2024 FECM / NETL Carbon Management Research Project Review Meeting

# A Data-driven Multiscale Phytotechnology Framework for Identification and Remediation of Leached-Metals-Contaminated Soil Near Coal Ash Impoundments

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# Our team

- **Bahareh Nojabaei (PI)**

Mining and Minerals Engineering, data analyses, fluid transport in porous media, underground multiphase multicomponent flow simulation

- **Hosein Foroutan (Co-PI)**

Civil and Environmental Engineering, Atmospheric science and remote sensing

- **Hoda Eldardiry (Co-PI)**

Computer Science, Artificial Intelligence and Machine Learning

- **Ryan Stewart (Co-PI)**

School of Plant and Environmental Sciences, Quantifying interactions between water, soil, and plant communities

- **Lee Daniels (senior personnel)**

School of Plant and Environmental Sciences , Rehabilitation of drastically disturbed soils

- **Mining Engineering Graduate Student: Salman Karim**
- **Computer Science Graduate Students**

# Background: Coal Combustion Product Impoundments

- Many older impoundments are not lined.

**Asheville Power Station**
Arden, NC 28704
Owned and Operated by Duke Energy Corporation

**Hazard Rating: High**

**Contamination**
BORON, CHLORIDE, CHROMIUM, IRON, MANGANESE, SELENIUM, TOTAL DISSOLVED SOLIDS, NITRATE, SULFATE AND THALLIUM, ARSENIC, LEAD, AND PH.

| Unlined Impoundment | |
|---|---|
| Impoundment Name | 1964 Ash Pond |
| Hazard Rating | High |
| Capacity | 72,664,773 gallons |
| Ash | 2,535,600 tons |
| Wastewater | 9,776,000 gallons |
| Dam Height | 100 |
| Active | Yes |

| Unlined Impoundment | |
|---|---|
| Impoundment Name | 1982 Ash Pond |
| Hazard Rating | High |
| Capacity | 290,007,390 gallons |
| Ash | 686,000 tons |
| Dam Height | 95 |
| Active | Yes |

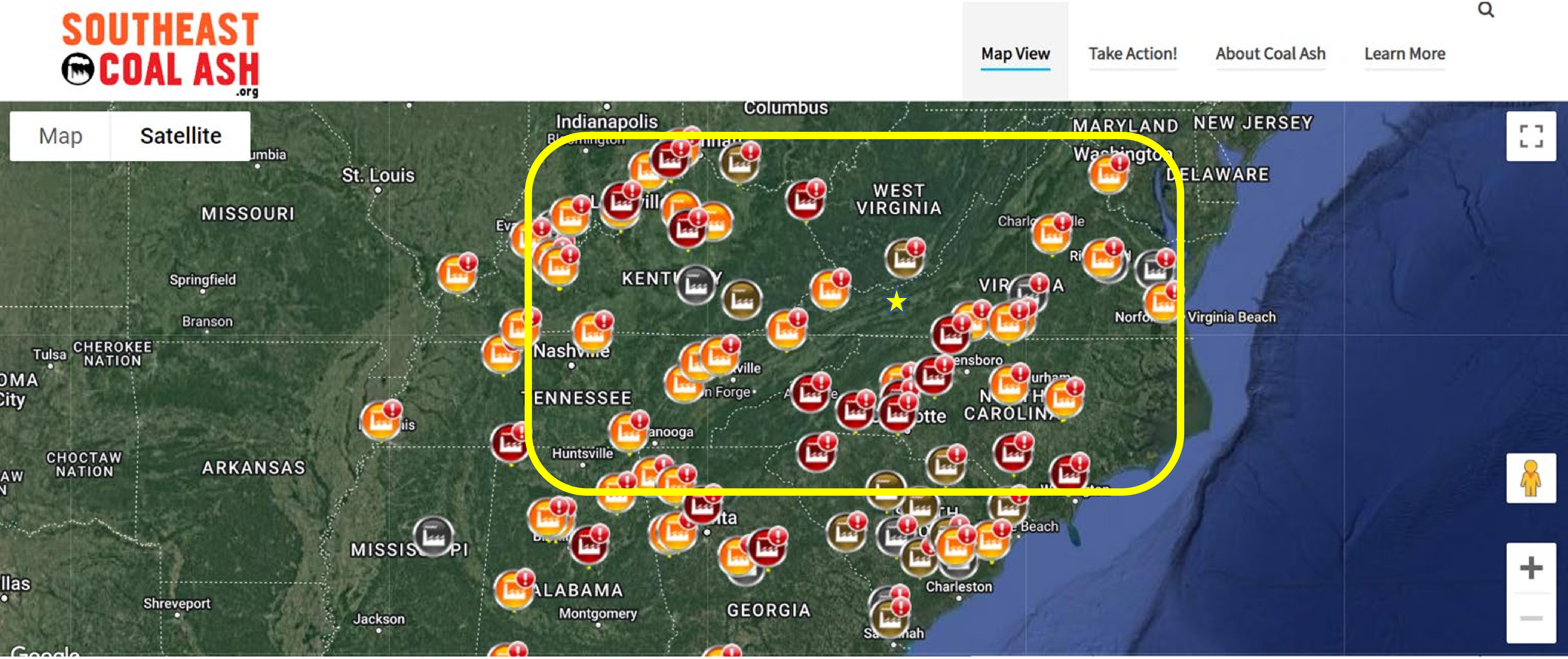
| Unlined Impoundment | |
|---|---|
| Impoundment Name | Stilling Pond |
| Hazard Rating | Not Rated |
| Active | Yes |


http://www.southeastcoalash.org/plant-page/?id=44

## Phytotechnology Development for Identification and/or Remediation of Sites Exhibiting Soil Contamination via Groundwater Transport of Metals from Coal Combustion Product Impoundments

- Identification of sites that need more aggressive monitoring and remediation
- Low-cost technology is needed to screen sites
- Facilitate a treatment development and deployment
- No removal of the affected soils or groundwater

# Coal combustion product impoundments in the region




http://www.southeastcoalash.org/

# Primary goals

- Using **phytotechnology** to identify leached-metal contamination
- **Not being limited to a few sites** (site identification should be the outcome, screening is important)
- **Not being limited to a few number of metal-leached contaminants**
- Facilitate (future) **development of phytoremediation**

# Remote sensing: Satellite imagery

**Benefits:**

- Low-cost technology
- Searching for visual ques
- Extended coverage over multiple states
- No site access needed.

**Challenges:**

- What kind of visual ques we are searching for?
- Low resolution
- What type of metal-leached contamination we are looking for?

# Image processing: searching for abnormalities

We don't know what the exact visual ques are!

Examples of contamination bio-indicators:

- Cadmium-induced stress for rice crops, indicator: color change (Liu et al., 2018)
- Cement dust pollution, indicator: effect on plant species density and diversity (Bayouli et al., 2021)
- Mercury in fly ash, indicator: presence in soil and vegetation samples (Huang et al., 2017)

→ **Search for both temporal and spatial abnormalities**

# Factoring out other influencers

**A Data-driven Smart Search!**

- Climate and environmental conditions
- Soil type and properties, pH, moisture
- Structural conditions: underground geological features

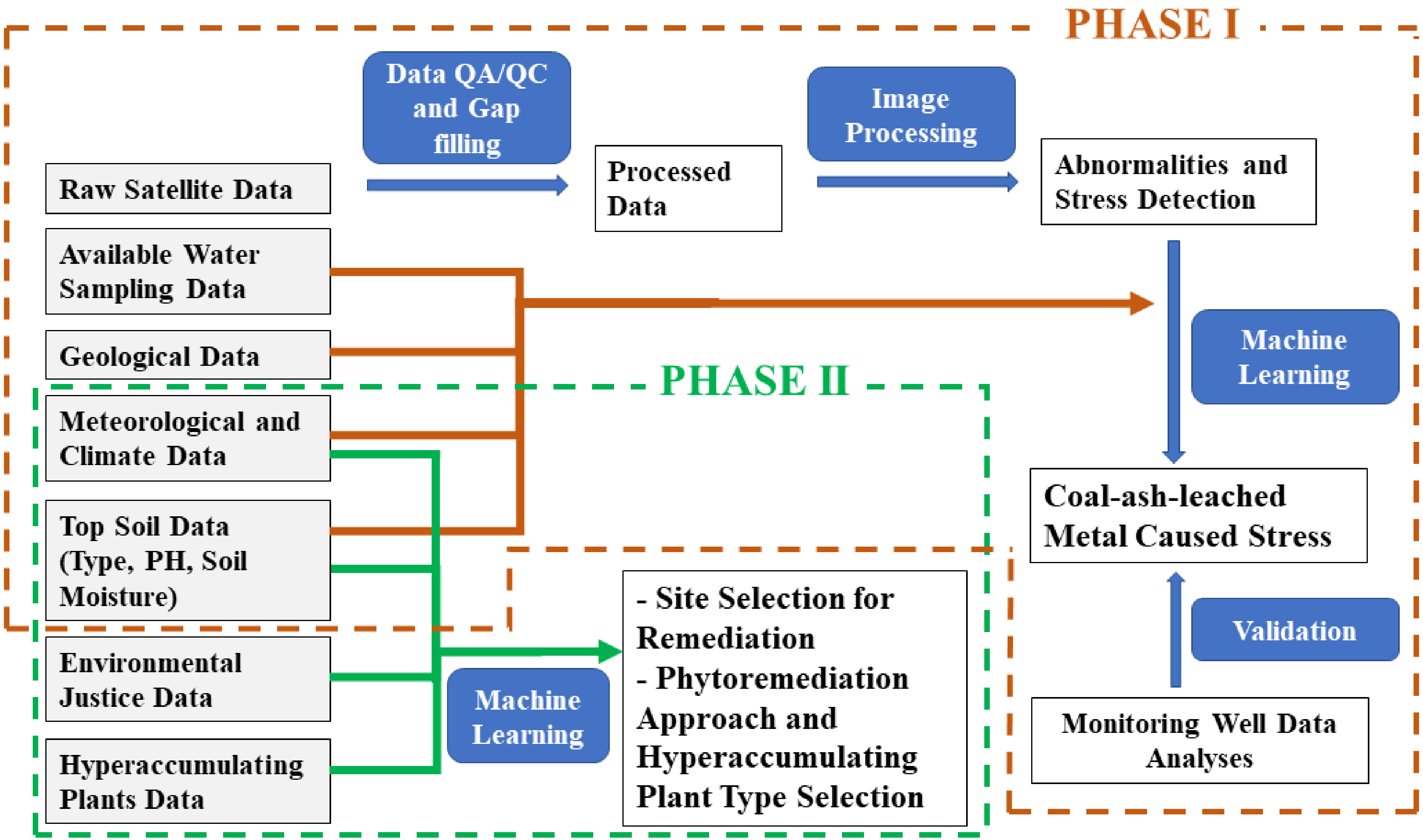
# How to validate our model?

- Underground contamination data from monitoring wells
- Geological modeling

# Phytoremediation

- Database of hyperaccumulating plants is available.
- How to select a site as a phytoremediation candidate? How can we rank them?
- What are the factors we should consider in order to select plant species?

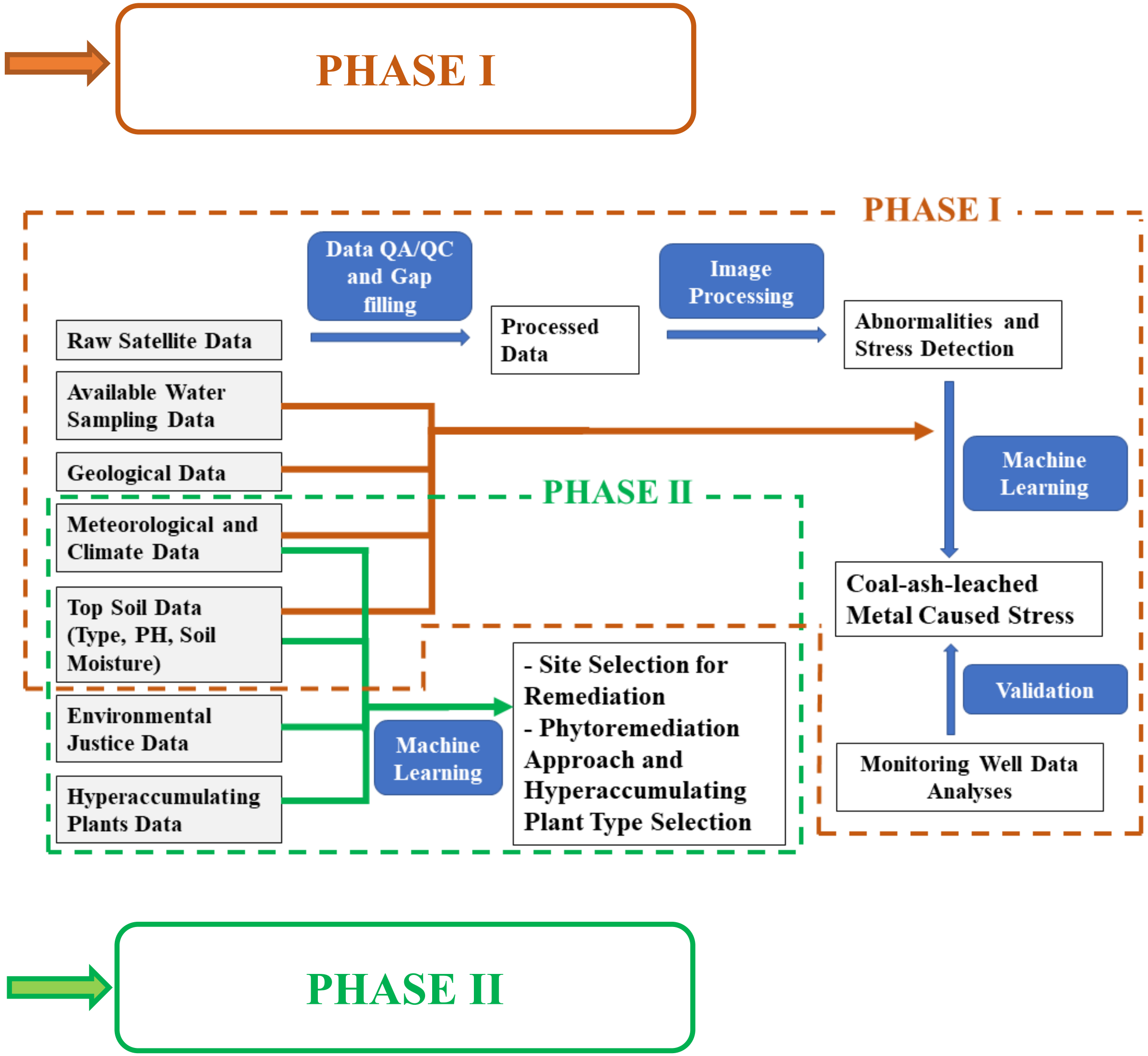
# Multiscale data-driven phytoindication and phytoremediation framework



# Main project objectives

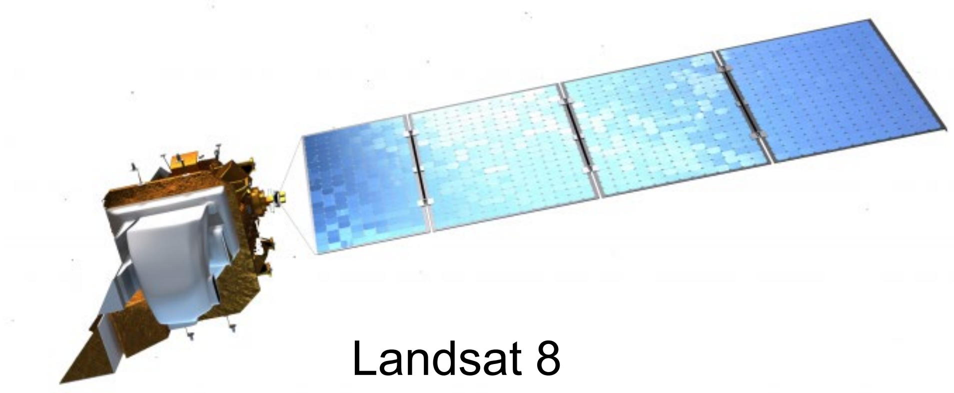
- Process and analyze multi-year satellite retrievals to find vegetation-related abnormalities.
- Develop a model correlating the leached-metal contamination and the above-mentioned abnormalities.
- Validate our data-driven model for a limited number of sites.

- Propose a phytoremediation approach based on the specifics of hyperaccumulator plants, sites, and environmental and geological conditions.
- Select and rank site candidates for phytoremediation based on environmental and meteorological conditions, soil type and condition, severity of contamination, and environmental justice metrics.

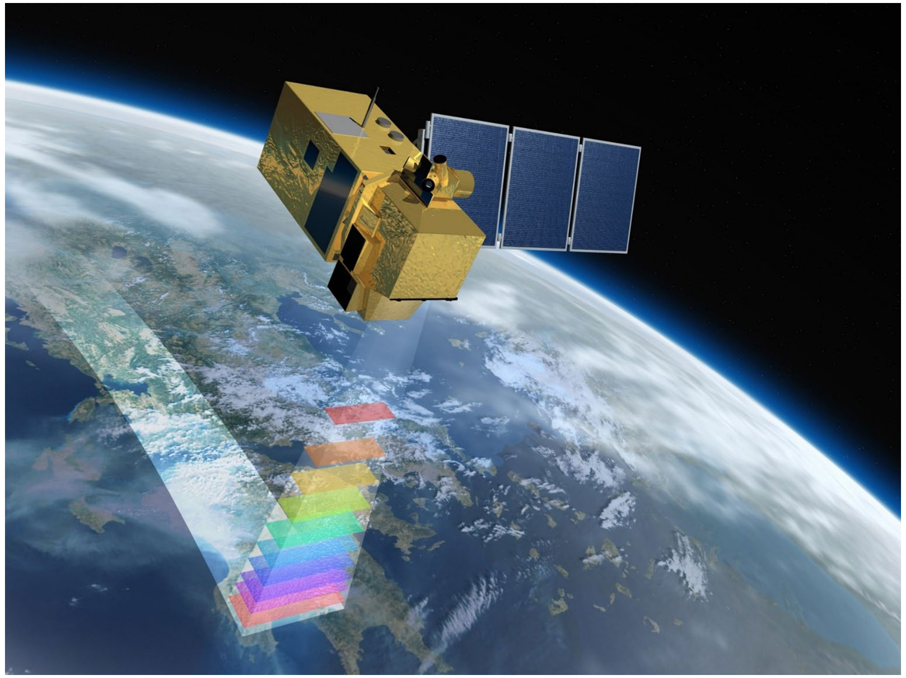


# Multiplatform satellite observations

- **Landsat 8 OLI (Operational Land Imager)**
  - Launched in 2013
  - Resolution : 30 m
  - Revisit cycle : 16 days
  - Number of bands : 9
- **Landsat 7 ETM+ (Enhanced Thematic Mapper Plus)**
  - Launched in 1999
  - Resolution : 30 m
  - Revisit cycle : 16 days
  - Number of bands: 8
- **Sentinel-2**
  - Launched in 2015
  - Resolution : 10-20 m
  - Revisit cycle: 10 days
  - Number of bands: 13



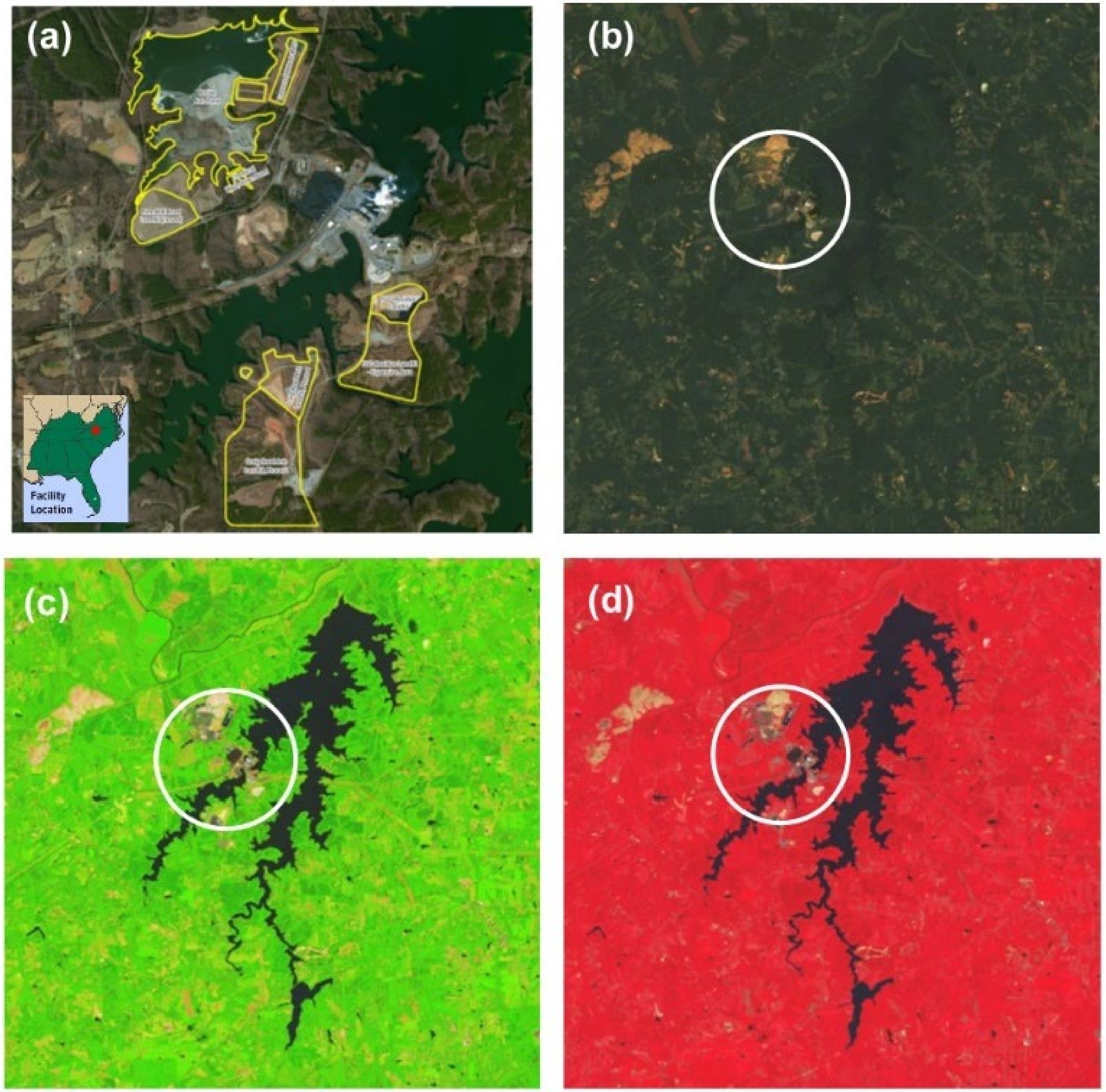
Landsat 8



Sentinel-2

# Multiband Capability of Landsat 8 OLI

Belews Creek Stream Station in Walnut Cove, NC that has a "high hazard" rating




Satellite view with natural color

Satellite view with false color (combination of bands 4, 5, and 6)

Satellite view with color infrared (combination of bands 3, 4, and 5)

# Satellite data post-processing

**Raw Satellite Data**

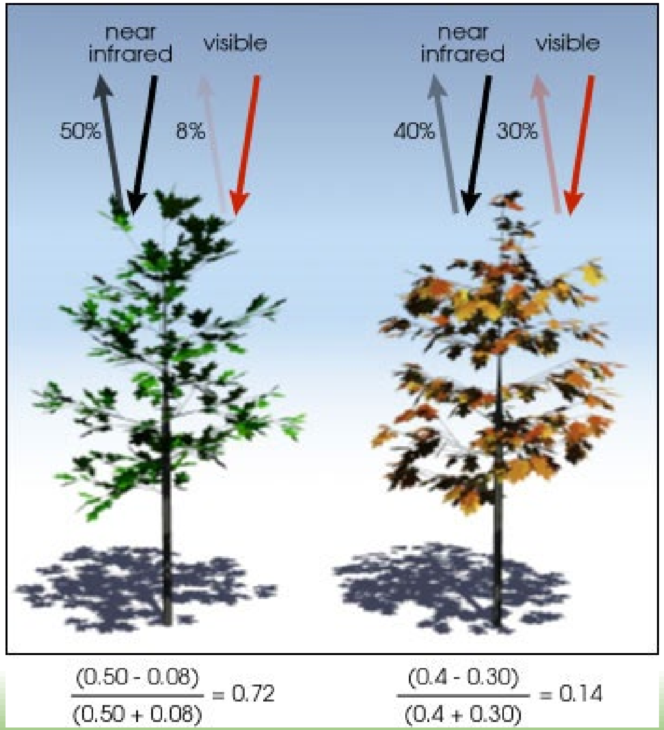
- Landsat 7 & 8
- Sentinel-2

**Data Post-Processing**

- QA/QC
- Filter out clouds
- Gap-fill
- Atmospheric correction

**Vegetation Indices**

- NDVI
- EVI
- NDWI1 & NDWI2
- CIRE
- REP
- MTCI
- NDRE1 & NDRE2




NDVI: Normalized Difference Vegetation Index
REP: Red Edge Position

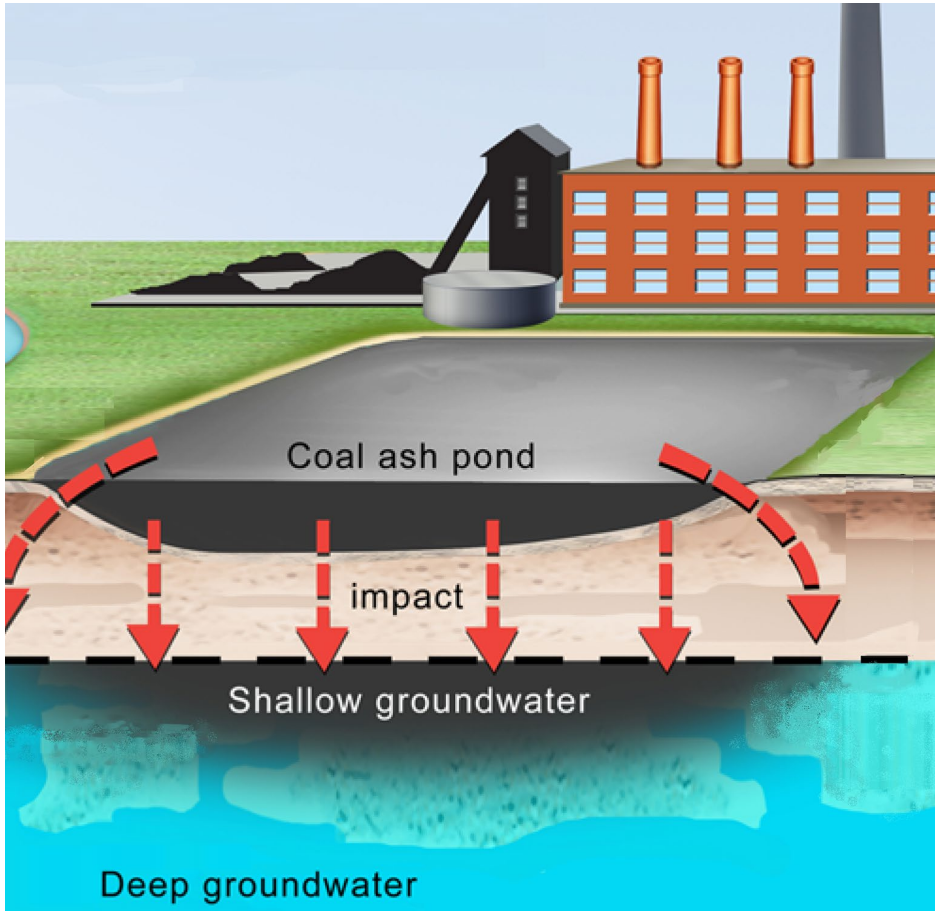
"NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation (left) absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation (right) reflects more visible light and less near-infrared light."

https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_2.php

# Contamination transport and leachability of contaminants

- Potential contaminants:

Cadmium, Lithium, Molybdenum, Boron, Arsenic, Manganese, Aluminum, Chromium, Selenium, and Mercury are present in the coal combustion products.




The degree of leachability and diffusion into the ground water system is different!

- Metal type and concentration,
- The aqueous phase pH,
- Soil and underground formation porosity and permeability
- Presence of fractures, faults, or any pathway from the impoundment to the underground water system

# Underground hydrological modeling for the sites with abnormalities

**Input data:**

- Contamination report from monitoring wells
- Geological maps of the flagged impoundments
- Available soil type and properties
- Local hydrological data

**Approach:**

Mass conservation equation will be solved along with, Darcy-type flow, diffusion and solubility of metal contaminants.

**Goal:**

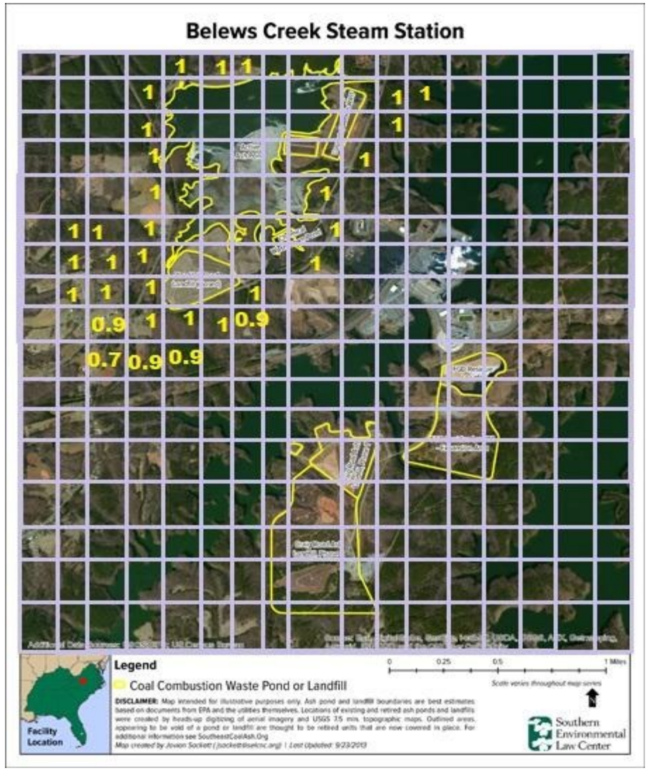
Map a probability function to the studied area

**One additional assessment tool to identify:**

1) whether the observed abnormality is because of leached metal contamination,

2) the type of leached metal(s) potentially contaminating the soil.

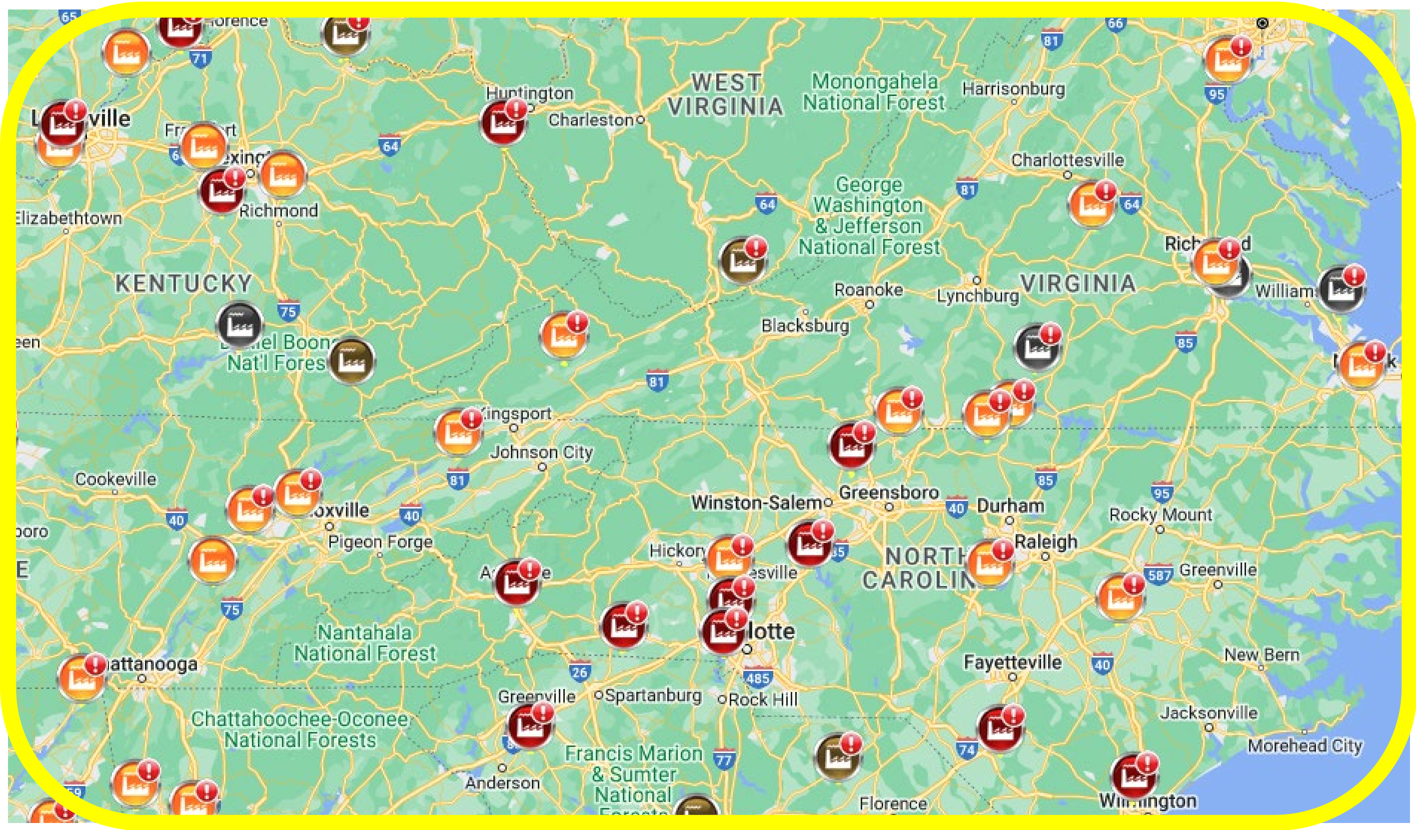
The probability function is a 2D map and provides values from zero to one for each pixel/location, zero being the lowest and one being the highest probability of any specific metal leached from the impoundment to that location's soil.




Selenium release from this plant caused local extinction of 80% all fish species in Belews Lake.

# Overview of study area

- 43 coal powerplants spanning in 7 states and owned & operated by 11 different companies.
- Built between 1940 to 1992 and 70% of powerplants are active.
- Generate 36663 MW in total and operate with 133 boilers.
- 31 different pollutants have been found (no contamination data is available for 8 plants).
- All powerplants have one or more associated contamination above safe threshold.
- Total number of known impoundments are 216.

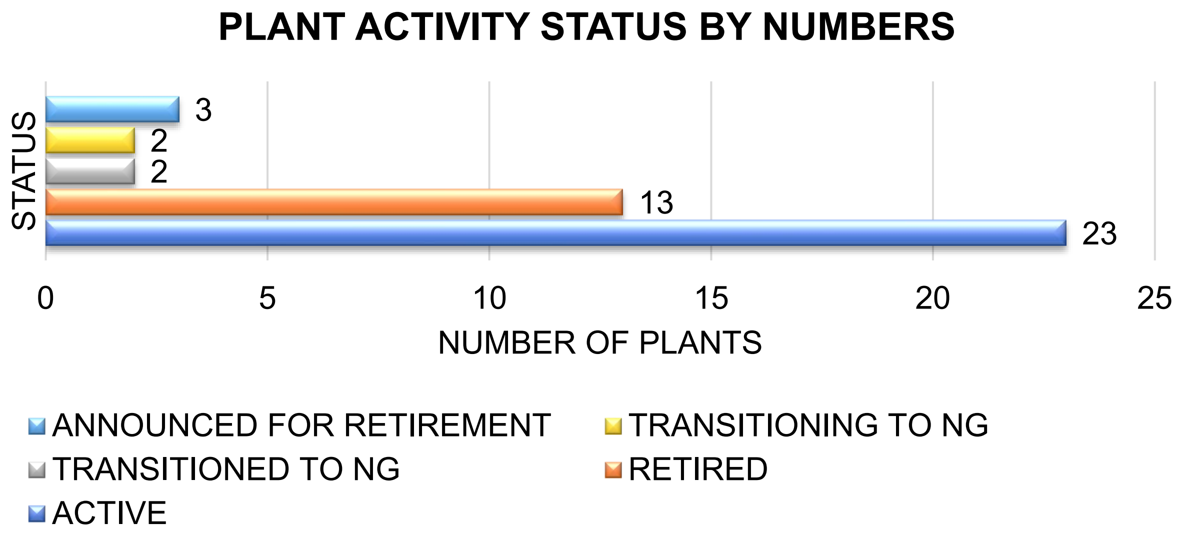


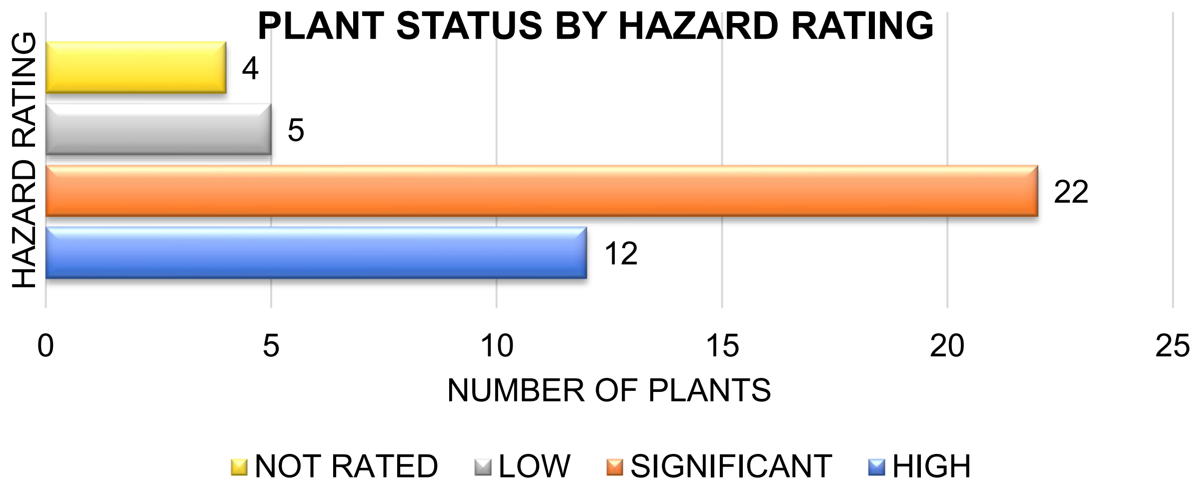

**ASHTRACKER.ORG**

**SOUTHEASTCOALASH.ORG**

**Available data**

# Some Statistics




| Constituents | Threshold | No of Plants above threshold |
|---|---|---|
| Arsenic | 0.01 mg/L | 27 |
| Cobalt | 0.006 mg/L | 25 |
| Boron | 3.0 mg/L | 23 |
| Molybdenum | 0.04 mg/L | 23 |
| Sulfate | 500.0 mg/L | 23 |
| Manganese | 0.3 mg/L | 22 |
| Lithium | 0.04 mg/L | 19 |
| Lead | 0.015 mg/L | 16 |
| Radium | 0.005 mg/L | 15 |
| Beryllium | 0.004 mg/L | 11 |
| Cadmium | 0.005 mg/L | 11 |
| Selenium | 0.05 mg/L | 9 |
| Thallium | 0.002 mg/L | 9 |
| Chromium | 0.1 mg/L | 7 |
| Antimony | 0.006 mg/L | 6 |
| Barium | 2.0 mg/L | 5 |
| Fluoride | 4.0 mg/L | 3 |
| Nickel | 0.1 mg/L | 3 |
| Strontium | 4.0 mg/L | 3 |
| Mercury | 0.002 mg/L | 2 |
| Ammonia | 30.0 mg/L | 1 |
| Nitrate | 10.0 mg/L | 1 |

# Google Earth Engine Workflow

- ➢ Open google earth engine code editor.
- ➢ Select region of interest and set map center.
- ➢ Load satellite-2 image collection from google cloud.
- ➢ Filter image collection with bands, datetime, cloud cover and region of interest.
- ➢ Add visualization parameters to visualize better.
- ➢ Add image collection to map.
- ➢ Define functions to calculate vegetation indices and biophysical parameters.
- ➢ Add calculated VI/BPI to image collection and add to map.
- ➢ Chart VI/BPI.

A simple code snippet is added here.

```
New Script *                                  Get Link  Save  Run  Reset  Apps
Imports (1 entry)
  var roi: Polygon, 4 vertices
//Select Region of Interest nad add to map
Map.addLayer(roi, {},'ROI', false);
Map.setCenter(-80.0641, 36.2922, 14);
//Load Image collection
var imColl = ee.ImageCollection('COPERNICUS/S2_SR_HARMONIZED')
                  .filterBounds(roi)
                  .filterDate('2017-03-28', '2023-03-28')
                  .select('B1','B2','B3','B4','B5','B6','B7','B8','B8A','B9','B11','B12', 'QA60')
                  .filter(ee.Filter.lt('CLOUDY_PIXEL_PERCENTAGE',30));
// add image collection to map
var visParam ={ bands: ["B4","B3","B2"], gamma: 1, max: 2994.6, min: 198.25714285714287, opacity: 1};
Map.addLayer(imColl.median().clip(roi), visParam,' True Color Image', true);
// Calculate EVI and the calculatd EVI band to image collection
var addEVI = function(image) {
  var calEVI = image.expression(
      '(2.5 * float((B8-B4)/( B8 + (6 * B4)-(7.5 * B2) + 1)))',
      {
        'B8': image.select('B8'),
        'B4': image.select('B4'),
        'B2': image.select('B2'),
      }).rename('EVI');
  return image.addBands(calEVI);
};
var evi = imColl.map(addEVI).select('EVI');
// Chart EVI
var chart_evi = ui.Chart.image.series({
  imageCollection: evi,
  region: roi,
  reducer: ee.Reducer.mean(),
  scale: 30
})
.setOptions({
          interpolateNulls: true,
          lineWidth: 1,
          pointSize: 3,
          title: 'Mean EVI over Time',
          vAxis: {title: 'EVI',titleTextStyle: {italic: false, bold: true}},
          hAxis: {title: 'Date', format: 'YYYY-MMM', gridlines: {count: 20},titleTextStyle: {italic: false, bold: true}}

  });
Map.addLayer(evi.median(), {}, 'EVI', false);
```

Check the app developed for all the calculation:

[Vegetation Indices Calculator]

# Vegetation indices calculation

$$NDVI = \frac{\text{NIR} - \text{Red}}{\text{NIR} - \text{Red}}$$

$$NDWI1 = \frac{\text{NIR} - \text{SWIR1}}{\text{NIR} + \text{SWIR1}}$$

$$NDWI2 = \frac{\text{NIR} - \text{SWIR2}}{\text{NIR} + \text{SWIR2}}$$

$$NDREI1 = \frac{\text{NIR} - \text{Red Edge 1}}{\text{NIR} + \text{Red Edge 1}}$$

$$NDRE2 = \frac{\text{NIR} - \text{Red Edge 2}}{\text{NIR} + \text{Red Edge 2}}$$

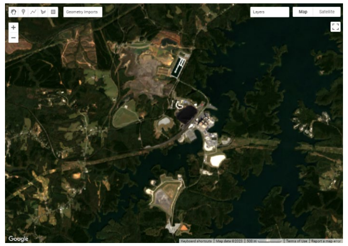
$$EVI = 2.5 * \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + 6 * \text{Red} - 7.5 * \text{Blue} + 1)}$$

$$SAVI = 1.5 * \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red} + 0.5)}$$

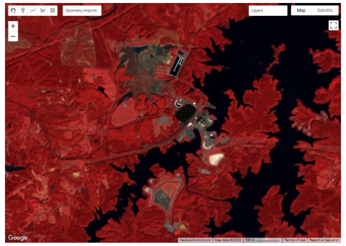
$$REP = 705 + 35 * \frac{\left(\frac{\text{Red} + \text{Red Edge 3}}{2 - \text{Red Edge 1}}\right)}{(\text{Red Edge 2} - \text{Red Edge 1})}$$

$$MTCI = \frac{\text{Red Edge 2} - \text{Red Edge 1}}{\text{Red Edge 1} - \text{Red}}$$

$$\text{CI}_{\text{RE}} = \frac{\text{Red Edge 3}}{\text{Red Edge 1}} - 1$$

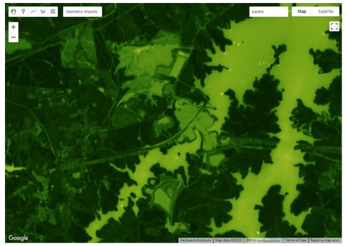


TRUE COLOR

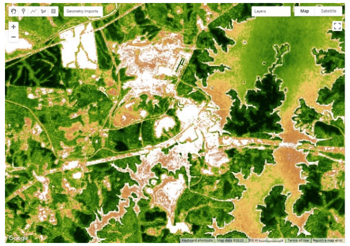


FALSE COLOR

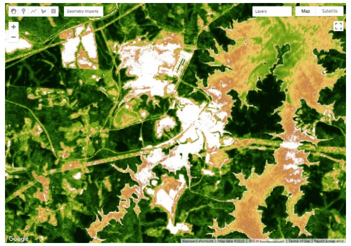
EVI



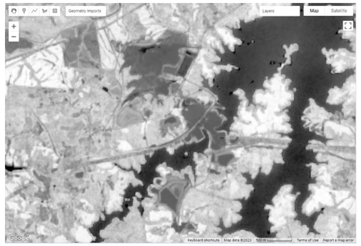
NDVI



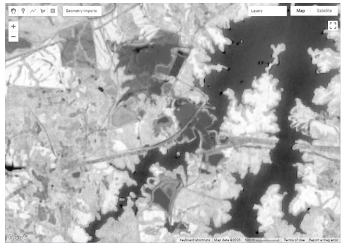
NDWI1



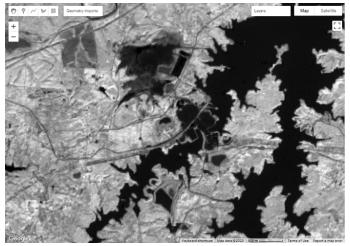
NDWI2



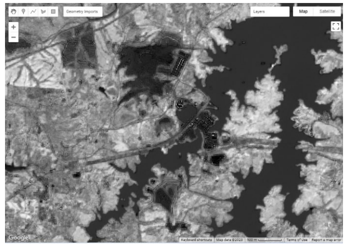
NDRE1



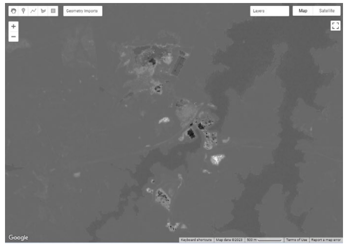
NDRE2



CERI



MTCI



REP

SAVI

# Biophysical parameter index

- Quantitative measurements that relate to the physical properties of plants.
- Used in remote sensing to estimate parameters related to vegetation status.

| | |
|---|---|
| $LAI = (NIR - 1.35 * Red) * 11.728$ | Leaf Area Index |
| $LCI = \frac{NIR - Red\ Edge\ 1}{NIR - Red}$ | Leaf Chlorophyll Index |
| $LCC = \left(\frac{NIR - Red\ Edge\ 1}{NIR - Red} * 0.1134\right) + 0.14$ | Leaf Chlorophyll Content |
| $CCC = \left(-1.3231 + 0.8364 * \left(\frac{NIR}{Green} - 1\right)\right)$ | Canopy Chlorophyll Content |
| $CVI = \frac{\left(\frac{NIR}{Green}\right)}{Green/Red}$ | Chlorophyll Vegetation Index |

# Sensitivity analysis

- Which vegetation indices are suitable and sensitive to high stress level for our study area?
- R-squared between VI and BPI have been calculated.

- for each calculation, linear regression, exponential regression, logarithmic regression, and polynomial regression have been used to establish correlations between the spectral indices.

# Coefficients of spatiotemporal variation (CSTV)

A standard deviation from mean calculated for the satellite images with space and time **factoring out all other influencers**

A higher CSTV value referred to abrupt stress, whereas a lower CSTV value indicated no stress or stable stress with a uniform changing trend during growth.

$$CSTV = \frac{|Qi - \bar{Q}|}{\delta}$$

$$Q_i = VI_{m+1,i} - VI_{m,i}$$

$$\bar{Q} = \sum_{i}^{j} \frac{Q_i}{j}$$

$$\delta = \sqrt{\sum_{i}^{j} (Q_i - \bar{Q})^2 / j}$$

$Qi$: the VI variations over time,

$\bar{Q}$ :area-averaged mean value,

$\delta$ :standard deviation of Q.

# Vegetation stress detection workflow

(i) Collecting multispectral satellite imagery data of sentinel-2 from Google cloud, prepossessing, and filtering the data with the required bands reducing cloud cover and atmospheric noise and other interference with area of interest for any specified time duration for further analysis,

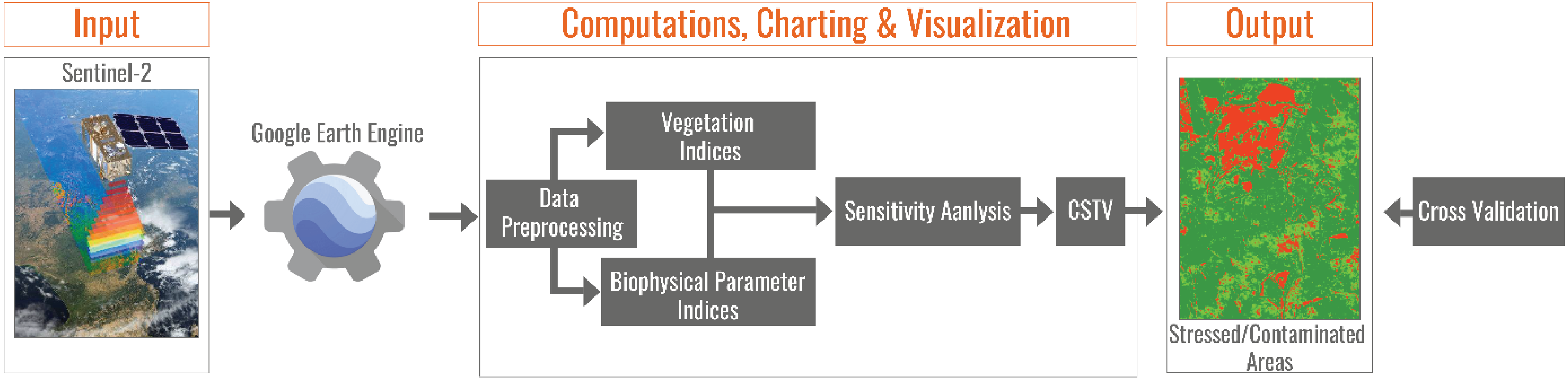
(ii) Calculating different vegetation indices (VI) and biophysical parameter indices (BPI),

(iii) Performing sensitivity analysis to find sensitive VI and BPI to leached metal induced vegetation stress,

(iv) Calculating coefficient of spatiotemporal variation (CSTV) for the better performing VI,

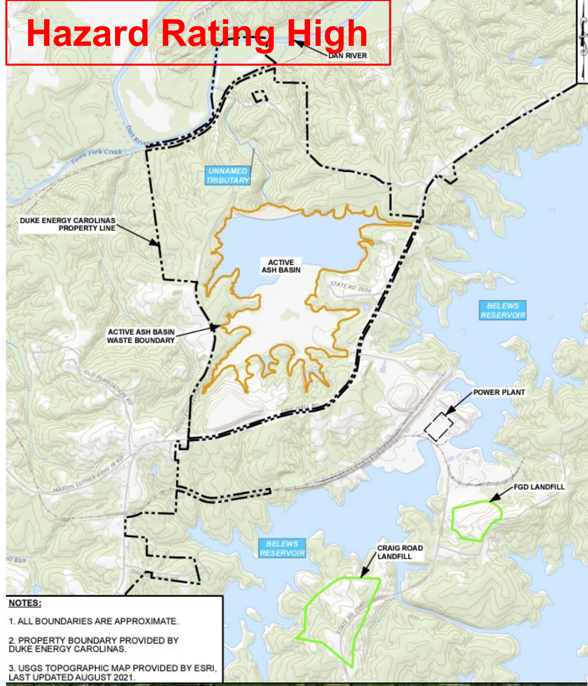
(v) Visualizing the calculated CSTV on map to identify the potential contaminated area with high vegetation stress,

(vi) Cross validation and comparison of the results with the ones from monitoring well data.

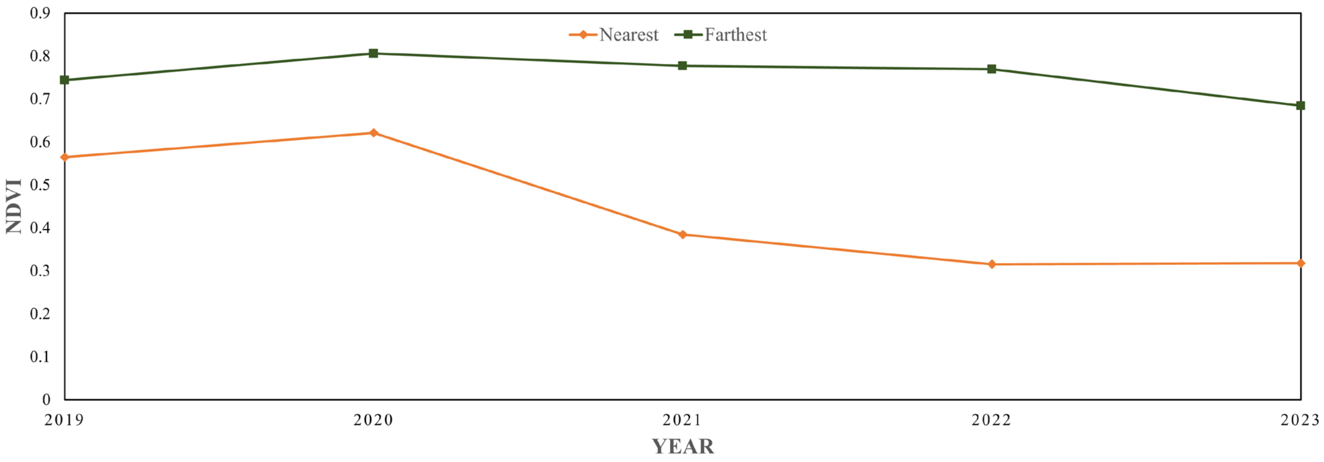


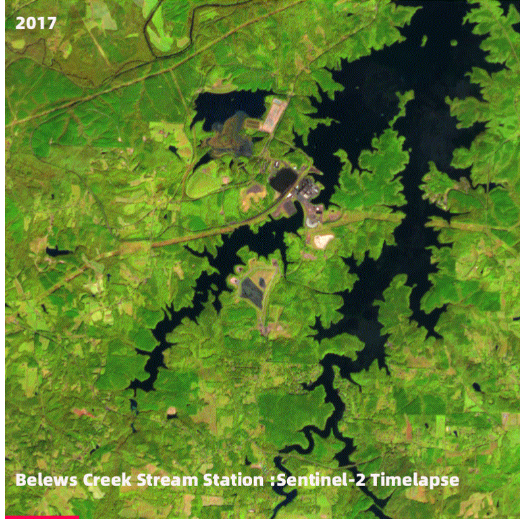
# Case study 1: Belews Creek steam station

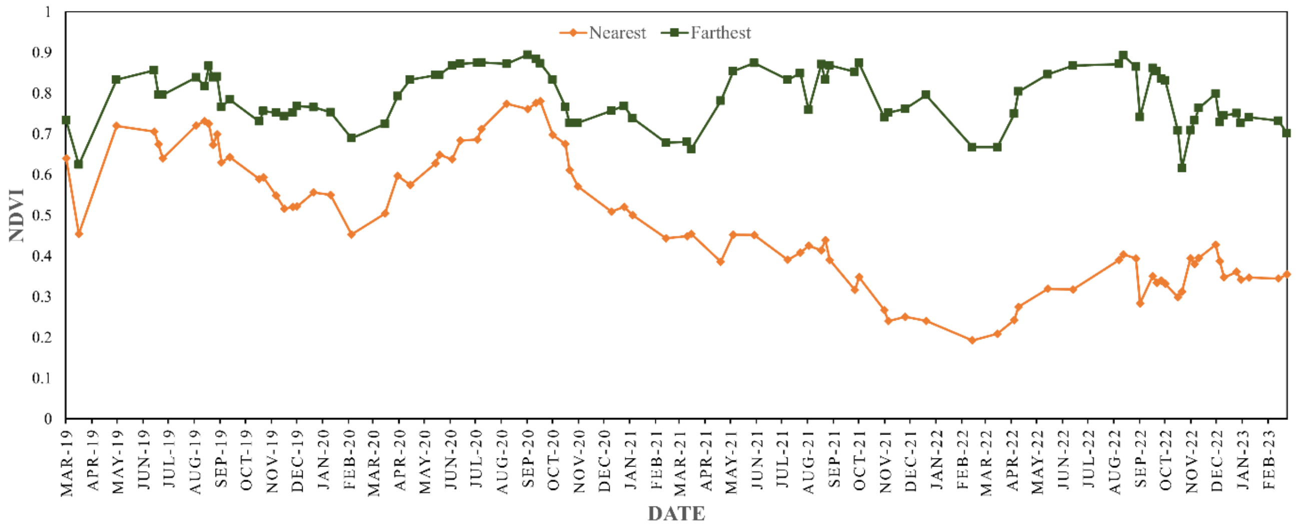
- **Owned and operated by Duke Energy**.
- Commercial operations began in 1974 with Unit 1 (1,120 MW), followed by Unit 2 (1,120 MW) in 1975.
- 3 impoundments: FGD Landfill, Craig Road Landfill, and Active Ash Basin.
- **104 groundwater monitoring wells**, 54 of which have been polluted above federal advisory levels based on samples collected between January 06, 2011, and April 15, 2019.
- **Groundwater at this site contains unsafe levels of arsenic, beryllium, boron, chromium, cobalt, lithium, manganese, mercury, molybdenum, radium, selenium, and sulfate**.
- Pollutants monitored and found below guidelines are antimony, barium, cadmium, copper, fluoride, lead, nickel, nitrate, and thallium.
- Duke Energy announced in 2022 that the facility would be shifted to natural gas by 2035.

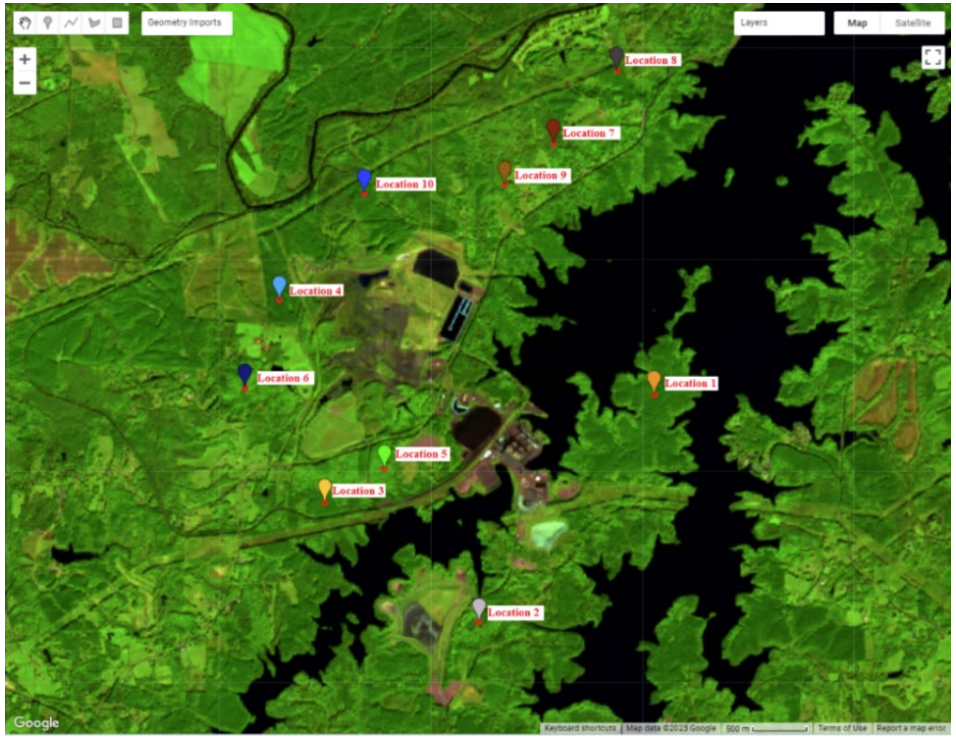



# NDVI time series



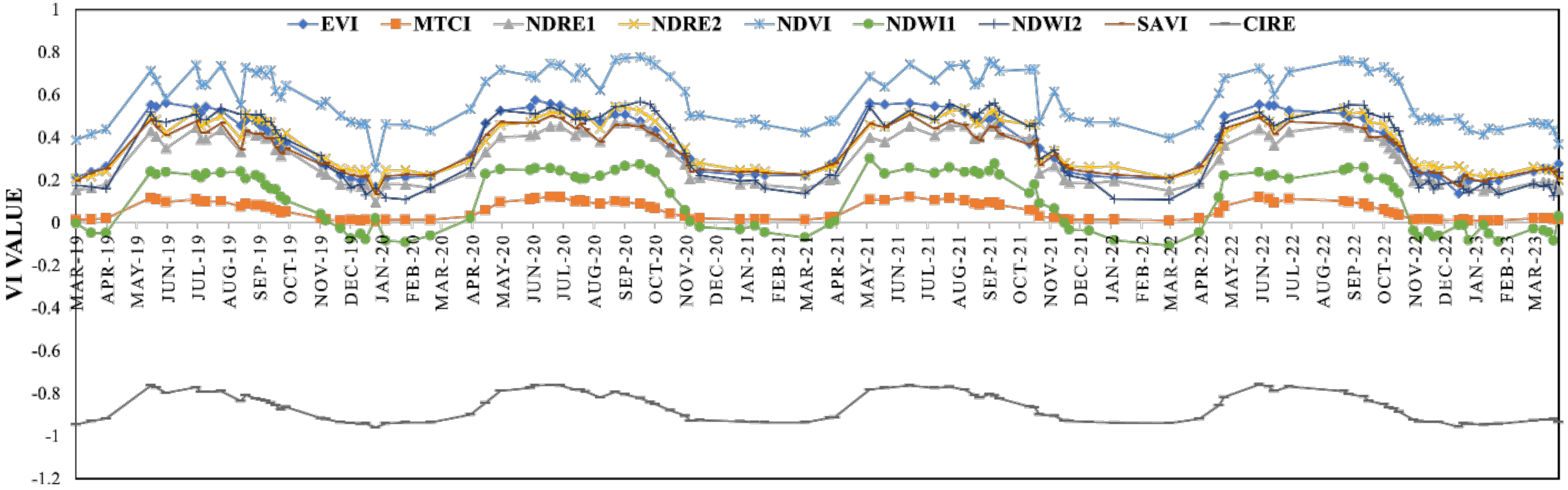



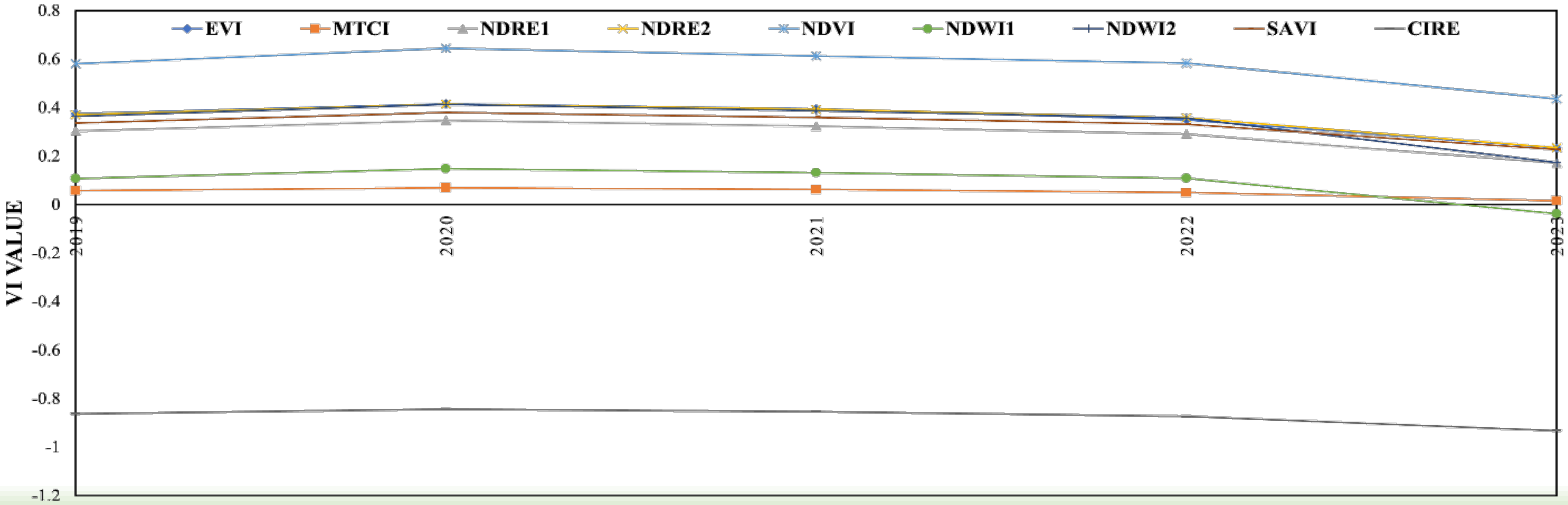



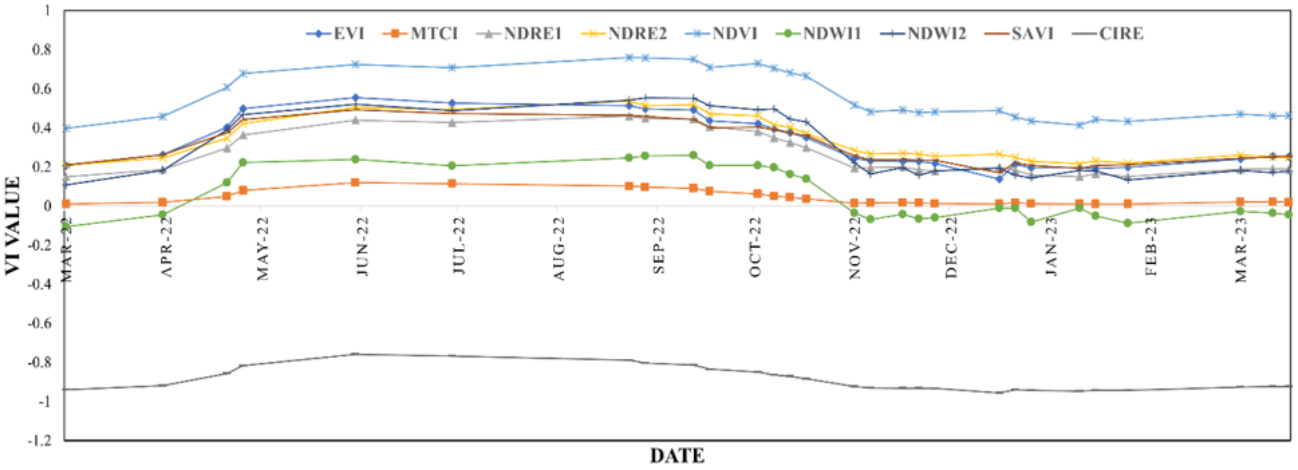
# Vegetation indices time series

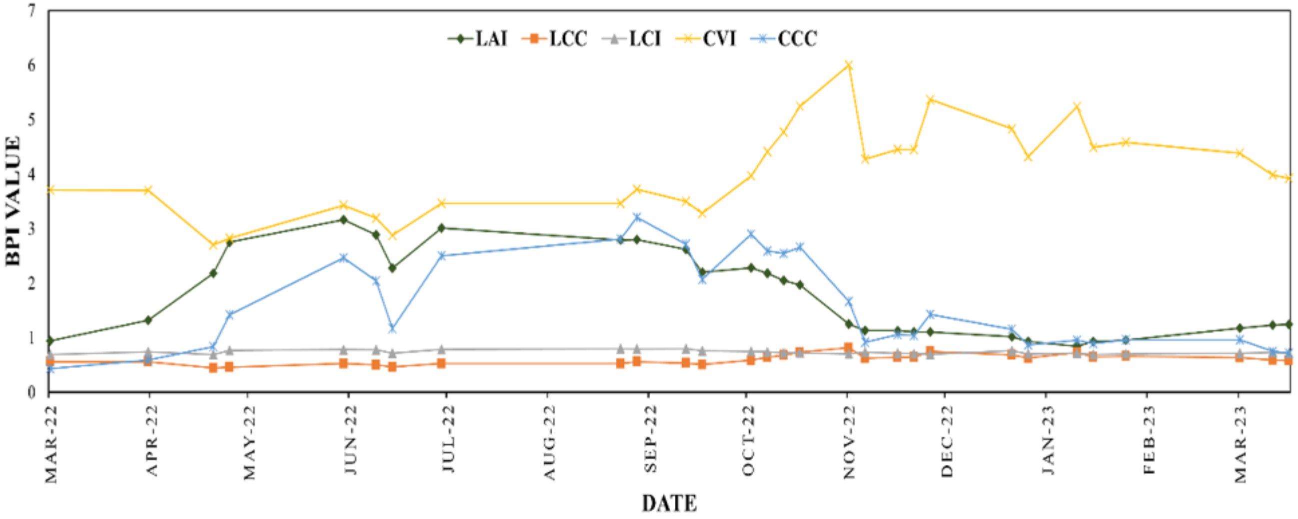
- Various vegetation indices has been calculated from Sentinel-2 satellite with less than 30% cloud cover.



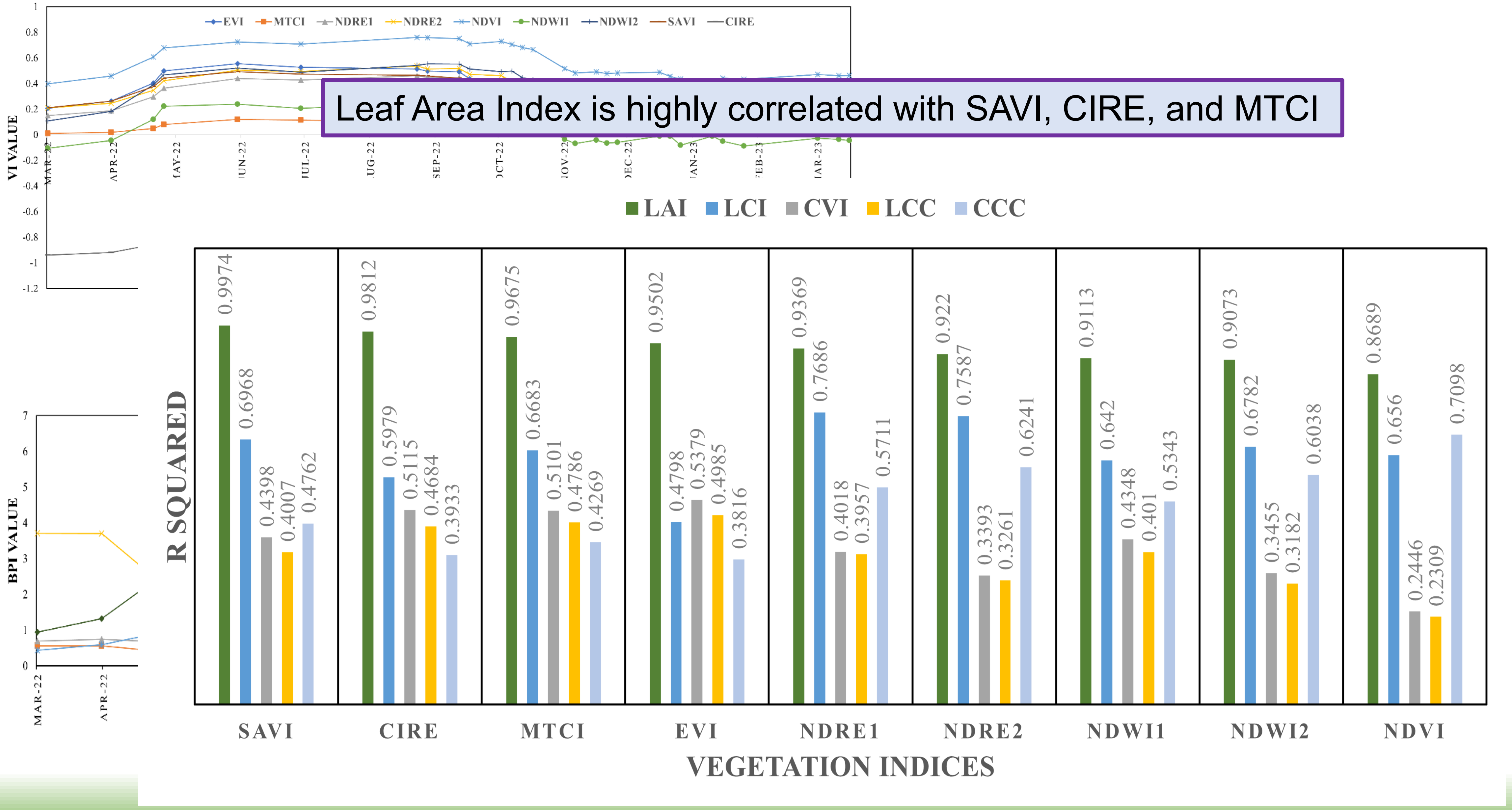



# VI/BPI sensitivity analyses



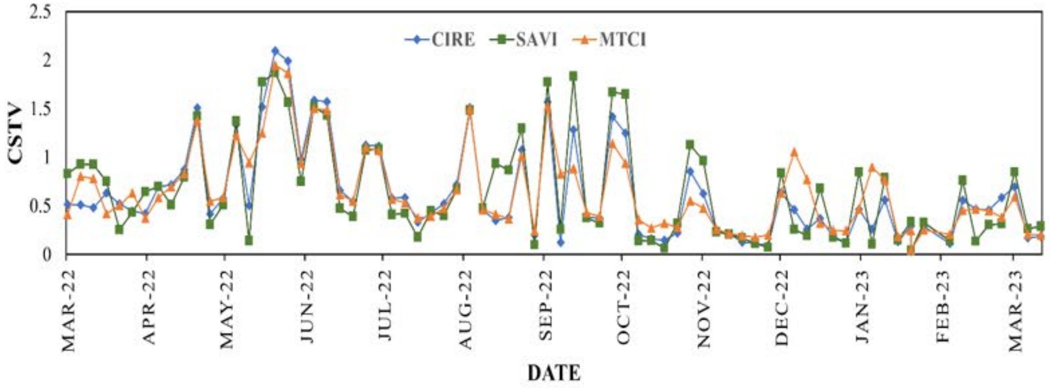



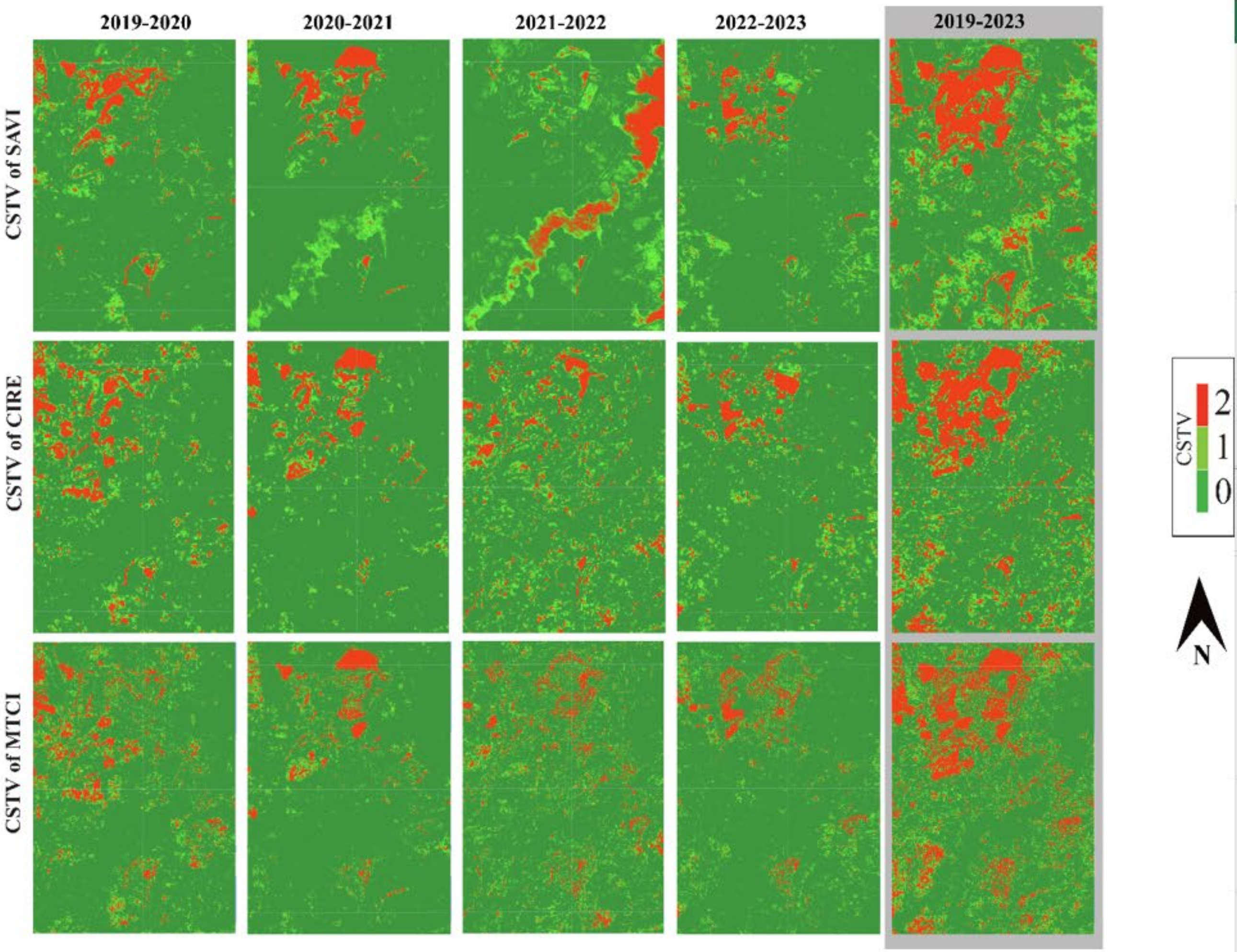
# VI/BPI sensitivity analyses



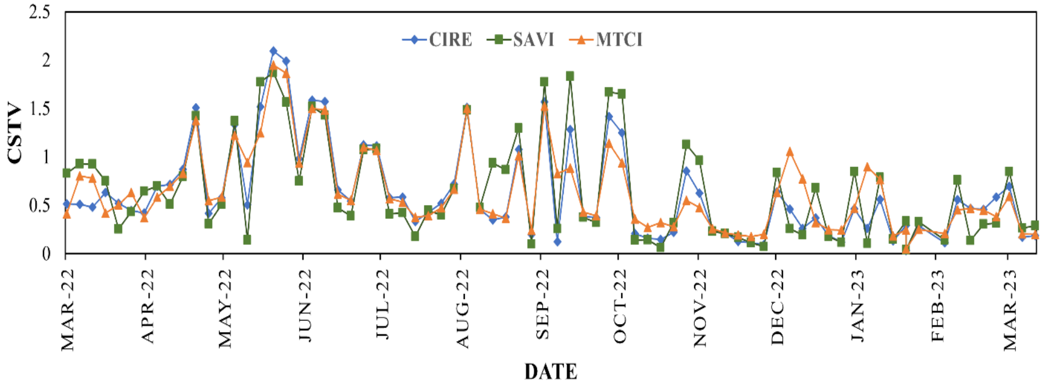

Leaf Area Index is highly correlated with SAVI, CIRE, and MTCI

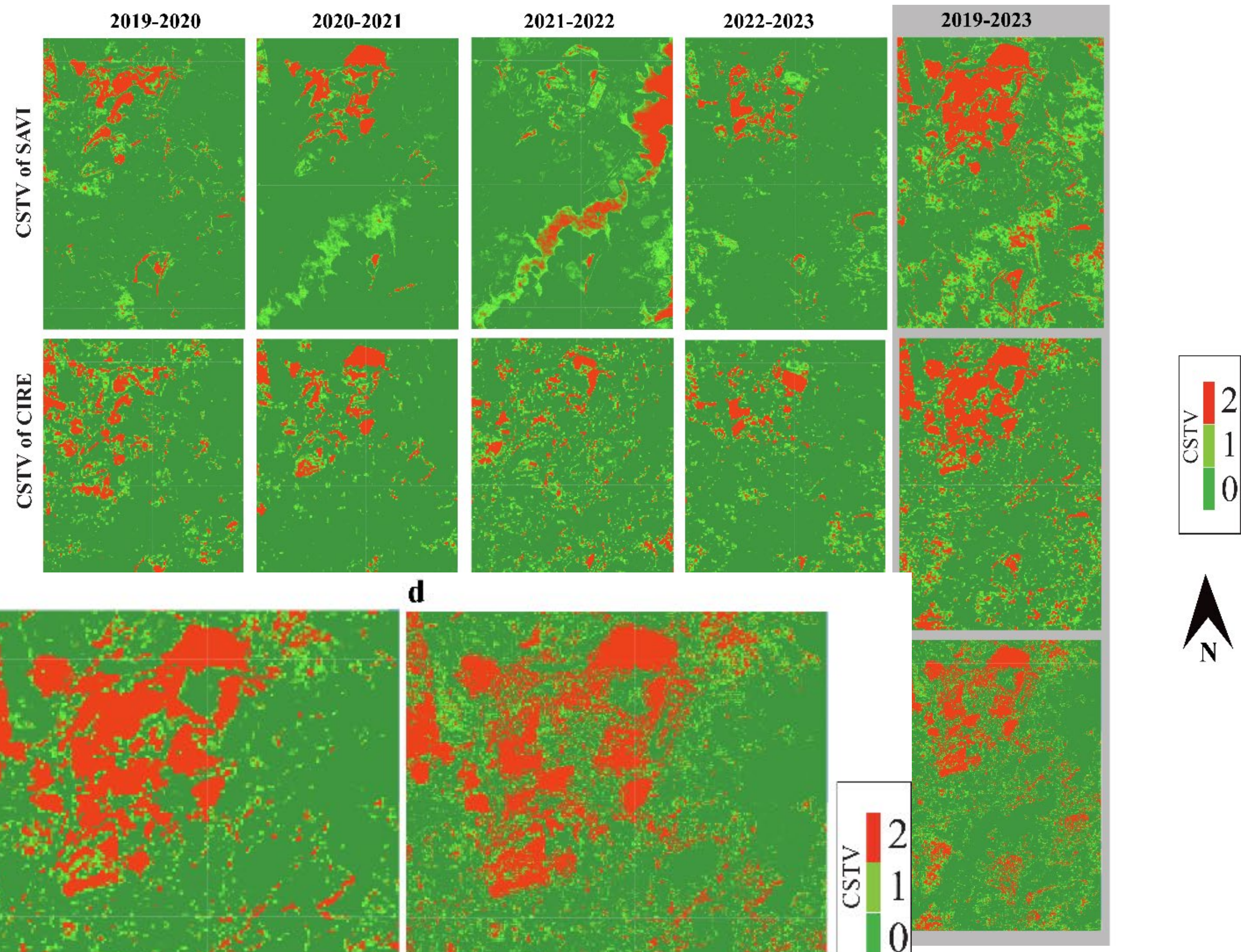
# CSTV calculation

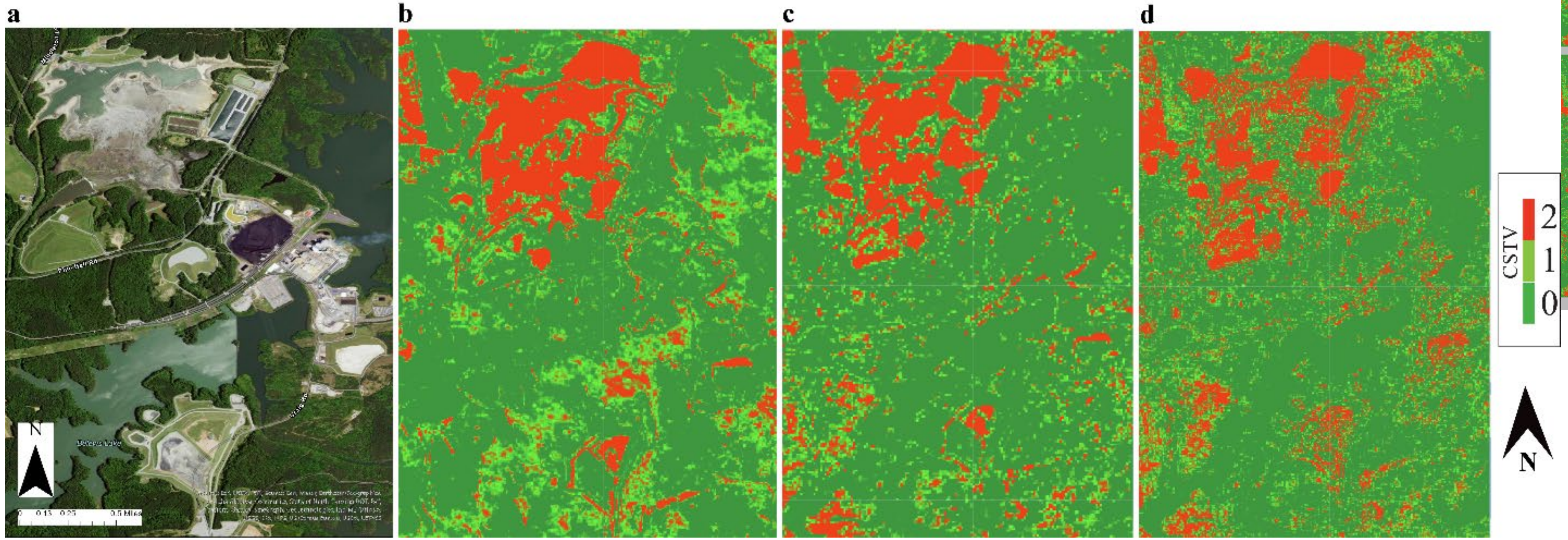


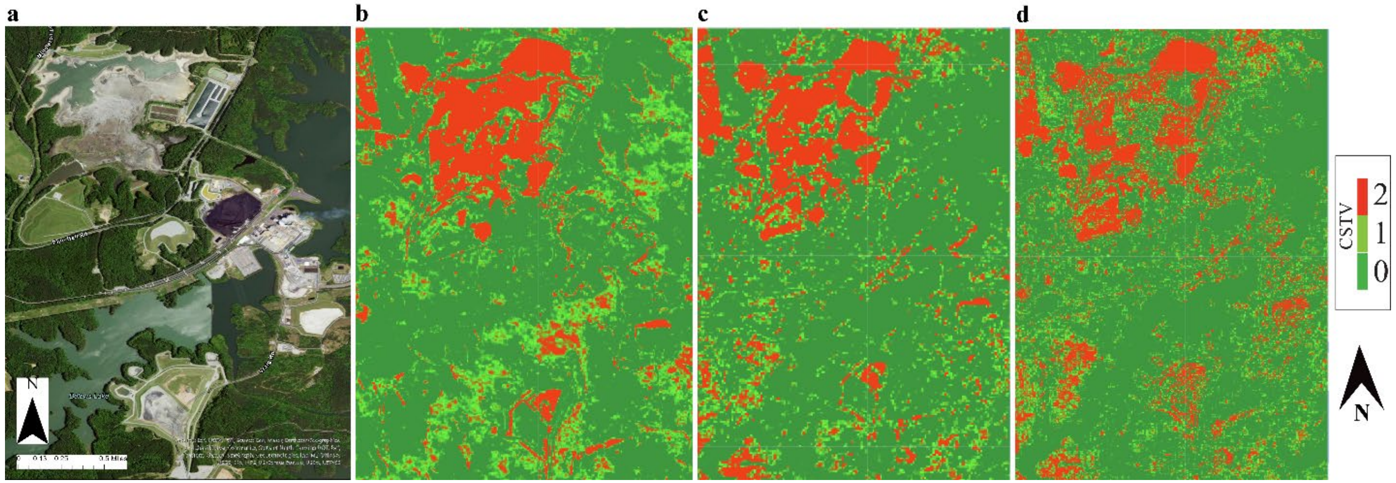
# CSTV calculation



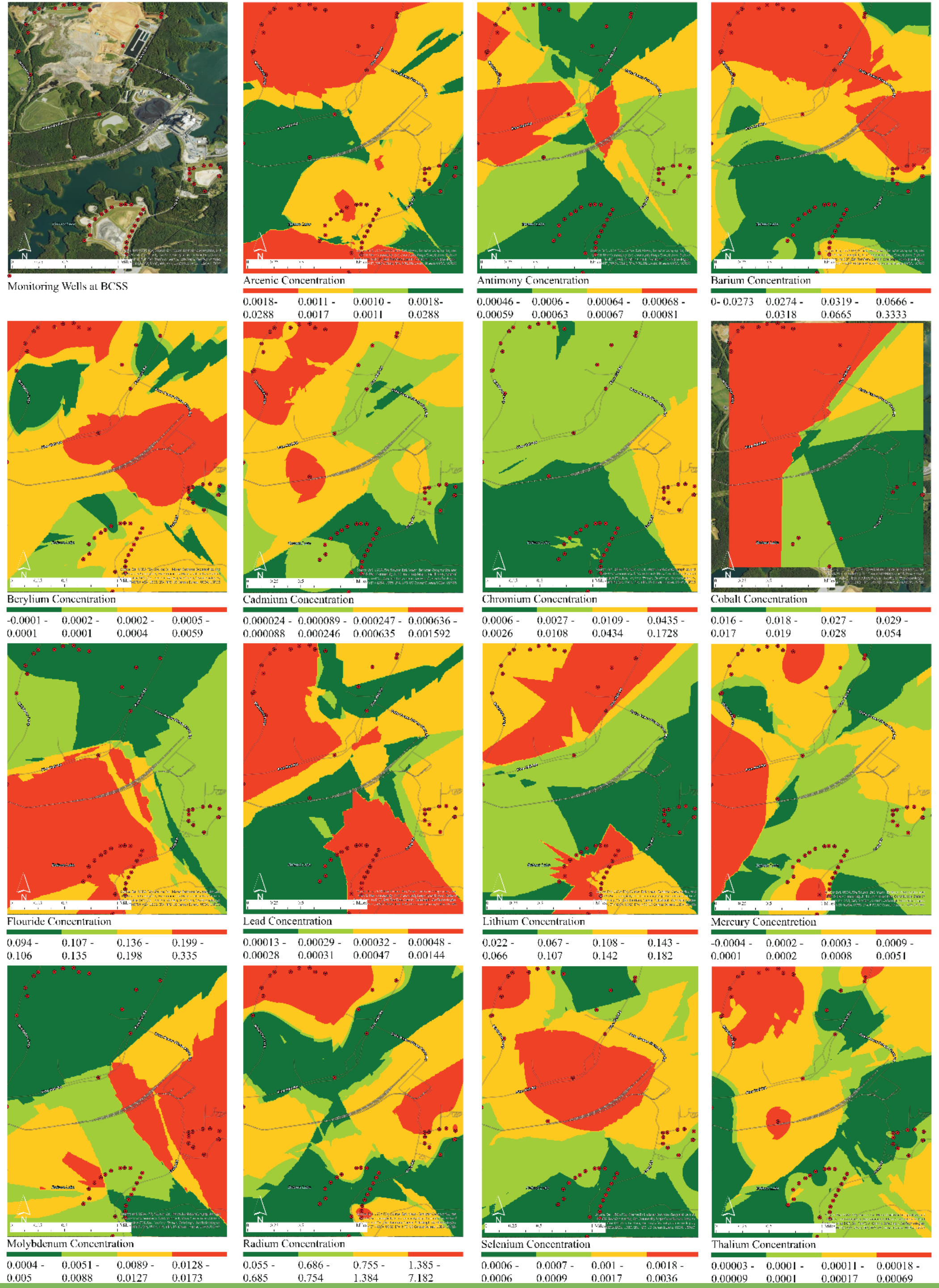



# Cross validation

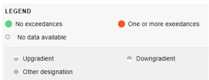



Ongoing work:

- searching for potential correlations between vegetation stress and type of leached metal



# Case study 2: Four Virginian power stations




**Chesterfield**

- Active plant  with significant hazard owned by Dominion Virginia Power in Chester, VA
- Capacity of 1353 MW built in 1952
- 4 impoundments, and 61 monitoring wells, 46 of which are polluted
- 12 contaminating elements (ammonia, arsenic, beryllium, boron, chromium, cobalt, lead, lithium, manganese, molybdenum, radium, sulfate).

**Bremo**

- Active plant  with significant hazard by Dominion Virginia Power in Bremo Bluff, VA
- Capacity of 254 MW, built in 1951,
- 3 impoundments, and 32 monitoring wells, 28 polluted
- 9 contaminants (arsenic, boron, cobalt, lead, lithium, manganese, molybdenum, radium, sulfate).

**Possum Point**

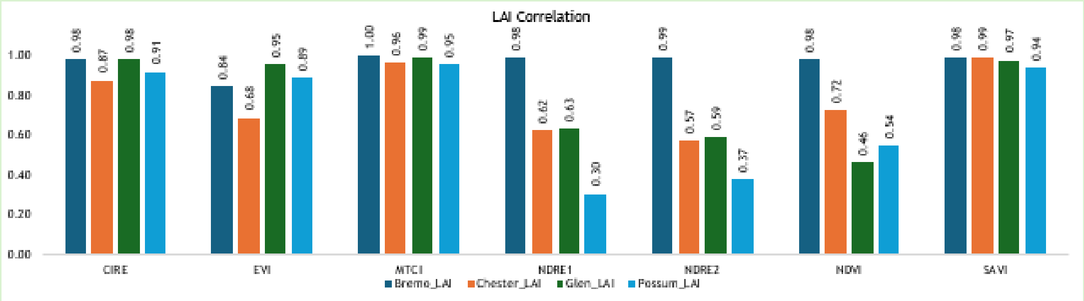
- Active with significant hazard plant in Dumfries, VA, also owned by Dominion Virginia.
- Capacity of 1235 MW, built in 1956
- 5 impoundments, and 36 monitoring wells, 18 polluted
- 7 known contaminants (arsenic, boron, cadmium, cobalt, manganese, nickel, radium).

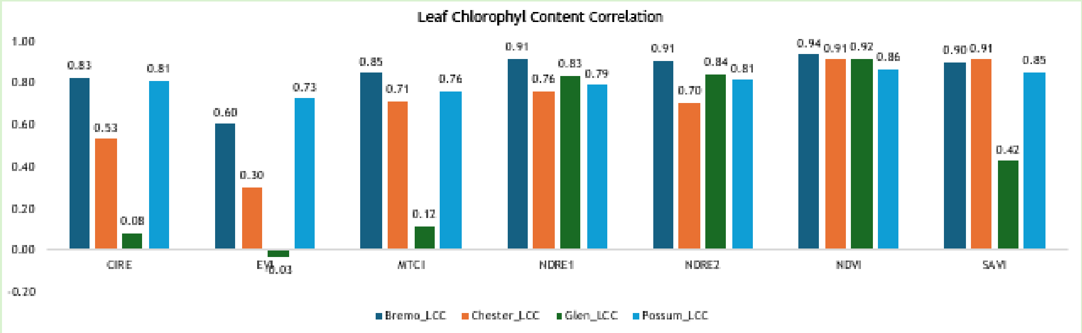
**Glen Lyn**

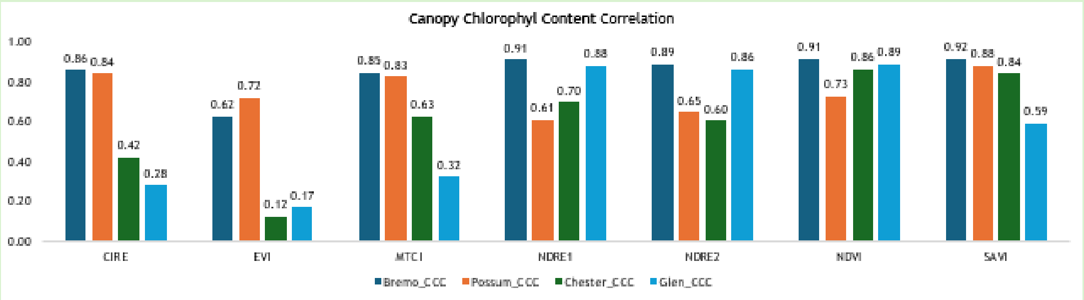
- Retired with low hazard and operated by Appalachian Power Company in Glen Lyn, VA
- Capacity of 338 MW, built in 1945
- 6 impoundments, and 19 monitoring wells, 17 polluted
- 8 contaminants (arsenic, boron, cobalt, lead, manganese, molybdenum, strontium, sulfate).

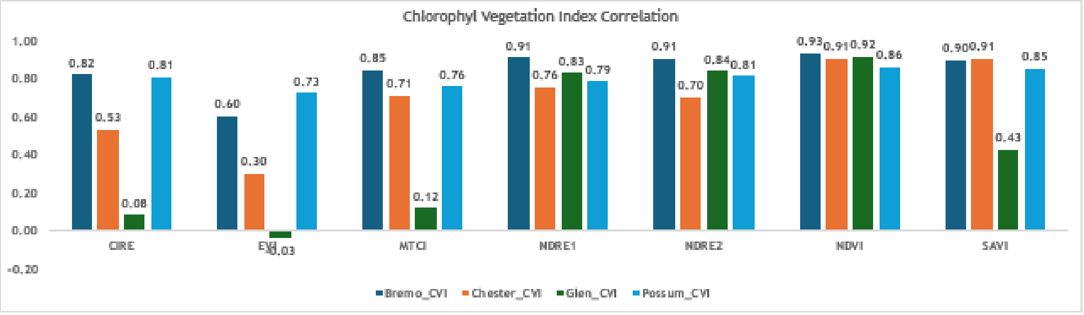
Arsenic, boron, cobalt and manganese are detected for all 4.

# Correlations between seven VI and four BPI of 4 sites



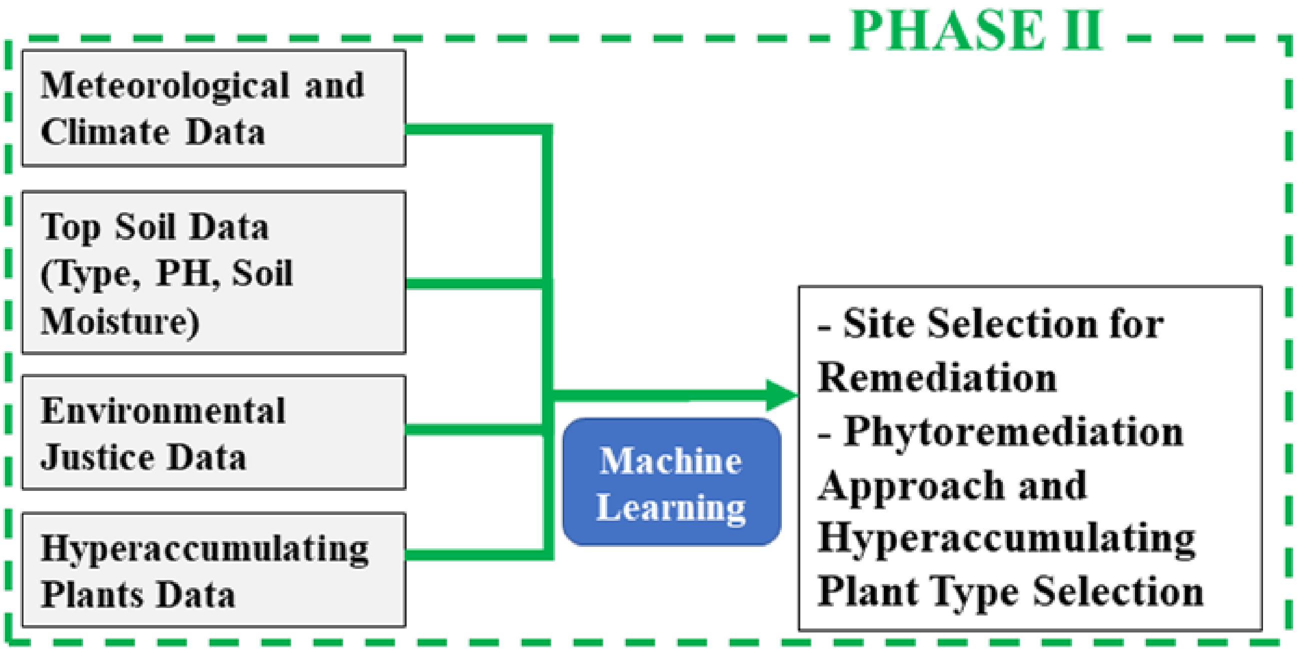




- Sentinel-2 image data from 2018 to 2023 were analyzed.
- Sensitivity analysis and correlation studies showed that NDVI performed the best across three of the four sites in measuring vegetation health/stress and strongly correlated with BPI indices: LCC, CCC, and CVI, while MTCI & SAVI were more correlated with LAI.
- NDVI, MTCI and SAVI were utilized to calculate CSTV and visualize the stressed areas.
- GEE based applications are developed for calculating and visualizing Vegetation Indices, Biophysical Parameter Indices and Co-efficient of Spatiotemporal Variations (CSTV) for further analysis of vegetation stress and contamination surrounding the power stations.

➢ Bremo: VI, BPI, CSTV
➢ Chesterfield: VI, BPI, CSTV
➢ Possum Point: VI, BPI, CSTV
➢ Glen lyn: VI, BPI, CSTV

# Phase II: propose locally adaptable phytoextraction approaches to remediate contaminated regions




- ❑ A content-based filtering ranking algorithm will be developed for effective and environmentally justified case-specific phytoremediation

Output:

- Ranking phytoremediation candidates
- Suggested plant species to be used for the phytoremediation of candidate sites

# Data Acquisition and Classification based on soil type and properties, hyperaccumulating plant types, and metal contamination types

**Which plants are a good fit for different sites?**

- **Plant type**
- **Soil type**
- **Climate**
- **Native or non-native**

New Phytologist

*Letters*

## A global database for plants that hyperaccumulate metal and metalloid trace elements

**Hyperaccumulator plants and the need for a database**

**Table 1** Hyperaccumulator species in the Global Database (as of September 2017) with the global records that are the highest concentrations reported to date

| Element | Threshold ($\mu g\ g^{-1}$) | Families | Genera | Species | Global records |
|---|---|---|---|---|---|
| Arsenic (As) | > 1000 | 1 | 2 | 5 | *Pteris vittata*[1] (2.3%) |
| Cadmium (Cd) | > 100 | 6 | 7 | 7 | *Arabidopsis halleri*[2] (0.36%) |
| Copper (Cu) | > 300 | 20 | 43 | 53 | *Aeolanthus biformifolius*[3] (1.4%) |
| Cobalt (Co) | > 300 | 18 | 34 | 42 | *Haumaniastrum robertii*[4] (1%) |
| Manganese (Mn) | > 10 000 | 16 | 24 | 42 | *Virotia neurophylla*[5] (5.5%) |
| Nickel (Ni) | > 1000 | 52 | 130 | 532 | *Berkheya coddii*[6] (7.6%) |
| Lead (Pb) | > 1000 | 6 | 8 | 8 | *Noccaea rotondifolia* subsp. *cepaeifolia*[7] (0.8%) |
| Rare earth elements (lanthanum, La; cerium, Ce) | > 1000 | 2 | 2 | 2 | *Dicranopteris linearis*[8] (0.7%) |
| Selenium (Se) | > 100 | 7 | 15 | 41 | *Astragalus bisulcatus*[9] (1.5%) |
| Thallium (Tl) | > 100 | 1 | 2 | 2 | *Biscutella laevigata*[10] (1.9%) |
| Zinc (Zn) | > 3000 | 9 | 12 | 20 | *Noccaea caerulescens*[11] (5.4%) |

[1]Ma *et al.* (2001); [2]Stein *et al.* (2017); [3]Malaisse *et al.* (1978); [4]Brooks (1977); [5]Jaffré (1979); [6]Mesjasz-Przybyłowicz *et al.* (2004); [7]Reeves & Brooks (1983); [8]Shan *et al.* (2003); [9]Galeas *et al.* (2006); [10]LaCoste *et al.* (1999); [11]Reeves *et al.* (2001).

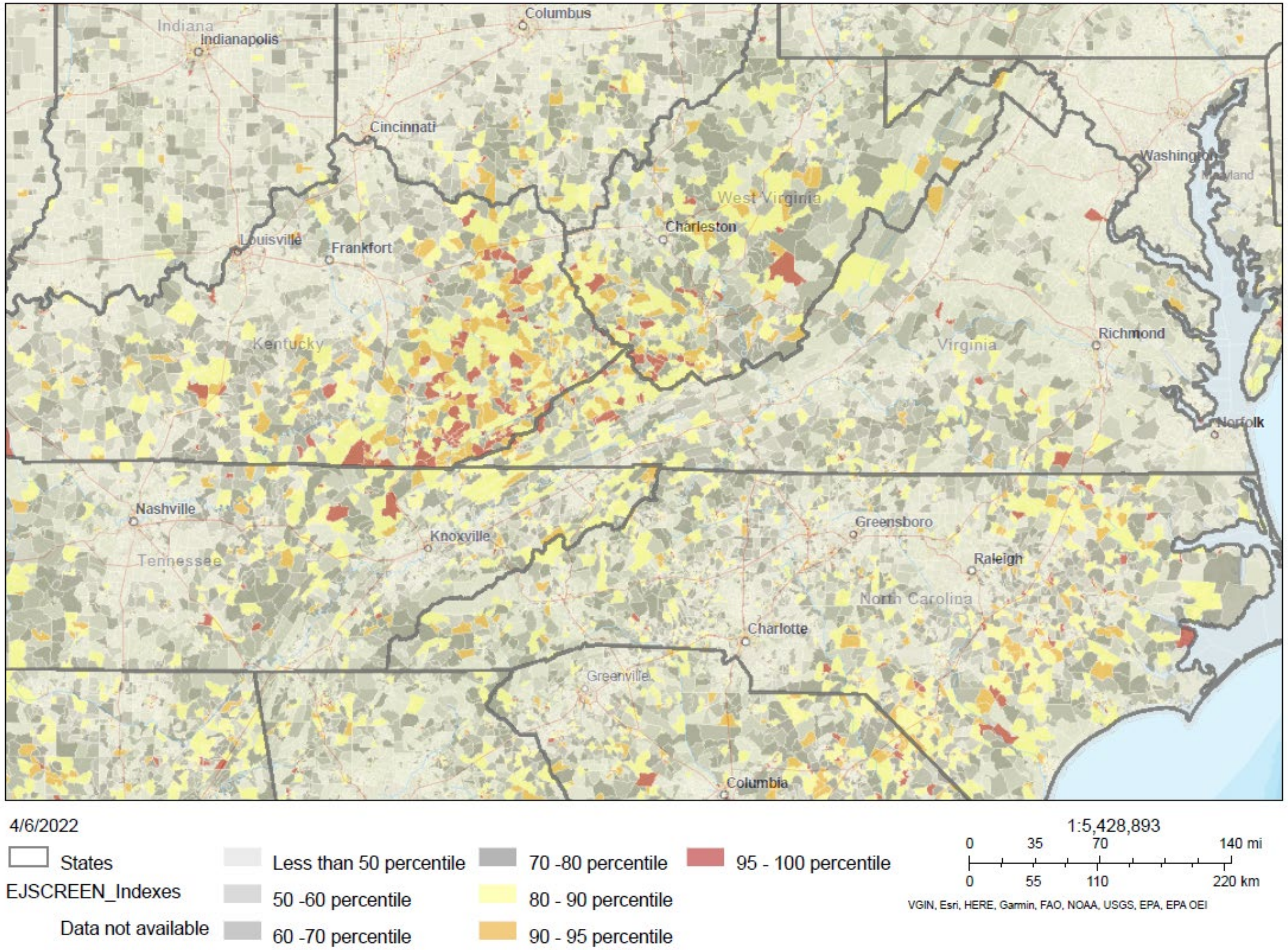
Reeves, R.D., Baker, A.J., Jaffré, T., Erskine, P.D., Echevarria, G. and van der Ent, A., 2018. A global database for plants that hyperaccumulate metal and metalloid trace elements. *New Phytologist*, *218*(2), pp.407-411.

# Data acquisition and classification based on environmental justice

Identify priority regions based on the data from **US EPA's Environmental Justice Screening and Mapping Tool (EJSCREEN)**

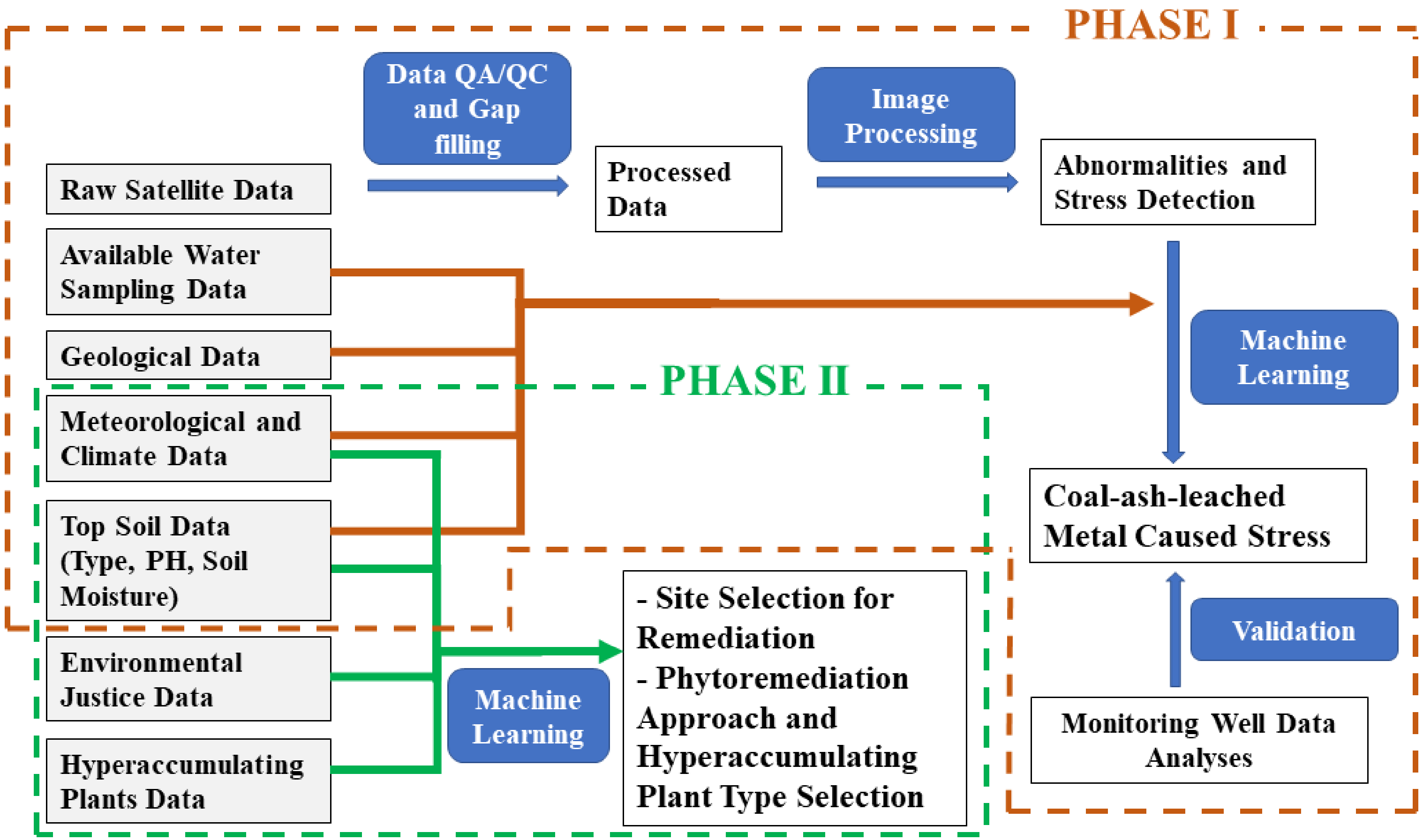
- % Low Income
- % Unemployed
- % Limited English Speaking
- % Less than High School Education
- Low Life Expectancy

**% Low Income**



# Project benefits

- A scalable, low-cost technology to screen a wide range of locations and to identify coal ash-sourced or mine tailings- sourced leached metal-contaminated areas.
- Train and educate students in a multi-disciplinary setting
- Potential application of phytotechnology in other fields (e.g. phyto-mining)
- Phytoremediation pilot design and implementation
- Post phytoremediation monitoring

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