Assessment of Water Quality in A Mining Community Using Remote Sensing and GIS Techniques*

[1]C. B. Boye, [1]R. Graham, [1]A. Asare, [1]A. E. K. Martey
[1]University of Mines and Technology, Box 237, Tarkwa, Ghana

Boye C. B., Graham R., Asare A., and Martey A. E. K**.** (2023), "Assessment of Water Quality in A Mining Community Using Remote Sensing and GIS Techniques", *Ghana Mining Journal*, Vol. 23, No. 1, pp. 1-10.

Abstract

Mining communities are faced with several environmental challenges associated with exploration, extraction and processing of minerals. The last few decades has witnessed massive activities of illegal small scale gold mining in or close to water bodies in most mining communities leading to pollution of the water resources. The traditional methods of monitoring water quality is a difficult task due to the extent of manual work required and the time involved. An alternative approach for assessing surface water quality is by using remote sensing data which has the advantage of broad coverage area and multi-temporal data availability for effective monitoring. This study used remote sensing techniques and field data to evaluate the water quality for the Prestea-Huni Valley Municipality. The normalized difference water index (NDWI) and normalized difference turbidity index (NDTI) were estimated from remote sensing data obtained from Landsat 9 satellite. The field samples were analysed at the Laboratory to determine some water quality parameters that is Total Suspended Solids (TSS) and Turbidity. These respective quality indicators values were used to produce interpolated maps for the study area using Inverse Distance Weighting approach. The values of the water quality indicators obtained from the reflectance values of the satellite images were found to be highly correlated with the measured water quality parameters acquired from the laboratory analysis. Very high turbidity and TSS values were recorded for most of the rivers in the study area, particularly the Ankobra which exceed the standard for drinking water set by the WHO and the Ghana water Company Limited. The utilization of GIS techniques and water quality indices in the assessment of water quality in this framework proved to be a beneficial contribution statistically to the monitoring and management of water resources.

Keywords: Remote Sensing**,** Surface water quality, Geographic Information System, Landsat, turbidity, Total Suspended Solids, Prestea-Huni Valley Municipality

1 Introduction

Water is a valuable natural resource that is essential for human, animal, and plant life cycles. Water in its pure state is tasteless, odourless, transparent and colourless, except for a slight blue undertone (Listyani and Peni, 2020). Surface and groundwater are particularly vital resources for human existence and health. It is reported that one in three people worldwide do not have access to safe drinking water, as such one of the United Nation's strategic development goals (SGD 6) seek to ensure access to clean water and sanitation for all (Bebbington and Unerman, 2018). Similarly, water protection is one of the priorities of the European Commission which adopted the Water Framework Directive (WFD) in 2000, that is a legislative framework for securing an adequate supply of high-quality water for all of Europe (Kontopoulou *et al*., 2017). In Africa, particularly, Ghana, both the Environmental Protection Agency (EPA) and the Ghana Standard Board (GSB) have specified the requirements for portable water for safe consumption. However, to obtain a comprehensive and consistent assessment of the condition of water, frequent observations and a well-organized monitoring programme are essential. This condition is hard to achieve in surface water located in most developing countries where frequent observations are carried out on only few selected stations on major rivers in a systematic manner due to limited resources. Meanwhile remote sensing and GIS techniques have also proffered another cost and time effective approach for water quality assessment with appreciable findings (Das *et a*l., 2021; Meena *et al*., 2021; Li *et al.*, 2023). While remote sensing techniques allow easy collection of large coverages of data at varying resolutions, GIS has proved to be a powerful tool for handling, processing, analysing and integrating spatial datasets (Batur and Maktav, 2019).

Water quality assessment is the appraisal of the physical, chemical, and biological conditions of water in connection with its current and potential uses, as well as its natural and anthropogenic environments (Johnson *et al*., 1997). The term "water quality" (WQ) is used when evaluating the degree to which pollutants in water adversely affect the surrounding environment (Alparslan *et al*., 2019).

Oftentimes, human interactions with the environment lead to pollution of water bodies particularly in mining communities where the topsoil is often cleared of its vegetation to enable surface mining activities to be carried out. Mining activities and alterations in land use and land cover endangers the safety of water resources (Gbedzi *et al*., 2022). Moreover, rapid population growth, modernization and the use of pesticides and fertilizers in agricultural production also have a negative impact on the quality of the world's surface

**Manuscript received January 09, 2023*
Revised version accepted June 22, 2023
https://doi.org/10.4314/gm.v22i1.1

waters, and these same factors alter the balance of natural life (Batur and Maktav, 2019). Prior to the industrial revolution and the rapid urbanization of the world, poor water quality was historically overlooked due to the huge sums of money required in the process (Alparslan *et al*., 2019). As the dynamics change water quality assessment has become crucial.

Previous studies focused on assessing the quality of water using sampled point data which have limited areal coverage (Luvhimbi *et al*., 2022; Liu *et al*., 2021; Soltani *et al*., 2021; Bhat *et al*., 2014). With the availability of remote sensing techniques which has the capacity to capture a broad field of view, remote sensing data is now being employed for effective water quality assessment. Remote sensing techniques have the advantage of broad coverage area and multi-temporal availability which is suitable for effective water monitoring strategies. GIS techniques also have the capability to capture, analyze, visualize and model geographically reference data with accuracy. Surface water quality characteristics could be precisely predicted for future research by means of GIS models created using band ratios and long-term acquisition of data (Batur and Maktav, 2019). Remote sensing techniques have been used extensively in recent times to assess the quality of surface water in some regions using various indexes such as Normalized Difference Water Index (NDWI), Normalized Difference, Chlorophyll Index (NDCI), Nitrogen Content Index (NI), Normalized Difference Turbidity Index (NDTI), and Total Suspended Matter (TSM) (Das *et al*., 2021; Meena *et al*., 2021; Li *et al*., 2023; Elhag *et al*., 2020). The authors' findings and conclusions provide a reasonable indication about the water quality status of those surface water bodies.

This study seeks to evaluate the water quality in the Prestea-Huni Valley Municipality in the Western Region of Ghana using remote sensing and GIS techniques for effective water monitoring and management.

1.1 The Study Area

The Prestea-Huni Valley Municipal in the Western Region of Ghana was selected for this study due to the long history of mining in the area. The Municipality is located in the eastern part of the Western Region and its capital town is Bogoso. It lies within latitudes 5°10' N and 5°40' N and longitudes 1°40' W and 2°10' W (Anon., 2014). It covers a land area of approximately 1 809 km^2, which constitutes about 7% of the total land area of the Region (Anon., 2011). It is bordered to the north by Wassa Amenfi East and Wassa Amenfi Central Districts, to the west by Wassa Amenfi West District, to the south by Tarkwa Nsuaem Municipality, to the south-west by Ellembelle District, to the east by Mpohor District, and the northeast by Twifo-Ati Mokwa District in the Central Region (Anon., 2011).

The topography of the Municipality is generally undulating with elevation ranging from 71 to 91 m above mean sea level. The Municipal is traversed by several rivers and streams including the Ankobra, Huni, Oppon, Bogo, Peme, Subri, Bonsa and Mansi. The rivers are used for fishing as well as for providing water to surrounding communities. The Municipality has a humid equatorial climate and its situated in Ghana's rainforest region. The two main seasons for rainfall are typically from March to July (major season) and from September to November (minor season). With a mean annual rainfall of 187.83 mm, the Municipality is known to have abundant rainfall. All year long, there are high temperatures with notable daily and seasonal changes. The annual average temperature range from 26ºC to 30ºC, while the humidity value ranges from 75 to 80% in the wet season and 70 to 80% in the dry season. There is considerable leaching of the base from the topsoil which is caused by excessive rainfall, humidity, and temperatures. The soil is deep, open, and acidic in many areas (Mensah *et al*., 2015; Wiafe *et al*., 2022). The Municipality has tropical rainforest vegetation with some trees reaching between 15 and 40 m tall. The natural vegetation is however, endangered due to unlawful mining and logging activities. Among the most important economic crops grown are citrus, cocoa, rubber, coffee, oil palm, and coffee (Anon., 2014). Fig. 1. shows the map of the study area.

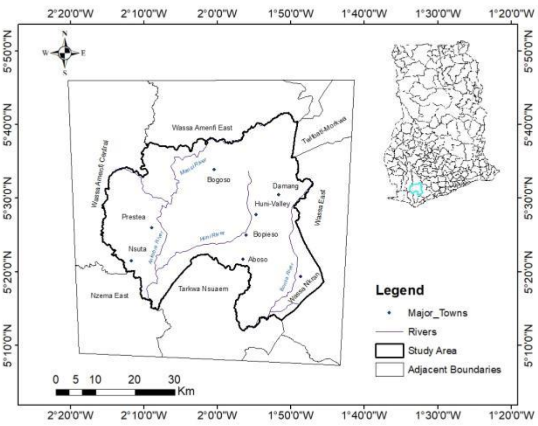

Fig. 1 A Map of the Study Area

2 Resources and Methods Used

The materials used include data, GNSS Receivers, water samples for laboratory analysis, ArcGIS and QGIS software. The methods used include processing of the Landsat 9 images, calculation of normalised difference of water index (NDWI), normalised difference of water turbidity index (MDTI), interpolation of laboratory water quality indicators and creation of water quality maps.

2.1 Data Used

Both primary and secondary data were used for this study. The primary data included positional data observed using handheld GNSS Receivers and thirty (30) water samples collected and labeled at the sampled locations within in the study area. The water samples were analysed at the Environmental Monitoring Laboratory on the UMaT Tarkwa campus for water quality parameters such as Turbidity and Total Suspended Solids (TSS). Also, a satellite image of the study area was downloaded from the Earth explorer website with the Landsat 9 LOI_TIRS sensor. The image was acquired on 21st December 2021 and downloaded on the 25th of August 2022 from the website of the United States Geological Survey. The format of the downloaded satellite data was in GeoTIFF with a spatial resolution of 30 m. Topographic data of the Study Area containing water bodies, towns and other features was also obtained from the Survey and Mapping Division of the Lands Commission and used for the production of maps.

2.2 Method Used

Fig. 2. shows the steps used to achieve the objective of the paper.

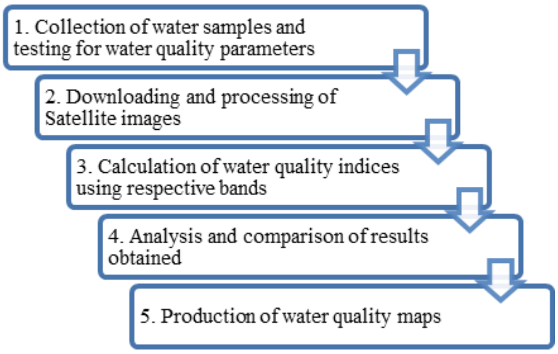

Fig. 2 A Flow Chart Showing the Methods Used

2.2.1 Water Sampling

A linear systematic sampling approach was adopted in this study with a sampling average interval of about 5 km along the major rivers in the study area subject to accessibility (Chang and Huang, 2000). To obtain a small but representative portion of the water from the major rivers in the study area at the sampling points, prescribed water bottles were procured and each bottled was labeled at the sampling point. The base of the bottle was held with one hand and the other hand was used to remove the lid to take the sample. Then the lid was replaced immediately and the geographic position was measured by means of a handheld GPS Receiver, and the sample was securely placed in a container. At the end of the field data collection exercise, the samples in the container was transported by means of a vehicle to the Laboratory Team at the Environmental Monitoring Laboratory at UMaT, Tarkwa for analysis.

2.2.2 Downloading and Processing of Satellite Images

Atmospherically adjusted satellite data were acquired from the United States Geological Survey website. To extract the reflectance values from the selected images, these images were processed with the help of the QGIS software. Processing was done in two steps. The first step was the conversion of digital numbers to at-sensor spectral radiance (Lλ), which removed the voltage bias and gains from the satellite sensor. In the second step, the at-sensor spectral radiance (Lλ) values were converted into Top-Of Atmosphere (TOA) reflectance (ρλ) values, taking into account the varying sun angles due to differences in latitude, season, and time of day, and the varying separation between the Earth and the sun.

2.2.3 Calculation of Water Quality Indices Using Respective Bands

The reflectance values of the processed images were used to calculate some water quality indices which included: the Normalized Difference Turbidity index (NDTI), and Normalized Difference Water Index (NDWI). Turbidity is the measure of the relative clarity of a liquid which affect the reflectance values.

2.2.3.1 Normalized Difference Water Index

The analysis of water bodies uses the Normalized Difference Water Index (NDWI). The near-infrared (NIR) and short-wave infrared (SWIR) bands are used in this index. In most instances, the NDWI can effectively improve water information. It is sensitive to built-up, which might cause water bodies to be overestimated. Low-reflecting water surfaces only reflect visible electromagnetic radiation. The blue region of the visible spectrum is where clear water reflects light the most strongly. Visible spectrum reflectance is increased in turbid water. Beyond near-infrared (NIR), there is no reflection. McFeeters (1996) created NDWI to improve the water-related landscape aspects.

Although NDWI is mostly used for studying vegetation liquid in space, it is found to be appropriate index for water body mapping and can enhance water information effectively (Taloor *et al*., 2021; McFeeters, 2007). According to Xu, (2006), turbidity estimations of water bodies could be derived from NDWI using remotely sensed data. Equation 4.3 was used for the computation of the NDWI.

$$\text{NDWI} = \frac{\text{NIR} - \text{SWIR 1}}{\text{NIR} + \text{SWIR 1}} = \frac{\text{Band 5} - \text{Band 6}}{\text{Band 5} + \text{Band 6}} \quad (2.1)$$

2.2.3.2 Normalized Difference Turbidity index

Turbidity in water bodies is calculated using the Normalized Difference Turbidity Index (NDTI) (Sherjah *et al*., 2023). Additionally, it is calculated using the spectral reflectance values of water pixels. It makes use of the fact that in clear water, electromagnetic reflectance is greater in the green wavelength than in the red spectrum (Schmit *et al*., 2018; Zhu *et al*., 2018). As a result, the reflectance of the red spectrum increases along with an increase in turbidity. Equation 2.1 was used for the computation of this index.

$$\text{NDTI} = \frac{\text{Red} - \text{Green}}{\text{Red} + \text{Green}} = \frac{\text{Band 4} - \text{Band 3}}{\text{Band 4} + \text{Band 3}} \quad (2.2)$$

2.2.4 Spatial Interpolation of Laboratory Values of Water Samples using Inverse Distance Weighting Method

Inverse Distance Weighted (IDW) interpolation is a deterministic spatial interpolation approach to estimate an unknown value at a location using some known values with corresponding weighted values (Gunarathna *et al*., 2016). IDW was used because it is fast, easy to compute, performs better than other interpolation methods and it is widely applicable (Lu and Wong, 2008; Gunarathna *et al*., 2016; Hu *et al*., 2023). The weight is the inverse distance of a point to each known point value that is used in the calculation. To determine the value of an unknown point x* from a set of known points x_1, x_2, $x_3 \ldots x_n$ with weights of w_1, w_2, $w_3 \ldots w_n$ the relation is expressed in Equation 2.4.

$$x* = \frac{x_1 w_1 + x_2 w_2 + x_3 w_3 + \ldots + x_n w_n}{w_1 + w_2 + w_3 + \ldots + w_n} \quad (2.4)$$

In this study, the values of unknown water quality indicators were interpolated from the measured values using IDW interpolation method. A total of 30 samples were collected along the Ankobra, Mansi (a tributary of the Ankobra) and Huni rivers which happens to be the major rivers in the study area. The total number of samples collected gave an indicative representative of the major water bodies for accurate interpolation in the study area constraints. The tested parameters were turbidity and total suspended solids (TSS). Figs. 3 and 4 show a map of the locations of the sample points and pictures of the field collection of water samples close to Prestea along one of the tributaries of the Ankobra river (A) and the main Ankobra river (B) respectively.

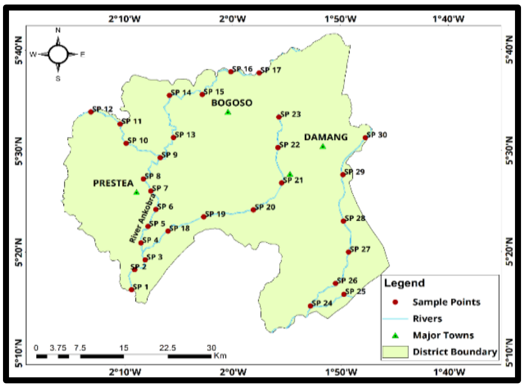

Fig. 3 Map Showing Location of Sample Points

Fig. 4 Pictures Showing Field Collection of Water Samples

3 Results and Discussion

3.1 Results

The study shows results of maps of the Normalized Difference Water Index Map, Normalized Difference Turbidity Index and the interpolated map of the Turbidity and the TSS.

3.1.1 Water Indicators

Table 1 shows the results after the computations of the various indices.

3.1.1.1 Normalized Difference Water Index

The Normalized Difference Water Index (NDWI) map of the study area is shown in Fig. 5. The results obtained after the computation of this indicator range from -0.0816 to 0.2433 and are shown in different shades of colour. The NDWI map represent clearly surface water body features and other features such as vegetation that have water content. The water feature and other features that have water content such as vegetation have positive values with non-water features such as bare land and built up having negative values. An average value of about 0.08 gives an indication that the area has more features containing water. The results show the water feature in pink colour with values ranging from -0.08 to 0.09. The combination of the green and NIR enable features with moisture content to be enhanced in the image for further analyses.

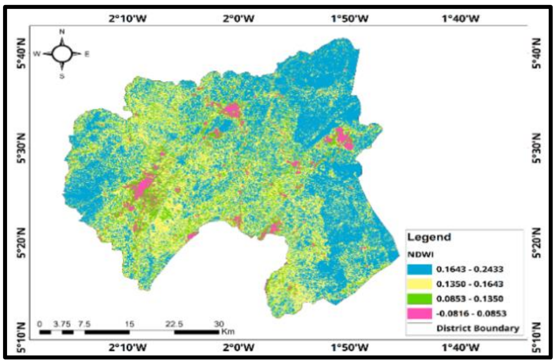

Fig. 5 Normalized Difference Water Index Map

3.1.1.2 Normalized Difference Turbidity Index

A map depicting the NDTI of the water bodies in the study area as shown in Fig. 6. The results obtained after the computation of this indicator range from -0.0662 to 0.0875 with the different values representing different feature classes shown by the colours, that is blue, pink, yellow and brown. The turbidity values for the surface water features shown in blue range from -0.0083 to 0.0875 reflecting loss of transparency of the water bodies in the study area. Positive NDTI indicates the presence of solids or colloidal particles in the water body, possibly due to human activities such as mining or farming close to the banks of the water bodies.Table 1 shows a summary of the NDWI and NDTI values obtained.

Table 1 Values for NDWI and NDTI Computation

Index	Maximum Value	Minimum Value	Average
NDWI	0.2433	-0.0816	0.08085
NDTI	0.0875	-0.0662	0.01065

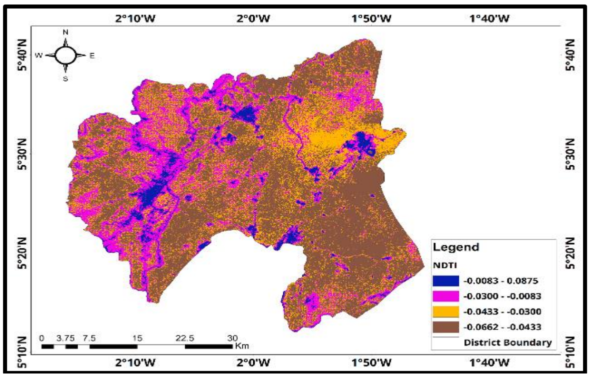

Fig. 6 Normalized Difference Turbidity Index Map

3.1.2 Results from Laboratory Analysis

Table 2 shows the World Health Organization (WHO) and Ghana Water Company Limited (GWCL) guidelines for drinking water.

Table 2 WHO and GWCL Guidelines for Drinking Water

PARAMETER	UNITS	PERMISSIBLE LIMIT	
		WHO	GWCL
Colour	Hz	15	0-50
pH	pH unit	6.5-8.5	6.5-8.5
Turbidity	NTU	5	0-15
Conductivity	µS/cm	1000	1000
Temperature	ºC	-	NGV
TSS	mg/L	0	1000

(Source: Anon., 2016)

3.1.2.1 Turbidity Map

The interpolated turbidity map of the study area is shown in Fig. 7 with the region in red showing locations with the highest turbidity values in the range of 5 746 to 7 939 NTU. Also, regions in the shades of blue shows relatively low turbidity with values ranging from 1 360 – 2 212 NTU. Generally, the turbidity of the water bodies in the study area increased from the eastern part towards the western section, with the basin of the Ankobra river recording the highest level of turbidity shown in red colour. This is followed closely by the Huni river, a tributary of the Ankobra river with values ranging from 2212 to 3218 NTU which is shown in cyan colour. The least polluted/turbid river in the study area is the Bonsa river which flows in the north south direction along the eastern part of the study area and recorded values less than 2212 NTU as shown in sea blue colour.

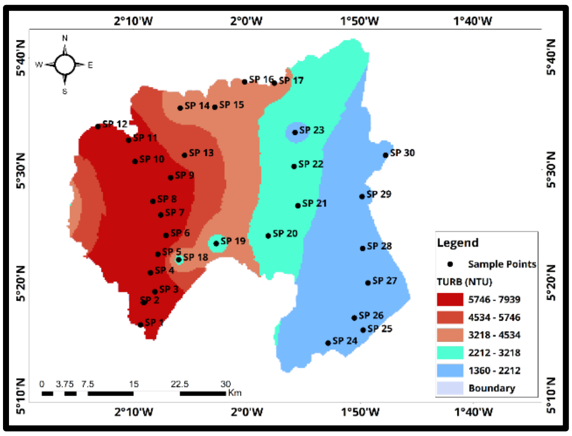

Fig. 7 Turbidity Map of Study Area

3.1.2.2 Total Suspended Solid Map

The map of the study area showing the levels of total suspended solids (TSS) in some major water bodies in the Municipality is shown in Fig. 8. Regions shown in red and blue have the highest and lowest TSS values ranging from 8 506-10 687 ppm and 2 131-3 741 ppm respectively. Generally the TSS values varied considerably across the study area, with values increasing from the eastern section towards the west. Considering the Western section of the study area, the TSS values showed an increasing trend from the northern section towards the south with the highest values (8 506 - 2131ppm) recorded along the lower course of the Ankobra river near Prestea.

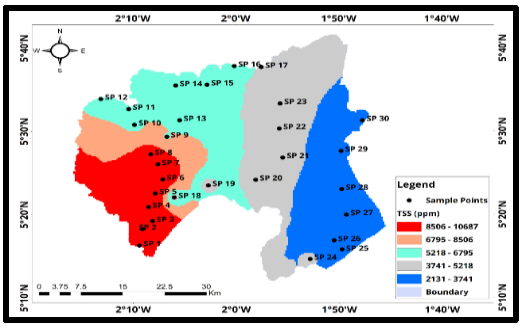

Fig. 8 Total Suspended Solids Map

3.1.2.3 Matrix Plot of Total Suspended Solids and Turbidity Values

The matrix plot of the Pearson correlation analysis with a 95% confidence level and correlation coefficient of 0.82 is shown in Fig. 9. A linear regression model fitted to the scatter plot yielded Equation 3.1, which shows that as turbidity increases, the total suspended solids in the water body also increases with a strong positive linear relationship. Turbidity reflects loss of transparency of the water bodies under consideration which is due to the presence of colloidal and/ or suspended solids in the water (Hannouche *et al.*, 2011).

$$TSS = 1\ 447 + 1.035 \times Turbidity \qquad (3.1).$$

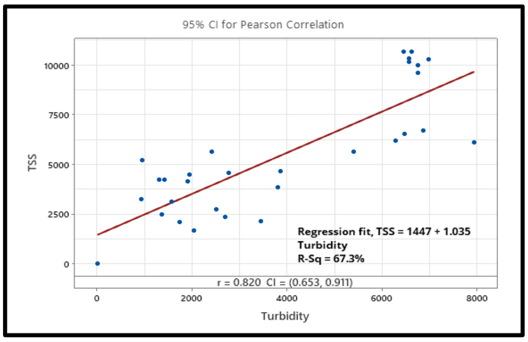

Fig. 9 Matrix Plot of Total Suspended Solids and Turbidity Values

3.1.2.4 Matrix Plot of Laboratory Analysis and Satellite Indices

The matrix plot of the Pearson correlation analysis with a 95% confidence level and correlation coefficient of 1.00 is shown in Fig. 10. A linear regression model fitted to the scatter plot satellite indices and the values obtained from the laboratory analysis yielded Equation 3.2. Laboratory analysis = 3 637 + 22 538 × Satellite Indices (3.2).

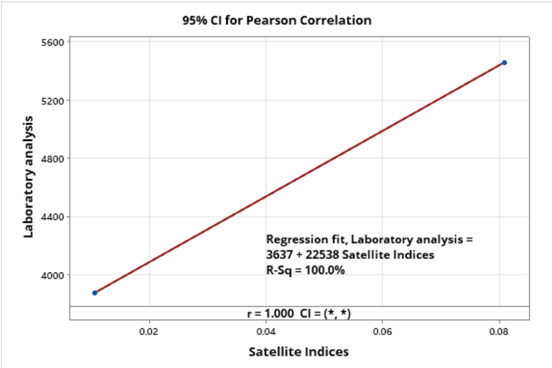

Fig. 10 Matrix Plot of Laboratory Analysis and Satellite Indices

3.2 Discussion

The main water quality parameter considered in this study is turbidity which is a measure of the transparency of a liquid and can be derived from the reflectance values of remotely sensed data. NDWI which measures the moisture content in surface features was determined for the study; however, the NDWI values obtained only enabled the features with moisture content such as surface water, vegetation and built up areas to be mapped with different colours making it possible for them to be classified in the image. Little information on the turbidity of the surface water features was observed in this study as suggested by McFeeters (2007). It was also observed that the contrast between the surface water features and the other features such as vegetation and built up was rather low (Fig 5).

From Fig 6 the NDTI map showed the turbidity values of the surface water features in blue with values ranging from -0.0083 to +0.0875, all other features (vegetation, built up and bare land) were shown as brown, purple and yellow with negative values. The positive values of NDTI indicate a higher level of turbidity, whereas the negative values indicate clean water. A visual inspection of the surface water features in Fig 5 as compared to the surface water features in Fig 6 show larger area coverage for Fig 6. The extended coverage area could be surface water from springs or tributaries joining the main rivers. The springs/tributaries are likely to be clearer compared with the main rivers (See Figs. 4 A & B). The negative values associated with the surface water features class could be from springs or small tributaries or runoffs that recharge the main rivers. The positive values of NDTI could be from the main rivers in the study area.

From Fig 7, the turbidity of the rivers tend to increase from the east towards the west with the southwestern part showing the highest levels (most polluted). All the values shown in Turbidity Map of the study area (Fig 7) are in excess of the WHO and GWCL permissible limits provided in Table 2. These areas include the basin of the Ankobra river near Prestea where the activities of illegal small scale gold mining is rampant. The removal of the top soil to access the ore and the processing of the ore in the surface water bodies by these illegal miners could be responsible for introducing mud and other substances into the rivers, thus the high levels of turbidity observed. The Huni river which is a tributary of the Ankobra river has relatively lower level of turbidity values (3741-5218 NTU) though there are some illegal small scale gold mining activities close to Bopieso (Owusu-Nimo *et al*., 2018). From Fig 7, the Bonsa river is relatively least turbid main river in the study area as limited number of illegal small scale gold mining activities are recorded in the catchment of the Bonsa river, most the illegal small scale mining mining activities are carried out underground. Other human activities such as farming close to water bodies, clearing of land exposing it to soil erosion by runoff and lumbering could also explain the high levels of turbidity of surface water bodies in the study area.

From Fig 8, the map showing the total suspended solids in the rivers of the study area range from 10687 to 3741 ppm which is far higher than the standards of WHO and GWCL as shown in Table 6. This is an issue of health concern, as inhabitants of the Municipality depend on the rivers for domestic use including drinking.

From Fig 9, the scatter plot between the measured turbidity values against the TSS gave a positive correlation. While turbidity reflects loss of transparency of the water bodies under consideration, TSS measures the presence of colloidal and/ or suspended solids in the water causing turbidity. The coefficient of proportionality (1.035) between TSS and turbidity thus depend on the geometric and optical characteristics of the suspended particles (Hannouche *et al*., 2011; Münzberg *et al*., 2017; Bright *et al*., 2018)). The coefficient of determination (0.67) obtained from Fig 9 explains the proportion of the variation in the turbidity that is predicted by the TSS and measures how well the linear model use the predict TSS outcome. The correlation coefficient between TSS and the turbidity (0.8) revealed strong linear relationship and indicates that total suspended solids forms part of the major contributing factors causing turbidity of water bodies. The other factor causing turbidity of water bodies could be dissolved solids.

From Fig 10, the perfect correlation between the laboratory analysis and that of the Satellite indices used show that findings of the laboratory analyses are consistent with the results from the Satellite indices; this confirms the assertion that remote sensing analysis could be used to assess the turbidity of surface water bodies. This approach can be applied to surface water bodies that are inaccessible for sampling or where laboratory analysis is limited due to financial constraints. It could also be used for preliminary assessment of turbidity of surface water bodies and for research purposes.

4 Conclusion and Recommendation

4.1 Conclusion

In this study, the feasibility of using satellite imagery for water quality studies in the Prestea-Huni-Valley Municipality was investigated. The large coverage of the Landsat 9 satellite was very efficient in this study, allowing for better monitoring of the turbidity of surface water bodies in the study area. The turbidity levels of the rivers in the study area are very high, exceeding the threshold values set by the WHO and the GWCL guidelines for drinking water. The Bonsa river is the relatively least polluted followed by the Huni river, with the most polluted river being the Ankobra river due to the activities of illegal small scale gold mining in the area as well as the method of mining adopted.

The NDWI used in the study enabled the moisture content of the surface water feature to be measured and enhanced for further analysis. The normalized difference turbidity water index (NDTI) enable the turbidity of the surface water features to be determined from the reflectance values of electromagnetic spectrum.

There was consistency in turbidity values between the satellite indicator (NDTI) used and the laboratory analysis. The total suspended solids and/ or colloidal particles introduced into the rivers through the operations of illegal small scale gold mining is the major cause of turbidity/pollution of the water bodies in the Prestea Huni-Valley Municipality in the western region of Ghana.

4.2 Recommendations

Since the routine monitoring of water quality parameters is costly and requires constant laboratory supplies and efforts, it is recommended that high spatial resolutions satellite such as Sentinel-2B be used in the monitoring of water quality for accurate results and efficiency. Further studies should be conducted to explore more applications areas of remote sensing for national development. Also the inhabitants should be educated to be selective in their choice of method of mining as well as sources of drinking water. Finally, stringent polices should be formulated by decision makers to control the menace of illegal small scale gold mining activities in order to preserve natural water resources and ecology in Ghana.

Acknowledgement

The authors are grateful to the Department of Geomatic Engineering of the University of Mines and Technology and the team at the Environment Monitoring Laboratory at UMaT for their support.

References

Abbas SH, Ismail IM, Mostafa TM, Sulaymon AH. (2014), "Biosorption of heavy metals: A review", *Journal of Chemical Science and Technology*, No. 3, pp. 74-102.

Ahmed Amin Soltani, Amar Oukil, Hamouda Boutaghane, Abdelmalek Bermad, Mohamed-Rachid Boulassel (2021), "A new methodology for assessing water quality, based on data envelopment analysis: Application to Algerian dams", *Ecological Indicators*, Vol. 121, pp. 106952.

Alley ER. (2007), "Water Quality Control Handbook", Vol. 2, New York: McGraw-Hill, pp. 82-95.

Alparslan, E., Coskun, H.G. and Alganci, U. (2009), "Water Quality Determination of Küçükçekmece Lake, Turkey by Using Multispectral Satellite Data", *The Scientific World JOURNAL*, Vol.9, pp. 1215–1229.

Anon. (2011), "Prestea – Huni Valley Municipal", *www.wikipedia.com*. Accessed: August 10, 202-2.

Anon. (2014), "Municipal Analytical Report: Prestea – Huni Valley Municipal", *Ghana Statistical Services.*

Anon. (2016), "Quality Assurance Manual for Ghana Water Company Limited", *www.epa.gov*. Accessed: August 10, 2022.

Anon. (2019), "Water, the Universal Solvent", U.S. Department of the Interior. *usgs.gov*. United States of America: USGS. Accessed: 8 August 2022.

Batur, E. and Maktav, D. (2019), "Assessment of Surface Water Quality by Using Satellite Images Fusion Based on PCA Method in the Lake Gala, Turkey", *IEEE Transactions on Geoscience and Remote Sensing*, Vol.57, No. 5, pp. 2983–2989.

Bebbington, J., and Unerman, J. (2018), "Achieving the United Nations Sustainable Development Goals: an enabling role for accounting research", *Accounting, Auditing & Accountability Journal*.

Bright, C.E., Mager, S.M. and Horton, S.L.(2018), "Predicting suspended sediment concentration from nephelometric turbidity in organic-rich waters" *River Research and Applications*, Vol. *34, No.* 7, pp.640-648.

Chang, H.J. and Huang, K.C., (2000), "Remainder linear systematic sampling" Sankhyā: The Indian Journal of Statistics, Series B, pp.249-256.

Cordy, Gail E. (2014), "A Primer on Water Quality", *USGS*.

Craig, P.J. (1998), "Book review: Chemistry of the elements", *Applied Organometallic Chemistry*, 2nd edition, Oxford, Vol.12, No. 12, pp. 880–880.

Das, S., Kaur, S., & Jutla, A. (2021), "Earth observations based assessment of impact of COVID-19 lockdown on surface water Quality of Buddha Nala, Punjab, India", *Water*, Vol.13, No. 10, 1363 pp.

Davis ML. (2010), "Water and Wastewater Engineering—Design Principles and Practice", New York: McGraw-Hill.

Du, Yun, Yihang Zhang, Feng Ling, Qunming Wang, Wenbo Li, and Xiaodong Li. (2016), "Water bodies' mapping from Sentinel-2 imagery with modified normalized difference water index at 10-m spatial resolution produced by sharpening the SWIR band." *Remote Sensing* Vol., 8, No. 4: 354.

Edzwald, J.K. (2010), "Water Quality and Treatment a Handbook on Drinking Water", McGraw-Hill, New York, pp. 70-82.

Gbedzi, D.D., Ofosu, E.A., Mortey, E.M., Obiri-Yeboah, A., Nyantakyi, E.K., Siabi, E.K., Abdallah, F., Domfeh, M.K. and Amankwah-Minkah, A. (2022). "Impact of mining on land use land cover change and water quality in the Asutifi North Municipal of Ghana, West Africa", *Environmental Challenges*, Vol.6, pp. 100441.

Gómez-Couso, H., Fontán-Saínz, M., Sichel, C., Fernández-Ibáñez, P., & Ares-Mazás, E. (2009), "Efficacy of the solar water disinfection method in turbid waters experimentally contaminated with Cryptosporidium parvum oocysts under real field conditions", *Tropical Medicine & International Health*, Vol.14, No. 6, pp. 620-627.

Graham, N. (1999), "Guidelines for Drinking-Water Quality", *Addendum to Volume 1 – Recommendations*, World Health Organisation, Geneva, 1998, Vol.1, No. 2, pp. 183.

Gunarathna, M. H. J. P., Kumari, M. K. N., and Nirmanee, K. G. S. (2016). Evaluation of interpolation methods for mapping pH of groundwater. *International journal of latest technology in engineering, management & applied science*, Vol.3, 1-5pp.

Hammer, M. J. (2011), "Water and Wastewater Technology", *Pearson Education*, Upper Saddle River, 7th Edition, pp. 750-800.

Hannouche, A., Chebbo, G., Ruban, G., Tassin, B., Lemaire, B.J. and Joannis, C. (2011), "Relationship between turbidity and total suspended solids concentration within a combined sewer system", *Water Science and Technology*, Vol. 64, No. 12, , pp.2445-2452.

Howard, G., Butler, H., Jouhar, A. J., and Poucher, W. A. (2012). Poucher's Perfumes, *Cosmetics and Soaps*: Volume 1: The Raw Materials of Perfumery. Springer Science & Business Media.

Hu, W., Xin, X., Zou, X., Li, L., Niu, S., Li, Q., Yu, G. and Wang, L. (2021), "Application of production splitting method based on inverse distance weighted interpolation in X Oilfield", Energy Reports, Vol. 7, pp.850-855.

Johnson, D.L., Ambrose, S.H., Bassett, T.J., Bowen, M.L., Crummey, D.E., Isaacson, J.S., Johnson, D.N., Lamb, P., Saul, M. and Winter-Nelson, A.E. (1997), "Meanings of Environmental Terms", *Journal of Environment Quality*, Vol.26, No.3, pp. 581.

Kontopoulou, E., Kolokoussis P. and Karantzalos K. (2017), "Water quality estimation in Greek lakes from Landsat 8 multispectral satellite data", *European Water*, Vol.58, pp. 191–196.

Li, C., Rousta, I., Olafsson, H., & Zhang, H. (2023), "Lake Water Quality and Dynamics Assessment during 1990–2020 (A Case Study: Chao Lake, China)", *Atmosphere*, Vol. 14, No 2, pp. 382.

Listyani, R.A.T. and Peni, S.N. (2020), "March. Potential of Water Pollution in Girimulyo, West Progo. In IOP Conference Series", *Earth and Environmental Science,* Vol. 448, No. 1, p. 012038, IOP Publishing.

Liu J, Zhang D, Tang Q, Xu H, Huang S, Shang D. (2021), "Water quality assessment and source identification of the Shuangji River (China) using multivariate statistical methods", *PLoS ONE*, Vol.16, No. 1.

Lu, G.Y. and Wong, D.W. (2008), "An adaptive inverse-distance weighting spatial interpolation technique", *Computers & geosciences*, Vol. 34, No. 9, pp.1044-1055.

Luvhimbi, N., Tshitangano, T.G., Mabunda, J.T. (2022), "Water quality assessment and evaluation of human health risk of drinking water from source to point of use at Thulamela municipality, Limpopo Province", *Sci Rep 12*, pp. 6059.

Mahesh Patil (2021), "What is pH and how is it measured", *https://chrominfo.blogspot.com*. Accessed: 8 Aug. 2022.

Meena, S. R., Chauhan, A., Bhuyan, K., & Singh, R. P. (2021), "Chamoli disaster: pronounced changes in water quality and flood plains using Sentinel data", *Environmental earth sciences*, Vol.80, No.17, 601 pp.

Mensah, A. K., Mahiri, I. O., Owusu, O., Mireku, O. D., Wireko, I., and Kissi, E. A. (2015). Environmental impacts of mining: a study of mining communities in Ghana, *Applied Ecology and Environmental Sciences*, Vol. 3 No. 3, 81-94pp.

Moriasi, D. N., Gitau, M. W., Pai, N., and Daggupati, P. (2015). Hydrologic and water quality models: Performance measures and evaluation criteria. *Transactions of the ASABE*, Vol. 58, No.6, 1763-1785pp.

Münzberg, M., Hass, R., Dinh Duc Khanh, N. and Reich, O. (2017), "Limitations of turbidity process probes and formazine as their calibration standard", *Analytical and bioanalytical chemistry,* Vol. 409, pp.719-728.

Owusu-Nimo, F., Mantey, J., Nyarko, K.B., Appiah-Effah, E. and Aubynn, A. (2018), "Spatial distribution patterns of illegal artisanal small scale gold mining (Galamsey) operations in Ghana: A focus on the Western Region" *Heliyon*, Vol., *4, No.* 2, p.e00534.

Patrick Higgins (2014), "The Basics of Chlorophyll Measurement in Surface Water".

Salim Aijaz Bhat, Gowhar Meraj, Sayar Yaseen, Ashok K. Pandit (2014), "Statistical Assessment of Water Quality Parameters for Pollution Source Identification in Sukhnag Stream: An Inflow Stream of Lake Wular (Ramsar Site), Kashmir Himalaya", *Journal of Ecosystems*, Vol.2, pp.18.

Schmit, T. J., Lindstrom, S. S., Gerth, J. J., and Gunshor, M. M. (2018)."Applications of the 16 spectral bands on the advanced baseline imager (ABI)", *Journal of Operational Meteorology*, Vol. *6, No. 04*|4, pp 33–46. https://doi.org/10.15191/nwajom.2018.0604

Sensorex (2021), "Three Main Types of Water Quality Parameters Explained". *https://chrominfo.blogspot.com*. Accessed: 8th August 2022.

Shen, G. (2020), "Campbell biology", *Journal of Biological Research-Thessaloniki*, Vol.27(1).

Sherjah, P.Y., Sajikumar, N. and Nowshaja, P.T. (2023), "Trophic Status Mapping of Inland Water Bodies Using Normalized Difference Indices Derived from Sentinel 2 MSI Imagery", *Journal of Hydrologic Engineering, Vol.* 28, No. 1, p.04022035.

Spellman, F. (2017), "The Drinking Water Handbook", *Boca Raton*, CRC Press, 3th Edition, pp.65-67.

Taloor, A.K., Manhas, D.S. and Kothyari, G.C, (2021), "Retrieval of land surface temperature, normalized difference moisture index, normalized difference water index of the Ravi basin using Landsat data", *Applied Computing and Geosciences*, Vol. 9, p.100051.

Tchobanoglous G, Burton FL, Stensel HD. Metcalf and Eddy (2003), “Wastewater Engineering: Treatment and Reuse”, Tata McGraw-Hill Limited, New Delhi, 4th Edition.

Tchobanoglous G, Peavy HS, Rowe DR. (1985), “Environmental Engineering”, New York: McGraw-Hill InterAmerican.

The Berkey (2020), “What is the Acceptable Total Dissolved Solids (TDS) Level in Drinking Water”.

Viessman W, Hammer MJ. (2004), “Water Supply and Pollution Control”, 7th edition, *Upper Saddle River: New Jersey Pearson Prentice Hall*.

Walter, William.G. (1961), “Standard Methods for the Examination of Water and Wastewater”, 11th edition, *American Journal of Public Health and the Nation’s Health*, Vol.51, No. 6, pp. 940–940.

Weingärtner, H., Teermann, I., Borchers, U., Balsaa, P., Lutze, H.V., Schmidt, T.C., Franck, E.U., Wiegand, G., Dahmen, N., Schwedt, G., Frimmel, F.H. and Gordalla, B.C. (2016), “Water, 1. Properties, Analysis, and Hydrological Cycle”, - *Ullmann’s Encyclopedia of Industrial Chemistry*, pp.1–40.

White C, Sayer J, Gadd G. (1997), “Microbial solubilization and immobilization of toxic metals: Key biogeochemical processes for treatment of contamination”, *FEMS Microbiology Reviews*, No. 20, pp. 503-516.

Wiafe, S., Awuah Yeboah, E., Boakye, E., and Ofosu, S. (2022). Environmental risk assessment of heavy metals contamination in the catchment of small-scale mining enclave in Prestea Huni-Valley District, Ghana, *Sustainable Environment*, Vol. 8, No.1.

Xu, H., (2006), “Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery”, *International journal of remote sensing*, Vol. 27, Bo. 14, pp.3025-3033.

Zhu, L., Suomalainen, J., Liu, J., Hyyppä, J., Kaartinen, H. and Haggren, H. (2018),“A review: Remote sensing sensors”, Multi-purposeful application of geospatial data, pp.19-42.

Zumdahl, S. Steven (2022), “Water”, *Encyclopaedia Britannica, https://www.britannica.com/science/water*. Accessed: 8 August 2022p.

Authors

Cynthia Borkai Boye is an Associate Professor of Geomatic Engineering at UMaT, Tarkwa, Ghana with over twenty years of experience. She holds BSc in Geodetic Engineering from KNUST, Professional Masters in Geo Informatics from ITC, Netherlands and PhD in Oceanography from the University of Ghana, Legon. She is a fellow of the WWAIMM, a member of GhIS, GhIE, LISAG and LIMAP among others. Her research and consultancy work include Shoreline Change Analyses and Prediction, Water Quality monitoring using remote sensing techniques, GIS Applications, and Sediment Modelling**.**

Graham Richmond is a Graduate of the University of Mines Technology (UMaT), Tarkwa with a Bachelor's degree in Geomatic Engineering. He is a student member of the Ghana Institution of Surveyors (GHIS) and a Youth Mapper as well. His areas of research interest include programming, machine learning and the Application of Geographic Information System (GIS) and Remote Sensing for Environmental Monitoring.

Abigail Asare is a Graduate of the University of Mines and Technology, Tarkwa. She has just completed her National Service with the Geomatic Engineering Department of UMaT and aspiring to do her Master degree in Geomatics. She is a student Member of Ghana Institution of Surveyors (GhIS). Her research interest is in Application of GIS and Remote Sensing for Environmental monitoring.

Martey Andrew Ed-Israel Kweite is a Graduate of the University of Mines Technology (UMaT), Tarkwa and holds a Bachelor's degree in Geomatic Engineering. He is a student member of the Ghana Institution of Surveyors (GhIS) and a Youth Mapper who contributes to OpenStreetMaps. His research interests include Shoreline Change Modelling and Prediction with Artificial Intelligence (AI) and Geographic Information System (GIS).