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Short-Term Sentinel-2 Spectral Signature Characterization for Suspended Sediment Assessment in Low-Turbidity Shatt Al-Hilla River, Iraq

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Abstract

Monitoring Suspended Sediment Concentration (SSC) is vital for water resource management, yet traditional methods face logistical challenges. This study evaluates Sentinel-2 imagery's efficiency in monitoring low-turbidity rivers, specifically Shatt Al-Hilla, Iraq. The methodology synchronized *in-situ* sampling from 30 inspection points (ranging from 8.9 to 20 mg/L) with Sentinel-2 data on February 1, 2026. A comprehensive analysis was conducted using SNAP software to correlate field SSC with the related spectral bands and indices. The analytical and statistical results revealed that a second-degree polynomial model using the red/green ratio and NDTI index provided the strongest statistical correlation, achieving an R^2 of 95.46% and 94.68% with a low RMSE of 0.51 and 0.56 mg/L, respectively. These results underscore remote sensing's ability to predict the suspended sediment concentrations in the river, distinguish between organic and mineral sediments with the aid of the other indices, and highlight Sentinel-2's effectiveness as a precise, data-driven alternative for monitoring water quality in low-turbidity environments, overcoming the limitations of traditional field-based assessments.

Keywords: Spectral Signature, Sentinel-2, Suspended Sediment Concentration, Low-Turbidity Rivers, Shatt Al-Hilla.

1. Introduction

The Shatt al-Hilla River, as it is locally known in Iraq, is the main source of fresh water that is essential for sustaining vital activities associated with it (Dinar et al., 2025). Suspended sediment concentration (SSC) consists of organic materials such as algae and detritus and inorganic mineral materials like silt, clay, and sand (Olivetti et al., 2025). The presence of these materials has significantly degraded the water quality, river morphology, and flow hydraulics, increasing the maintenance costs (Al-Qaisi et al., 2025; Igbozurike et al., 2025); this necessitates regular monitoring of water quality in rivers like Shatt Al-Hilla to maintain its suitability and adequacy for various uses (Efthimiou, 2025). Although the traditional estimation methods are considered accurate (Kim et al., 2025), they have many limitations: they are time-consuming, costly, limited both spatially and temporally, and require intensive labor (Ayyad et al., 2025). This is where remote sensing technologies come in as a modern alternative to conventional methods, providing a comprehensive monitoring technique to assess the SSC in rivers (Hasab et al., 2020; Nones &

Guo, 2025). Sentinel-2 satellites (S2A, S2B, and S2C), carrying the MSI (Multispectral Instrument) sensor, are undertaken by the European Space Agency (ESA) for Earth monitoring with a high spatial resolution of 10 m for bands B2, B3, B4, and B8; in addition to the high temporal resolution, this makes them an ideal choice for monitoring rivers, especially those of small width cross-section (Rivoire et al., 2025).

Despite the progress in remote sensing for monitoring low-turbidity rivers, there are still challenges like the low signal-to-noise ratio; it is difficult to separate water signals from bed reflectance, especially in dry seasons when the depth of water becomes shallow (H. Chen et al., 2025). Furthermore, there is a lack of studies that deal with the creation and analysis of spectral signatures, particularly with Shatt Al-Hilla.

Therefore, the primary objective of this study is to create a one-day unified spectral signature specified for Shatt Al-Hilla derived from the Sentinel-2C (S2C) satellite on 1 February 2026 as a dependable baseline for future studies. Furthermore, a comprehensive analysis of its spectral-related bands and indices is to be conducted in light of the field-measured SSC values, assessing the suspended sediments and turbidity levels and status, whether of mineral or organic origin, in addition to concluding whether remote sensing technologies are suitable for low-turbidity rivers like Shatt Al-Hilla monitoring by conducting the required statistical operations to explore that. This study aims, likewise, to provide a basic environment and tools that can be relied upon in the future by researchers and institutions interested in both the environmental and hydraulic aspects of Shatt Al-Hilla water quality, utilizing a more comprehensive time period and enabling the performance of full monitoring of the river water quality without resorting to the field methods whose drawbacks were mentioned previously.

2. Methodology

2.1 Study Area

Shatt Al-Hilla is one of the main branches of the Euphrates, which is located within the Babylon governorate in the middle part of the country (Jasim et al., 2025). It initiates upstream of the Al-Hindiya Barrage, which regulates its flow. Its own head regulator is located at 44°16'4.29"E, 32°43'41.42"N (GCS WGS 1984) up to the diversion of the Shatt Al-Diwaniya and Daghara Rivers for a length of about 98 km in a meandering course (Majed & Abed, 2025). The river is characterized by paramount hydraulic and strategic importance; it is regarded as the main artery feeding water to many cities and towns for agricultural, industrial, and municipal usage. In addition, it is conveying water to provide many water supply plants located in the Babylon as well as the Diwaniya Governorates, which supplies them with drinking water (Al-Yaseen et al., 2025). The river passage through urban, industrial, and agricultural locations and its water quality are affected by different types of pollutants such as domestic and industrial sewage and surface runoff; they have many consequences like eutrophication affecting the light reflectance and the spectral signature (Alsultani & Talib Fahad, 2025).

The study area (Euphrates River zone), illustrated with details in Figure 1 and Table 1 in the appendix, has climates characterized as arid to semi-arid (Abbas & Hamza, 2025), with a relatively stable riverine environment distinguished by low to medium turbidity where the Euphrates has no tributaries compared with the Tigris River (the other main river in Iraq), which has many tributary rivers supplying water to it; therefore, the optical characteristics of

river water are affected by the seasonal variation of the water levels according to the seasonal fluctuation of discharges passing in, leading to temporary fluctuation in the turbidity (Stahl, 2026). This should be taken into consideration for spectral signature creation.

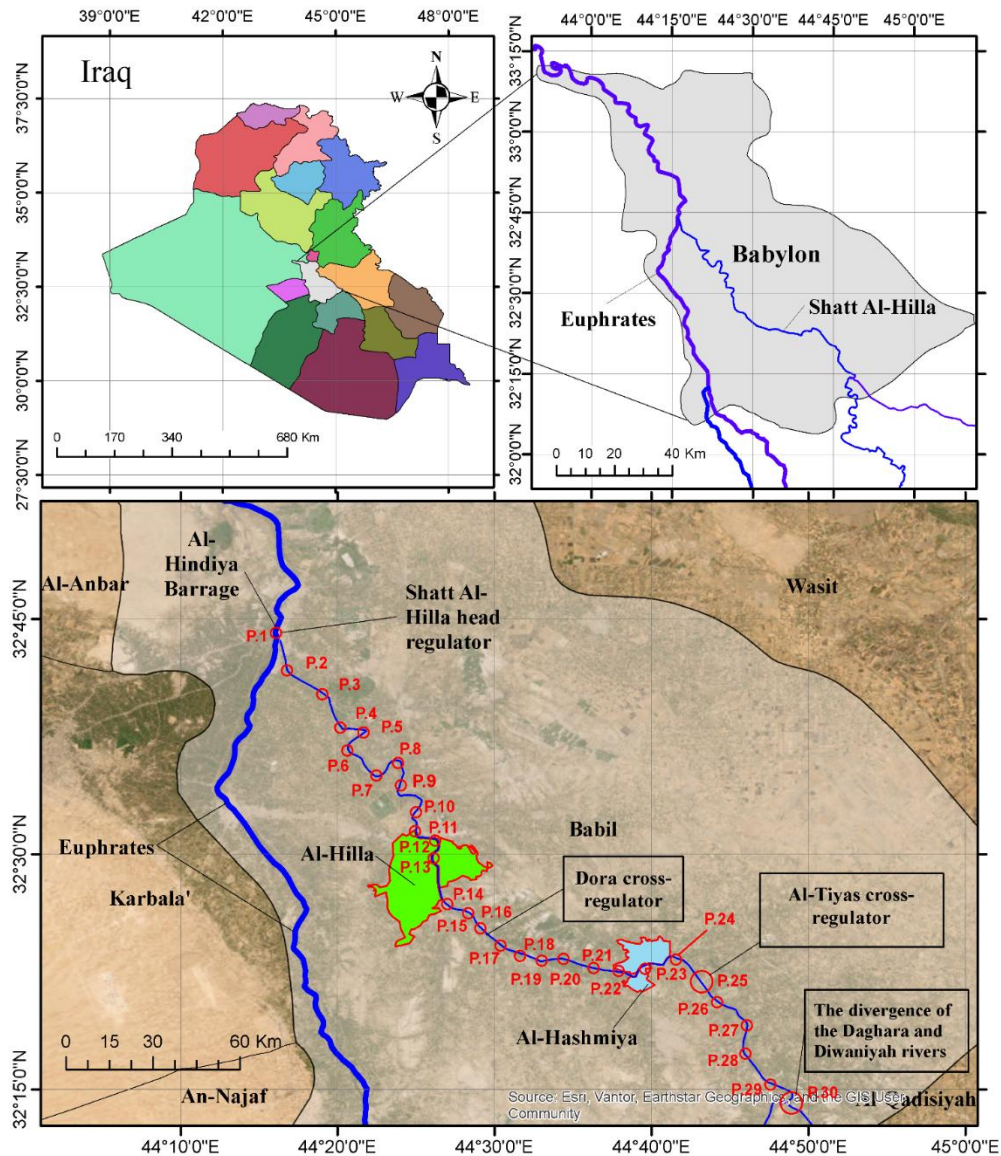


Figure 1. Geographic location of the study area with main features and inspection points along the Shatt Al-Hilla River's length.
(Source: Esri, Digital Globe, coordinate system: GCS WGS 1984).

2.2 Data Collection

The data collection process consists of three parts: Date and weather pre-suitability checking before collecting field data, testing the previously checked *in-situ* collected samples, and collecting synchronized satellite images.

2.2.1 Satellite Images Date and Weather Suitability

Confirming any satellite visiting date and time and cloud-free satellite imagery should be assessed before in situ sampling. Weather conditions for the inspection date, from the Copernicus Sentinels Official Website—Sentinel-2 Acquisition Plans, are used to predetermine the locations and dates of satellite observations for the study area

(Sentinel Online, 2026), as well as cross-referenced using the Meteoblue meteorological platform (Meteoblue AG, 2026). The multimodal forecast confirmed a complete decrease in cloud cover during the Sentinel-2 overpass time.

2.2.2 Field Samples: Collecting and Testing

Tempo-spatially synchronal water samples with satellite images are to be collected according to U.S. Geological Survey (USGS) guidelines for fluvial sediment sampling at each selected point by the approved DH-48 sampling apparatus (Brown et al., 2025). Each sample of 1000 ml is to be kept according to ISO 5667-3 in a clean glass bottle and transported to the laboratory for testing. The testing method was done according to ASTM D3977 guidelines by vacuum filtration and the drying method using 1.2-micron glass-sized filter paper, and the resulting SSC is computed in mg/L (Yunus et al., 2025).

2.2.3 Satellite Images Collection

One-day unified spectral signature creation for Shatt Al-Hilla on a specified day and at specified locations obliges synchronized images from any of the Sentinel-2 satellites (S2A, S2B, and S2C) with multispectral instrument (MSI) sensors (Tejjido-Murias et al., 2025). The Copernicus browser is a source for level-2A ready-to-use using Sen2Core (Official Atmospheric Correction Processor for Sentinel-2) algorithms (*Copernicus Browser*, 2026). Sentinel-2 satellites are chosen due to their high spatial resolution, reaching 10 m in the main bands to cover the narrow widths of the river in some places. It must download images after checking for their validity against clouds; the high percentage of clouds can damage the selected images and make them unusable (Su et al., 2025). The synchronization of captured images with field inspection points, both temporally and spatially, must be ensured. The extracted bands must be resampled to verify the unification of bands of different resolutions by SNAP desktop software (SO & YOKOTA, 2026).

2.3 Spectral Bands

SSC-related spectral reflectance blue (B2), green (B3), red (B4), red-edge (B5), and near-infrared (NIR) (B8) bands, which are the reflected electromagnetic energy with specific wavelengths captured by satellite sensors, are used to build the SSC spectral signature for a river on a specified day (White, 2026). These bands are to be calculated using SNAP desktop version 13.0.0 supported by ESA (Ng-Cutipa et al., 2025). The spectral bands required to build the SSC spectral signature are explained in detail in Table 1 below.

Band name	Band ID	Central wavelength (nm)	Spatial resolution (m)	Typical application
Blue band	B2	490	10	Water penetration, soil/vegetation discrimination
Green band	B3	560	10	Vegetation health, water turbidity
Red band	B4	665	10	Chlorophyll absorption, vegetation stress
Red edge	B5	705	20	Sensitive to chlorophyll content, vegetation monitoring
NIR	B8	842	10	Biomass, vegetation vigor, water/soil studies

Table 1. Spectral characteristics and typical applications of the selected Sentinel-2 MSI bands related to SSC (SENTINEL-2 User Handbook, 2013).

2.4 Spectral Indices

Spectral indices are mathematical combinations collecting two or more distinct spectral bands (Kourounioti et al., 2025); they are calculated using SNAP desktop (MECA et al., 2025) and utilized to extract specific information to enhance the response of a particular substance, such as chlorophyll or sediments in water, and suppress the effect of other backgrounds, such as soil sheen, shadows, or atmosphere (Luo et al., 2025). In order to make a comprehensive analysis of the SSC in Shatt Al-Hilla, the following indices were adopted:

- A. NDWI (Normalized Difference Water Index): Utilized to distinguish between water and land by remote sensing. Its value ranges from -1 for water saturated with sediments or vegetation cover to 1 for clear and/or deep water (Shaimaa et al., n.d.; Yadav et al., 2025). It can be calculated by the formula proposed by McFeeters (Shaimaa et al., n.d.; Xue et al., 2025):

$$NDWI = \frac{B_3 - B_8}{B_3 + B_8} \quad (1)$$

- B. NDTI (Normalized Difference Turbidity Index), utilized essentially to estimate the turbidity in river water by remote sensing, ranges between 1 to characterize high turbidity water and -1 for clear water or low turbidity (Joshi et al., 2026); it can be calculated by (Yépez et al., 2024):

$$NDTI = \frac{B_4 - B_3}{B_4 + B_3} \quad (2)$$

- C. NDVI (Normalized Difference Vegetation Index), utilized essentially to estimate the vegetation cover, such as the Eichhornia plant in rivers as an example, ranges between 1, which characterizes high vegetative water, and -1 for watershed or ice areas (Wang et al., 2026). It can be calculated by (Nazhifah et al., 2025):

$$NDVI = \frac{B_8 - B_4}{B_8 + B_4} \quad (3)$$

- D. Red/green ratio: It is direct physical information utilized essentially to estimate turbidity, distinguishing water and vegetation cover and water quality monitoring; the positive values indicate turbid water, while negative values indicate low-turbidity water (Feng & He, 2025). It can be calculated as follows (Wright, 2018):

$$\frac{Red}{Green} = \frac{B_4}{B_3} \quad (4)$$

- E. NDSSI (Normalized Difference Suspended Sediment Index) is utilized essentially to estimate SSC, water quality control, and sediment dynamics in rivers studied by remote sensing, supporting water resources management, in addition to reducing the bottom effect. Its value ranges between 1, characterizing high SSC in water, and -1 for clear water (Rajendran et al., 2023a). NDSSI can be calculated by (dos Santos et al., 2023):

$$NDSSI = \frac{B_2 - B_8}{B_2 + B_8} \quad (5)$$

- F. NDCI (Normalized Difference Chlorophyll Index) is utilized essentially to estimate chlorophyll-A in river water and consequently algae bloom and water quality; in addition, it is useful for biological noise isolation. Its value ranging between 1 characterizes high chlorophyll in water, and -1 illustrates clear water or high inorganic turbidity (Tahmasebi et al., 2024). NDCI can be calculated by (Altuntas et al., 2025):

$$NDCI = \frac{B_5 - B_4}{B_5 + B_4} \quad (6)$$

Despite the fact that the red/green ratio and NDTI are built of the same bands (B3, B4), calculating both of them is not considered a repetition, but it is necessary to validate the results; the red/green ratio is very sensitive for

low SSC values, and NDTI describes the general state of the river, while the red/green ratio gives an analysis of how close or far B3 and B4 are from each other (Abraham et al., 2025).

2.5 The SSC Spectral Signature

It is defined by the unique relation constructed between the wavelength central values measured in nanometers and the percentage surface reflectance of water. In the ideal case, clear water absorbs almost all electromagnetic rays, especially in long wavelengths (infrared rays), while it reflects light in short wavelengths (blue and green). Spectral signature construction for a river has many advantages; it can be summarized by identifying the pollutant and turbidity type, spatial and temporal observation of the river's water quality, calibration of field measuring instruments, and derivation of spectral indices (Knight & Abd Elbasit, 2022).

2.6 Pre-processing

Sentinel-2 level 2-A images captured at the specified date must be prepared before the required spectral bands are to be calculated; it consists of two images, A and B, to cover the whole length of the river. First, image resampling is conducted to unify the spatial resolution of all spectral bands to 10 m for each image, ensuring pixel alignment across different wavelengths for accurate band math operations (Soares et al., 2025). Consequently, the two resampled images should be combined together by the mosaicing process if it is required, which is necessary to ensure the radiometric normalization and feathering/blending of the images. Moreover, the resampled large area images preferred to have the required study area cropped to reduce the data size and facilitate the processing process, and focusing on the required area is done easily by the spatial subsetting process (Martínez-Ruedas et al., 2025). Furthermore, land/water masking may be needed to solve the “Mixed Pixels” problem in narrow top widths where the pixels of land and water are mixed by the MNDWI index (Girma et al., 2025).

2.7 SSC Spectral Signature Extraction

All the spectral bands required for SSC spectral signature construction noted in Table 1 are extracted from the SNAP (X. Chen et al., 2025). Their associated spectral indices mentioned in section 2.4 and calculated by Equations 1 to 6 are used to interpret the signature.

2.8 Single-Day Sampling Strategy

The rationale for adopting a single-day synchronous approach (February 1, 2026) was to minimize environmental and radiometric uncertainties that typically arise from multi-temporal datasets (Karmoude et al., 2025). In low-turbidity fluvial systems, optical properties are highly sensitive to seasonal variations in solar zenith angles and atmospheric water vapor. By focusing on a single, cloud-free satellite overpass perfectly synchronized with high-density field sampling (30 points), we effectively controlled these external variables. This strategy ensured that the derived spectral reflectance is a direct function of the Suspended Sediment Concentration (SSC) rather than a manifestation of seasonal atmospheric fluctuations or changes in bottom-reflectance interference, which is critical for establishing a high-precision baseline for low-turbidity water bodies (Zhou et al., 2023).

2.9 Statistical Validation

To assess the precision and strength of the developed SSC models and relations, a rigorous statistical validation was performed using the Coefficient of Determination (R^2) and the Root Mean Square Error (RMSE). While R^2 was utilized to evaluate the strength and proportion of variance explained by the regression models, RMSE provided a direct physical measure of prediction accuracy in mg/L, representing the deviation between satellite-derived estimates and *in-situ* observations. This dual-metric approach ensures a robust evaluation of model reliability, confirming the effectiveness of the selected spectral indices in accurately quantifying suspended sediment concentrations in low-turbidity river environments (Deus, 2025).

3. Results and Discussion

This section presents the development of a unique, one-day unified spectral signature for Shatt Al-Hilla, derived from the integration of *in-situ* measurements and synchronized Sentinel-2C reflectance data. By analyzing the spectral response of twenty training points, evaluate the sensor's capability to detect low-turbidity variations. Furthermore, a scientific characterization of the observed sediment types is provided to validate the sensitivity of the satellite-derived reflectance to the physical properties of the river's suspended load.

3.1 Field Measurements

The field measured SSC data resulting from collecting and laboratory examining the river water samples of the thirty specified inspection points detailed in Table 1 in Appendix section on 1 February 2026 and previously verified the visiting time and the cloud ratio to ensure the synchronization and acceptability of Sentinel-2C imagery extraction are graphically represented in Figure 2, and all details are formulated numerically in Table 2 in the Appendix section.

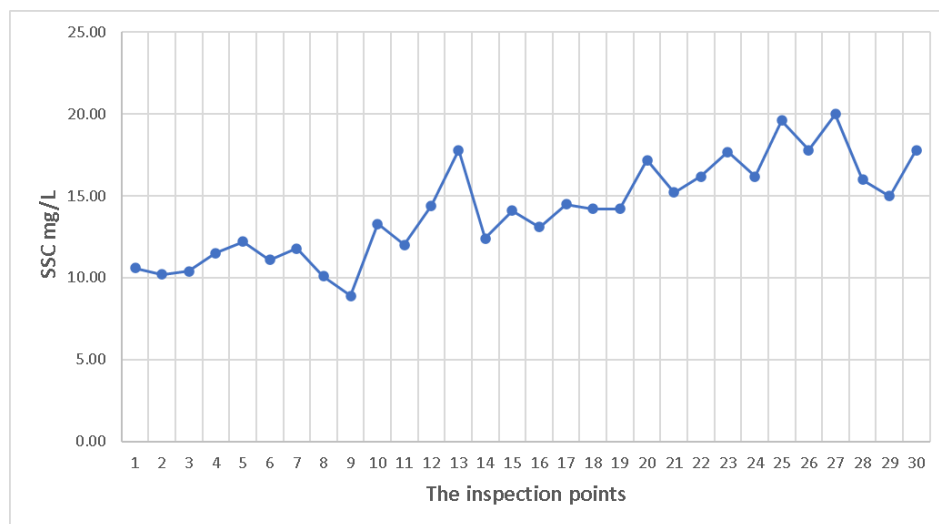


Figure 2. Field-measured SSC levels on 1 February 2026 for all inspection points

Generally, Figure 1 illustrates the gradual rise of SSC down the river length; although there is the presence of some oscillations, the overall trend shows an observed increase of SSC levels as we progress through the checkpoints, reflecting the accumulation of SSC or the environmental changes that are affecting the SSC.

Points 4, 5, 6, 14, 16, 21, 23, 26, 28, and 30 are selected as testing points, while the others are used as training points. Point 15 has the values of P15A mentioned in Table 2 in the Appendix, which is selected rather than P.15B due to a lower cloud ratio.

3.2 SSC Related Spectral Bands and Indices

SSC-related spectral bands and indices analysis on 1 February 2026 results are graphically represented in Figures 3 and 4 and numerically listed in Table 2 in the Appendix. They were extracted by SNAP Desktop 13.0.0 from two images, A and B, Figure 1 in Appendix, downloaded by the add-on of Copernicus Browser covering the area of study based on S2C on the specified date. P14 has been excluded, which has a negative B2 value; it is physically not real; they usually arise from atmospheric correction artifacts (overcorrection). In addition, P.13 is excluded too to conform to the consistency of the model due to abnormal behavior (outlier), where it has a positive NDSSI while the other points have negative values and its spectral bands are characterized by low values, referring to abnormal reflectance or some measurement error. Finally, the thirty inspection points after the exclusion of P13 and P14 become 28 points; they are divided into 19 for training and 9 for testing (P4, 5, 6, 16, 21, 23, 26, 28, and 30). All their spectral bands and indices are shown in Figures 3 and 4.

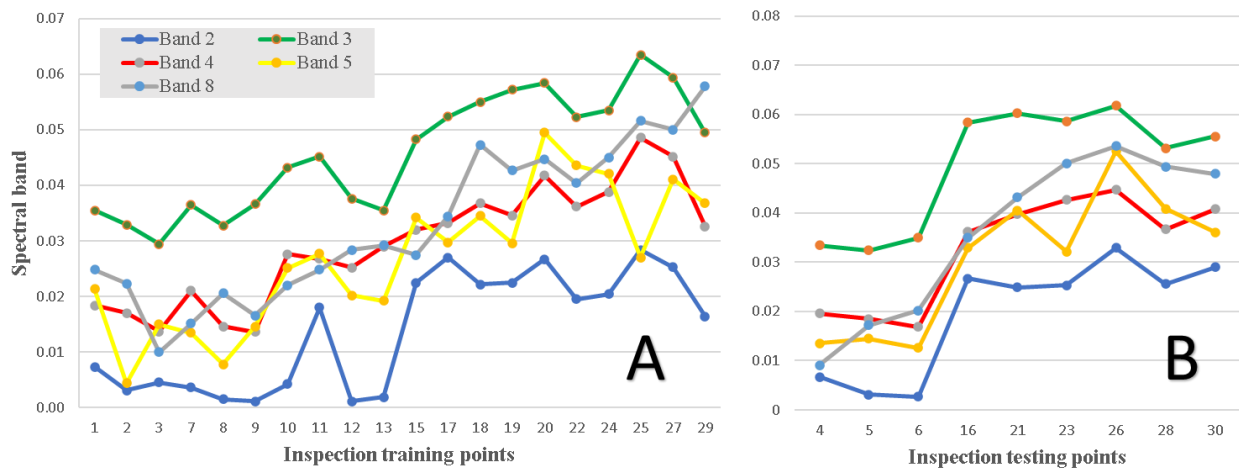


Figure 3. The spectral bands for (A) the training points, (B) the testing points

Figure 3 reveals that the reflectance in the blue band clearly shows the lowest values compared with the others; in contrast, the green band recorded the higher reflectance, while bands 4, 5, and 8 lie with intermediate values.

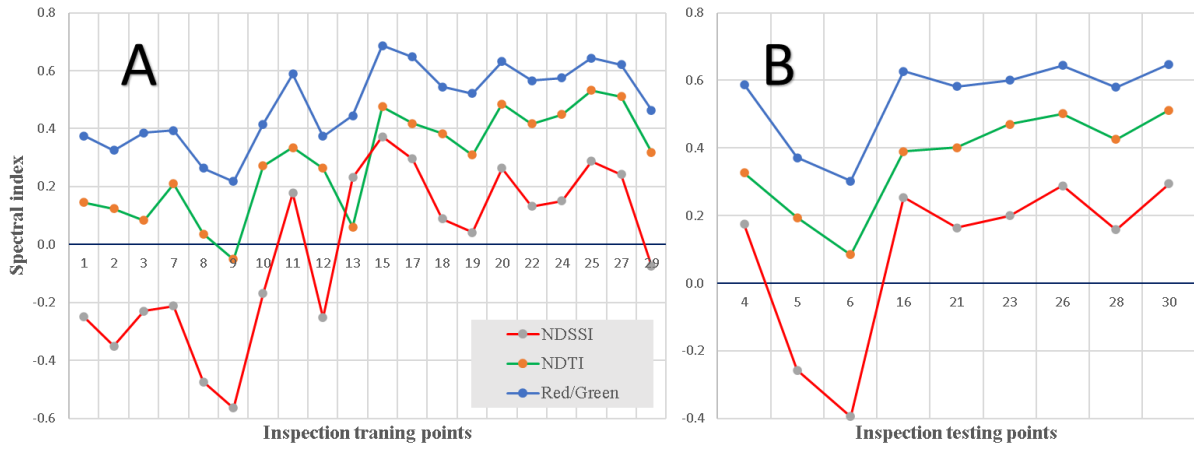


Figure 4. The SSC-related spectral indices for (A) the training points and (B) the testing points

Figure 4 shows the three SSC-related spectral indices for the inspection points; the red/green index recorded the higher values compared with the others. The NDTI and NDSSSI indices show an oscillation about zero with negative and positive values, reflecting their sensitivity to spectral changes. Comparing the testing and training values, the general trends are similar, referring to the consistency of behavior between the two groups.

3.3 Comprehensive Statistical Validation

The measured field SSC data of the nineteen training points along Shatt Al-Hilla that were plotted against the synchronized spectral bands B2, B3, B4, B5, and B8 gained from the Sentinel-2C imagery by SNAP desktop that dated to 1 February 2026; these plotted relations can be statistically checked by evaluating the coefficient of determination (R^2) for them as shown in Figure 5.

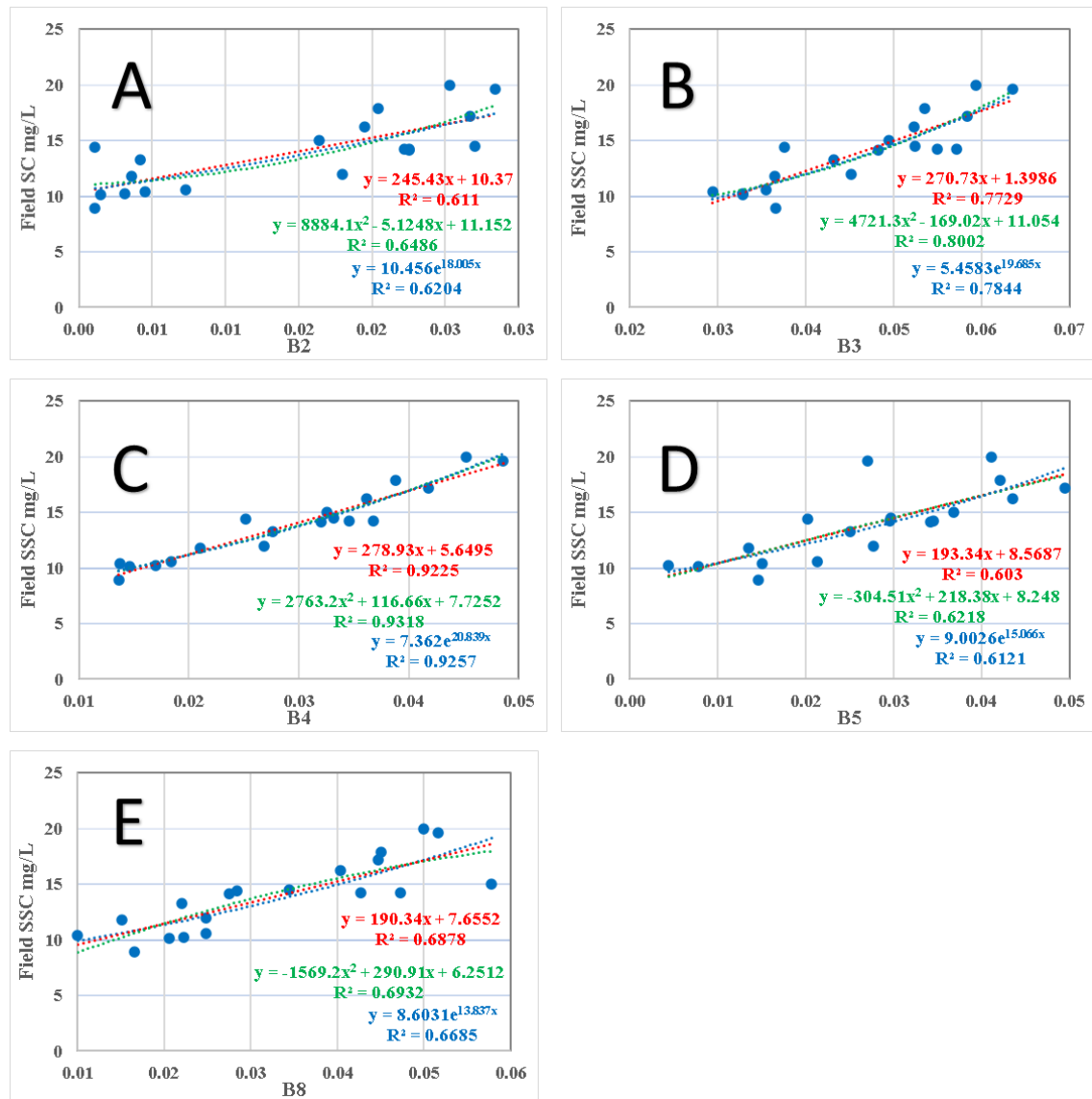


Figure 5. The Field SSC versus spectral bands: (A) blue band, (B) green band, (C) red band, (D) red-edge band, (E) NIR band, for the nineteen training points

Figure 5. Three relations examined, linear, second-degree polynomial, and exponential for each band, illustrate the highest correlation between SSC and light reflectance in the red (B4) and green bands (B3) of R^2 equal to 93.18% and 80.02% of the second-degree polynomial, respectively, for the nineteen training points; thus, B4 and B5 have a high correlation accuracy with field-measured SSC, while the other bands have a lower correlation and lower activity of SSC changes' explanation in Shatt Al-Hilla.

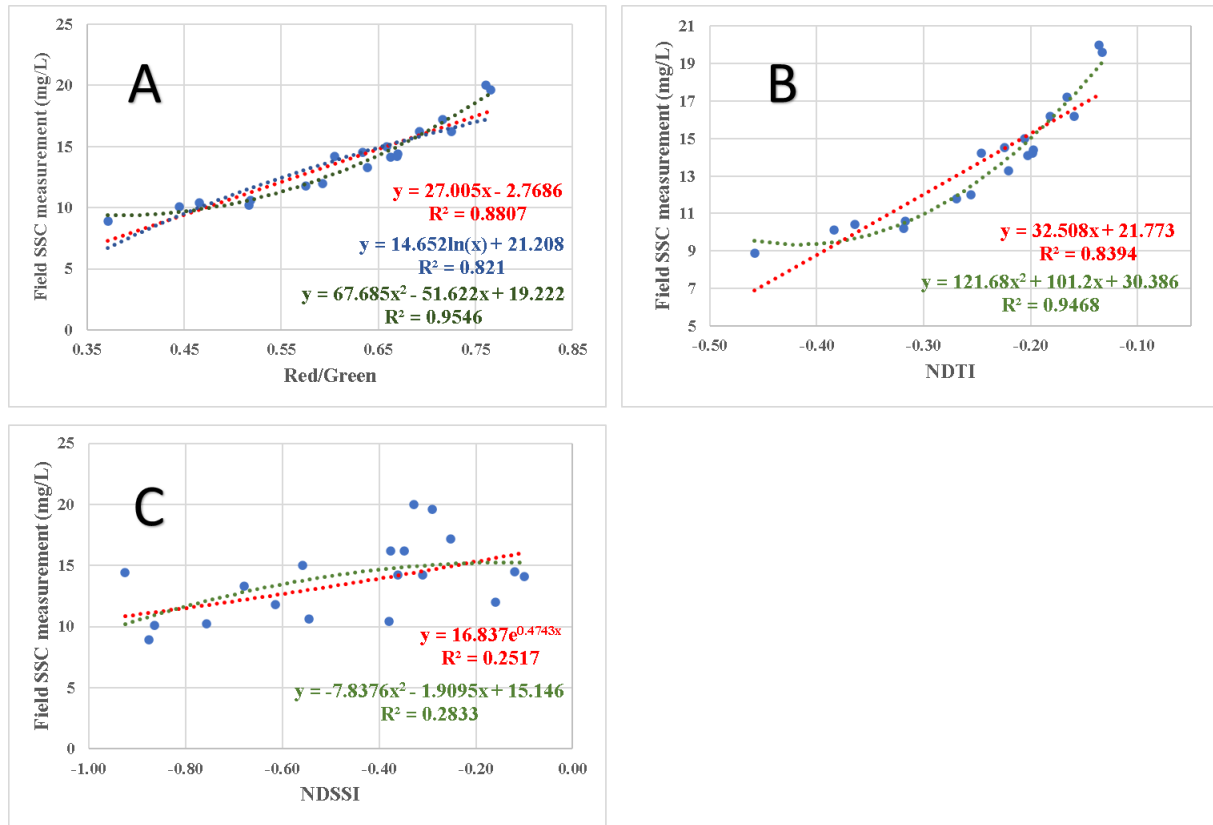


Figure 6. The field-measured SSC versus spectral SSC-related indices: (A) red/green index, (B) NDTI index, (C) NDSSI index, for the nineteen training points

Figure 6 shows the best correlation of the red/green index with the field-measured data of R^2 equal to 95.46% and 94.68% of the second-degree polynomial for the red/green and NDTI indices, respectively, for the nineteen training points, revealing their sensitivity in Shatt Al-Hilla, while the NDSSI, which has an R^2 lower than 30%, shows its weakness in SSC prediction. No exponential relations are used for NDTI and NDSSI due to their negative values.

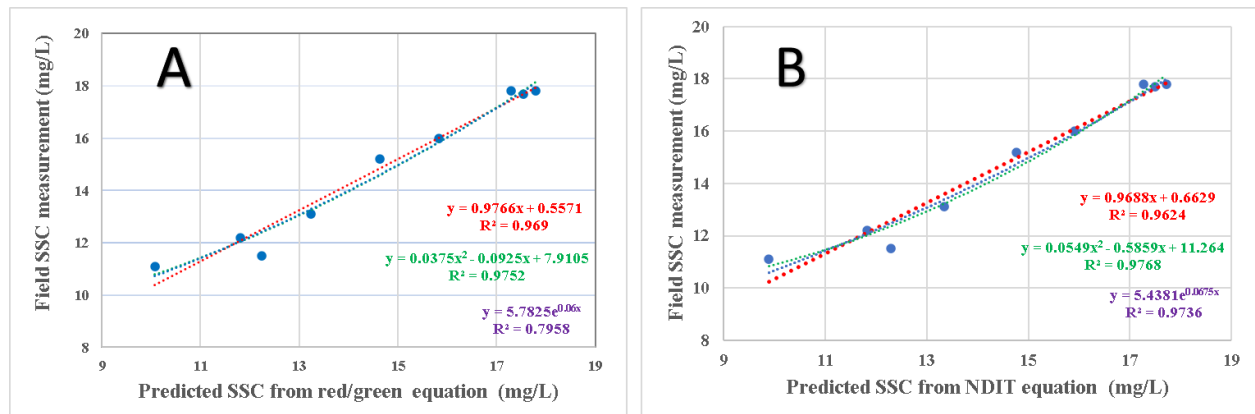


Figure 7. The correlation models in (A) red/green and (B) NDTI demonstrate that the R^2 of the second-degree polynomials are 97.52% and 97.68%

The two diagrams in Figure 7 compare the predicted values of SSC and the measured SSC field values for the nine testing points using three different relations, linear, exponential, and second-degree polynomial, and evaluate RMSE for each relation. The details are mentioned in Table 3 in the Appendix. The correlation in (A) red/green and

(B) NDT The R^2 of second-degree polynomial are 97.52% and 97.68%, respectively revealing that the developed models are the most suitable and precise to represent the SSC levels for the testing points in Shatt Al-Hilla. At the measuring date, the RMSE of the two correlations are 0.51 and 0.56, , respectively, indicating that the red/green has a lower deviation than the others. The superiority of the second-degree polynomial in the Red/Green and NDTI models suggests a non-linear interaction between water surface reflectance and suspended particles, which is typical in low-turbidity environments where backscattering reaches a saturation point differently across the spectrum.

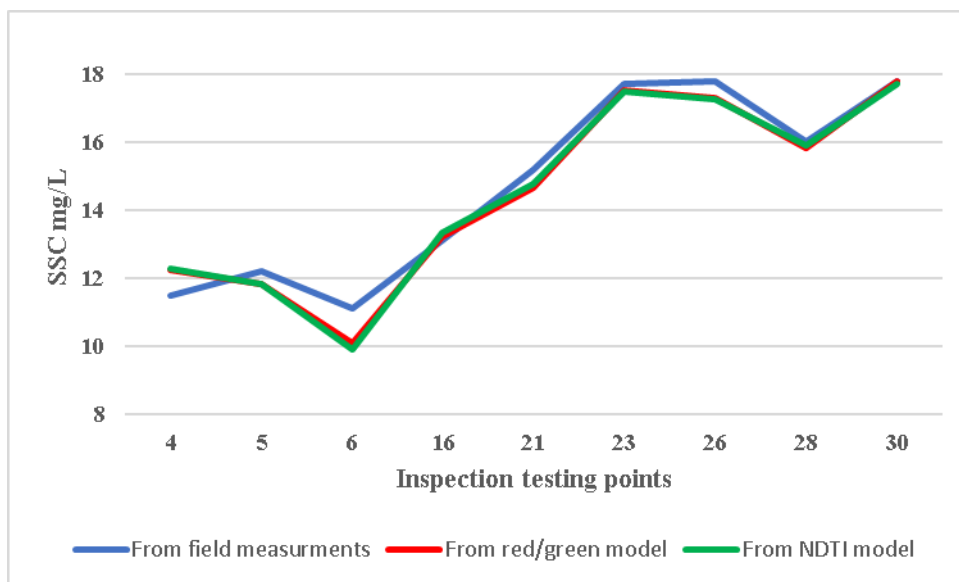


Figure 8. The SSC values at each testing points for the measured at field in blue, predicted values extracted from the red/green ratio second-degree polynomial equation from Figure 6 (A), and predicted values extracted from the NDTI second-degree polynomial equation from Figure 6 (B)

Figure 8 examining the SSC in the nine testing points reveals the matching with RMSE of 0.52 and 0.56 mg/L for between the the field measured data and the predicted data utilizing the second degree polynomial equations in Figure 6 (A) and (B) respectively, that matching with low RMSE indicates the success of both red/green ratio and NDTI to represent the SSC status in Shatt Al-Hilla.

3.4 One-day Unified Spectral Signature Creation

The one-day unified spectral signature for Shatt Al-Hilla was constructed by averaging the surface reflectance values of the 28 synchronized inspection points captured by the S2C satellite on February 1, 2026. The results revealed that the average SSC for the river was 14.71 mg/L, which was established as a reliable radiometric baseline for its low-turbidity state. This baseline serves as a standardized physical reference that can be applied to any geographic point along the river's course using the same spectral analysis protocol. By establishing this reference, researchers and environmental agencies can monitor future deviations in water quality or sediment loading by matching real-time spectral responses to this baseline, significantly reducing the necessity for intensive and costly field-based laboratory testing.

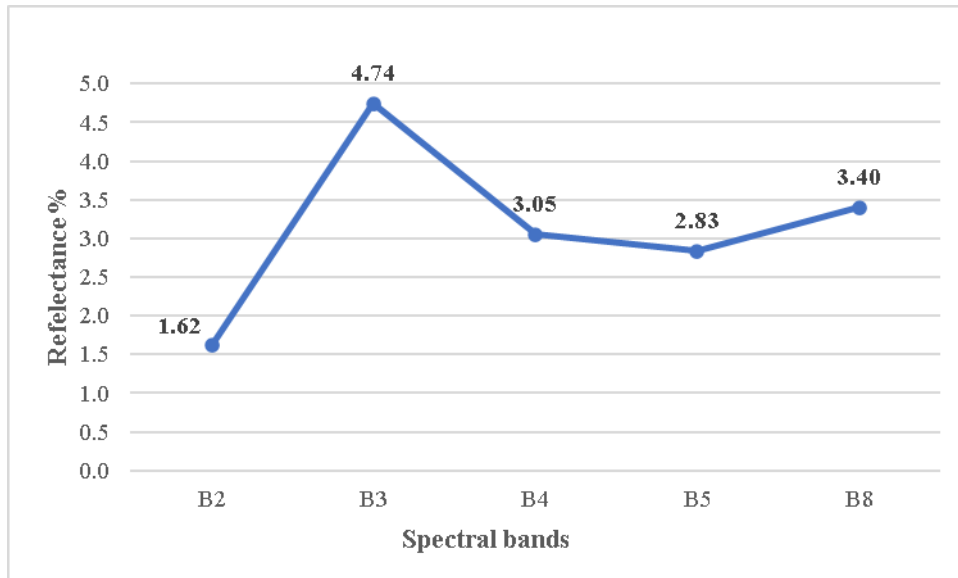


Figure 9. Unified spectral signature of Shatt Al-Hilla for the inspected points on 1 February 2026.

The unified spectral signature in Figure 9 reveals the variance in reflectance between bands; the green band (B3) has the maximum reflectance of 4.74% referring to signal intensity at this wavelength, than the other bands in Shatt Al-Hilla. The spectral indices for this signature are NDWI, NDTI, NDVI, RED/GREEN, NDSSI, and NDCI are 0.1646, -0.2169, 0.0543, 0.6435, -0.3546, and -0.03742 respectively evaluated according the equations 1 to 6.

3.5 Unified Spectral Signature Analysis

The analysis of unified spectral signature shown in Figure 7 can be analyzed as follows:

- 1- Blue band (B2-1.62%): the low reflectance of light in that band is attributed to the absorption by the presence of known colored dissolved organic materials and non-algal particles (NAP) or detritus, which have high absorption coefficients at shorter wavelengths (blue). In addition, chlorophyll-a has a high absorption at that band (about 430-490 nm). It is necessary to know that in the blue band the clear water shows a high reflectance of blue light.
- 2- Green band (B3-4.74%) peak reflectance: in that band (central wavelength of 560 nm), the absorption is significantly minimized due to clear water or the presence of colored dissolved organic materials (CDOM) and chlorophyll; in contrast, the backscattering will rise due to tiny suspended materials (sediments). This difference between low absorption and high scattering creates this noticeable peak; that behavior is typical in water that contains low to medium turbidity.
- 3- Red band (B4-3.05%): The unified spectral signature at the red band is lower due to the light attenuation in the second main absorption region for chlorophyll-A, synchronized with the rise of the water absorption coefficient in the red spectrum. The 2.94% is a result of precise balance, where the water absorption tends to reduce the signal while the mineral-suspended sediments measured in the field (14.71 mg/L) act to raise it through physical scattering; this makes the red band the most efficient in water turbidity sensing.
- 4- Red edge (B5-2.83%): The gradual decrease to 2.83% in this band (705 nm) reflects the dominance of water absorption over biological scattering in Shatt Al-Hilla. Scientifically, the absorption coefficient of water in

this region is higher than in the red band, which inherently suppresses the reflected energy. This continuous decline provides clear evidence for the absence of a 'red-edge peak'—a feature typically driven by algal bloom activity and chlorophyll scattering. Consequently, the optical signature confirms that the physical effect of mineral sediments and water absorption outweighs any potential algal bioactivity (fluorescence) in the study area.

- 5- NIR (B8-3.40%): Anomalous response in this band compared to clear water that absorbs completely the NIR rays. The rise in NIR values to 3.40%, surpassing the red band, is an irrefutable signature of the presence of SSC in the water sample. Due to the big difference in particle size of suspended sediments and clear water particles, they scatter NIR rays strongly back into the satellite sensor before being attenuated by water absorption by water.

3.6 Unified Spectral Appendices Analysis

The spectral response is subject to physical competition between water absorption and sediment particles' scattering; the peak reflectance is still confined to the green band B3, as in Figure 9, within an SSC of 14.71 mg/L (low-medium turbidity). Till the increase in turbidity, the scattering signal will increase gradually to override the absorption, causing a shift towards red (red shift), and the peak moves to B4. The dominance of peak reflectance in the green band with a mean value of 4.74% presented spectral conclusive evidence consistent with the physical properties of low-turbidity water. On the other hand, this conclusion explains the negative value of -0.2169 of NDTI and 0.6435 of the red/green ratio.

The NDCI index of -0.03742, which is calculated generally as a function of B4 and B5, has a negative value, meaning mathematically that the reflectance in the red band is higher than in the red edge band, revealing the absence of peak scattering specialized to algal cells. This negative trend provides further spectral evidence that the observed turbidity in Shatt Al-Hilla is primarily driven by mineral sediments rather than biological activity (chlorophyll-A).

The positive value of NDWI of 0.1646 ensures the efficiency of isolating the water area from the land. The low positive NDWI value in low-to-medium turbidity and low-depth rivers like Shatt Al-Hilla may refer to some mixed pixels, but it is still positive, proving a good isolation and giving the extracted spectral signature the required accuracy.

The near-zero NDVI value of 0.0543 is a confirmation of the absence of the river from dense vegetation cover or floating algae (like *Eichhornia crassipes*), ensuring that the captured spectral signal is for SSC without floating green materials.

NDSSI of -0.3546: the low negative value common in low- turbidity rivers reflect the relatively low SSC compared to the high absorption capacity of water in the NIR spectrum. The NDSSI value represents the quantitative signature of sediments' concentration of 14.71 mg/L, proving that the river water still behaves as an absorber more than a scatterer in long wavelengths.

3.7 Comparison with Previous Studies

The study results widely conform with much global and local literatures that uses Sentinel-2 in monitoring water quality in rivers (Assaf et al., 2025; Jiang et al., 2025; Sukkuea et al., 2025). The strong correlation of R^2 at about 85% utilizing the spectral reflectance red/green ratio and NDTI index consistent with previous studies (Jiang et al., 2025; Miao et al., 2025; Rajendran et al., 2023b), validating that the red and NIR bands are highly sensitive to mineral SSC in river environments of low to moderate turbidity.

4. Conclusions

- 1- The high ability of Sentinel-2 with the MSI sensor to monitor low-turbidity rivers like Shatt Al-Hilla overcomes the challenges of the signal-to-noise percentage in these environments.
- 2- The selection of Sentinel-2 has a crucial role due to its spatial resolution (10 m), allowing full coverage of the narrow width of the river in some sections strictly, which could not be provided by other satellites.
- 3- The research article reveals that the river water on the inspection date has a unified spectral signature peak value at the green band of 4.74%. By the analysis of B5 and a negative NDCI value of -0.03742, it was concluded scientifically that there is an absence of high algal activity, proving that the recorded turbidity (mean 14.71 mg/L) is a physically mineral turbidity (not of biological origin).
- 4- It is noticed an abnormal response in B8 rising to 3.4%; this is conclusive evidence of the existence of mineral-suspended sediments, which are responsible for scattering that light before absorption by water.
- 5- The study found that the best statistical relation to predict the SSC was by using a second-degree polynomial correlating the SSC with the red/green ratio.
- 6- These red/green ratio and NDTI correlations achieved a high R^2 of 97.52% and 97.68%, with an RMSE of 0.51 and 0.56 mg/L respectively; these statistical values reflect the reliability of the extracted results in predicting SSC with the lowest deviation from the field measurements, eliminating the need for intensive and expensive fieldwork.
- 7- The study concluded that remote sensing provides a modern and precise alternative for the traditional methods, contributing to reducing time, costs, and efforts, with full spatial and temporal coverage for examining SSC in rivers.
- 8- The research paper provides a working environment, and essential tools (one-day unified spectral signature) can be achieved by researchers and water resource institutions to monitor the quality of water in Shat Al-Hilla. However, to enhance the model's accuracy and overall stability, additional testing is recommended at different dates and times of year (multi-temporal validation) by testing seasonal changes in the river discharge and sunlight angle in consideration, enabling the model to predict SSC values in different hydrological conditions.
- 9- The SSC testing points predicted results in Figure 8 built based on red/green and NDTI of second-degree polynomial equations of their spectral bands illustrated in Figure 5, show a great matching with the field measured SSC with RMSE of 0.52 and 0.56 mg/L.

References

- Abbas, A., & Hamza, Z. (2025). Evaluation of the Satellite Rainfall Data in Central Region of Iraq. *The Iraqi Geological Journal*, 169–186. <https://doi.org/https://doi.org/10.46717/igj.2025.58.2b.12>
- Abraham, B. I., Jasim, A. A., Mahmood, M. R., Mahmood, H. R., Alalwan, H. A., & Mohammed, M. M. (2025). Water Body Detection Using Sentinel-2 Imagery Through Particle Swarm Intelligence: A Novel Framework for Optimizing Spectral Multi-Band Index. *Eng*, 6(3), 59. <https://doi.org/https://doi.org/10.20944/preprints202502.0909.v1>
- Al-Qaisi, A. Z., Ali, I. H., Ali, Z. H., Al-Saeedy, F., & Al Yousif, M. A. (2025). Empirical modeling of sediment deposition in Iraqi water channels through laboratory experiments and field validation. *Int. J. Comput. Methods Exp. Meas*, 13(3), 507–519. <https://doi.org/https://doi.org/10.56578/ijcmem130304>
- Alsultani, R., & Talib Fahad, A. (2025). An integrated hybrid life cycle assessment framework for evaluating the impact of wastewater sources on river water quality. *IOP Conference Series: Earth and Environmental Science*, 1545(1), 012056. <https://doi.org/https://doi.org/10.1088/1755-1315/1545/1/012056>
- Altuntas, O. Y., Saygi, M., & Colkesen, I. (2025). Long-Term Monitoring of Coastal Water Quality Using Sentinel-2 Satellite Images and Google Earth Engine: The Case Study Izmir and Erdek Bays. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 48, 37–43. <https://doi.org/https://doi.org/10.5194/isprs-archives-xxviii-m-6-2025-37-2025>
- Al-Yaseen, B. M., Alahmed, S. G. K., & Hussein, N. A. (2025). What insights can a spatiotemporal and multivariate analysis provide about the water quality? The report from Iraq. *Journal of the Geographical Institute "Jovan Cvijic", SASA*, (00), 21. <https://doi.org/https://doi.org/10.2298/ijgi250613021a>
- Assaf, M. N., Abdelal, Q., Hussein, N. M., Halaweh, G., & Alzubaidi, A. J. (2025). Water quality monitoring and management: integration of machine learning algorithms and Sentinel-2 images for the estimation of Chlorophyll-a. *Modeling Earth Systems and Environment*, 11(5), 348. <https://doi.org/https://doi.org/10.1007/s40808-025-02543-4>
- Ayyad, A. M., Eltanahy, E. G., Hussien, M. H., & Refaay, D. A. (2025). Response surface optimization of sedimentation efficiency for sustainable green microalgae harvesting using automated non-invasive methods. *Microbial Cell Factories*, 24(1), 165. <https://doi.org/https://doi.org/10.1186/s12934-025-02765-2>
- Brown, J. E., Van Zante, C. A., & Mixon, R. (2025). Adaptive instrument design strategy for collecting water, sediment samples and stage data in remote, ephemeral arroyos in the arid southwestern United States. *Geochemistry: Exploration, Environment, Analysis*, 25(4), geochem2024-030. <https://doi.org/https://doi.org/10.1144/geochem2024-030>

- Chen, H., Gao, X., & Yuan, R. (2025). Advances in Remote Sensing and Sensor Technologies for Water-Quality Monitoring: A Review. *Water* (20734441), 17(20). <https://doi.org/https://doi.org/10.3390/w17203000>
- Chen, X., Lou, G., Li, H., Zhang, X., Liu, S., Gao, Q., Tao, C., & Chen, Q. (2025). An Enhanced Machine Learning Approach for Regional Total Suspended Matter Concentration Retrieval Using Multispectral Imagery. *Water*, 17(22), 3252. <https://doi.org/https://doi.org/10.3390/w17223252>
- Copernicus Browser. (2026). https://browser.dataspace.copernicus.eu/?zoom=5&lat=44.76234&lng=35.31006&themeId=DEFAULT-THEME&visualizationUrl=U2FsdGVkX1%2Fr50RppBVWcmtQd7%2FYIuA4Mof7NR0BvTSVnwAybUEn5oTumR79M%2BvBmCTFltyzONoqJ1jROD5Tv4cUJEWb6STZ0tryPQH9c9cgKosGQgmzkD8kBh%2Fi%2B5zY&datasetId=S2_L2A_CDAS&demSource3D=%22MAPZEN%22&cloudCoverage=30&dateMode=SINGLE
- Deus, D. (2025). Comparison of Multiple Linear Regression and Artificial Neural Network Models in Retrieving Water Quality Parameters Using Remotely Sensed Data. *South African Journal of Geomatics*, 14(1). <https://doi.org/https://doi.org/10.4314/sajg.v14i1.11>
- Dinar, H. H., Al-Qaisi, A. Z., & Jasim, H. K. (2025). Novel Fuzzy Optimization Model of Future Climate Change Impacts on Water Resources of Al-Hilla River, Babylon, Iraq. *International Journal of Environmental Sciences*, 11(1), 1–19. <https://doi.org/https://doi.org/10.64252/h3kcfk59>
- dos Santos, R. B., Pires, J. S., Gherardi, D. F. M., & de Morisson Valeriano, M. (2023). *Impacts of Beach Nourishment in Balneaurio Camboriuu, SC, on Suspended Solids Dynamics in the Water*.
- Efthimiou, N. (2025). Suspended Load Estimation in Data Scarce Rivers. *Water Resources Management*, 39(1), 311–378. <https://doi.org/https://doi.org/10.1007/s11269-024-03973-y>
- Feng, Y., & He, Y. (2025). Imaging estuarine surface salinity using Sentinel-2: a case study in the Pearl River Estuary. *Ocean and Coastal Research*, 73, e25016. <https://doi.org/https://doi.org/10.1590/2675-2824073.24026>
- Girma, W., Awoke, A. G., Hailu, H., & Melesse, A. M. (2025). Evaluation of water extraction indices for spatial mapping of surface water bodies using Sentinel-2: GIS and remote sensing approaches: the case of Ethiopia. *H2Open Journal*, 8(5), 402–421. <https://doi.org/https://doi.org/10.2166/h2oj.2025.002>
- Hasab, H. A., Dibs, H., Dawood, A. S., Hadi, W. H., Hussain, H. M., & Al-Ansari, N. (2020). Monitoring and assessment of salinity and chemicals in agricultural lands by a remote sensing technique and soil

moisture with chemical index models. *Geosciences*, 10(6), 207.
<https://doi.org/https://doi.org/10.3390/geosciences10060207>

- Igbozurike, J. C., Adeyefa, A. O., Obateru, R. O., & Olusola, A. O. (2025). Spatial variability of sediment grain size across stream orders in the headwater catchment of Omi River Basin, southwestern Nigeria. *Acta Geophysica*, 1–17. <https://doi.org/https://doi.org/10.1007/s11600-025-01560-2>
- Jasim, H. K., Tayyeh, H. K., & Hussein, A. M. (2025). Studying the Effects of Heavy Metals Concentrations on selected Water Treatment Plants in Babylon Governorate. *Journal of Water Resources and Geosciences*, 4(1), 28–44.
- Jiang, X., Wang, S., Li, J., Spyrakos, E., Yao, H., Zhang, F., Tyler, A. N., & Zhang, B. (2025). Water transparency and color in large rivers observed by Sentinel-2 MSI and its implications for SDG 6.3. 2 monitoring. *International Journal of Applied Earth Observation and Geoinformation*, 143, 104826. <https://doi.org/https://doi.org/10.1016/j.jag.2025.104826>
- Joshi, P., Chauhan, A., Gupta, P., Liou, Y.-A., & Tran, D.-P. (2026). Reviving River Yamuna: evaluating water quality in Delhi through ground and remote sensing analysis in 2021. *International Journal of Environmental Science and Technology*, 23(2), 114. <https://doi.org/https://doi.org/10.1007/s13762-025-06843-1>
- Karmoude, Y., Idbraim, S., Saidi, S., Masse, A., & Arbelo, M. (2025). Efficient argan tree deforestation detection using Sentinel-2 time series and machine learning. *Applied Sciences*, 15(6), 3231. <https://doi.org/https://doi.org/10.3390/app15063231>
- Kim, J., Kwon, S., Chung, S., & Kim, Y. Do. (2025). Turbidity and suspended sediment relationship based on sediment composition and particle size distribution. *Scientific Reports*, 15(1), 16286.
- Knight, J., & Abd Elbasit, M. A. M. (2022). Characterisation of coastal sediment properties from spectral reflectance data. *Applied Sciences*, 12(13), 6826. <https://doi.org/https://doi.org/10.3390/app12136826>
- Kourounioti, O., Temenos, A., Temenos, N., Oikonomou, E., Doulamis, A., & Doulamis, N. (2025). UAVINE-XAI: eXplainable AI-Based Spectral Band Selection for Vineyard Monitoring Using UAV Hyperspectral Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. <https://doi.org/https://doi.org/10.1109/jstars.2025.3555788>
- Luo, Z., Deng, M., Tang, M., Liu, R., Feng, S., Zhang, C., & Zheng, Z. (2025). Estimating soil profile salinity under vegetation cover based on UAV multi-source remote sensing. *Scientific Reports*, 15(1), 2713. <https://doi.org/https://doi.org/10.1038/s41598-024-82868-9>

- Majed, H., & Abed, B. S. (2025). Improving the performance of Hurriya-Dagharah Irrigation project using Aqua-Crop Model. *Association of Arab Universities Journal of Engineering Sciences*, 32(2), 11–22. <https://doi.org/https://doi.org/10.33261/jaaru.2025.32.2.002>
- Martínez-Ruedas, C., Yanes-Luis, S., Linares-Burgos, R., Gutiérrez-Reina, D., & Castillejo-González, I. L. (2025). Assessment of CNN-based methods for discrimination of olive planting systems with Sentinel-2 images. *Computers and Electronics in Agriculture*, 234, 110311. <https://doi.org/https://doi.org/10.2139/ssrn.5023066>
- MECA, I. A., GUI-BAHNER, R., HERBEI, M., HORABLAGA, A., & POPESCU, C. A. (2025). EXISTENT PYTHON LIBRARIES FOR REMOTE SENSING AND VEGETATION INDEXES CALCULATIONS-A CASE STUDY. *Research Journal of Agricultural Science*, 57(3). <https://doi.org/https://doi.org/10.59463/rjas.2025.3.28>
- Meteoblue AG. (2026). *Weather Maps | Live Satellite & Weather Radar - meteoblue*. https://www.meteoblue.com/en/weather/maps/baghdad_iraq_98182#coords=13/32.72189/44.28242&map=sunshine~daily~auto~sfc~none
- Miao, H., Zhang, R., Song, Z., & Chang, Q. (2025). Estimating winter wheat canopy chlorophyll content through the integration of unmanned aerial vehicle spectral and textural insights. *Remote Sensing*, 17(3), 406. <https://doi.org/https://doi.org/10.3390/rs17030406>
- Nazhifah, S. A., Putri, A., & Kiftiyani, U. (2025). Comparative Evaluation of NDVI-Based Vegetation Classification Using Rule-Based Thresholding and Random Forest Models. *Cyberspace: Jurnal Pendidikan Teknologi Informatika*, 9(2), 22–32. <https://doi.org/https://doi.org/10.22373/agmq9j89>
- Ng-Cutipa, W. L., Lobato, A., González, F. J., Georgalas, G. P., Zananiri, I., Carvalho, M., Cardoso-Fernandes, J., Somoza, L., Piña, R., & Lunar, R. (2025). Spectral angle mapper application using Sentinel-2 in coastal placer deposits in Vigo Estuary, Northwest Spain. *Remote Sensing*, 17(11), 1824. <https://doi.org/https://doi.org/10.3390/rs17111824>
- Nones, M., & Guo, C. (2025). Remote sensing as a support tool to map suspended sediment concentration over extended river reaches. *Acta Geophysica*, 1–14. <https://doi.org/https://doi.org/10.21203/rs.3.rs-5571429/v1>
- Olivetti, D., Roig, H. L., Martinez, J.-M., Ferreira, A. M. R., Marinho, R. R., Mincato, R. L., & Martins, E. S. P. R. (2025). Inland Water Quality Monitoring Using Airborne Small Cameras: Enhancing Suspended Sediment Retrieval and Mitigating Sun Glint Effects. *Drones*, 9(3), 173. <https://doi.org/https://doi.org/10.3390/drones9030173>

- Rajendran, S., Al-Khayat, A., Abdulla, J., Chatting, M. E., Sadooni, F., & A Rahman SA Al-kuwari, H. (2023a). Sentinel-2 Retrieval of Suspended Sediment Concentration (Ssc) in the Arabian Gulf Water of Arid Region. *Rahman SA Al-Kuwari, Hamad, Sentinel-2 Retrieval of Suspended Sediment Concentration (Ssc) in the Arabian Gulf Water of Arid Region*. <https://doi.org/https://doi.org/10.2139/ssrn.4396684>
- Rajendran, S., Al-Khayat, A., Abdulla, J., Chatting, M. E., Sadooni, F., & A Rahman SA Al-kuwari, H. (2023b). Sentinel-2 Retrieval of Suspended Sediment Concentration (Ssc) in the Arabian Gulf Water of Arid Region. *Rahman SA Al-Kuwari, Hamad, Sentinel-2 Retrieval of Suspended Sediment Concentration (Ssc) in the Arabian Gulf Water of Arid Region*. <https://doi.org/https://doi.org/10.2139/ssrn.4396684>
- Rivoire, L., Clerc, S., Bruniquel, J., Boccia, V., & Dransfeld, S. (2025). *Inter-sensor Level 1 radiometric performance assessment using Deep Convective Clouds Method: Application to Sentinel-2 and Landsat 8 and 9*. <https://doi.org/https://doi.org/10.3390/rs16234445>
- Sentinel Online. (2026). *Sentinel-2 Acquisition Plans - Sentinel Online - Sentinel Online*. <https://sentinels.copernicus.eu/copernicus/sentinel-2/acquisition-plans>
- SENTINEL-2 User Handbook. (2013). *SENTINEL-2 User Handbook Sentinel-2 User Handbook SENTINEL-2 User Handbook Title Sentinel-2 User Handbook Issue 1 Revision 1 SENTINEL-2 User Handbook*.
- Shaimaa, H. S., MALIK, M. I., & AL-JAAFARI, F. M. (n.d.). *ANALYSIS OF SURFACE WATER IN WASIT GOVERNORATE USING THE NDWI BASED ON LANDSAT IMAGERY*. <https://doi.org/https://doi.org/10.47832/2717-8234.25.7>
- SO, M. R., & YOKOTA, S. (2026). IDENTIFYING VEGETATION SUCCESSION SITES TO REPURPOSE AS STORAGE SPACES IN THE ALLUVIAL PLAIN OF THE LOWER TONE RIVER BASIN, JAPAN. *Journal of Landscape Ecology*, 19(3). <https://doi.org/https://doi.org/10.2478/jlecol-2026-0022>
- Soares, V. B., Parreiras, T. C., Furuya, D. E. G., Bolfe, É. L., & Nechet, K. de L. (2025). Mapping Banana and Peach Palm in Diversified Landscapes in the Brazilian Atlantic Forest with Sentinel-2. *Agriculture*, 15(19), 2052. <https://doi.org/https://doi.org/10.3390/agriculture15192052>
- Stahl, D. J. (2026). *Two Rivers Entangled: An Ecological History of the Tigris and Euphrates in the Twentieth Century*. Stanford University Press.

- Su, X., Cui, J., Zhang, J., Guo, J., Xu, M., & Gao, W. (2025). “Ground–Aerial–Satellite” Atmospheric Correction Method Based on UAV Hyperspectral Data for Coastal Waters. *Remote Sensing*, 17(16), 2768. <https://doi.org/https://doi.org/10.3390/rs17162768>
- Sukkuea, A., Akkajit, P., Suwannarat, K., Foithong, P., Afsarimanesh, N., & Alahi, M. E. E. (2025). AI-Driven Time Series Forecasting of Coastal Water Quality Using Sentinel-2 Imagery: A Case Study in the Gulf of Thailand. *Water*, 17(12), 1798. <https://doi.org/https://doi.org/10.3390/w17121798>
- Tahmasebi, P., Biglari Gholdareh, S., Bashtamian, S. M., Hosseini, S. P., & Golmohammadi Ghane, P. (2024). Comparison of Landsat-8 and Sentinel-2 Satellite Images to Estimate the Amount of Chlorophyll-a in Zaribar Lake. *Environmental Sciences*, 22(4), 571–584. <https://doi.org/10.48308/envs.2024.1373>
- Teijido-Murias, I., Barrio-Anta, M., & López-Sánchez, C. A. (2025). Sentinel-1 and Sentinel-2 data for predicting forest stand variables in GEE: A case study of timber plantations in northern Spain. *Forest Systems*, 34(3), 20986. <https://doi.org/https://doi.org/10.5424/fs/2025343-20986>
- Wang, J., Pan, H., Sheng, S., & Song, W. (2026). Spatiotemporal Dynamics and Multi-Path Driving Mechanisms of Vegetation Net Primary Productivity in Tibetan Plateau (2001–2022): Coupling Analysis of Geodetector and PLS-SEM. *Land*, 15(2), 262. <https://doi.org/https://doi.org/10.3390/land15020262>
- White, K. (2026). Remote sensing for palaeoenvironmental studies in drylands. In *Paleoenvironmental Reconstruction in Arid Lands* (pp. 27–39). CRC Press. <https://doi.org/https://doi.org/10.1201/9781003761501-2>
- Wright, D. (2018). Sentinel-2 as a tool for quantifying suspended particulate matter in the Tamar Estuary, UK. *The Plymouth Student Scientist*, 11(2), 3–33.
- Xue, B., Wang, Y., Song, Y., Liu, C., & Ai, P. (2025). Multi-Feature Fusion and Cloud Restoration-Based Approach for Remote Sensing Extraction of Lake and Reservoir Water Bodies in Bijie City. *Applied Sciences*, 15(21), 11490. <https://doi.org/https://doi.org/10.3390/app152111490>
- Yadav, B., Sawant, S., & Sayyad, S. (2025). Assessing Water Quality Using the Normalized Difference Water Index (NDWI): A Remote Sensing Approach with Satellite Imagery. In *Recent Trends in Applied Physics and Material Science* (pp. 377–380). CRC Press. <https://doi.org/https://doi.org/10.1201/9781003684718-121>
- Yépez, S., Velásquez, G., Torres, D., Saavedra-Passache, R., Pincheira, M., Cid, H., Rodríguez-López, L., Contreras, A., Frappart, F., & Cristóbal, J. (2024). spatiotemporal variations in biophysical water quality

parameters: an integrated in situ and remote sensing analysis of an Urban Lake in Chile. *Remote Sensing*, 16(2), 427. <https://doi.org/https://doi.org/10.3390/rs16020427>

Yunus, A. P., Ishan, A., Magesh, N. S., Sajinkumar, K. S., Scaringi, G., Siva Subramanian, S., & Oommen, T. (2025). Rapid evacuation of suspended sediment loads during landslides in steep gradient rivers. *Environmental Research Communications*, 7(3), 031002. <https://doi.org/https://doi.org/10.1144/geochem2024-030>

Zhou, T., Cao, B., Qiu, J., Cai, S., Ou, H., Fan, W., Yang, X., Xie, X., Bo, Y., & Zhang, G. (2023). Mapping suspended sediment changes in the Western Pacific Coasts. *Remote Sensing*, 15(21), 5192. <https://doi.org/https://doi.org/10.3390/rs15215192>

Declarations

Availability of data and materials

All datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request. Sentinel-2 satellite imagery used in this research was obtained from the European Space Agency (ESA) Copernicus Open Access Hub.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

[Osama Abdulwahid Al-Obaidi] designed the study and performed spectral analysis. [Atheer Zaki Al-Qaisi and Hayder Dibs] contributed to image processing and mapping. All authors participated in drafting and revising the manuscript, and approved the final version.

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References

Appendix

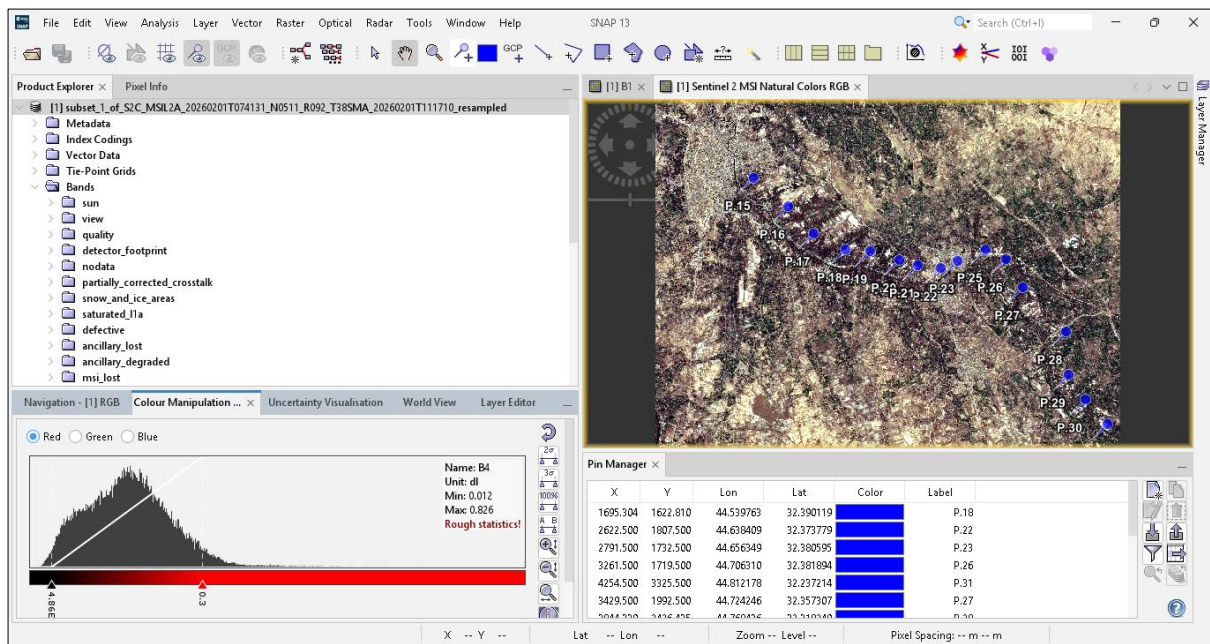


Figure 1. Spectral bands and indices extraction by SNAP Desktop 13.0.0 for the study area dated on 1 February 2026

Satellite Image	Station ID	Longitude (E°)	Latitude (N°)	Cloud ratio (%)
B	P.1	32°43'39"	44°16'15"	9.692235
	P.2	32°41'22"	44°17'07"	
	P.3	32°40'04"	44°19'18"	
	P.4	32°38'16"	44°20'05"	
	P.5	32°37'52"	44°21'45"	
	P.6	32°36'45"	44°20'39"	
	P.7	32°35'31"	44°21'48"	
	P.8	32°35'43"	44°23'16"	
	P.9	32°34'29"	44°24'00"	
	P.10	32°32'46"	44°25'00"	
	P.11	32°31'26"	44°25'00"	
	P.12	32°30'56"	44°26'19"	
	P.13	32°29'57"	44°26'03"	
	P.14	32°28'17"	44°26'25"	
	P.15	32°27'10"	44°26'39"	
A	P.15	32°27'10"	44°26'39"	0.917847
	P.16	32°27'10"	44°26'39"	
	P.17	32°25'40"	44°28'49"	
	P.18	32°24'14"	44°30'23"	
	P.19	32°23'25"	44°32'23"	
	P.20	32°23'19"	44°33'57"	
	P.21	32°22'52"	44°35'46"	
	P.22	32°22'36"	44°36'54"	
	P.23	32°22'26"	44°38'18"	
	P.24	32°22'50"	44°39'23"	
	P.25	32°23'25"	44°41'06"	
	P.26	32°22'55"	44°42'23"	
	P.27	32°21'26"	44°43'27"	

P.28	32°19'06"	44°46'06"
P.29	32°16'49"	44°46'18"
P.30	32°15'30"	44°47'21"

Table 1. Coordinates, cloud ratio, and SSC values of the thirty sampling points along Shatt Al-Hilla dated on 1 February 2026

ID	B2	B3	B4	B5	B8	NDWI	NDTI	NDVI	B4/B3	NDSSI	NDCI	SSC
P.1	0.0073	0.0355	0.0184	0.0213	0.0248	0.1774	-0.3173	0.1481	0.5183	-0.5452	0.07300	10.60
P.2	0.0031	0.0329	0.0170	0.0044	0.0223	0.1920	-0.3186	0.1349	0.5167	-0.7559	-0.5888	10.20
P.3	0.0045	0.0294	0.0137	0.0150	0.0100	0.4924	-0.3643	-0.1561	0.4660	-0.3793	0.04530	10.40
P.4	0.0067	0.0334	0.0196	0.0135	0.0091	0.5718	-0.2604	-0.3659	0.5868	-0.1519	-0.1843	11.50
P.5	0.0031	0.0324	0.0185	0.0145	0.0172	0.3065	-0.2731	-0.0364	0.5710	-0.6946	-0.1212	12.20
P.6	0.0027	0.0350	0.0169	0.0126	0.0202	0.2681	-0.3487	0.0889	0.4829	-0.7642	-0.1458	11.10
P.7	0.0036	0.0365	0.0210	0.0135	0.0151	0.4147	-0.2696	-0.1634	0.5753	-0.6150	-0.2174	11.80
P.8	0.0015	0.0328	0.0146	0.0078	0.0206	0.2285	-0.3840	0.1705	0.4451	-0.8643	-0.3036	10.10
P.9	0.0011	0.0366	0.0136	0.0146	0.0166	0.3759	-0.4582	0.0993	0.3716	-0.8757	0.03550	8.90
P.10	0.0042	0.0432	0.0276	0.0251	0.0220	0.3252	-0.2203	-0.1129	0.6389	-0.6794	-0.0474	13.30
P.11	0.0180	0.0452	0.0268	0.0277	0.0248	0.2914	-0.2556	-0.0388	0.5929	-0.1589	0.01650	12.00
P.12	0.0011	0.0376	0.0252	0.0202	0.0284	0.1394	-0.1975	0.0597	0.6702	-0.9254	-0.1101	14.40
P.13	0.0019	0.0355	0.0290	0.0192	0.0292	0.0974	-0.1008	0.0034	0.8169	-0.8778	-0.2033	17.80
P.14	-0.0087	0.0376	0.0206	0.0170	0.0191	0.3263	-0.2921	-0.0378	0.5479	-2.6731	-0.0957	12.40
P.15 B	0.00500	0.03600	0.02130	0.02320	0.01660	Neglected*						14.10
P.15 A	0.02250	0.0483	0.03200	0.03420	0.02750	0.2744	14.10	-0.0756	0.6625	-0.1000	0.03320	14.10
P.16	0.02670	0.0584	0.03620	0.03290	0.03500	0.2505	14.50	-0.0169	0.6199	-0.1345	-0.0478	13.10
P.17	0.02700	0.0524	0.03320	0.02970	0.03440	0.2074	14.20	0.0178	0.6336	-0.1205	-0.0556	14.50
P.18	0.02220	0.0550	0.03680	0.03450	0.04730	0.0753	14.20	0.1249	0.6691	-0.3612	-0.0323	14.20
P.19	0.02250	0.0572	0.03460	0.02960	0.04270	0.1451	17.20	0.1048	0.6049	-0.3098	-0.0779	14.20
P.20	0.02670	0.0584	0.04180	0.04950	0.04470	0.1329	12.40	0.0335	0.7158	-0.2521	0.08430	17.20
P.21	0.02490	0.0603	0.03980	0.04050	0.04320	0.1652	-0.2048	0.0410	0.6600	-0.2687	0.00870	15.20
P.22	0.01950	0.0523	0.03620	0.04360	0.04040	0.1284	-0.1819	0.0548	0.6922	-0.3489	0.09270	16.20
P.23	0.02530	0.0586	0.04270	0.03220	0.05010	0.0782	-0.1570	0.0797	0.7287	-0.3289	-0.1402	17.70
P.24	0.02040	0.0535	0.03880	0.04210	0.04500	0.0863	-0.1593	0.0740	0.7252	-0.3761	0.04080	16.20
P.25	0.02840	0.0635	0.04860	0.02700	0.05160	0.1034	-0.1329	0.0299	0.7654	-0.2900	-0.2857	19.60
P.26	0.03290	0.0618	0.04470	0.05260	0.05360	0.0711	-0.1606	0.0905	0.7233	-0.2393	0.08120	17.80
P.27	0.02530	0.0594	0.04520	0.04110	0.05000	0.0859	-0.1358	0.0504	0.7609	-0.3280	-0.0475	20.00
P.28	0.02560	0.0532	0.03670	0.04090	0.04940	0.0370	-0.1835	0.1475	0.6898	-0.3173	0.05410	16.00
P.29	0.01640	0.0495	0.03260	0.03680	0.05780	-0.0774	-0.2058	0.2788	0.6586	-0.5580	0.06050	15.00
P.30	0.02900	0.0556	0.04080	0.03610	0.04800	0.0734	-0.1535	0.0811	0.7338	-0.2468	-0.0611	17.80

Table 2. The spectral bands and indices of the thirty sampling points taken along Shatt Al-Hilla examined on 1 February 2026 (* P15A and B appears twice in SC2 images; P15B neglected due to high cloud ratio)

Point	Field SSC	Predicted SSC from red/green model	Predicted SSC from NDTI model
4	11.50	12.24	12.29
5	12.20	11.81	11.82
6	11.10	10.08	9.89
16	13.10	13.23	13.34

21	15.20	14.64	14.76
23	17.70	17.54	17.5
26	17.80	17.29	17.27
28	16.00	15.82	15.91
30	17.80	17.79	17.72
RMSE		0.51	0.56
Avg.		14.71	

Table 3. The field-measured SSC and the predicted SSC utilizing red/green and NDTI indices model equations. The RMSE of the nine testing points taken along Shatt Al-Hilla examined on 1 February 2026.