A Cloud-Based System for Monitoring Water Quality in Tuul River from Space

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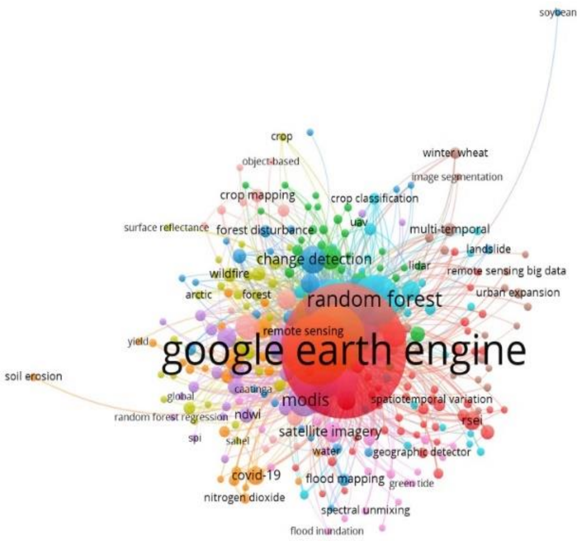
Abstract: *The Tuul River is an essential water source for the water supply and ecological sustainability of Ulaanbaatar. In this study, using Sentinel-2 satellite imagery data from April 21, 2025, the water quality of the Tuul River was assessed using physical parameters such as turbidity, color, and hydrogen ion concentration in accordance with national standards such as MNS ISO 5667:2001, MNS 0900:2018, MNS 4586:2024, and MNS 3900:1986. For this purpose, the Modified Normalized Difference Water Index (MNDWI), the Normalized Difference Turbidity Index (NDTI), which indicate the state of water quality, were calculated. The results of the field survey conducted on April 20, 2025 were compared and verified with the results of physicochemical measurements and analyses taken within the framework of the "Water Quality Study of the Tuul River in the Ulaanbaatar City Area" project implemented by the "Institute of Chemistry and Chemical Technology" in 2021. Using the Google Earth Engine platform, it was demonstrated that large amounts of data can be processed over a wide range of space and time, regardless of computer power, and that this methodology can support and in some cases replace field research.*

Keywords: *Water quality, physical parameters, turbidity, color, hydrogen ion*

Introduction

The Tuul River is the primary water resource for Ulaanbaatar, the most densely populated region in Mongolia. Nearly 80% of the city's drinking water supply is sourced from groundwater that is recharged by the Tuul River. In addition, agricultural activities, livestock husbandry, and small- to medium-sized industries have developed along the river basin, directly impacting both the quantity and quality of the river's water resources. Due to rapid urbanization, population growth, solid waste, and wastewater discharge, the water quality of the Tuul River has deteriorated in recent years, posing a serious threat to ecological balance. In particular, the inadequate operation of Ulaanbaatar's Central Wastewater Treatment Plant has resulted in the direct discharge of untreated wastewater into the river, creating potential public health risks. Nevertheless, the Tuul River also flows through the city's green spaces, recreational areas, and tourism zones, making it an invaluable cultural, ecological, and social asset. Therefore, protecting the Tuul River, promoting its sustainable use, and reducing pollution are not only environmental priorities, but also fundamental to ensuring the quality of life and sustainable development of society.

Literature Review



Source: Andres Velastegui-Montoya et al., 2023

Figure 1: Literature Review

As of May 27, 2024, an examination of the Web of Science and other scientific databases indicates that since 2005, a total of 507 research articles have employed Google Earth Engine (GEE). The number of studies utilizing this cloud-based platform has grown significantly since 2015. Furthermore, since 2020, researchers have increasingly applied GEE across a wide range of domains, including water quality, land use, forest change, and climate impacts, which together account for more than 80% of the total studies. In recent years, the GEE platform has enabled researchers to process large-scale satellite datasets and compute water quality indicators with high accuracy.

Table 1: Summary of Related Studies (Literature Review)

№	Authors (Year)	Data Used	Methodology	Key Findings
1	Kapalanga et al. (2021)	Sentinel-2 satellite data	Indices, multivariate regression model	Results showed strong agreement with in-situ measurements; validated the effectiveness of remote sensing.
2	Liu et al. (2024	Sentinel-2 satellite data	Усны Water Quality Index (CWQI), NH_4^+-N, TP modeling	CWQI RAE = 9.80%; NH_4^+-N, TP with $R^2 = 0.62$ and 0.61; demonstrated feasibility of remote monitoring.
3	Pizani et al. (2020)	Sentinel-2 MSI, Landsat-8 OLI	Multivariate regression model; parameters such as Chl-a, Secchi depth, temperature	Optical active parameters with $R^2 > 0.75$; DO and pH $R^2 > 0.8$; temperature poorly correlated ($R^2 = 0.03$).

4	Ibrahim et al. (2021)	In-situ water quality data, Sentinel-2	Novel Spectral Reflectance Indices (NSRIs), ANN model	For PO_4^{3-}, ANN model achieved $R^2 = 0.98$ (calibration) and 0.89 (validation); NSRIs ranged $R^2 = 0.52–0.77$.
5	Dulmaa et al. (2021)	In-situ water quality measurements	Seasonal monitoring of physico-chemical and pollution indicators at sampling sites	Increased pollution detected around Ulaanbaatar; natural self-purification observed but incomplete.
6	Zablan et al. (2023)	Landsat and Sentinel-2 satellite data	GEE platform; NDTI, NDCI indices; ArcGIS Pro “emerging hotspot” analysis	From 2000–2021, water transparency and Chl-a decreased; cold spots dominated; monitoring program simplified.

Methodology

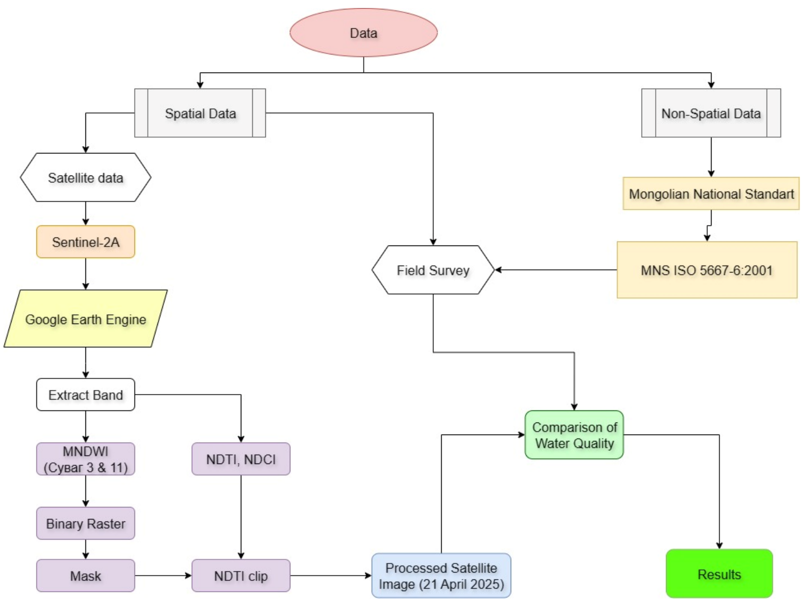


Figure 2: Methodological Framework

- To calculate water quality indices such as the Normalized Difference Turbidity Index (NDTI) and other turbidity-related indices based on Sentinel-2 satellite imagery using the JavaScript programming language on the Google Earth Engine platform.

- To conduct field sampling of water from the Tuul River in accordance with the Mongolian standard MNS ISO 5667-6:2001 and other relevant regulatory documents related to water quality sampling.
- To validate and assess the estimated turbidity indices by comparing them with in-situ measurements.

Research Result

1. Condition of the Tuul River

Using Google Earth Engine, Sentinel-2 imagery of the Tuul River from 2016, 2020, and 2024 was processed. MNDWI was calculated, and a water mask was applied to extract and delineate the river.

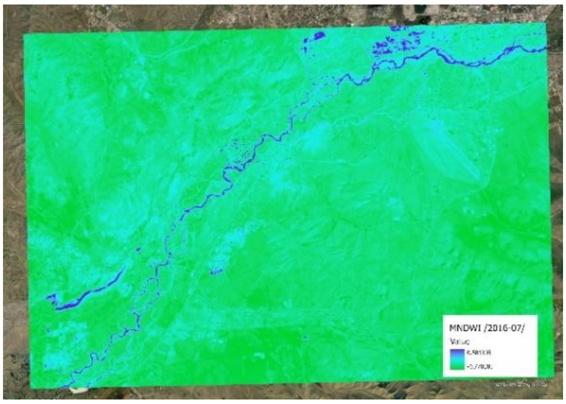


Figure 3: Calculated MNDWI Results (July 2016)

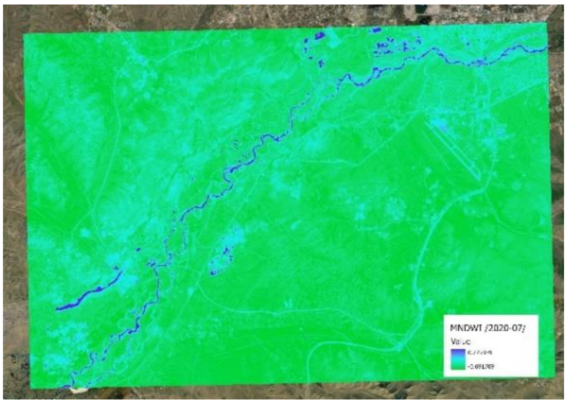


Figure 4: Calculated MNDWI Results (July 2020)

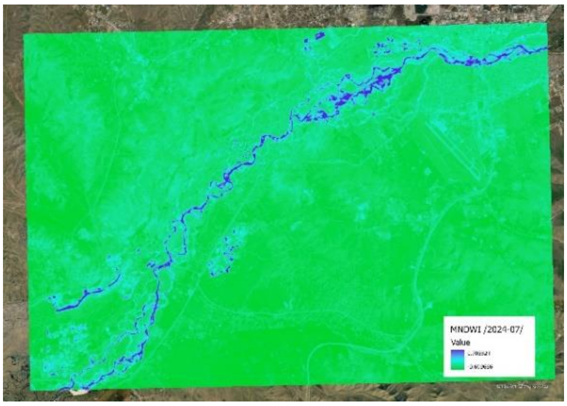


Figure 5: Calculated MNDWI Results (July 2024)

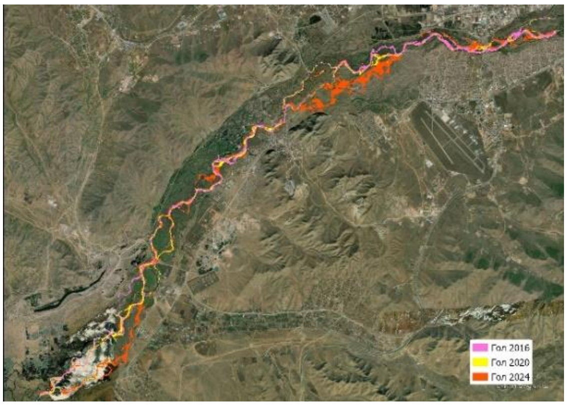


Figure 6: Flow of the Tuul River in 2016, 2020, and 2024

An analysis of land cover dynamics along the Tuul River from 2016 to 2024 revealed notable spatial changes in erosion and accumulation. Comparing three periods (2016–2020, 2020–

2024, and 2016–2024) showed a gradual decrease in erosion from 0.71 to 0.62, while accumulation increased sharply, especially during 2020–2024, reaching 3.41 compared to 1.01 in the earlier period. This growth may reflect natural recovery processes or human-led restoration activities. Areas showing no change also expanded slightly (from 1.021 to 1.410), indicating that part of the river system remained relatively stable over time.

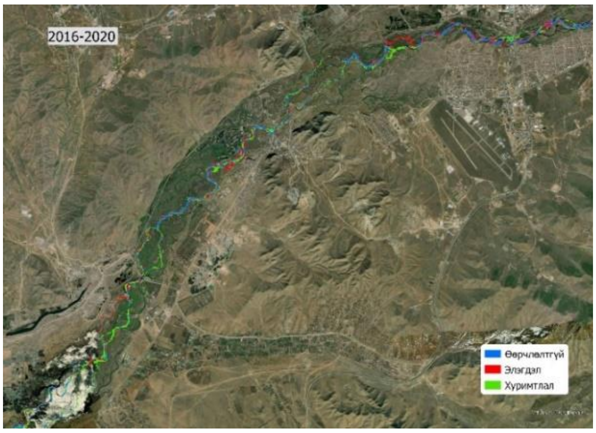


Figure 7: River Status from 2016 to 2020

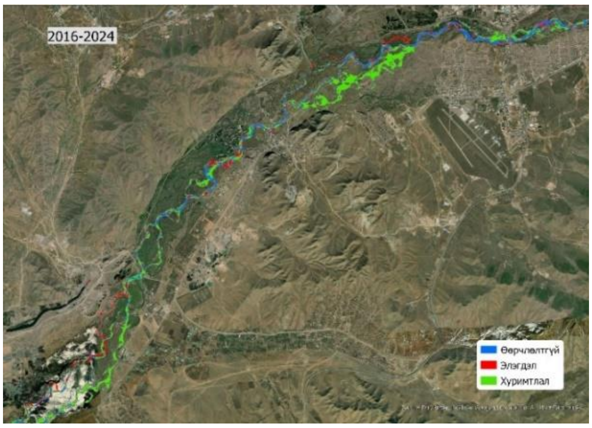


Figure 8: River Status from 2016 to 2024

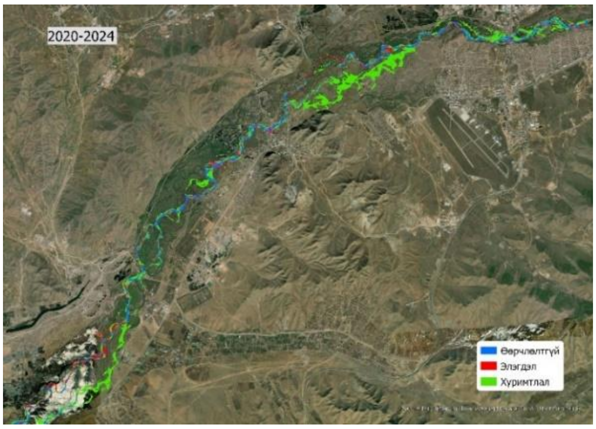


Figure 9: River Status from 2020 to 2024

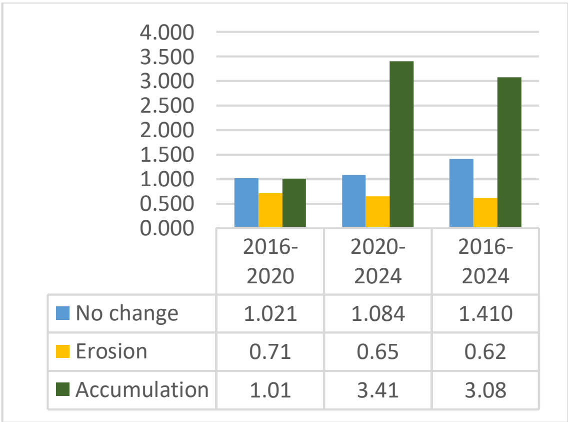


Figure 10: Status Trend Graph

2. Normalized Difference Turbidity Index (NDTI)

The turbidity of the Tuul River for the years 2016, 2020, and 2024 was assessed using Google Earth Engine. The Normalized Difference Turbidity Index (NDTI) was calculated based on Sentinel-2 imagery to identify and quantify turbidity levels in the river.

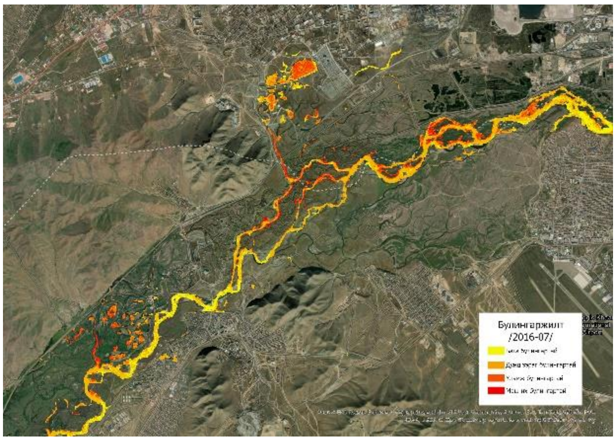


Figure 11: Calculated NDTI Results (July 2016)

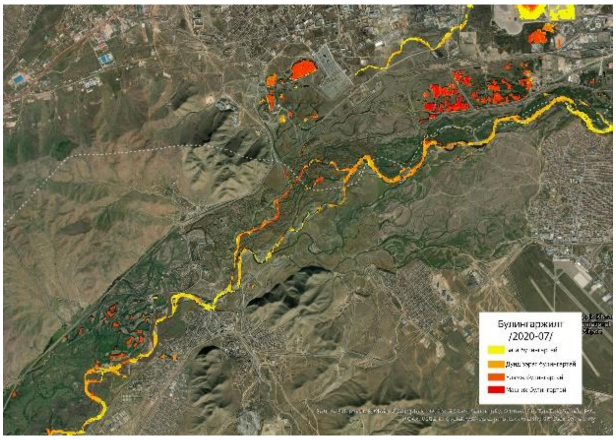


Figure 12: Calculated NDTI Results (July 2020)

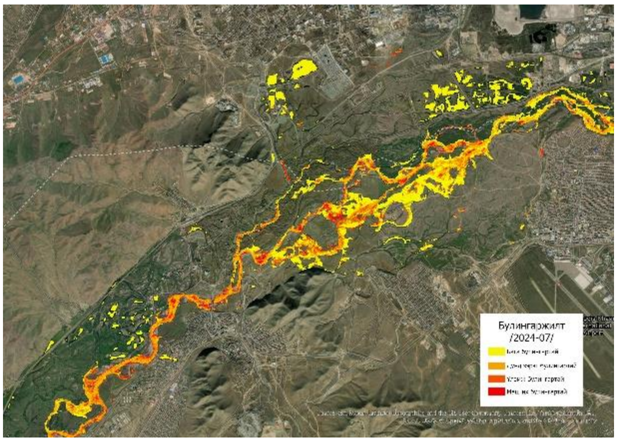


Figure 13: Calculated NDTI Results (July 2024)

In 2016, turbidity along the Tuul River basin was predominantly low to moderate. However, certain areas in the southwestern region and at the outskirts of the city exhibited zones of elevated and very high turbidity. By 2020, turbidity levels had increased, with significant intensification observed in the northwestern and southwestern sections. In 2024, the most pronounced changes were recorded: areas of very high turbidity expanded considerably. Along the riverbanks and in the city's peripheral green zones, turbidity shifted from moderate to high levels, while areas of low turbidity also increased.

3. Field Survey

Field sampling was conducted in accordance with the MNS ISO 5667-6:2001 standard. On April 20, 2025, water samples were collected from the Tuul River to determine key physical water quality parameters, specifically turbidity and color, and to validate the results obtained from satellite-based calculations. Sampling was carried out at four monitoring points used by the Water, Meteorology, and Environmental Monitoring Agency for seasonal river water quality measurements, allowing a direct comparison between field observations and remote sensing data.

Figure 14: Location of the Four Sampling Points

Sampling Point 1

The first sample, taken just downstream of the Central Wastewater Treatment Plant, showed clear signs of pollution. The water had a strong odor, appeared dark and turbid, and contained floating debris, suggesting incomplete treatment and poor water quality. Further chemical and biological analysis is needed to assess pollution levels and evaluate the plant’s treatment efficiency.

Figure 15: Sampling Process near the Central Wastewater Treatment Plant (CWTP)

Sampling Point 2

The second sample, taken from the right bank of the Tuul River near Sonsgolon Bridge, showed relatively better water quality than the area near the wastewater treatment plant. No foul odor was detected, and the water had a natural brownish color, though it remained turbid and cloudy—likely due to soil runoff, human activity, or sediment accumulation in slower flow areas. Further chemical analysis is needed to confirm these observations and assess water quality more accurately.

Figure 16: Sampling Process near Sonsgolon Bridge

Sampling Point 3

The third sample was collected from the section near Yarmag Bridge. This area is not directly influenced by the Central Wastewater Treatment Plant, and as such, no unpleasant odors were detected, indicating a relatively clean environment.Compared to the section near Sonsgolon Bridge, the water appeared slightly lighter brown and only mildly turbid. Overall, no significant pollution was observed in terms of odor or color.

Figure 17: Area Surrounding Yarmag Bridge

4. Sampling Point 4

The fourth sample was collected near Marshal Bridge along the Tuul River. Compared to areas near the Central Wastewater Treatment Plant, water quality conditions at this location were more favorable. No unpleasant odors were detected from the water, and no surrounding factors were observed that could negatively impact air quality in the vicinity.

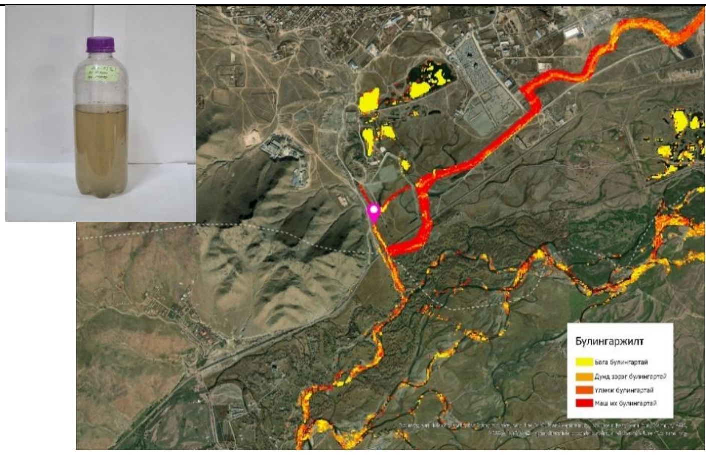
Figure 18: Area Surrounding Marshal Bridge

In terms of color, the water near this section was slightly brown compared to the area around Sonsgolon Bridge, which is consistent with natural conditions. The river flow was relatively stable and moderately strong, potentially supporting the self-purification capacity of this section. Overall, the surrounding environment was relatively simple, and sampling was conducted without major difficulties.

Comparison of Remote Sensing and Field Survey Results

Sentinel-2 imagery from April 21, 2025, was used to calculate the Normalized Difference Turbidity Index (NDTI) for the Tuul River using Bands 3, 4, and 11. The results were compared with field data collected on April 20, 2025, confirming that remote sensing effectively estimates key physical water quality parameters. The first field sample, taken near the Central Wastewater Treatment Plant (47°52'11.61"N, 106°41'35.08"E), was collected to assess water color, sediment content, and turbidity in an area directly affected by the plant's discharge.

Table 2: Sampling Point 1



Parameter, Unit	Color	pH
Permissible Limit (MNS 4586:2024)	20	6.5 – 8.5
Measured Value in Tuul River	150	10

Note: The physical water quality parameters, including color, turbidity, and hydrogen ion concentration (pH), were assessed based on the permissible limits set in MNS 4586:2024. The water sample collected near the Central Wastewater Treatment Plant exceeded these limits. The color of the water was measured at 150, appearing dark brown, while the pH value was 10, indicating highly alkaline conditions. This water is not suitable for drinking or domestic use; however, it can be used directly for purposes that do not require strict water quality standards.

The second field sample was collected near Sonsgolon Bridge at coordinates 47°52'25.66" N, 106°46'57.72" E. This site is located considerably farther from the Central Wastewater Treatment Plant and was expected to have relatively better water quality conditions. However, sample collection could reflect varying conditions due to natural factors, river flow dynamics, and human activities.

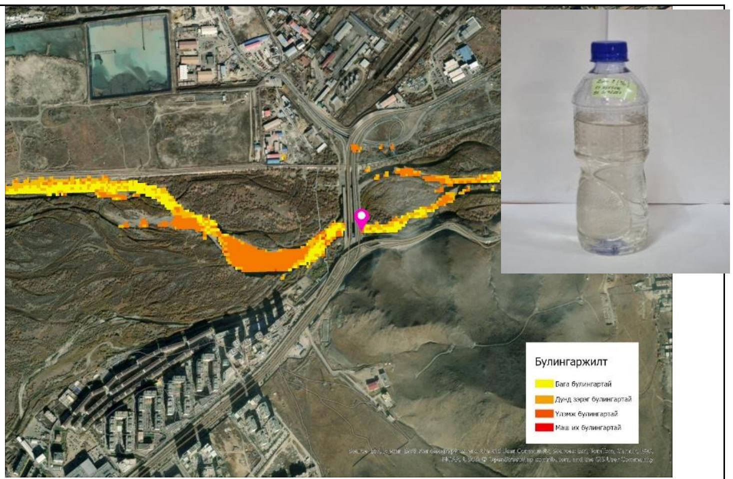
Table 3: Sampling Point 2

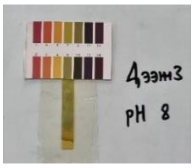
Parameter, Unit	Color	pH
Permissible Limit (MNS 4586:2024)	20	6.5 – 8.5
Measured Value in Tuul River	45	7

Note: The physical water quality parameters, including color, turbidity, and hydrogen ion concentration (pH), were assessed based on the permissible limits set in MNS 4586:2024. The water sample collected near Sonsgolon Bridge exceeded the standard limit for color, measured at 45, indicating moderate brown coloration. The pH value was 7, indicating neutral conditions. This water is suitable for all uses except drinking. If all parameters comply with the drinking water standards (MNS 0900:2018), it can be safely used as potable water.

The third field sample was collected near Yarmag Bridge at coordinates 47°53'11.22" N, 106°51'51.32" E. This site is suitable for studying river flow and water quality. Compared to other sections, the river near Yarmag Bridge exhibited distinct characteristics in terms of appearance and flow velocity. Variations in water color and clarity were observed, particularly in areas where the river flow increased, indicating potential changes in water quality associated with higher flow conditions.

Table 4: Sampling Point 3



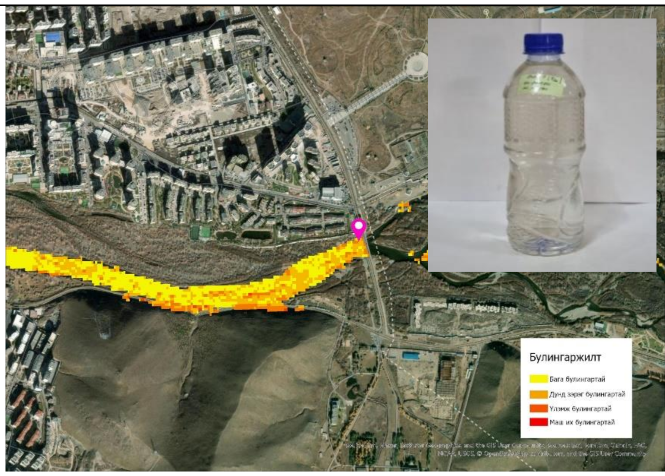


Parameter, Unit	Color	pH
Permissible Limit (MNS 4586:2024)	20	6.5 – 8.5
Measured Value in Tuul River	25	8

Note: The physical water quality parameters, including color, turbidity, and hydrogen ion concentration (pH), were assessed based on the permissible limits set in MNS 4586:2024. The water sample collected near Yarmag Bridge exceeded the standard limit for color, measured at 25, indicating a faint coloration. The pH value was 8**,** indicating slightly alkaline conditions. This water is suitable for all uses except drinking. If all parameters comply with the drinking water standards (MNS 0900:2018), it can be safely used as potable water.

The fourth field sample was collected near Marshal Bridge at coordinates 47°53’17.3" N, 106°56’20.4" E. This site was selected to assess river flow and water quality. Compared to the previous sampling points, water color and clarity were more stable. The characteristics of the water at this location varied depending on river flow velocity and surrounding environmental conditions.

Table 5: Sampling Point 4



Parameter, Unit	Color	pH
Permissible Limit (MNS 4586:2024)	20	6.5 – 8.5
Measured Value in Tuul River	25	8

Note: The physical water quality parameters, including color, turbidity, and hydrogen ion concentration (pH), were evaluated based on the permissible limits specified in MNS 4586:2024. The water sample collected near Sonsgolon Bridge exceeded the standard limit for color, measured at 25, indicating a faint coloration. The pH value was 8**,** indicating slightly alkaline conditions. This water is suitable for all purposes except drinking. If all parameters comply with the drinking water standards (MNS 0900**:**2018), it can be safely used as potable water.

Conclusion and Recommendation

This study demonstrated the potential of using Google Earth Engine (GEE) and Sentinel-2 satellite imagery to remotely monitor physical parameters of water quality. By calculating spectral indices such as the Modified Normalized Difference Water Index (MNDWI) and the Normalized Difference Turbidity Index (NDTI), the study provided an effective way to assess water color, turbidity, and related physical characteristics. Compared to traditional field-based measurements, this remote sensing approach enables broader spatial coverage, frequent observation, and consistent monitoring over time.

The GEE platform, with its cloud-based and high-performance processing capability, allows rapid analysis of large satellite datasets and supports multifaceted spatial and temporal studies.

This makes it possible to evaluate both natural and human-induced impacts on water quality and to track changes across

Following national and international standards such as MNS ISO 5667:2001 and MNS 0900:2018 ensured data reliability and comparability. Overall, the study highlights that the integration of remote sensing and GEE provides a practical, scalable, and accurate solution for continuous water quality monitoring, environmental assessment, and sustainable water resource management.

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