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Remote Sensing Approaches for Water Quality Assessment

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Abstract: ***Water quality of rivers is conventionally assessed through field sampling and laboratory analysis. These methods give reliable point measurements, but they may not capture spatial variation along a river reach. This paper presents the framework and preliminary study for evaluating satellite remote sensing as a supporting tool for water quality assessment of a selected stretch of the Kadalundi River at Oravamburam, Malappuram district, Kerala. Recent studies on Google Earth Engine (GEE), Sentinel-2 imagery and optical water-quality indicators are reviewed, the study area is characterised, and an integrated methodology is proposed that combines satellite observations with field and laboratory measurements. Study-area selection and the proposed station plan are complete. Satellite processing, field sampling and validation are planned for the next phase, so no water-quality conclusions are drawn in this paper.***

Keywords: Remote sensing; water quality; Sentinel-2; Google Earth Engine; Normalized Difference Water Index; Kadalundi River; Oravamburam; field validation.

I. INTRODUCTION

Water is essential for domestic use, agriculture, industry, fisheries and the maintenance of aquatic ecosystems. Rivers and other inland water bodies are shaped by natural processes and human activities, including surface runoff, soil erosion, sediment transport, land-use change and wastewater discharge [1]. Regular assessment is therefore needed to understand river conditions and to support sustainable water management. Parameters such as pH, dissolved oxygen (DO), electrical conductivity (EC), turbidity, total dissolved solids (TDS) and total suspended solids (TSS) are routinely measured through sampling and laboratory tests. Repeated monitoring at many locations, however, is time-consuming and resource-intensive, and a limited number of sampling points may not represent spatial variation along an entire river reach.

Satellite remote sensing provides a complementary approach by observing large areas without direct contact. Optical sensors record reflected solar radiation in several spectral bands, and this reflectance is influenced by suspended sediments, phytoplankton, coloured dissolved organic matter, water depth and atmospheric conditions [1]. Systematic reviews report that such observations can support the monitoring of chlorophyll-a, turbidity and suspended solids in inland waters [2], [3]. Google Earth Engine (GEE) enables the filtering, masking and processing of large satellite archives without requiring local high-performance computing [4].

The aim of this work is to assess the applicability of satellite remote sensing for evaluating selected water-quality indicators in a river stretch at Oravamburam, Malappuram district, Kerala, through comparison with field-based measurements. The specific objectives are to (i) delineate the study stretch; (ii) process Sentinel-2 imagery for water-body identification; (iii) investigate suitable optical indicators; (iv) collect field and laboratory data at representative stations; (v) compare satellite-derived results with field observations where data are compatible; and (vi) evaluate the accuracy and limitations of remote sensing for a relatively narrow inland river.

II. STUDY AREA AND BACKGROUND

A. Location

Oravamburam is located near Manjeri in Malappuram district, Kerala, within a tropical environment with seasonal rainfall and substantial surface-water resources. The study focuses on a selected reach of the Kadalundi River associated with this locality. For analysis, the reach may be divided into upstream, middle and downstream sections so that spatial variation can be compared.

B. Physical and Environmental Characteristics

Malappuram district has a tropical monsoon climate influenced by the southwest and northeast monsoons. Heavy rainfall can increase surface runoff, turbidity and suspended sediment concentration, whereas lower flows during dry periods reduce dilution. The season of image acquisition and sampling must therefore be considered when interpreting results.

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The surrounding landscape may include residential areas, agricultural land, vegetation, roads and other built surfaces. Residential areas may contribute domestic wastewater, agricultural land may contribute soil and nutrients in runoff, and exposed soil can increase sediment input. These are potential influences to be investigated and are not confirmed pollution sources.

C. Suitability for Remote Sensing

Sentinel-2 imagery is suitable for this reach because it provides multispectral information for water-body identification and for the investigation of certain optical indicators. However, narrow river channels contain mixed pixels representing water, vegetation, sediment and adjacent land. Cloud cover, shadows, seasonal water-level changes and the optical properties of the river also affect results. Cloud-free imagery and carefully located sampling points are therefore essential for reliable analysis.

III. LITERATURE REVIEW

A. GEE-Based Surface Water Monitoring

Joshi et al. [4] reviewed the use of GEE, satellite remote sensing and artificial intelligence for surface water monitoring. The authors highlighted the pressures of urbanisation, industrial activity, agricultural runoff and domestic wastewater on water quality, and noted that conventional field sampling is expensive, time-consuming and limited in spatial and temporal coverage. The review identified chlorophyll-a, turbidity, suspended sediment concentration, water colour and surface temperature as indicators that can be investigated from satellite data. Chlorophyll-a can be estimated using the Normalized Difference Chlorophyll Index (NDCI), turbidity using the Normalized Difference Turbidity Index (NDTI), and water bodies can be separated from land using the Modified Normalized Difference Water Index (MNDWI). Their case study of reservoirs and lakes in Nebraska, USA, showed seasonal changes in water extent and algal activity, and the authors concluded that GEE can support the simultaneous monitoring of water quantity and selected quality indicators. Limitations identified include cloud cover, dense vegetation, difficulty in monitoring small water bodies, computational restrictions and the need for programming skills. Parameters such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD) could not yet be estimated reliably from satellite observations alone.

B. Kerala Case Studies

Sherjah et al. [5] investigated the feasibility of GEE for monitoring inland water quality in Vembanad Lake, Kerala, and in two lakes in the USA. Sentinel-2 Level-1C imagery was used, and field measurements were collected at 22 sampling locations in Kochi Kayal on 26 January 2021.

The Sensor Invariant Atmospheric Correction (SIAC) algorithm available in GEE was assessed for retrieving bottom-of-atmosphere reflectance. The normalised difference between the green and red bands (ND34) was identified as a suitable indicator for the Trophic State Index (TSI). Across six sets of imagery, the estimated TSI values showed a mean error of less than 17%, and the authors emphasised the importance of accurate atmospheric correction. Prasad et al. [6] applied Sentinel imagery to assess water quality dynamics in the coastal waters of Kollam, Kerala, while Ganga Krishnan et al. [7] assessed land-use/land-cover change and climate variability in Akkulam Lake using remote sensing. Together, these studies demonstrate the relevance of satellite methods to Kerala's water bodies, although the reported approaches differ in water type and objective.

C. Reviews of Sensors, Parameters and Methods

Xu et al. [1] reviewed MODIS, Landsat, Sentinel-2 and Sentinel-3 for inland water quality monitoring. MODIS is suitable for large-scale, long-term observation, whereas Landsat and Sentinel-2 provide higher spatial resolution for local variations. Chlorophyll-a, total suspended solids (TSS), coloured dissolved organic matter (CDOM) and turbidity can be estimated from spectral reflectance, while dissolved oxygen, total nitrogen and total phosphorus generally require indirect models or field measurements. Empirical, machine-learning and deep-learning models were discussed, and the authors stressed that field data are essential for model development and validation. Ngamile et al. [2] conducted a PRISMA-based systematic review of 142 peer-reviewed articles published between 2002 and 2024. The review found that Sentinel-2 is well suited to inland water monitoring because of its spatial resolution, that chlorophyll-a and TSS received the most attention, and that small inland water bodies and non-optically active parameters remain comparatively underexplored. Ellis et al. [3] highlighted that water quantity and quality are generally studied separately: of 7,920 publications between 1991 and 2021, only 225 (about 3%) assessed both explicitly. The authors also noted that cloud interference, limited resolution and difficulty in detecting some chemical constituents remain significant constraints.

D. Summary of the Literature

The reviewed studies show that satellite remote sensing, GEE and machine-learning methods are effective, cost-efficient and time-saving for monitoring inland water quality and surface-water change. Sentinel-2 is consistently identified as a useful sensor for inland rivers and lakes. However, the literature also identifies persistent limitations: cloud cover, atmospheric interference, mixed pixels, model uncertainty, and the difficulty of estimating non-optically active parameters. Small rivers are comparatively under-studied. These gaps motivate an integrated design that combines satellite indicators with field and laboratory validation at a narrow inland river.

IV. METHODOLOGY

A. Sequence of Work

The methodology integrates satellite remote sensing with field-based water-quality assessment. The study begins with study-area selection and field sampling, followed by acquisition and processing of Sentinel-2 imagery in GEE. The NDWI is used to identify and extract water surfaces, and spectral indicators are analysed for relationships with field measurements. The results are then presented as maps, graphs and tables, as summarised in Fig. 1.

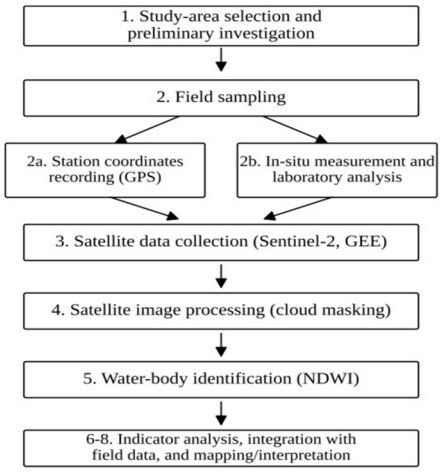


Fig. 1. Methodological sequence adopted for the study, from study-area selection to water-quality mapping and interpretation.

B. Study-Area Selection and Station Design

Sampling points are selected across accessible and representative portions of the river stretch. Stations are chosen according to accessibility, river conditions and potential environmental influences, and the preliminary station plan is given in Table I. These are proposed station categories, not verified sampling points; final positions are to be fixed after a site visit. Each station is assigned an identifier (S1, S2, and so on), and its latitude and longitude are recorded with a GPS-enabled device so that the same locations can be matched to satellite pixels. Stations are placed away from shorelines where possible, because mixed land–water pixels can distort results in narrow rivers. A schematic of the station arrangement is shown in Fig. 2.

TABLE I
PROPOSED FIELD INVESTIGATION

Station	Proposed location	Purpose
S1	Upstream section	Reference conditions
S2	Upstream approach to the locality	Conditions before the central section
S3	Central section of Oravamburam	Water quality within the main study area
S4	Near residential development	Settlement-related influences
S5	Near a drainage entry, if present	Drainage-related influences
S6	Downstream section	Conditions after the selected stretch
S7	Near agricultural land, if present	Potential agricultural runoff influence
S8	Additional comparison station	Improved spatial coverage where suitable

Source: adapted from the Phase 1 project report.

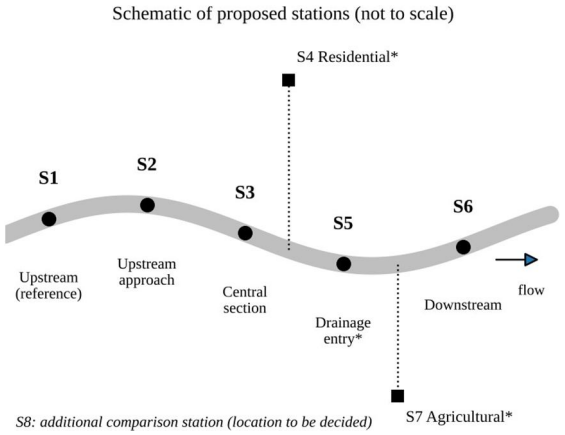


Fig. 2. Schematic of proposed stations along the study reach (not to scale). * Station established only if the feature is present.

C. Field and Laboratory Measurements

At each accessible station, water samples are collected in clean, labelled containers and handled according to the requirements of the analytical method. The date, time, weather, recent rainfall, sampling depth, water appearance and nearby activities are recorded. Sampling is carried out as close as practicable to the satellite acquisition date. Some parameters are measured in situ with calibrated portable instruments, while others are analysed in the laboratory following standard methods such as the APHA Standard Methods for the Examination of Water and Wastewater [8]. The parameters and methods are listed in Table II. Measured values form the reference (ground-truth) dataset against which satellite-based indicators are calibrated and validated.

TABLE II
PARAMETERS FOR FIELD AND LABORATORY ANALYSIS

Parameter	What it indicates	Suitable method
pH	Acidity or alkalinity	Calibrated pH meter
Electrical conductivity (EC)	Electrical conductance of water	EC meter
Total dissolved solids (TDS)	Dissolved substances	TDS meter or laboratory method
Turbidity	Cloudiness from suspended particles	Turbidity meter (NTU)
Total suspended solids (TSS)	Suspended particulate matter	Gravimetric laboratory method
Dissolved oxygen (DO)	Oxygen available in water	DO meter or approved laboratory method
Chlorophyll-a	Algal pigment concentration	Appropriate laboratory analysis

D. Satellite Data Acquisition

Sentinel-2 multispectral imagery is accessed through GEE. Images are selected according to the study boundary, the observation period and the availability of relatively cloud-free data, and the acquisition date, product type and cloud conditions are recorded. The bands considered and their potential applications are summarised in Table III and their nominal central wavelengths are compared in Fig. 3. Blue, green and red bands are used for optical characteristics and suspended material, the near-infrared band supports water–land separation, and the red-edge and shortwave-infrared bands support chlorophyll-related and water/land discrimination analyses at 20 m resolution.

TABLE III
SENTINEL-2 BANDS AND POTENTIAL APPLICATIONS

Band	Resolution	Potential application
B2 – Blue	10 m	Water colour and optical properties
B3 – Green	10 m	Water-body identification and water indices
B4 – Red	10 m	Suspended material and chlorophyll-related analysis
B5 – Red edge	20 m	Chlorophyll-related analysis
B8 – Near-infrared	10 m	Water/land separation
B11 – SWIR	20 m	Water/land discrimination in suitable indices

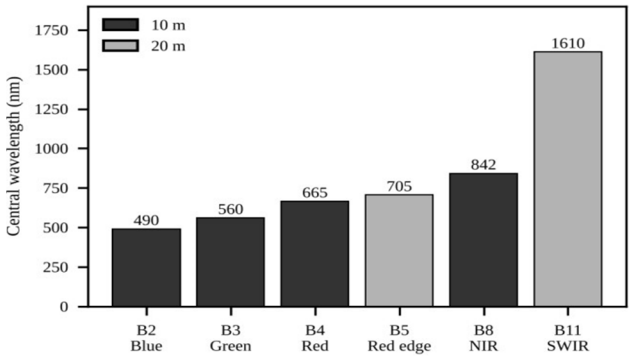


Fig. 3. Nominal central wavelengths of the Sentinel-2 bands listed in Table III. Dark bars denote 10 m bands and light bars denote 20 m bands.

E. Image Processing and Water-Body Extraction

The image collection is filtered to the study boundary and the selected dates. Cloud and cloud-shadow pixels are masked using the Sentinel-2 Scene Classification Layer or cloud-probability data. If several images are combined into a composite, the compositing method and observation period are documented. Processed imagery is inspected in true colour and, where useful, false colour to distinguish water, vegetation, exposed soil and built-up land. The Normalized Difference Water Index (NDWI) [9] helps separate water surfaces from surrounding terrestrial features, and for Sentinel-2 it is calculated from the green band (B3) and the near-infrared band (B8):

$$NDWI = (B3 - B8) / (B3 + B8) \quad (1)$$

NDWI is a water-identification index and is not a direct measure of overall water quality. The Modified NDWI [10], which uses the green and shortwave-infrared bands, may also be considered where suitable imagery is available.

F. Integration, Validation and Mapping

Spectral values or calculated indices are extracted from the water pixels corresponding to each GPS sampling point. Acquisition and sampling dates are compared, and rainfall or discharge events between the two dates are documented. Where the dates, locations and parameter definitions are compatible, the satellite-derived estimates are compared with the field measurements, and suitable statistical relationships are examined only where the data support them. The processed imagery, water mask, sampling locations and selected indicators are then presented in GEE and, if required, QGIS as location maps, NDWI water masks, indicator maps and comparison graphs.

V. PLANNED ANALYSIS AND EXPECTED OUTCOMES

At the completion of Phase 1, satellite processing, field data collection, water-quality testing and validation have not yet been carried out; they are planned for Phase 2. Phase 2 will consist of study-area mapping and delineation, satellite data collection and processing, field survey and sampling, estimation of water-quality indicators from imagery, GIS mapping and spatial interpretation, and result analysis. The expected outputs are study-area maps, field-measurement tables, satellite-derived indicator maps where technically justified, and an assessment of the suitability of remote sensing as a supporting tool for inland water-quality monitoring. Any conclusions will be based only on processed imagery and verified field or laboratory results.

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VI. CONCLUSION

This paper has presented the background, study-area characterisation and methodological framework for assessing satellite remote-sensing approaches for water quality in a selected stretch of the Kadalundi River at Oravamburam, Malappuram district, Kerala. A review of the literature indicates that Sentinel-2 imagery processed in GEE can support water-body mapping and the investigation of optical indicators, but that cloud cover, mixed pixels and the difficulty of estimating non-optical parameters require field validation. The study area has been selected and a preliminary station plan has been developed. The next phase will acquire satellite imagery, conduct field and laboratory measurements, and compare satellite-derived indicators with observed values, thereby providing practical insight into the applicability and limitations of remote sensing for this river reach.

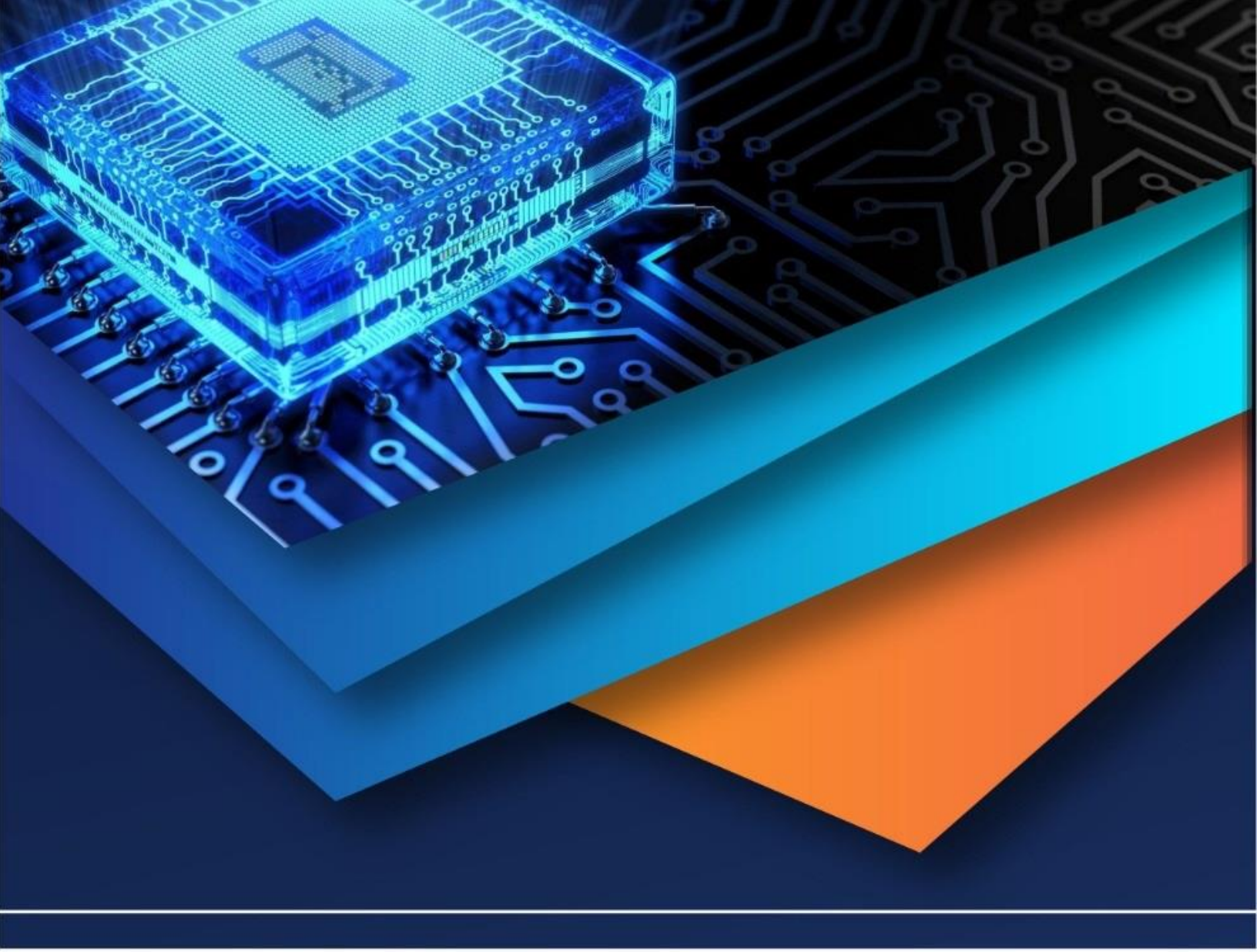
VII. ACKNOWLEDGMENT

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