Mulungushi University Multidisciplinary Journal
ISSN: 2958-3926
Vol. 5 No. 2

https://research.mu.ac.zm/research/index.php/mu

An assessment of the impacts of land use change on water quality and discharge – a case study of Chongwe catchment

Goodson Masheka[1*], Chewe Mwila[1], Mweene Himwiinga– Mufiti[1], Muumbe Lweendo[1]

[1] Mulungushi University, Department of Engineering, Kabwe, Zambia; Email: mashekagoodson@gmail.com
[1]Mulungushi University, Department of Engineering, Kabwe, Zambia; Email: chewechewe19971@gmail.com
[1]Mulungushi University, Department of Engineering, Kabwe, Zambia; Email: mweenehimwiinga@gmail.com
[1]Mulungushi University, Department of Engineering, Kabwe, Zambia; Email: muumbek@gmail.com

*Correspondence, Goodson Masheka, Email mashekagoodson@gmail.com

ARTICLE HISTORY: Received 23 September 2024; **Accepted** 31 January 2025

ABSTRACT

The impact of Land Use and Land Cover (LULC) changes on water quality and discharge is critical for regional water security. In this study, the effects of LULC changes on water quality and discharge in Zambia's Chongwe River were evaluated. Spatio-temporal changes in LULC from 1980 to 2021 were analyzed at 10-year intervals, correlating LULC changes with river water quality. To determine trends in water quality, the study employed the Mann-Kendall (MK) test for statistical assessment. Time-series Landsat images were analyzed through supervised classification, allowing quantification of LULC changes over time. Five main LULC classes were identified based on spectral reflectance signatures, focusing on Agriculture, Forest, Built-up, and Grasslands. Significant shifts in land use patterns were observed between 1980 and 2021. Built-up and agricultural lands expanded, while forest and grassland areas declined. From 1980 to 1990, agricultural land increased from 0.91% to 1.08%, built-up land from 0.87% to 1.10%, and grasslands from 64.93% to 68.62%. In contrast, forest lands decreased from 32.96% to 29.03% and water bodies from 0.34% to 0.19%. Between 2000 and 2021, agricultural land rose from 5.63% to 11.01%, and built-up land from 1.32% to 4.65%, while forest land decreased from 31.01% to 24.12%, grasslands from 61.90% to 60.17%, and water bodies from 0.14% to 0.05%. The MK test results for water quality parameters such as pH, EC, TDS, Na, Cl, and Mg showed an increasing trend, while temperature, Fe, K, and $SO4^{2-}$ decreased over the catchment at the four sampling stations. These trends are primarily attributed to expanded built-up areas and agricultural land, leading to increased impervious surfaces and enhanced surface runoff from cultivated lands, which transports chemical fertilizers to the river. Furthermore, dry season discharge levels were found to be significantly affected by water abstraction for irrigation and domestic use.
The study concluded that LULC changes significantly correlate with water quality. Specifically, agricultural land showed a negative correlation with discharge in the dry season, while built-up areas exhibited a positive correlation.

Keywords: Discharge, water quality, land use/land cover (LULC), geographical information system (GIS), remote sensing (RS)

INTRODUCTION

The International Geosphere-Biosphere Program (IGBP) focuses on two main research areas: Biosphere Aspects of the Hydrological Cycle (BAHC) and Land Use/Cover Change (LUCC). Studies investigating the environmental consequences of LUCC have provided beneficial insights for regional sustainable development. With the rapid pace of urbanization and unrestricted expansion of urban areas, land use patterns have transformed significantly, creating an urgent need to consider the effects on natural resources, particularly on water resource quality and availability [1].

Land use changes often exacerbate soil erosion, affecting all aspects of the water cycle and increasing pollution from non-point sources within watersheds [2]. Protecting watersheds requires a deep understanding of the link between land use changes and water resources, a connection of substantial value. Research highlights a significant correlation between land use and water resources in terms of both quality and quantity. Economic activities and human practices that drive land use changes are closely associated with the concentration of pollutants in water bodies [3]. Generally, water quality is found to be better in undeveloped, natural areas like woodlands [4]. Water quality is influenced by complex interactions among land use types, topography, and socio-cultural activities. Agricultural land, for instance, is typically the primary source of pollutants in river water [7]. Research in China's Dianchi Lake Basin has shown that different land use types significantly impact water quality [10]. A study in a river system in Bangladesh found a strong positive correlation between water quality and agricultural land ($r = 0.68$, $P < 0.01$) and a strong negative correlation with urbanized areas ($r = -0.94$, $P < 0.01$) [11].

In this paper, we focus on the Chongwe River Catchment, chosen for its economic and geographic significance. Recent studies indicate that rapid population growth, socio-economic development, and climate change have severely impacted water resources in the Chongwe Catchment, leading to challenges in water supply for human consumption and agriculture. However, limited research has examined the relationship between land use change, population growth, and water quality and quantity in this region. This knowledge gap can hinder the creation of effective, sustainable water resource management plans. This study seeks to investigate the effects of land cover changes on water quality and quantity, aiming to understand the relationship between land use change and water resources. Such an assessment is crucial for developing strategies and policies to mitigate the significant impact of land use on water quality.

Background: study area

The Chongwe River catchment is estimated to cover an area of about 5168.66Km^2 and is located in Zambia between latitude 1455'40" to 1543'19" S and longitude 28°13'°53" to 2921'24" E as shown in Figure 1. The catchment extends over Lusaka, Chisamba, Chongwe, Chibombo and Kafue districts. It occupies about 45% of the city of Lusaka [8].

The Catchment is split into the upper, middle and lower parts. The most common land use type in the upper and middle half is agriculture and livestock production. Approximately 6.5Km^2 of land is now being used for a variety of irrigation schemes in small and large scale farming. The main crops that are grown are groundnuts, maize, wheat, vegetables, cotton, flowers and horticultural crops. The other half is chiefly a built up area. The lower half is mostly forest and bushlands providing a natural habitat for animals and other wild creatures [6].

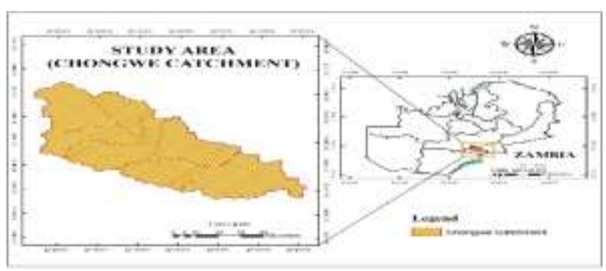


Figure 1. Location map of Chongwe river catchment.

METHODOLOGY

Flow chart

To elucidate the systematic approach followed in the research; this section delves into the ' Flow Chart,' which outlines the research technical flow chart and technique utilized to ensure methodological rigor and accuracy. This is illustrated in Figure 2 below.

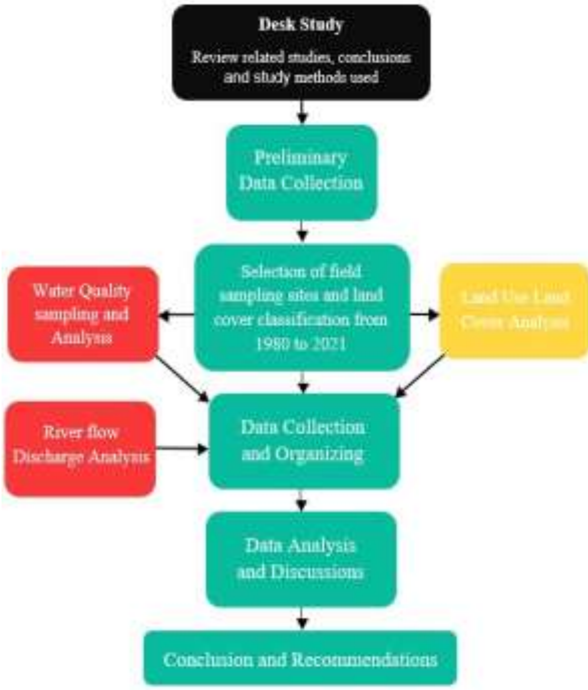


Figure 2. Research technical flow chart and technique.

Materials and Methods

Land Use Land Cover Detection and Analysis in the Chongwe River Catchment

Chongwe catchment was clipped out using a shape file of the catchment boundary. The method that was adopted for this task was supervised image classification which was carried out using Landsat 4-5 for 1980, 1990, 2000, 2010 and Landsat 8 for 2021. Supervised classification is centered around pattern recognition skills and Information that helps the system define statistical criteria or signatures for data classification. The Maximum Likelihood Classifier (MLC) parametric decision rule was used to carry out the image classification. The classification comprised of a predefined scheme which included classes namely Forest lands, Grasslands, Agriculture lands, built up areas and water bodies. The scheme represented in Table 3 was based on field information.

Table 1. A description of the land use and land cover classes used in this research.

Land Use/Land Cover Class	Cover Description
Forest Lands	Woodland, Forest Area, Dense trees, shrubs
Grasslands	Grasslands, Pasture land, small shrubs and Bareland
Agriculture Lands	Irrigation and Rain fed farms
Built Up Areas	Urban area, Building, Commercial, Industrial area, Airport, Road, Green houses, Residential Area, Sand Plain, Excavation sites and other related infrastructure
Water bodies	Reservoirs, Dams, Rivers/Streams, ponds, Wetland

A flowchart for land us map analysis of Chongwe river catchment is shown below.

Figure 3. Flowchart for land use/land cover map analysis of Chongwe river catchment.

Water sampling and Analysis of physical, chemical and biological quality parameters

Sampling and analysis were carried out based on Zambian standard (ZS), 2010 for water quality analysis. For the secondary data, the tests were conducted quarterly per annum between 2012 and 2021. Sampling sites are shown in figure 6. The sampling carried out was considered because the results that were produced were comparable with the data set that that was provided by WARMA from 2012 to 2021. All the equipment that was used for sampling was cleaned and rinsed with distilled water before carrying out the sampling exercise.

Trend Analysis of water quality

The trend analysis of water quality was carried out with the Kendall's t test as shown in equation 1,

$$\boldsymbol{Var(s)} = \frac{[\boldsymbol{n(n-1)(2n+5)-\sum_t t(t-1)(2t+5)}]}{\boldsymbol{18}}$$ [Equation 1]

Where t represents the extent of any given time and $\sum_t$ denotes the sum across all the ties in the water quality data. For n > 0, the standard normal variant is expressed:

$$z = \begin{cases} \frac{s-1}{\sqrt{Var(s)}} & if\ s > 0 \\ 0 & if\ s = 0 \\ \frac{s+1}{\sqrt{Var(s)}} & if\ s < 0 \end{cases}$$

An increasing trend is detected when the value of S is positive in Equation 1 and a negative S value depicts a decreasing trend. This test interprets that if:

- H0: There is no trend in the series
- Ha: There is a trend in the series
- If the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha, but if the opposite occurs then the null hypothesis is not rejected.

The Kendall's t test was performed with the use of an extension of Microsoft Excel which is XL stat 2016.

Furthermore, the Man-Kendall trend test was carried out for all the sampling stations and the averages of the results were computed to have an overview of how the catchment at the 4 sampling sites has been behaving with respect to the water quality.

Measurement of river flow discharge

The gauge stations of interest in this study were station 5-016, 5-024 and 5-025 which are Ngwerere at Ngwerere weir, Chongwe-Ngwerere confluence and Chongwe at great east road bridge respectively.

Station Rating Equations

For two stations it was impossible to use the wading method such as Chongwe bridge great east road and Ngwerere weir, therefore the stage method was employed. All gauge stations had gauge plates thus measuring stage data was the alternative route in which it required the use of stage/discharge rating equations for the various gauge stations.

The correlation between discharge and water level can be expressed with a rating equations. The rating curves usually conform with a formula as shown in Equation 2.

$$Q = C \times (h + a)^N$$ [Equation 2]

Where:

Q = Discharge (m^3/s)
C = Calibration parameter (1)
H = Water level (m)
a = Water level at which discharge is zero (m)
N = Calibration parameter (1)

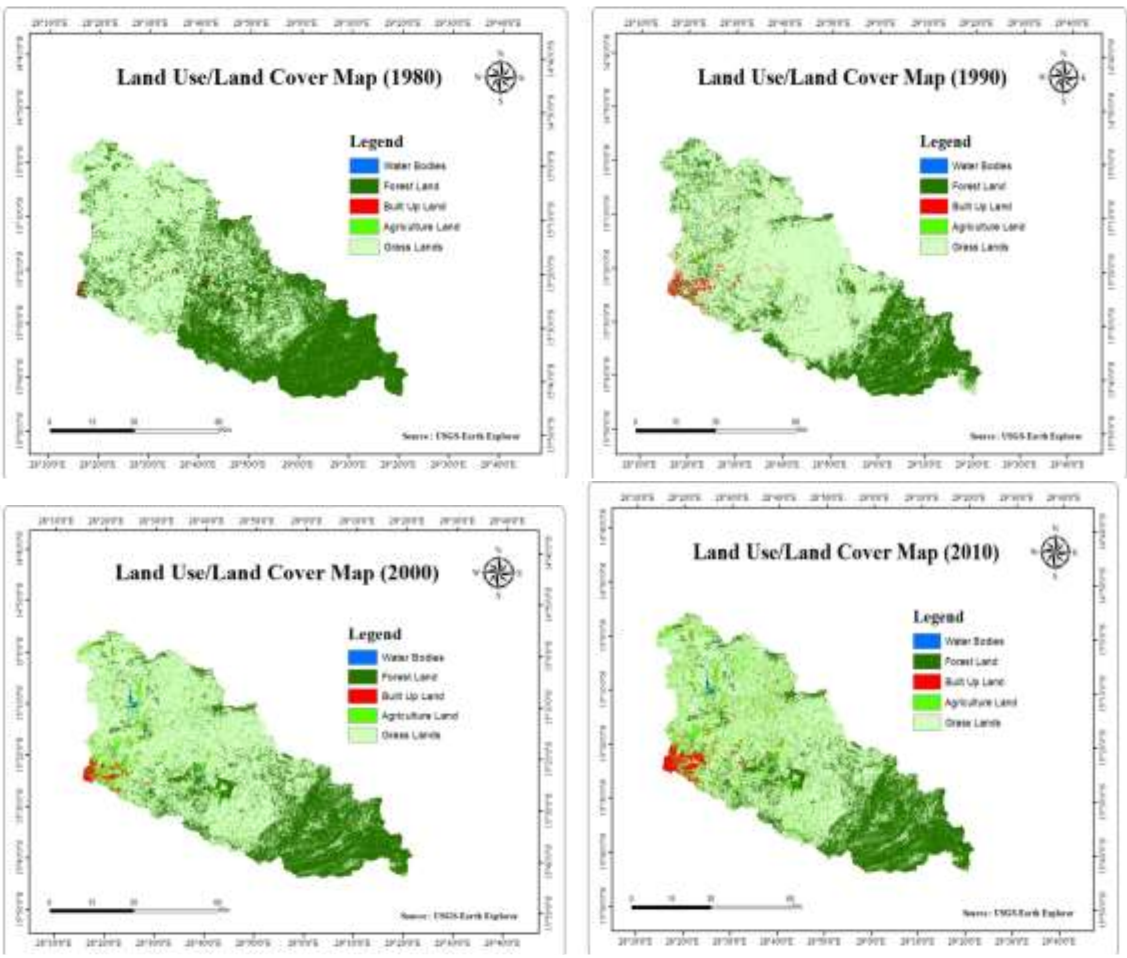
RESULTS AND DISCUSSIONS

Land Use/Land Cover Classification

Figure 4 shows the Land use/Land cover data was obtained from the analysis of Landsat images through the help of GIS and Remote sensing technology.

As shown in Figure 4 between 1980 and 2021, Agriculture lands increased from 0.91% to 11.01%, Built up land from 0.87% to 4.65%, whereas Forest lands decreased from 32.95% to 24.12%, Grasslands from 64.93% to 60.17% and Water bodies from 0.34% to 0.05%.

For all the years of interest, the increase in the Agricultural lands is due to the fact that there has been an increase in the Socio-economic activities and development of commercial irrigation farms based on field observation.
Furthermore, the increase of built up lands is as a result of the expansion of Lusaka city towards Chongwe catchment. Lusaka city being a capital city is bound to attract various socio-economic activities, thus built up lands are expected to continue increasing towards Upper and central part of the catchment area. Forest lands have been reducing and can be related to the transformation of Forest lands into Built up lands and Agricultural land. Further, it was stated that the Chongwe river catchment supplies a substantial amount of charcoal to Lusaka city which can ultimately be as a result of the reduction in forest land.



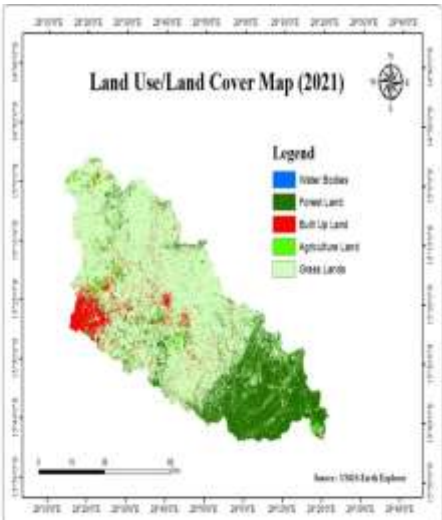


Figure 4. Land Use/Land Cover Maps for 1980,1990,2000,2010 and 2021.

Grasslands fluctuating percentages is due to the fact that there have been common traditional farming practices where agriculture land has been transformed to grasslands and Vice-versa. Additionally, deforestation left large areas of land bare, leading to an increase in grasslands between 1980 and 2021.

Lastly, Water body percentages have been decreasing and are related to the fact that there is a big conversion of farming that is rain fed to farming that is irrigation based.

Flow discharge results and analysis

According to Figure 5 when we observe the station in the month of January, the increment in built up land and the concurrent decrease in forest land increased discharge in the Chongwe River catchment during the rainy season. In addition, the construction of buildings and roads increased the flow rate and ultimately increased the discharge of rivers, thus there is a positive correlation between the increase in discharge in the river and built areas.

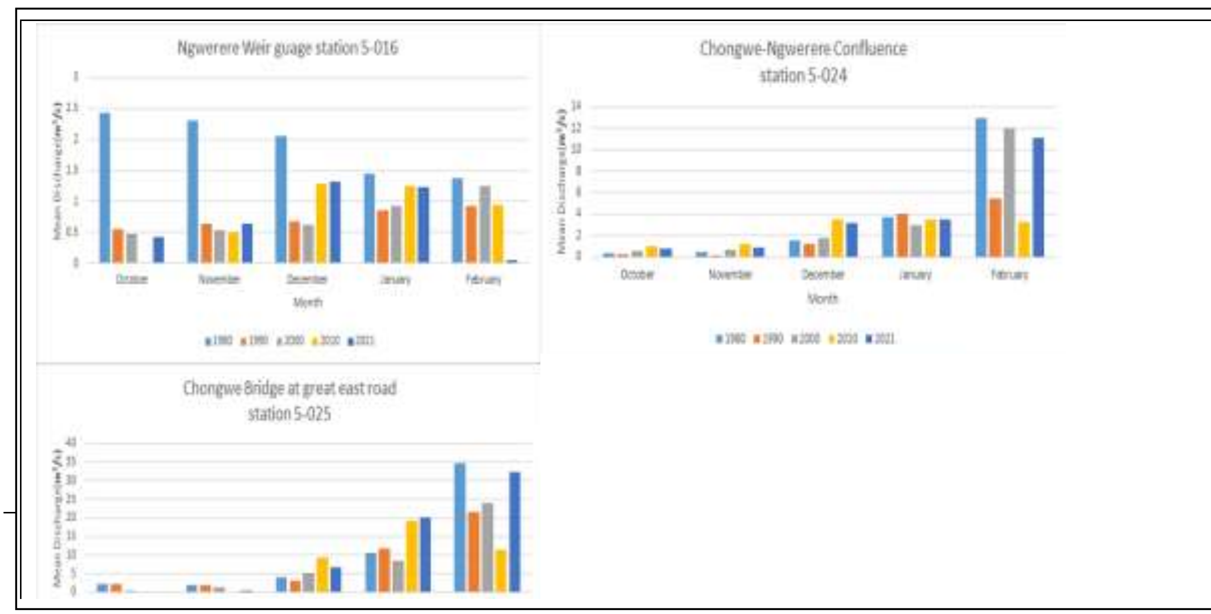


Figure 5. Histograms of gauge stations 5-016, 5-024 and 5-025

The reduced river discharge in the dry seasons of October may be associated to logging and increased built up land and agriculture land. The year 1980 was observed to have had 0.91% of agriculture land and increased to 11.01% by 2021, based on these results we can correlate agriculture land to the drop in discharge levels that is as a result of abstraction, thus there is a negative correlation between Agriculture land and discharge.

Water Quality Trend results and Analysis

Built Up Lands

According to the man Kendall results in Table 2 Cl, TDS and Electrical Conductivity gave a positive value of S meaning that there was an increase in each of the stated parameters over time. Therefore, the positive correlation between built up land and TDS, Cl and Electrical conductivity is attributed to the runoff from construction sites as well as weathering. Further the increment of Chlorides in receiving waters maybe attributed to Road salts.

Table 2. A description of the land use and land cover classes used in this research.

Parameter	S Value	Sen's slope	P Value	Comment
pH	3.25	-0.0315	0.690	No significant Trend
EC	1.5	58.72	0.865	No significant Trend
Temp	-7	-0.317	0.804	No significant Trend
TDS	1	107.5	0.432	No significant Trend
Na	13.25	18.128	0.349	No significant Trend
K	-9.5	-14.223	0.529	No significant Trend
Fe	-0.75	-10.055	0.902	No significant Trend
SO_4^{2-}	-0.75	-11.35	0.740	No significant Trend
Cl^-	4	5.671	0.611	No significant Trend
Mg	1.25	0.775	0.645	No significant Trend

Note: All for 2012 to 2021

Agricultural Lands

For agricultural lands, the land clearing activities may lead to salinity problems in the river and the sediment run off from loose soils on cultivated land as well as decomposition of organic matter in the catchment may lead to acidic problems in the catchment. The results of this study support this statement that is we observe a reduction of the pH and Fe over time.
Furthermore, according to this study, Na had been increasing over time this may be as a result of chemical fertilizers on agricultural land and the increase in surface run off also plays a role in the positive correlation of agriculture land with Na and Mg.

Forest and grasslands

Forests and grasslands in relation to water quality depict a negative correlation. This revealed that as forest land increases, water quality degradation reduces and vice-versa. As Tu, j. [9] highlighted results that stated forest and grasslands are indicators for good water quality.

CONCLUSION

The correlation between Land use/Land cover change with discharge and water quality was determined and the main causes of the water quality deterioration and rapid reduction in discharge in dry season was determined. The positive correlation between built up land and water quality deterioration was attributed to the runoff from construction sites as well as weathering. The reduced river discharge in the dry seasons was attributed to increased built up land and agriculture land. The results from the study showed a positive correlation between land use change with water quality and discharge.

RECOMMENDATIONS

Better agriculture practice method should be employed in this area and proper planning must be carried out in order to protect the ground water.

REFERENCES

Szewrański, S., Chruściński, J., Van Hoof, J., Kazak, J.K., Świąder, M., Tokarczyk-Dorociak, K. & Żmuda, R., (2018) A location intelligence system for the assessment of pluvial flooding risk and the identification of storm water pollutant sources from roads in suburbanised areas. Water, 10(6), p.746.

Muangthong, S., & Shrestha, S. (2015). Assessment of surface water quality using multivariate statistical techniques: Case study of the Nampong River and Songkhram River, Thailand. Environmental Monitoring and Assessment, 187(9), 1–12.

Bu, H., Meng, W., Zhang, Y., & Wan, J. (2014). Relationships between land use patterns and water quality in the Taizi River basin, China. Ecological Indicators, 41, 187–197.

Griffith, J. A. (2000). Geographic techniques and recent applications of remote sensing to landscape-water quality studies. Water, Air, & Soil Pollution, 138(1), 181–197.

Hess, T. M., Sumberg, J., Biggs, T., Georgescu, M., Haro-Monteagudo, D., Jewitt, G., Ozdogan, M., Marshall, M., Thenkabail, P., Daccache, & Marin, F. (2016). A sweet deal? Sugarcane, water and agricultural transformation in Sub-Saharan Africa. Global Environmental Change, 39, 181–194.

Nguvulu, A., Shane, A., Mwale, C. S., Tena, T. M., Mwaanga, P., Siame, J., Chirambo, B., Lungu, M., Mudenda, F., Mwelwa, D., & Chinyanta, S. (2021). Surface water quality response to land use land cover change in an urbanizing catchment: A case of Upper Chongwe River Catchment, Zambia. Journal of Geographic Information System, 13(5), 578–602.

Tena, T. M., Mwaanga, P., & Nguvulu, A. (2019). Impact of land use/land cover change on hydrological components in Chongwe River Catchment. Sustainability, 11(22), 6415.

Tu, J. (2011). Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. Applied Geography, 31(1), 376–392.

Zhang, Z., Li, J., Hu, Z., Zhang, W., Ge, H., & Li, X. (2023). Impact of land use/land cover and landscape pattern on water quality in Dianchi Lake Basin, Southwest of China. Sustainability, 15(4), 3145.

Gani, M. A., Sajib, A. M., Siddik, M. A., & Moniruzzaman, M. (2023). Assessing the impact of land use and land cover on river water quality using water quality index and remote sensing techniques. Environmental Monitoring and Assessment, 195(4), 449.