Evaluating Spatio-temporal Dynamics of Water Quality in the Atchafalaya Basin Using Landsat 8 & 9 Surface Reflectance Imagery

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Abstract

The Atchafalaya Basin, a critical ecological and hydrological region in Louisiana, faces growing water quality challenges driven by anthropogenic modifications and fragmentation. While conventional in situ water quality monitoring provides accurate measurements, its limited spatial and temporal coverage makes it inadequate for assessing pollution dynamics across such a vast and complex watershed. This study therefore employs the use Landsat 8 & 9 Collection 2, Level 2 to evaluate the spatio-temporal dynamics of water quality in the Atchafalaya Basin from 2010 to 2024. By leveraging the high spatial (10–20 m) and temporal (5-day) resolution of Landsat 8 & 9 imagery, the research examines key indicators of water quality, including chlorophyll-a, turbidity, and secchi depth variations in the basin. Chlorophyll-a results showed predominantly low to moderate concentrations in 2015 (0-25 µg/L), indicating largely oligotrophic to mesotrophic conditions, but by 2024 chlorophyll-a concentrations exceeded 25 µg/L across most parts of the basin, especially in the southern region signifying a shift toward eutrophic conditions. Water clarity and turbidity exhibited similar patterns, with Secchi depth declining from a maximum of 4.2 m to 3.7 m (reduced water clarity) and widespread values near 0.2 m in 2024, while turbidity ranged from 3.4 to 180 NTU, showing broader spatial distribution of elevated turbidity in 2024. To address the declining condition of the basin, restoration efforts focus on adaptive water management, sediment control, and habitat improvement, while remote sensing effectively retrieves surface water reflectance values to monitor restoration progress and water quality changes in the Atchafalaya Basin.

1. INTRODUCTION

The Atchafalaya River Basin (ARB) is the largest remaining bottomland hardwood wetland in the United States. It is one of the most productive wetlands in the world and the last of its kind in North America. In addition to providing critical wildlife habitat, the ARB functions as a flood relief outlet and important filter for the Mississippi River, slowing its flow and trapping nutrients and pollution to improve water quality before it empties into the Gulf (TNC, 2025). Thus, features of the Mississippi River and Tributaries (MR&T) flood control system, including the Old River complex and the Atchafalaya Basin Floodway system, define the flow and sediment resources entering the basin and influence the basin's evolution.

However, over the past 10,000 years or more, the Mississippi River has changed its path several times, ranging from the current location of Bayou Teche to today’s route past Baton Rouge and New Orleans (ANHA, 2026). The basin therefore protects millions of people from the Mississippi River floods, from New Orleans to Baton Rouge, from Lafayette to Morgan City and hundreds of other cities and communities (Basinkeeper, 2025). More efforts to control the Mississippi River floods include the Corps of Engineers (CoE) constructing levees, which cut more than half the surface of the ARB, and manipulating bayous and waterways by draining the floodplains (Basinkeeper, 2025). The oil companies also built pipelines and oil access canals, which unfortunately destroyed three-fourths of the natural system. (Basinkeeper, 2025). Human interference in the basin has resulted in tremendous losses of valuable wetlands, siltation, sedimentation and pollution in the basin (Basinkeeper, 2025).

More so, these natural processes and human activities are further limiting the effectiveness of flow and sediment resources in creating new wetlands by affecting sediment delivery, deposition, and retention (Coastal Wetlands Planning, 2026). Decades of hydrologic manipulation have disconnected the river and its surrounding floodplain, preventing the natural overflow of water into the backswamp (Basinkeeper, 2025). For instance, sediment coming down the Atchafalaya River, which is fed by the combined waters of the Mississippi and Red Rivers and directed by the Old River Control Structure, is filling in and shallowing bayous, canals, and lakes throughout the Basin (Macaluso, 2025). As a result, the basin is experiencing degraded water quality, declining forest health, and compromised wildlife habitat (TNC, 2024). If not controlled, sediments will eventually fill the basin, taking away the ability of the basin to hold flood waters that protect millions of people (Basinkeeper, 2025).

This makes it essential to evaluate water surface elevations and spectral reflectance using traditional or remote sensing techniques to provide valuable insight into the water quality conditions of water resources. Even though traditional and in-situ water quality sampling can be accurate, it is time-consuming, expensive, and has limited coverage with lower precision. Unlike remote sensing techniques, which provide large-scale water quality monitoring, high temporal coverage, and reasonable accuracy (Sun et al., 2024). While existing studies in the Atchafalaya River Basin (ARB) have applied remote sensing techniques and in situ measurements of surface water reflectance to examine hydrodynamic processes, the use of multispectral Earth-observation satellites for long-term water quality assessment remains limited.

Based on this, this study evaluates the spatio-temporal dynamics of water quality using Landsat 8 and 9 surface reflectance imagery, addressing a clear research gap. By assessing consistent, long-term satellite-based analysis of water quality patterns of the river, the main objective is to demonstrate the efficiency of using remote sensing satellites to monitor spatio-temporal dynamics of water quality in the basin. The goal is to analyze the seasonal fluctuations of water quality parameters, namely Chlorophyll-a (Chl-a), Secchi Depth & Turbidity, to

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evaluate the downstream and upstream water quality differences over time and assess the effectiveness of ongoing restoration efforts in the ARB.

2. RESEARCH METHODOLOGY

2.1 Study Area

The ARB (figure 1) is located in the central part of the coastal zone between Lafayette and Baton Rouge. It is about 20 miles in width and stretches about 140 miles in length, southward to the Gulf (ANHA, 2026). It has an area of about 1.4 million acres (Basinkeeper, 2025) and encompasses 58,400 acres of wetlands in St. Mary Parish (Coastal Wetlands Planning, 2026). The basin boundaries are the Mississippi River and Tributaries (MR&T) system levees below Berwick and Calumet to the north, Bayou Shaffer southward along the bank of the Lower Atchafalaya River to its mouth then following the shoreline around Atchafalaya Bay to Point Au Fer to the east, and a north-south line extending through Point Chevreuil to the west (Coastal Wetlands Planning, 2026). Its boundaries define the flow and sediment resources entering the basin. It is America's largest swamp, encompassing more than 250,000 acres of iconic cypress and tupelo gum forests, winding bayous, and lakes that give way to growing deltas as the Atchafalaya River's sediment-heavy waters near the Gulf (Macaluso, 2025). The most ecologically vital parts of the basin include some 885,000 acres of forested Wetlands and 517,000 acres of marshland (Basinkeeper, 2025). The basin also supports high biodiversity, hosting about 65 species of reptiles and amphibians, over 250 bird species, mammals such as black bear, nutria, fox, muskrat, beaver, otter, and raccoon, and more than 100 species of fish and other aquatic life. Generally, this basin is unique among the basins because it has a growing delta system with nearly stable wetlands (Coastal Wetlands Planning, 2026).

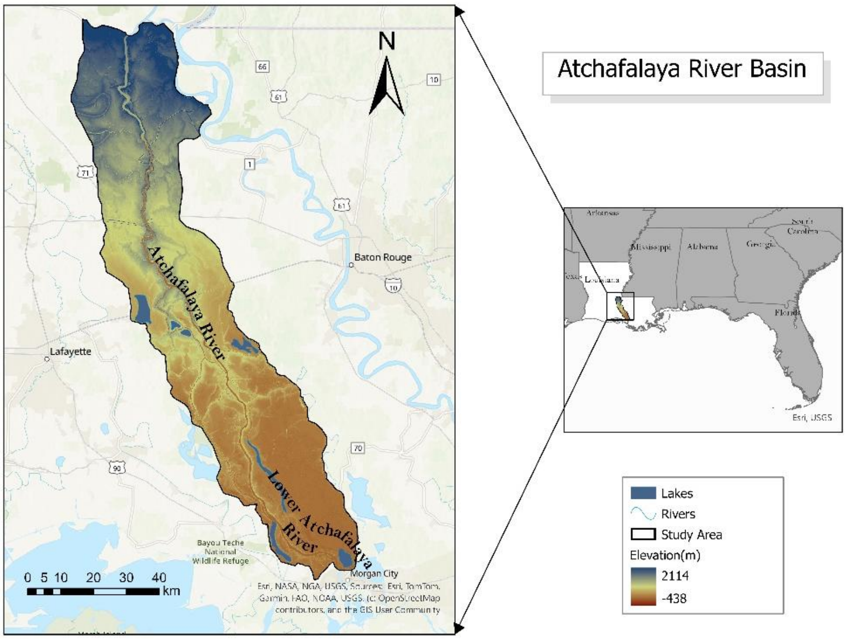

Figure 1: Atchafalaya River Basin

2.2 Data Acquisition

The watershed boundary dataset for ARB downloaded from the United States Geological Survey (USGS) was uploaded as a custom asset shapefile in Google Earth Engine (GEE), where all subsequent data for this study were acquired. GEE enables effective geospatial studies by providing a robust cloud computing infrastructure and access to a large collection of petabytes of satellite imagery, with the ability to do world-scale analysis (Loh, et al., 2023). For this study, Landsat 8 (Operational Land Imager) and Landsat 9 Surface Reflectance Level 2 imagery (Collection 2, Tier 1) were acquired for 2015, 2020, and 2024 to ensure consistent spatial and spectral coverage across the study area. The imagery for each year was filtered spatially to the boundary of the basin and temporally using the full calendar year (January 1 to December 31). To calculate the Normalized Difference Water Index (NDWI), surface reflectance (SR) bands 3 and 5 were used in GEE to accurately mask and enhance surface water detection. Thus, the NDWI is used to highlight open water features in a satellite image, allowing a water body to "stand out" against the soil and vegetation (Analytics, 2023). The three indices, namely Turbidity, Chlorophyll-a, and Secchi depth, were also computed in GEE. These datasets formed the basis for subsequent processing and

2.2 Data Processing

Data for this study was fully coded in JavaScript using the Code Editor Platform in GEE, considering that it provides access and processing of data from public or private catalogues to any user (Loh, et al., 2023). This platform was used to analyze and generate the mean composite results of each parameter, thus Turbidity, Chlorophyll-a, and Secchi depth. Landsat 8 and Landsat 9 image collections were merged into a single dataset and analyzed using a custom Google Earth Engine function 'addIndices' to derive water-related indices and proxies. This function computed turbidity from the red-to-green band ratio (SR_B3 & SR_B4), chlorophyll-a from the green-to-blue band ratio (SR_B3 & SR_B2), and Secchi depth as an inverse function of Turbidity. Both Landsat 8 (Operational Land Imager) and Landsat 9 Surface Reflectance Level 2 imagery (Collection 2, Tier 1) were atmospherically corrected, hence required no preprocessing. The resulting index layers were aggregated to generate an annual mean composite output for each parameter in each year. The final composite outputs were clipped to the basin boundary and retained at a 30-m spatial resolution for visualization, mapping, and further analysis.

3. RESULTS & DISCUSSION

3.1 Normalized Difference Water Index (NDWI)

The NDWI is usually calculated using the GREEN-NIR (visible green and near-infrared) combination, which allows it to detect subtle changes in water content of the water bodies (Analytics, 2023). In other words, it is a spectral index for delineating and monitoring content changes in surface water (Ojumu, 2023). Taking advantage of the NIR (near-infrared) and GREEN (visible green) spectral bands, the NDWI is capable of enhancing the water bodies in a satellite image (Analytics, 2023). For this study, the NDWI aids water resource management by identifying water content while monitoring and evaluating flooding events (Ojumu, 2023).

As seen in Table 1, NDWI value ranges from -1 to 1, with zero being the threshold, the cover type is water if NDWI is > 0 and it is non-water if NDWI ≤ 0 (Ji et al., 2009). According to the EOS Data Analytics, the higher values approaching +1 usually appear blue and correspond to either a high water content or a water surface, while the lower values all the way to -1 are the tell-tale signs of drought conditions, unless the area of interest is a non-aqueous surface (Analytics, 2023).

NDWI Range	Interpretation
0.2 – 1	Water Surface
0.0 – 0.2	Flooding, humidity
-0.3 – 0.0	Moderate drought, non-aqueous surfaces
-1 – -0.3	Drought, non-aqueous surfaces

Table 1: Interpreting NDWI – (Analytics, 2023)

From the results in figure 2, 2015 had a high NDWI value of 0.3 and a lower NDWI value of – 0.7, indicating Water Surface and, Drought, non-aqueous surfaces respectively. Similarly, in 2020 and 2015, the basin experienced a high NDWI of 0.5 and 0.3 respectively while maintaining a lower NDWI of -0.7 in all the years. The high values indicate a clear water surface signal usually associated with open water bodies such as rivers, lakes or inundated wetlands. Meanwhile, in addition to the low NDWI values representing drought, non-aqueous surfaces, the northern and central parts of the basin in all three years had an average value of -0.7 whereas in 2020, the southern parts exhibited low NDWI values yet a higher value of 0.5 representing water surface.

The NDWI results is indicative of the Atchafalaya River being reengineered to carry more water, which meant it carried more mud as well. Thus, mud is filling in old lakes and some of the bayous that branched away from the river were closed, forcing the current to carry mud south into the Gulf (Upholt, 2022).

3.2 Chlorophyll-a Concentration

Remote estimation of Chlorophyll-a (Chl-a) has long been used to investigate the responses of aquatic ecosystems (Zhao et al, 2023). C ompared with traditional methods, remote sensing of water environments collects water reflection spectral data using satellite sensors and then constructs a remote sensing inversion model of the water environment parameters to quantitatively retrieve Chl-a (Zeng, et al., 2020). Chl-a is a predominant type of chlorophyll which can be used to classify trophic state and also a measure of the amount of algae and cyanbacteria growing in a waterbody (EPA, 2025).

According to the Texas Commission on Environmental Quality (TCEQ), the trophic state of a waterbody refers to its nutritional status and is indicated by measurements of nutrients and algae. As explained in Table 2, higher TSI values indicate higher nutrient concentrations, often associated with eutrophic (nutrient-rich) conditions that can lead to algal blooms and degraded water quality (Twumasi, et al., 2024).

Class Code	TSI Range	Description
1	TSI < 30	Oligotrophic (low nutrient, high clarity)
2	30 ≤ TSI < 40	Mesotrophic (moderate nutrient, moderate clarity)
3	40 ≤ TSI < 50	Eutrophic (high nutrient, low clarity)
4	50 ≤ TSI < 60	Hypereutrophic (very high nutrient, very low clarity)

Table 2: TSI Classification – (Twumasi, et al., 2024)

Inferring from the results in figure 3, 2015 is observed to have recorded low values of Chl-a concentration within a 0 - 10 TSI range indicating low nutrient levls, relatively higher water clarity

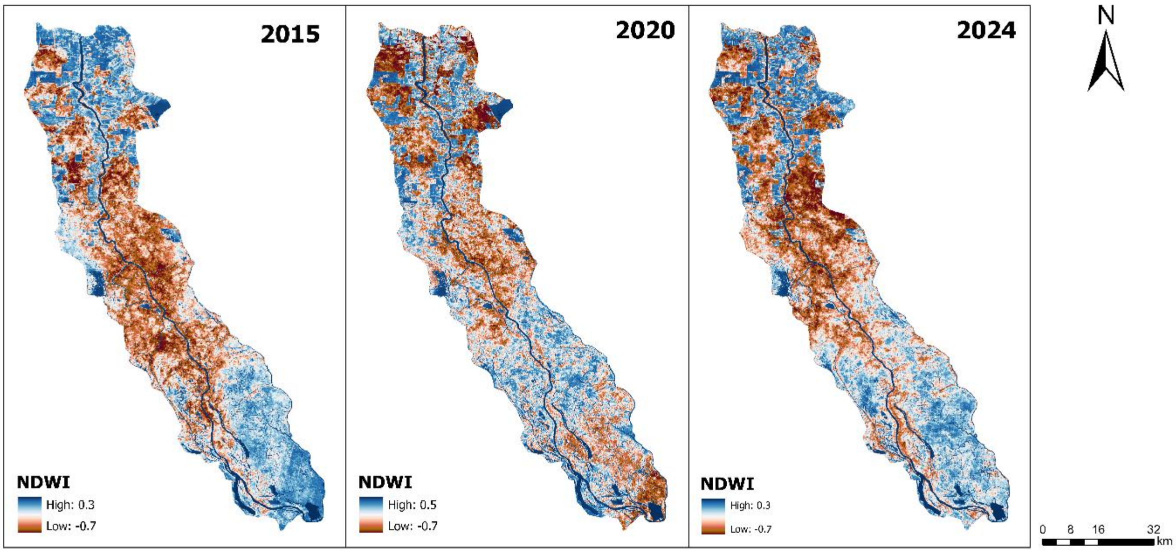

Figure 2: NDWI Mean Composite Maps (2015, 2020 & 2024)

hence oligotrophic. However, from the map, a few areas depicted in red colored pixels indicate relatively high TSI values above 25 µg/L. Comparing this observation to 2020, the basin recorded more medium levels of Chl-a presence with visibly red and yellow pixels indicating less presence of Chl-a in those areas. On the other hand, the year 2024 recorded higher Chl-a presence especially from the central to the southern part of the basin. A general observation from the three mean composite maps indicate that most parts of the river depicted by a thin strip of red pixels is an indication of high presence of Chl-a concentration.

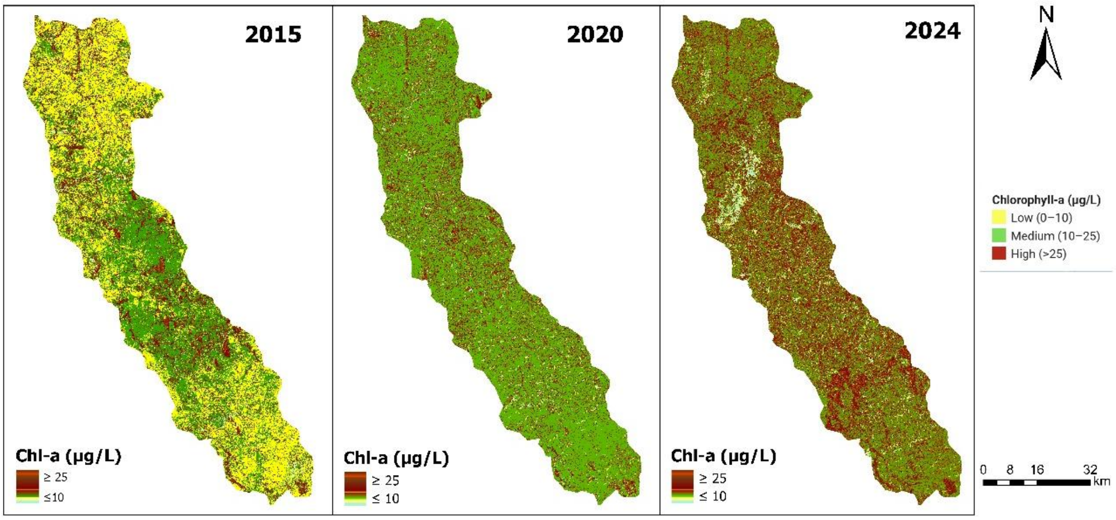

Figure 3: Chl-a Mean Composite Maps (2015, 2020 & 2024)

Eventhough the presence of algae could be a natural component of freshwater ecosystems, too much of these can result in decreased levels of dissolved oxygen, green scums and bad odor thereby reducing the quality of the water. In return, water quality degradation causes an increase in algal blooms and phytoplankton biomass (Twumasi, et al., 2024). According to the EPA, one of the symptoms of degraded water quality condition is the increase of algae and cyanobacteria biomass as measured by the concentration of chlorophyll-a (EPA, 2025). Waters with high levels of nutrients from fertilizers, septic systems, sewage treatment plants and urban runoff may have high concentrations of chlorophyll-a and excess amounts of algae and cyanobacteria (EPA, 2025).

3.3 Secchi Depth

The Secchi depth, also known as the Secchi disk depth, is a measure of water clarity and transparency. This parameter is essential because Water transparency is one of the key components describing the water quality and the productivity of natural waters (Alikas & Kratzer, 2017). Even though there is no comparable routine transparency measure used in streams, most articles have reported satellite-derived Secchi depth values which was used to derive table 3.

Secchi Depth (m)	Water Clarity Class	Interpretation
< 0.2	Very Low Clarity	Extremely Turbid Water
0.2 – 1.0	Low Clarity	Poor Transparency
1.0 – 2.0	Moderate Clarity	Intermediate Transparency
> 2.0	High Clarity	Relatively Clear Water

Table 3: Secchi Depth Values [(Liu, et al., 2019); (Zeng, et al., 2020)]

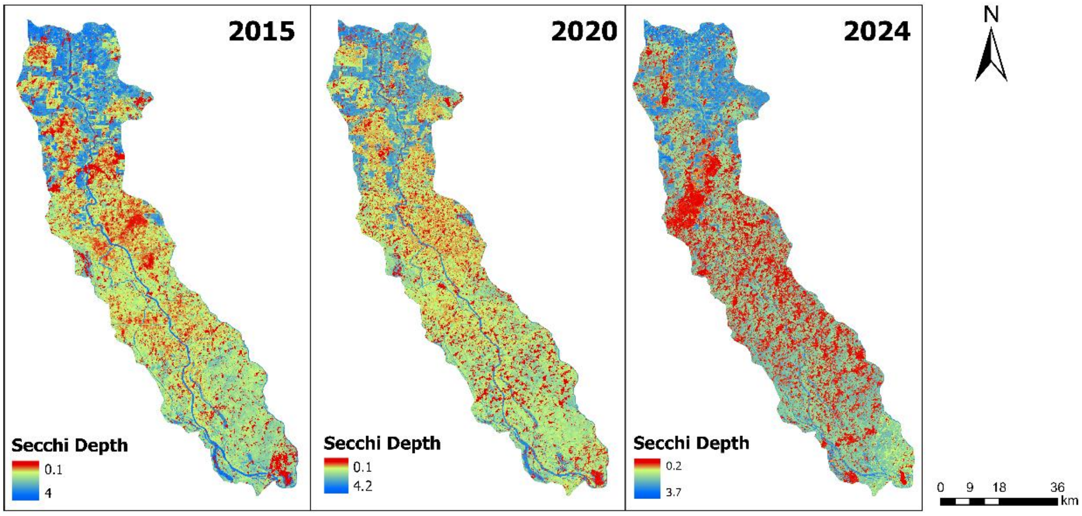

Figure 4: Secchi Depth Mean Composite Maps (2015, 2020 & 2024)

The Secchi Depth results for ARB ranged between 0.1 to 4.2m. In 2015, most of the northern parts of the basin recorded high water clarity values above 2m whereas most of the central part of the basin in figure 4 clearly shows very low water clarity of 0.1. Compared to 2020, the central parts of the basin that showed low water clarity recorded moderate clarity which is an improvement from 2015. By 2024, there is a sudden spread of low water clarity across the basin where the central parts down to the southern parts of the basin are showing lower clarity values of 0.2, similar to the Chl-a results, indicating an extremely turbid water.

Typically, for in-situ measurements, a white or black-and-white disc (diameter 20 to 30 cm) is commonly lowered into the water to measure water clarity (or transparency) of aquatic environments, and the depth at which it just disappears from a viewer at the surface is called the Secchi disk depth (Liu, et al., 2019). However, Liu et al., (2019) further opine that, even though this in-situ method can provide an accurate determination of Secchi depth values, this approach cannot provide data in a synoptic manner. Instead, satellite remote sensing is widely used to map the distribution of Secchi depth values over broad areas (Liu, et al., 2019). The Secchi depth is influenced by the three main optical components: chlorophyll-*a* (Chl-*a*), coloured dissolved organic matter (CDOM), and total suspended matter (TSM) (Alikas & Kratzer, 2017).

3.4 Turbidity

Spatiotemporal monitoring of turbidity is essential in water resource management and environmental protection of aquatic ecosystems. Wu et al., (2025) define turbidity as a comprehensive indicator of water scattering ability linearly related to the backscattering coefficient. That is, the cloudiness or haziness of a liquid caused by suspended particles that are inorganic, organic, biological, or anthropogenic, that scatter and absorb light (Alpha, 2025). Turbidity values are reported in nephelometric turbidity units (NTUs) or Secchi depths (in meters) depending on the method used for measurement (EPA, 2021). In this case, values below 1 NTU indicate low turbidity (clear water), values between 1–5 NTU indicate slight cloudiness, and values above 50 NTU ind icate very turbid conditions associated with high suspended sediment loads or runoff.

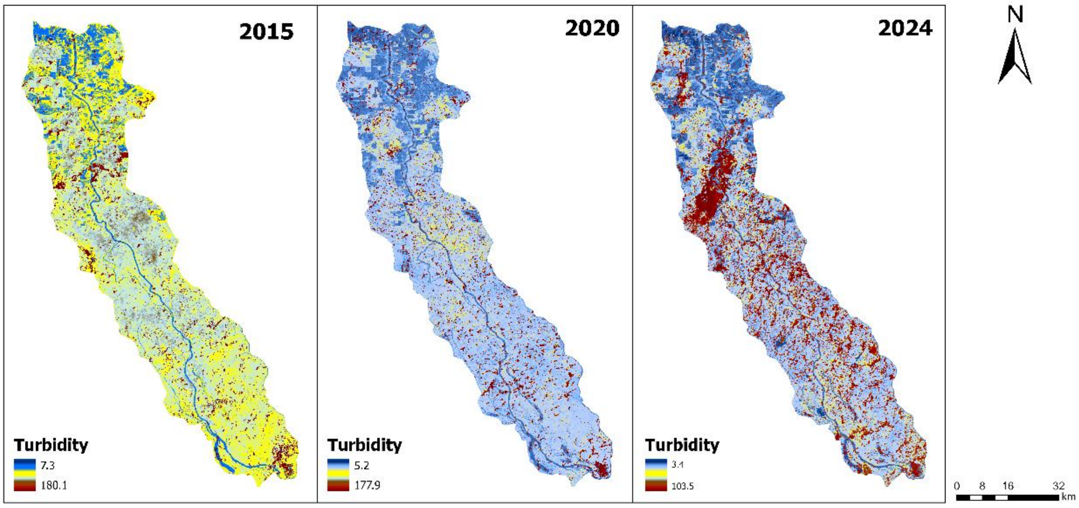

Figure 5: Turbidity Mean Composite Maps (2015, 2020 & 2024)

The turbidity results in figure 5 range between 3.4 to 180 NTU. In 2015 for instance, most parts of the northern basin were less turbid yet the highest turbidity value of 180 NTU was recorded. By 2020, lesser turbidity values of about 5.2 NTU were recorded indicating a clearer basin, and then in 2024, the turbidity values dropped even low to about 3.4 NTU. However, visually, the mean composite map of 2024 shows the spread of more turbid areas with a value of 103 NTU from the central to the southern areas within the basin, which aligns with the Chl-a and Secchi depth observations.

When the turbidity in water increases, the water becomes less transparent, thereby reducing the amount of light passing through it and vice versa. In terms of remote sensing, turbid water reflects more light due to increased light scattering by suspended particles whereas less turbid or clearer water absorbs more light and reflects less back to the sensor. This parameter matters because clarity is more than a visual characteristic, it reflects the chemical, physical, and biological conditions of a water body (Alpha, 2025).

Turbidity (NTU) Range	Water Quality Context
< 1	High Quality (Treated Drinking Water)
1 – 5	Normal conditions (Municipal Surface Water Sources)
10 – 50	Moderate Sediment (Rivers and Lakes)
50 – 200	Increased Turbidity (Stormwater & Runoff)
200+	Extremely Turbid (Wastewater/ Industrial Discharges)

Table 4: Typical NTU Ranges in Different Water Types

Overall, the ability to track water flow patterns by tracking turbid waters will enhance the characterization of water movement and aid in planning (Allen, et al., 2008).

4. RESTORATION EFFORTS IN THE ARB

The Nature Conservancy, a habitat restoration and preservation-focused nonprofit group, is working closely with the Department of Wildlife and Fisheries through the Sustainable Rivers Program to develop specific recommendations on how water levels and habitat can be better managed in the basin to improve fisheries, wildlife, and forests (Macaluso, 2025). The results of each processed parameter revealed the high presence of Chl-a and turbid situation of the basin in almost decade. Most parts of the basin are experiencing mud deposition which is filling up the surrounding lakes and bayous. As the river runs through the basin, the swamps face a paradox of water flow and sedimentation, whereby increased river flow through the basin to deliver sediments choke the lakes and bayous. On the other hand, when the river does not run into the backstamps, the sediments grow stagnant (Upholt, 2022) thereby reflecting turbid conditions as seen in the results. Based on this, the first efforts to save the basin were focused on stagnant water, especially by the Army Corps of Engineers. The basin was split into 13 "water management units," or WMUs, which could be individually managed so as to address issues of both mud accumulation and water quality (Upholt, 2022).

The Lower Atchafalaya Basin Floodway System (ABFS) is another restoration project that had six major goals, that is, to improve water quality, enhance fish and wildlife, and control sediment flow through water management, recreation, public access, environmental protection, flood control, and water circulation/canal closure (Inman, 2021). Among other recommendations are inundating the basin's floodplains early enough in the year and long enough for bass and sac-a-lait to successfully spawn. This intention is to draw down water in the early summer before high temperatures kill oxygen levels, and pulsing water through the Old River Control Structure into the Basin in the late summer to improve water quality (Macaluso, 2025).

Furthermore, The Nature Conservancy is also working to cultivate an enduring appreciation for the Atchafalaya River Basin for future generations. Through land acquisition, they have an opportunity to access more places to pursue on-the-ground monitoring and land stewardship. They are also working with local communities on cultivating a culture of restoration and with partners and scientists in the conservation and academic communities on exploring cutting-edge approaches to complex issues surrounding the conservation of such a vast and diverse swamp forest (TNC, 2025).

Notably, most of these projects are accompanied by remote sensing reflectance of surface water across Atchafalaya Basin to provide measurements that aid planning processes. For instance, hand-held spectrometer measurements were collected from a boat at 35 locations selected to represent a range of suspended sediment concentrations and properties from a variety of hydrodynamic and physical settings typically encountered across the Atchafalaya basin (Jensen, et al., 2020). These water management plans inform restoration efforts that seek to rejuvenate the basin's quality by identifying patterns of sedimentation, river flow, land loss and land gain.

5. CONCLUSION

By capturing the reflection, absorption, and scattering signals of solar radiation, this study examined the spatial distribution and temporal dynamics of key water quality parameters including Chlorophyll-a, Secchi Depth and Turbidity. Water quality dynamics in the Atchafalaya Basin were examined from 2015 to 2024 using high resolution Landsat 8 and 9 Surface Reflectance imagery. Results showed clear visual variability in chlorophyll-a concentration with low concentrations in 2015, representing oligotrophic conditions with relatively high water clarity. However, most parts of the basin exhibited moderate chlorophyll-a levels with localized patches of high chlorophyll-a distribution. By 2024, there was a pronounced increase and spatial expansion of chlorophyll-a concentrations exceeding 25 µg/L, particularly across the southern basin, classifying large portions of the water body as eutrophic reflecting high nutrient enrichment.

Although moderate improvements in water clarity were observed in 2015 and 2020 through the Secchi depth results, 2024 showed a widespread decline in transparency. The Secchi depth patterns closely aligned with the turbidity distribution which showed the central and southern parts of the basin in 2024 recorded low transparency as well as high turbidity. Despite the lower maximum turbidity value of 103 NTU in 2024, the spatial patterns revealed broader areas of elevated turbidity. This condition reflects the persistent mud deposition filling lakes and bayous, in which increased river flow delivers sediments that choke waterways thereby increasing turbid conditions throughout the basin.

In response to declining conditions in the basin, several restoration efforts led by The Nature Conservancy, in collaboration with the Louisiana Department of Wildlife and Fisheries and the U.S. Army Corps of Engineers, have focused on adaptive water management through the Sustainable Rivers Program. These efforts include the establishment of water management units to address localized sedimentation and water quality challenges, as well as implementation of the Atchafalaya Basin Floodway System to regulate sediment transport, improve water circulation, and enhance fish and wildlife habitat. Additional restoration strategies involve seasonal floodplain inundation, controlled drawdowns, and pulsed flows through the Old River Control Structure to improve oxygen levels and spawning conditions.

To establish the efficiency of leveraging remote sensing techniques in water resource management, the results have demonstrated that impacts on the Atchafalaya basin with its low-lying topography are not easily quantifiable without measuring the spectral reflectance of surface water. Additionally, restoration initiatives are increasingly supported by remote sensing and field-based spectral measurements, which provide critical data for tracking sediment dynamics, water quality trends, and restoration outcomes. This reinforces the role of integrated monitoring approaches in guiding long-term ecological resilience and sustainable management of the Atchafalaya Basin. Overall, the flow of water and the retrieval of parameters including chlorophyll-a, suspended particulate matter (SPM) and turbidity are critical to evaluating the ecological health of the Atchafalaya basin. These are essential indicators of pollution levels, ecosystem productivity, and broader environmental conditions that inform water resource management decisions.

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