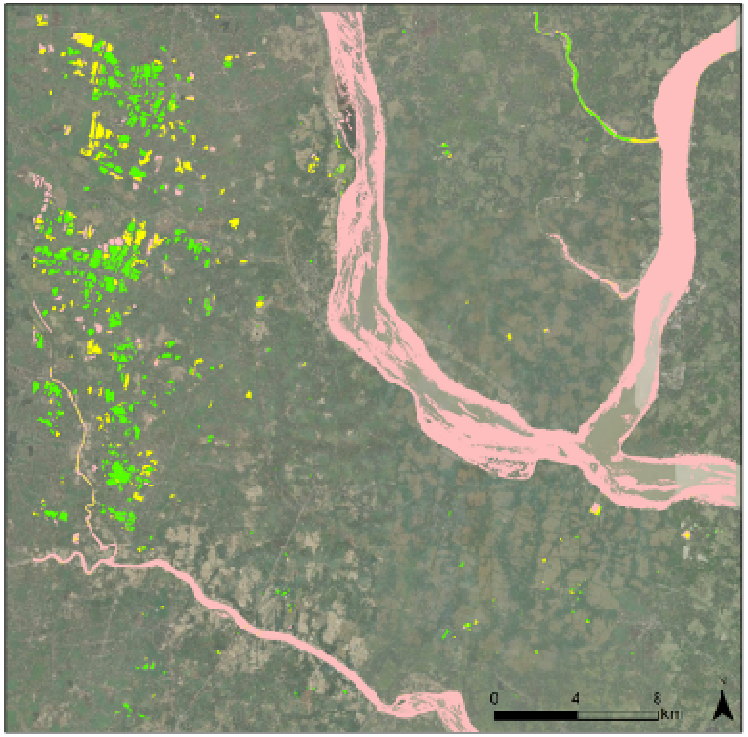
> 100 mg/L

Preliminary results –
TSM database collection

WP4. Results

OCCURRENCE FREQUENCY OF THE 3 LEVELS OF TOTAL SUSPENDED MATTER

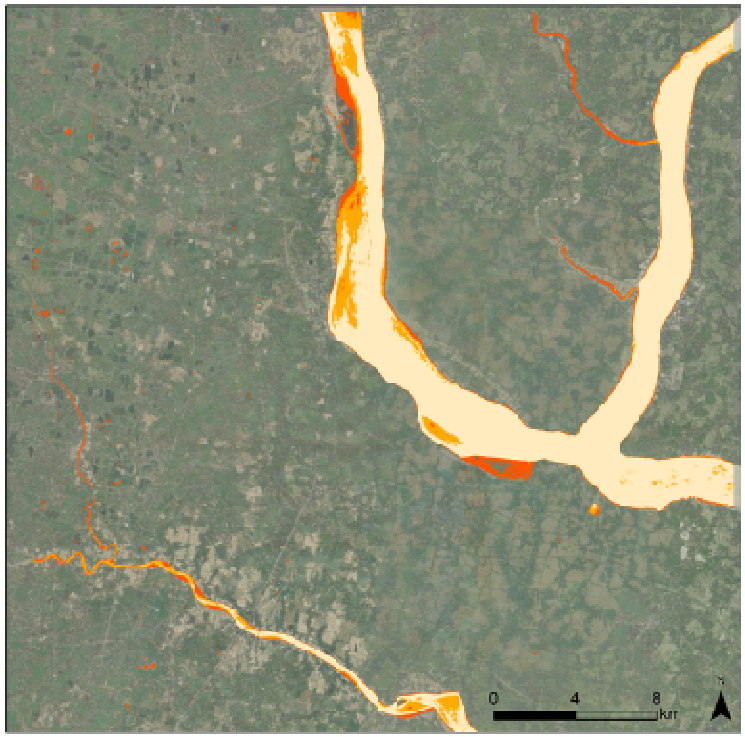
Low TSM (< 50 mg/L)



Frequency of occurrence

- < 50 %
- 50 - 65 %
- > 65 %

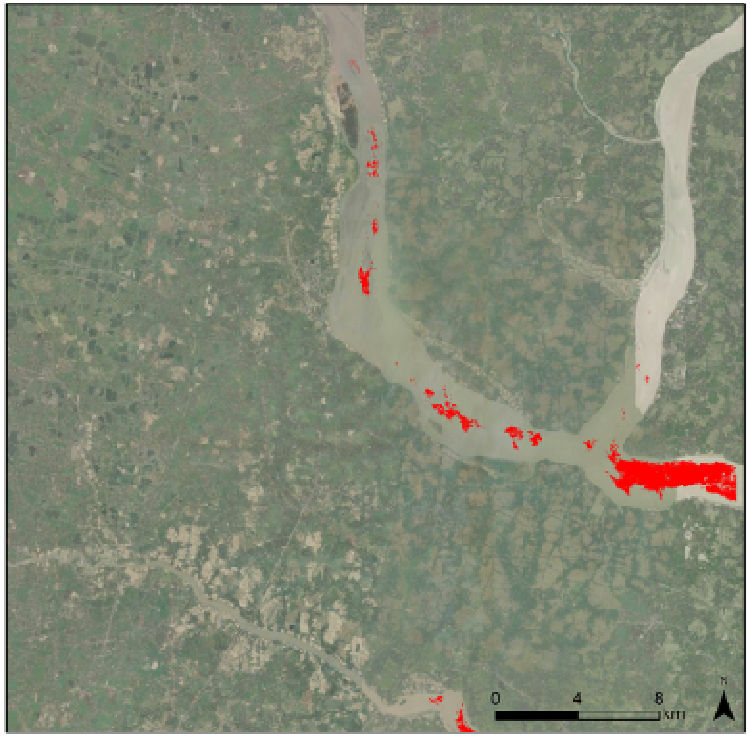
Medium TSM (50 to 100 mg/L)



Frequency of occurrence

- < 30 %
- 30 - 50 %
- > 50 %

High TSM (> 100 mg/L)



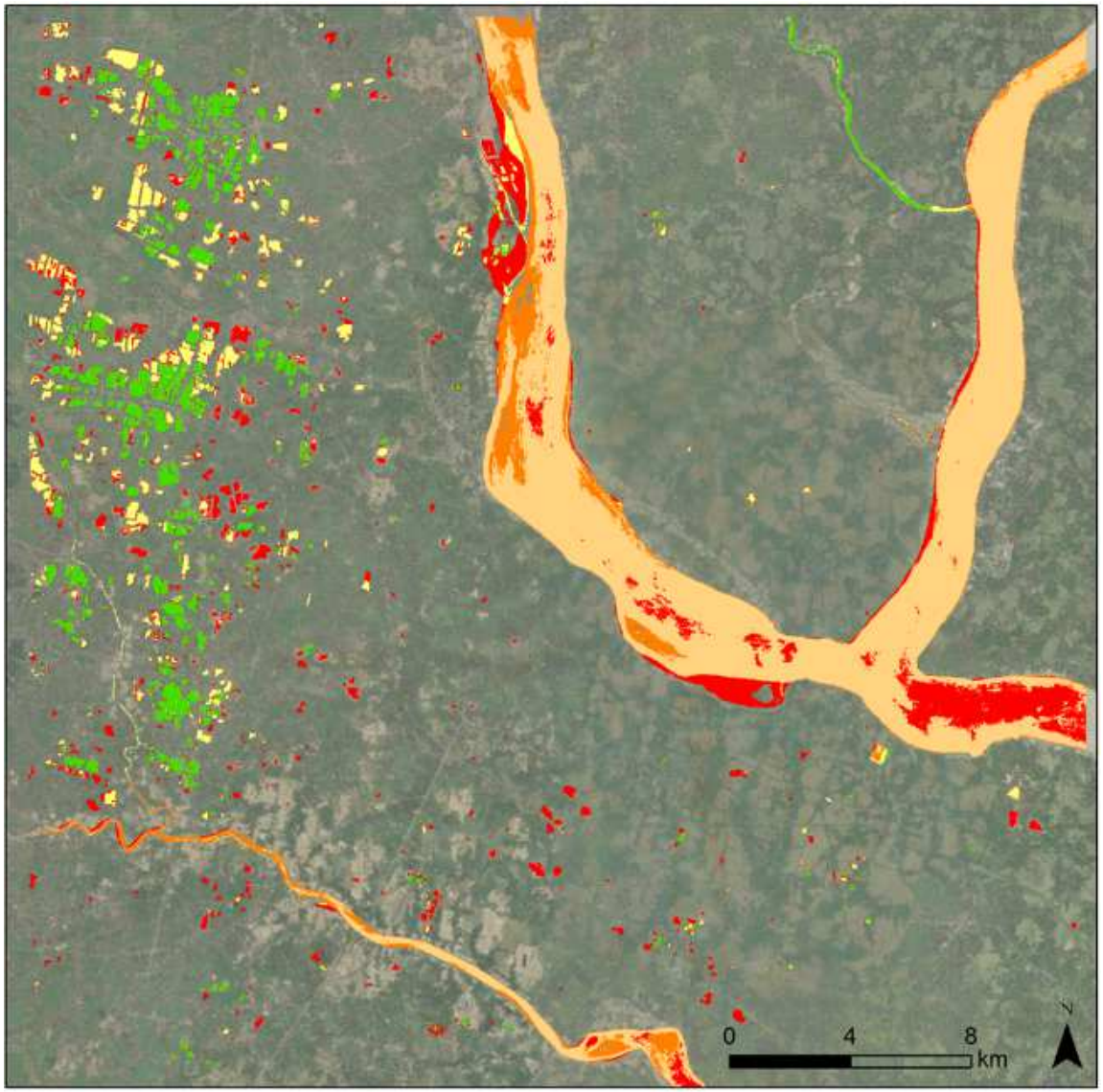
Frequency of occurrence

- < 30 %
- > 30 %

WP4. Results

POTENTIAL OF CLEAR WATER STORAGE

Negligible potential of clear water storage
Low to moderate potential of clear water storage
Seasonal potential of clear water storage
High potential of clear water storage



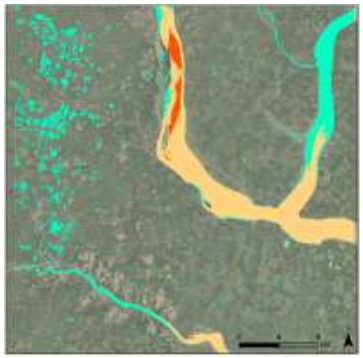
Final results – Combining flooding frequency & TSM conditions

WP4. Results

TO GO FURTHER

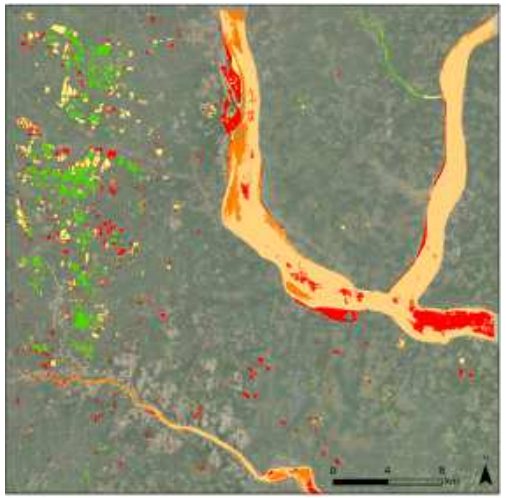
Flooding clusters

TSM conditions



ACHIEVED

Potential of clear water storage v1



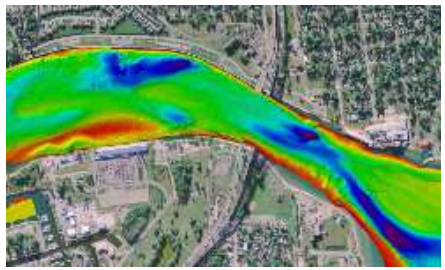
ADDITIONAL PROCESSES:

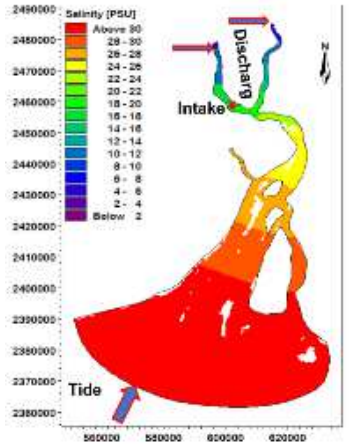
+ More dates/images
+ Distinct wet/dry season

SUPPLEMENTARY DATA:

LU/LC

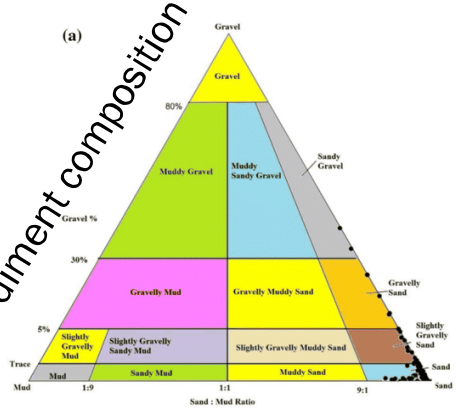
Bathymetry



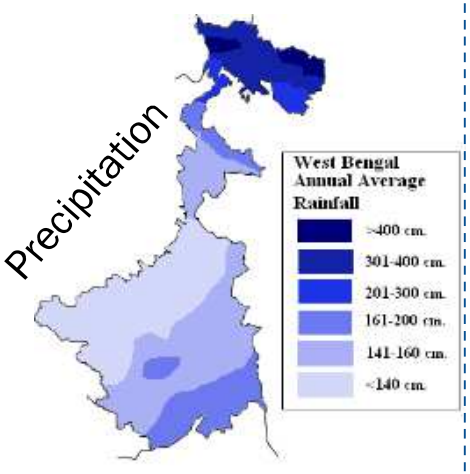


Salinity

Sediment composition



Precipitation



WP3. Potential surface storage site Inventory

- **INPUTS**

  WP1, WP2 and outputs

  DEM, soil,...

- **TASKS.**

  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

- OUTPUTS

  1) A list of potential water-storage sites will be produced
  2) TN1

WP3 Potential surface storage site Inventory

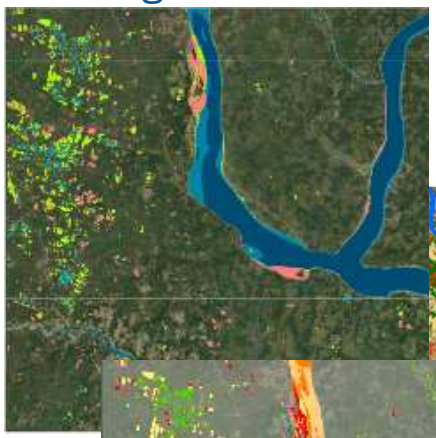
Challenge

- 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.

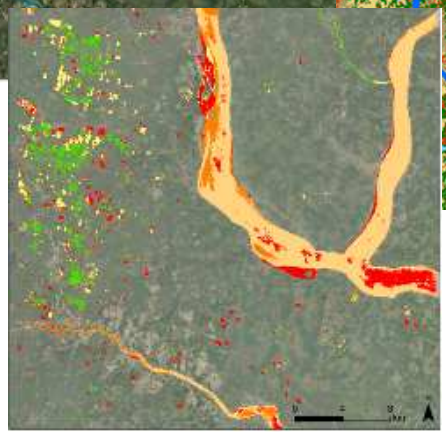
Solution

- **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.

Flooding clusters



LU/LC



Potential of clear water storage

MCDA Criteria:

Flooding Frequency Types

1 < 25% 2 30 to 60 % 3 Semi permanent 4 Permanent	Types 2 & 3 but more far away than 500m that permanent water bodies for avoiding salinization from the estuary influence.

Water Quality Types

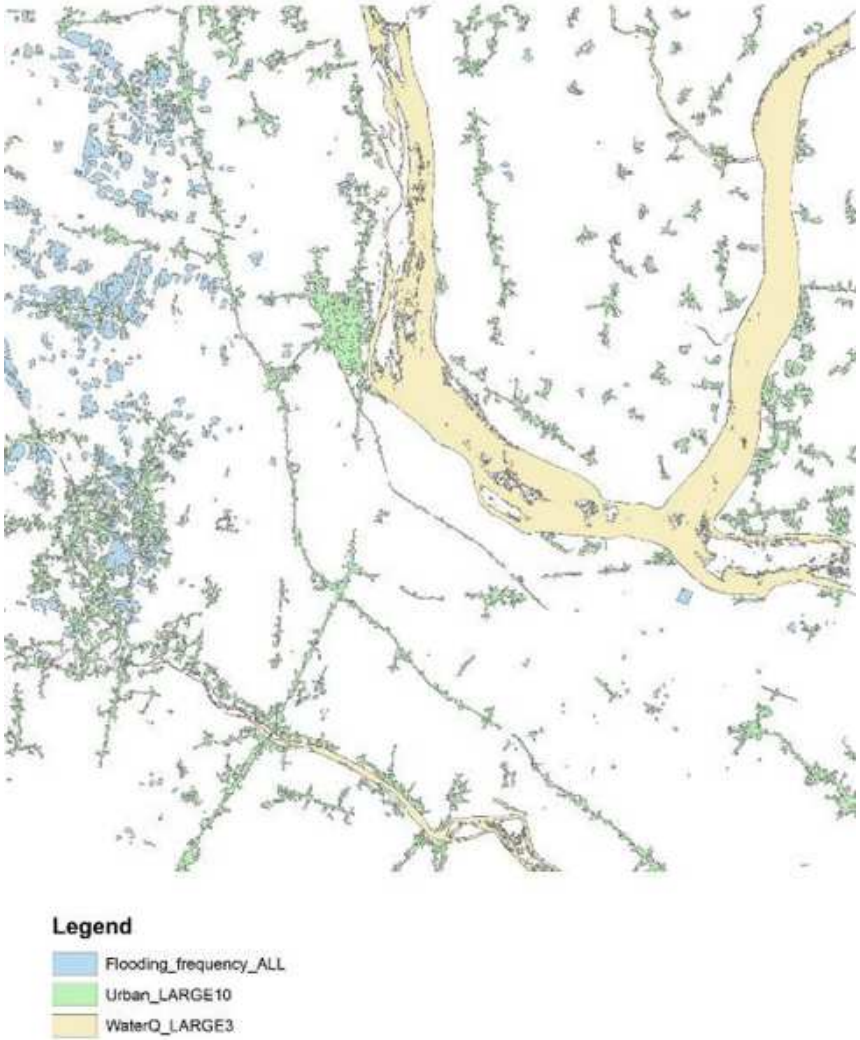
1 High fraction of TSM / embankment 2 Flooded with seasonal high concentration of TSM 3 Flooded with medium concentration of TSM 4 Seasonally flooded and with low concentration of TSM 5 Flooded and low concentration of TSM	Categories 3 to 5 as the lowest concentration values. This was done as a measure not to excessively reduce the potential areas.

LULC

Only « Residential Urban Soil » patches larger than 10ha are kept as main urban areas that can develop the necessary infrastructure for developing the Potential Surface Storage Sites. 1000m Maximum distance between a Potential Surface Storage Site and large urban patches.

WP3 Potential surface storage site Inventory

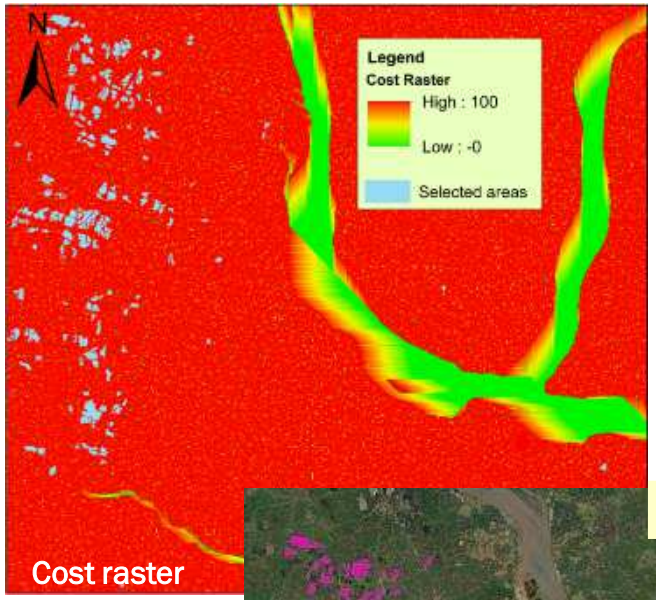
MC layers



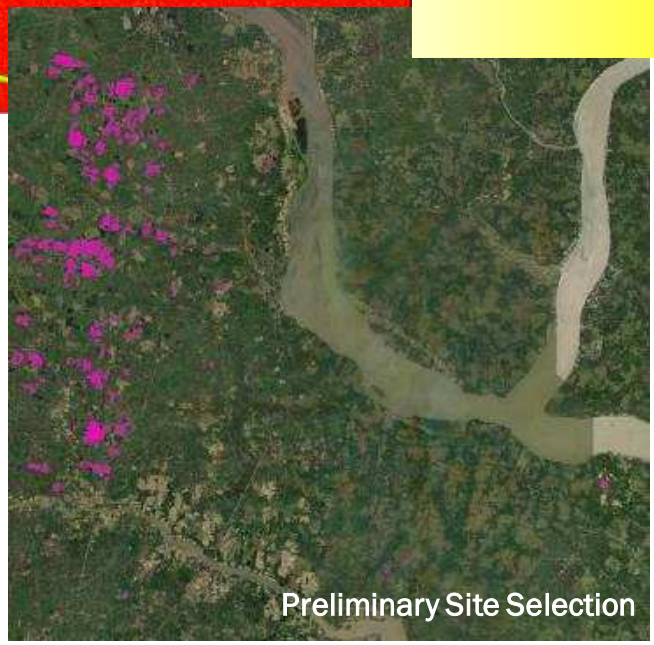
MCD Analysis

Preliminary Site Selection

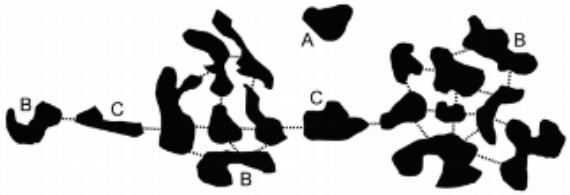
WP3 Potential surface storage site Inventory



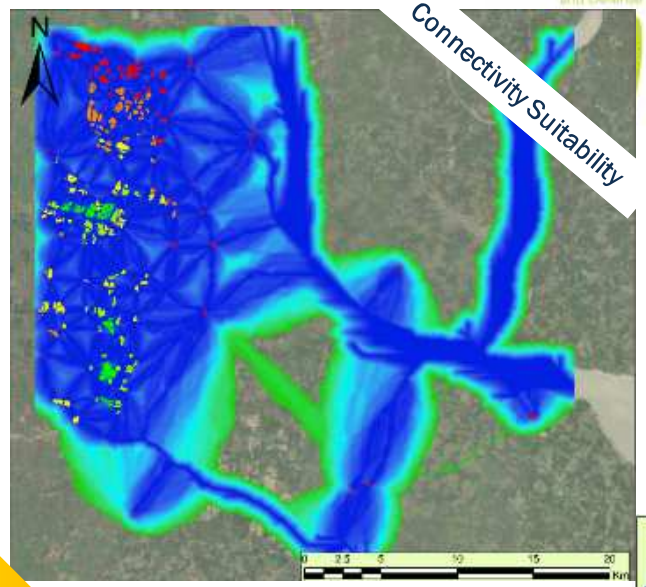
Cost raster

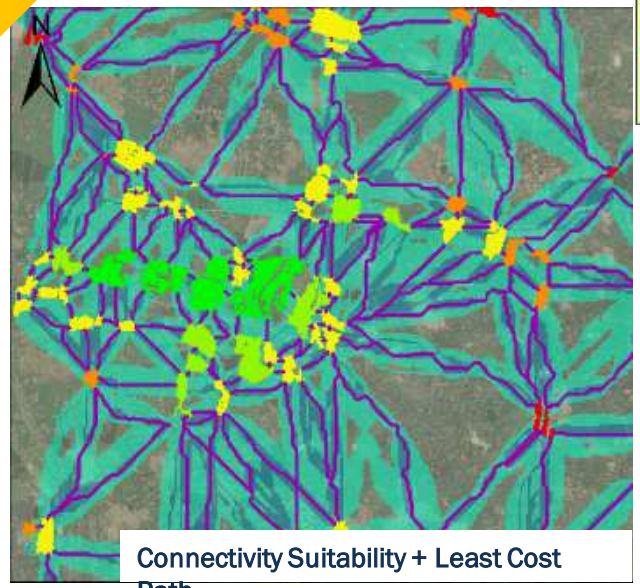


Preliminary Site Selection

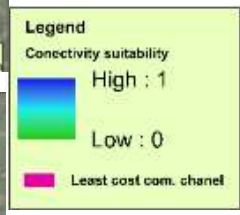


Connectivity Analysis

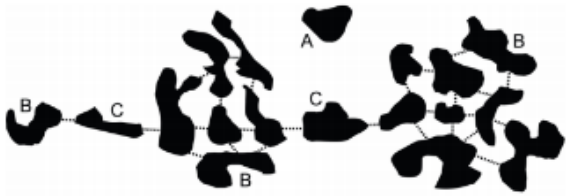




Connectivity Suitability + Least Cost Path

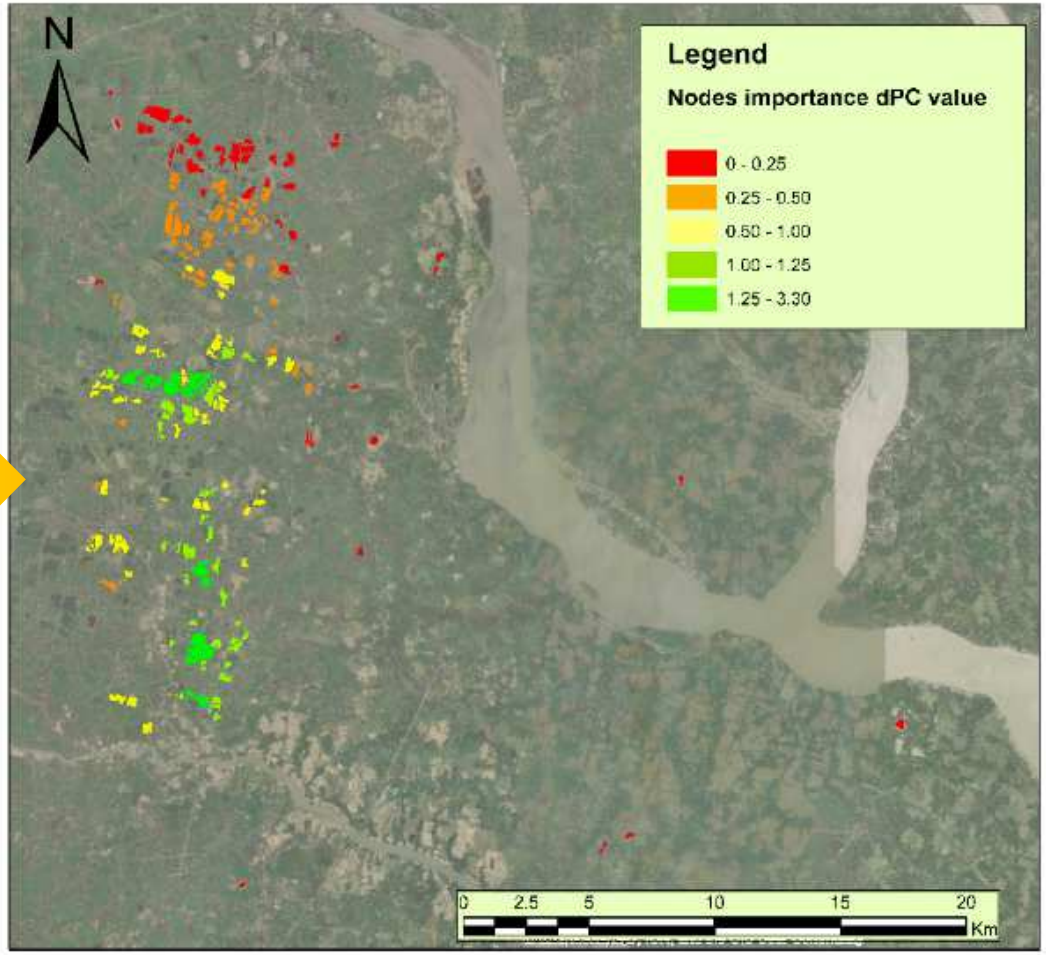


WP3 Potential surface storage site Inventory



Connectivity Analysis

Site Classification after Connectivity Analysis



Only those sites presenting dPC values above 1 are selected to be considered Potential Water Reservoirs.

WP3 Potential surface storage site Inventory

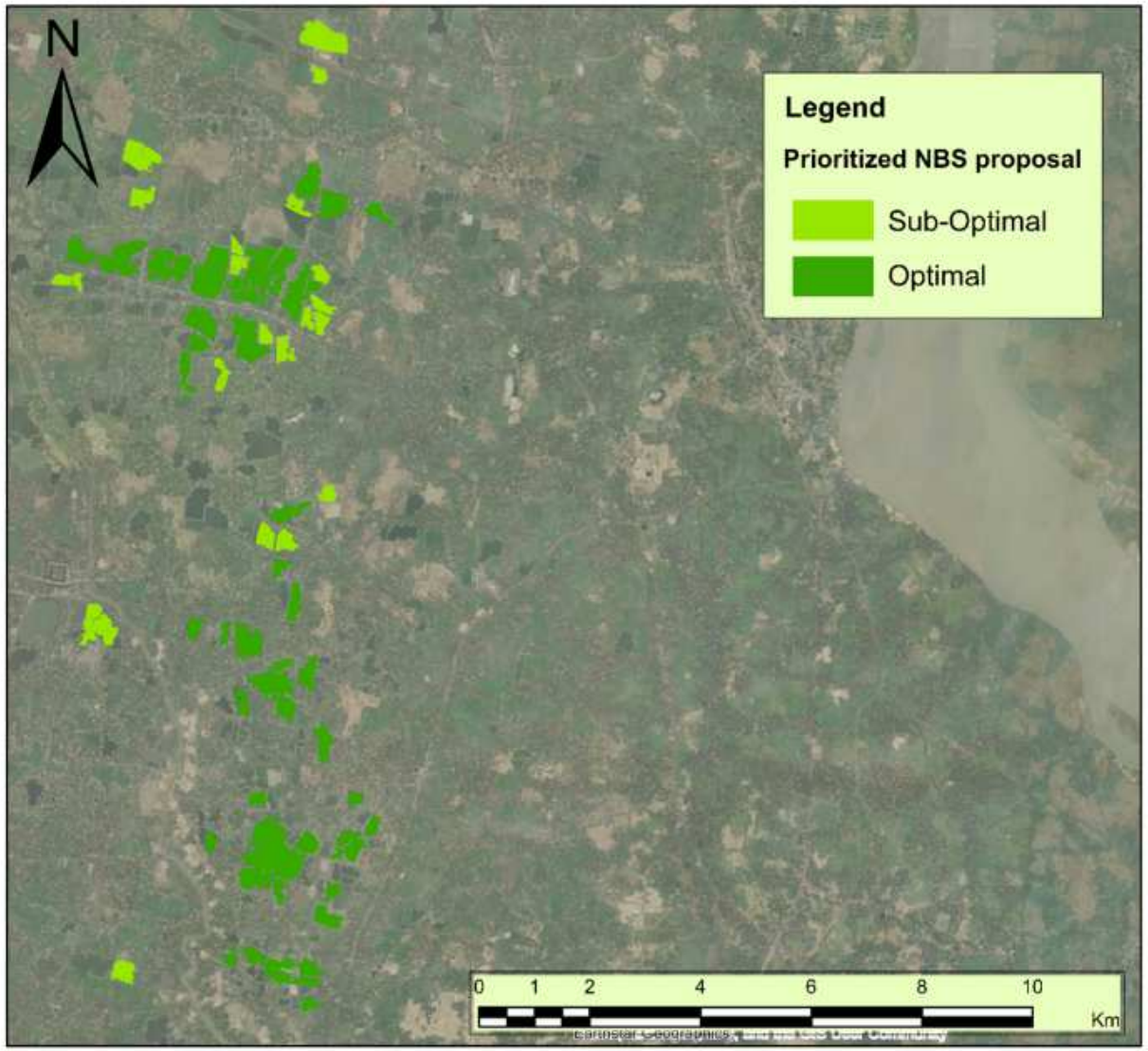
- Results

  - **A set of interconnected potential water reservoirs has been identified.**

TO GO FURTHER

- Further study needs to be done, and **feedback** needs to be provided **from local stakeholders**.
- **MC criteria can be revised** based on stakeholders' inputs.
- A further analysis considering **salinity inputs** and **tidal effects** would increase the number of candidates, as northern affluent channels could be considered.

  - The focus has been put on **potential inland water reservoirs (not river influenced)**, to avoid salinity problems.
  - Among the potential reservoirs, two categories have been identified: ***Optimal* and *Sub-optimal*.**
  - The actual site selection is by far **the most conservative of all options.**



CONCLUSIONS AND FUTURE WORK

04

Conclusions

- The SAR-based method applied in this project to delineate the extent of the waterbodies offers a way to generate large sets of georeferenced, reliable and comparable water layers in a semi-automated mode not affected by cloud cover or a lack of illumination
- However, Narrow channels are poorly identified with SAR resolutions used
- For long term series there is no same quality and availability with older satellites, limiting detailed historical studies
- Limitation of the number of images used and availability along he season may bias some results, e.g. of flooding dynamics or siltation
- S-2 and Pleiades are useful for LU/LC, The classification with training datasets has proven very successful. VHR improves significantly the level of details, but is costly.
- For the selection of the storage sites a method based on weighted multi criteria factors has been selected and analyzed, applied to interconnected water masses
- We have mainly focused on potential inland water reservoirs, in order to avoid salinity problems. This is by far the most conservative of all options.
- Specific events of a non-stationary nature are decisive in the dimensioning and decision-making when identifying the freshwater supply corridors, like the Cylone Yass which effect was assessed

.

Recommendations and Future Work

- Increasing the dataset (e.g. exploit the high revisit capabilities and preprogramed operation of Sentinel satellites). The more complete the time series, the higher the accuracy.
- Also fine definition with commercial VHR SAR images can be very useful (e.g. narrow channels)
- The study of inter-annual anomalies and other climate drivers should be more elaborated
- LU/LC “legend” can be adapted o more detailed, according to particular needs, or extended to wider areas or monitor pressures (agriculture/ aquaculture, industrialisation, coastal erosion…)
- All analyses could be extended up and downstream or to the whole watershed / hydrographic region, which can yield new conclusions
- Turbidity studies can be extended , e.g. to determine harmful algal bloom hot spots
- Feed back needs to be provided by the stakeholders to validate de potential site selection obtained with the analysis methods showed in this study
- Supplementary information (e.g. LU/LC, salinity, sediment composition, soil maps, demographic maps, aquifers , bathymetry…) can feed the model for more accurate and robust statistics
- Further analysis considering salinity inputs and tidal effects would increase the number of candidates, closer to the rivers, e.g. the northern affluent channels could be considered.

¿Questions?

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