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Land Use and River Water Quality Relationships in the Muda River Basin, Malaysia

Shah Christirani Azhar*

Centre of Foundation Studies for Agricultural Science, Universiti Putra Malaysia, Seri Kembangan, Selangor, Malaysia

**Corresponding author:* christirani@upm.edu.my

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Abstract

The river water quality worldwide has declined progressively as an implication of improper land-use practices. In this study, the Geographic Information System and Multiple Linear Regression analysis were used to determine the river water quality that is associated with various effects of land use, particularly in the north-western part of Peninsular Malaysia. The study employed secondary water quality data consisted of 22 water quality variables at four different buffer zones: 500, 1000, 1500 and 2000 m. The land use data were sorted into four land use categories: agricultural, forestry, urban areas, and others. Out of 88 regression models examined, only eight significant models were obtained. The analysis indicates a weak association between the water quality and land use for nitrates ($0.08 < R^2 < 0.14$, $p < 0.05$) and calcium ($0.10 < R^2 < 0.17$, $p < 0.05$) within all the investigated zones. Interestingly, although the catchment area is covered by 55 % of agricultural land and 35 % of the forest, the findings revealed that the river water quality is not significantly affected by the land use activity. Hence, the results provide new perspectives on the associations of river water quality and land use in the areas dominated by agricultural activities.

Keywords Geographic information system, Muda River basin, land use, water quality, multiple linear regression

INTRODUCTION

River water plays a central role in the survival of plants, animals, and humans on the earth. Therefore, the efforts to maintain the river water quality should be implemented intensively, continuously and given top priority by the authorities. The key influencing factor that causes the decline of river water quality is the land use change which is closely interrelated to escalations of human activity [1,2,3]. In general, land use change and human activities such as deforestation, intensive agriculture, and rapid urbanization are often interrelated with high concentrations of water contaminants [4,5,6]. The decline of river water quality can pose a threat to human health, negative effects on the environment, disturb aquatic life and lack of clean water resources. In light of the above background, water pollution prevention requires an in-depth understanding of the correlation between land use change and water quality. This relationship will explain the variation of river water quality which assistances in terms of ecosystem management and water resource conservation [2].

Many studies report a significant association between land use class and water quality on agricultural, urban and forest areas [7,8,9]. Agricultural land use has a strong effect on greater nutrient levels, such as phosphorus and nitrogen [10,11,12,13]; sediments [14,15]; pathogens, pesticides, metals, and salts [16,17]. While, the generation of runoff from urban area discharge a group of pollutants including rubber waste, major nutrients and heavy metals [18]; microbial contaminants [19]; synthetic chemicals [20], and pesticides [21] On the contrary, water catchment areas with natural forests have fewer pollutants [22], higher dissolved oxygen levels, lower ammoniacal nitrogen and nitrogen nitrate [23]; and lower runoff coefficients [24]. However, the association between land use and water quality is inconsistent for diverse regions due to variances in natural, anthropogenic, economic activity, sources of pollution, physical environment, and stakeholder policies [7].

Pollution control essentials a thorough considerate of water quality and impacts of land uses at the whole river basin [25,26,27] and the buffer zone spatial scales [28,29,30]. Advanced spatial tools such as Geographic Information System (GIS) combined with water quality evaluation techniques make the study suitable [31,32,33]. However, very few studies have examined the effects of land use through hydrology by combining statistical analysis and modelling approaches [34]. Additionally, many of the studies have only been presented in a short period, either one year [35], or a limited number of years [36]. In only very few cases, have the river water quality been examined over longer periods, like ten years [2,37,38]. Consequently, the variability and the complexity of the spatial patterns have on the influence of land uses on river water quality have not been fully explored [39]. Thus, the situation remains uncertain; partly because each watershed has unique features which influence the source water quality.

The Muda River basin (MRB), situated in the north-western part of Peninsular Malaysia is the largest agricultural sector in Malaysia. Agricultural-related operations, such as animal and crop farming, cover approximately 55% of the total area of the MRB [40]. Meanwhile, about 35% of the catchment area is still covered by forests [40]. Therefore, logging activities, agriculture, and agro-based industries, like rubber and palm oil processing factories, are the main economic activities in the area. Meanwhile, the MRB plays a key source of water for domestic and agricultural uses in Kedah and Penang which provides more than 80% of the water requirement for both states. In recent years, concerns have grown regarding the wide variations in water quality indicate that the MRB is affected by various sources [40]. Therefore, there is a need to determine the reasons behind the wide variations in water quality in the catchment area. However, no preliminary investigations of river water quality and land use patterns or their associations at the MRB have been explored before. Identifying the land use impacts on water quality is critical to assist the government in planning and making decisions that go towards achieving and sustaining a healthy water quality.

The main objective of this study is to determine the river water quality that is associated with various effects of land use (agriculture, forestry, and urban areas) within the basin. The results provide the relationship between land use and water quality that can be referred by stakeholders to optimize the land use and control water quality.

MATERIALS AND METHODS

Study Area

Muda River basin (MRB) (Figure 1) is lies within the latitudes of 100^o 20’ 33.05” E and 100^o 56’ 17” E and the longitudes of 5^o 24” 56.46” N and 6^o 10’ 51.25” N [41]. The main river in the MRB is the Muda River. Its flow originates from the northern mountainous area of Kedah making the upper-middle reaches of the basin based in Kedah. Generally, the water quality of the Muda River watershed is classified as Class II [42]. Figure 1 shows the nine water quality monitoring stations that are located on the Muda River and its tributaries. Four monitoring stations (MD01, MD04, MD05, and MD06) are located on the main river. Meanwhile, the monitoring stations MD07 and MD08 are located at Tawar River, MD09 is located at Ketil River, and MD02 and MD03 are located at Jerung River. The north-eastern part of MRB is mountainous, with a height of more than 76 m above sea level and surrounded by hills. Some areas are designated as forest reserves due to the presence of the Muda dam at the upstream watershed. The dominant vegetation types along the river are paddy, oil palm trees, nipa palm trees, and rubber trees.

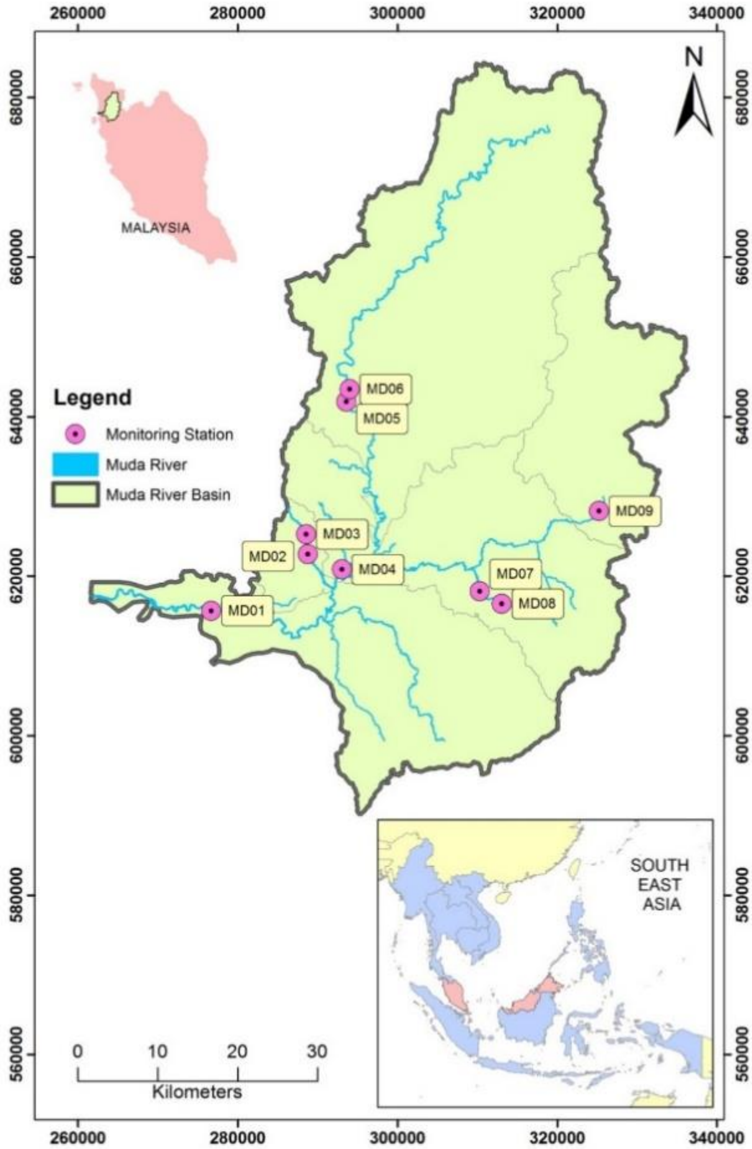

Figure 1 Location of the Muda River basin in Peninsular Malaysia

The Land Use Data

The land use statistics necessary for the present research were extracted from the available digitized land use maps for the years 1990, 1997, 2000, 2002, 2004, and 2007 (scale 1: 50,000). The six digitized land use maps were obtained from the Department of Agriculture, Malaysia. Additionally, to the maps, a digital topographic map (scale 1: 25,000) of Kedah and Penang from the main library of University Putra Malaysia, to serve as a source of river network data as well as a reference map. The map was issued by the Department of Survey and Mapping, Malaysia. For delineation of MRB, a Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) for Malaysia of 90x90 m (3-arc second) resolution, the coordinates of the water quality monitoring stations and the stream network were employed. The delineation process was performed based on the procedure recommended by the Economic Social Research Institute (ESRI).

The six land use maps were processed in the ArcGIS v9.2 environments in such a way to produce the land use data. The buffer zones of interest to this study comprised four buffer zones (500 m, 1000 m, 1500 m, and 2000 m). The dominant land uses in the river basin for each of these years were then sorted and categorized into four land use classes: agriculture, forest, urban, and “others”. A listing of the land use types which were categorized under each of the four land use classes of interest is given in Table 1.

Table 1 The land use composition of the four land use classes of interest

Land use class	**Constituent land use types**
Agriculture	Rubber plantation, oil plantation, mixed-agriculture, orchard, and paddy.
Forest	Forest.
Urban areas	Urban areas, estate buildings and associated areas, and recreational areas.
“Others”	Ponds, lakes, roads, bushes, and cleared lands.

The River Water Quality Data

The water quality data consisted of the values of monitored water quality variables at nine monitoring stations located on the mainstream of the Muda River and its tributaries. The secondary data of water quality was obtained from the Water Quality Division of the Department of Environment Malaysia. The water quality sampling was conducted four times a year (January, April, July, and October) involving 22 water quality variables (WQV) from the year 1998-2007. Whereas, the 22 water quality variables constituting the water quality dataset were: turbidity(Turb), electrical conductivity(EC), pH, temperature(Temp), salinity (Sal), Escherichia coli (E. coli); total coliform(Coliform), dissolved oxygen(DO), biochemical oxygen demand(BOD), chemical oxygen demand (COD),suspended solids(SS), ammoniacal nitrogen (NH_3-N), nitrate nitrogen (NO_3-N),chlorine (Cl),phosphate (PO_4-P),calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), dissolved solids (DS), and total solids (TS). The dataset was composed of 7920 entries derived from 22 WQV on 360 samples.

Multiple Linear Regressions

Multiple linear regression (MLR) is a statistical tool for predicting the outcome of the dependent variable from several independent variables [43] as well as to calculate the percentage of the contribution of independent variables to the dependent variable. In this study, MLR was conducted to model the linear relationship between the land use categories (independent variables) and each water quality variables (dependent variable) that examined. From the model, the WQV that is associated with various effects of land use (agriculture, forestry, and urban areas) for each buffer zones can be identified. The general MLR equation as follows:

$$y_i = b_0 + \sum_{i=1}^{n} b_i x_i$$

where y_i refers to each water quality variables, b_0 is the regression constant, and b_i is the regression coefficient of the land use categories, x_i where x_1 = Agriculture, x_2 = Forest, x_3 = Urban and x_4 = Others. Overall, there are 88 regression models examined (22 WQV × 4 buffer zone) using 160 entries of land use data (4 land use categories × 4 buffer zone × 10 years).

The best fitting of regression linear equations determines by a coefficient of determination, R^2. The R^2 explains how much of the variation in the dependent variable is accounted for by the variation in the independent variables [44] The R^2 is calculated for all possible models for each water quality variable in four investigated buffer zones (500 m, 1000 m, 1500 m, and 2000 m). The best linear model is specified by the model with the largest R^2 [44]. MLR was performed using XLSTAT version 2015.2 add-in software.

RESULTS AND DISCUSSION

Land Use Descriptive Statistics

At the whole river basin scale, Table 2 shows that the land use ranks were consistent during the study period (1998-2007) where the highest of land use areas in descending order were as follows: agriculture, forest, others, and urban lands. The data shows the area of the agricultural land and "others" land use decreased by 6.21 % and 0.40 %, respectively. However, the forest cover increased by 5.88 % and the urban area grew by 63.52 % during the study period. The urban areas had only increased by 46.40 km^2 but in terms of percentage, this small area increment corresponded to a high percentage increase.

Table 2 Total land use areas ranks (1998-2007)

Year	Land use class (km^2)			
	Agriculture	**Forest**	**Others**	**Urban**
1998	1920.45	1122.83	139.06	73.06
1999	1920.01	1122.86	138.97	73.28
2000	1886.68	1111.36	164.79	87.40
2001	1886.78	1111.38	164.75	86.62
2002	1879.01	1110.65	162.57	10.03
2003	1878.78	1110.77	162.82	96.91
2004	1859.69	1132.71	144.51	95.23
2005	1857.65	1132.94	144.65	108.96
2006	1800.69	1188.85	141.52	108.80
2007	1801.26	1188.85	138.51	119.47

The land use maps that correspond to every spatial scale that was investigated for the years 1998 and 2007 are shown in Figures 2 to 9. For comparison purposes, the researcher's approach in the coming discussions is to set the land use type and area characteristics of the first study year (1998) as baseline data against which to compare the rest of the land use statistics. Hence, the details on the land use areas for each spatial scale of the year 1998 are provided in Table 3.

Table 3 The land uses and individual spatial scale areas in the year 1998

Spatial scale	Land Use (km^2)			
	Agriculture	**Forest**	**Urban**	**Others**
500 m buffer zone	240.58	9.33	7.89	25.37
1000 m buffer zone	441.21	26.75	14.93	39.22
1500 m buffer zone	622.62	49.26	20.59	49.95
2000 m buffer zone	788.77	78.33	25.39	60.35

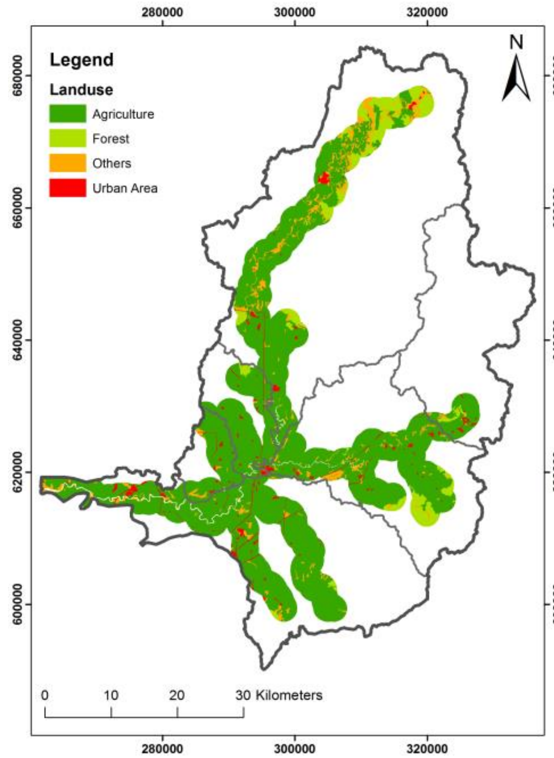

Figure 2 2000 m buffer zone, 1998

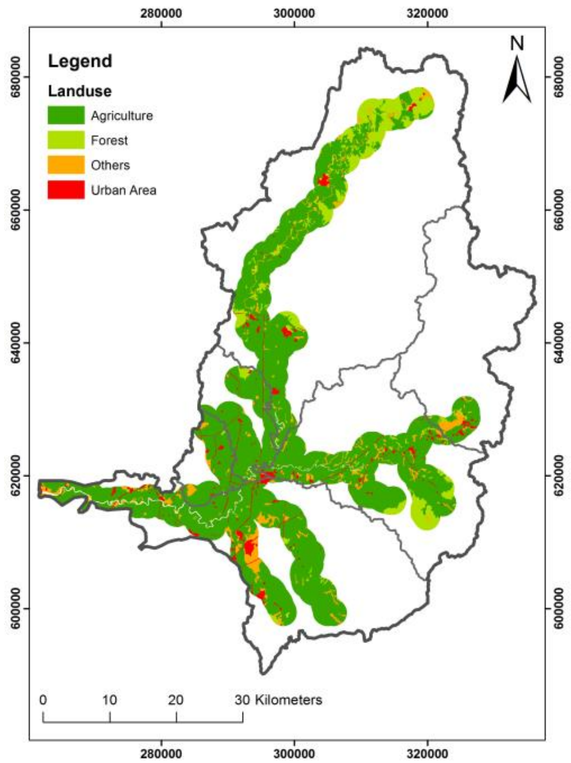

Figure 3 2000 m buffer zone, 2007

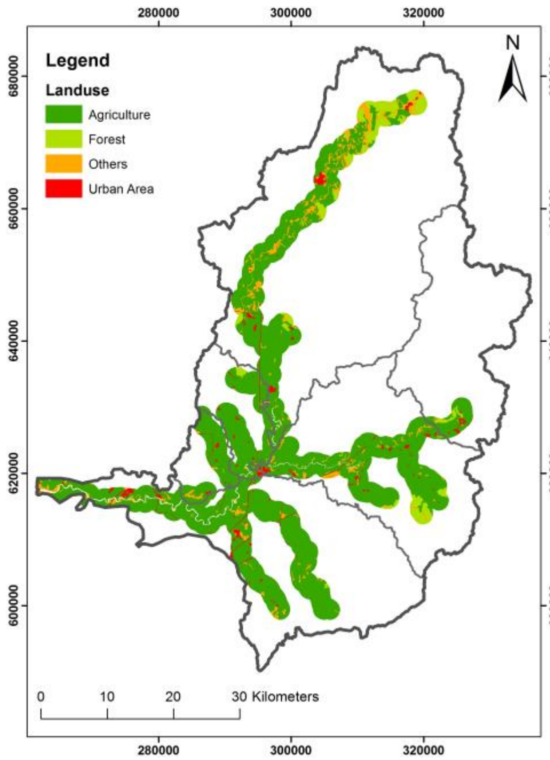

Figure 4 1500 m buffer zone, 1998

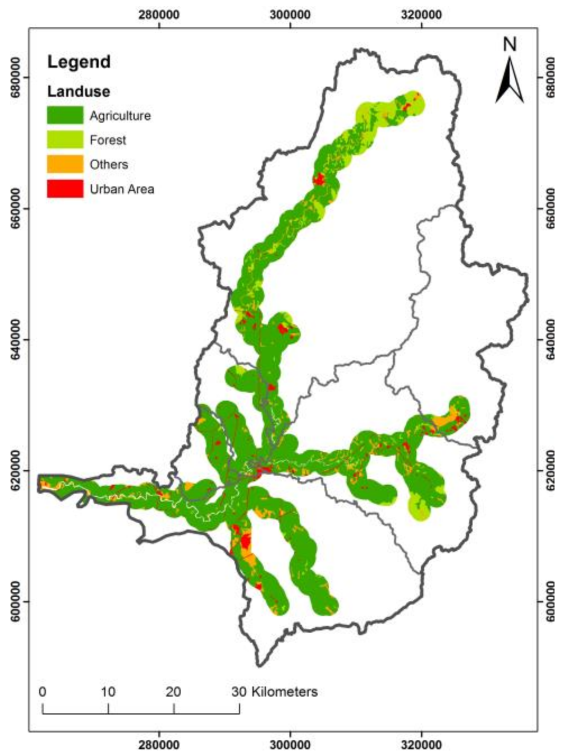

Figure 5 1500 m buffer zone, 2007

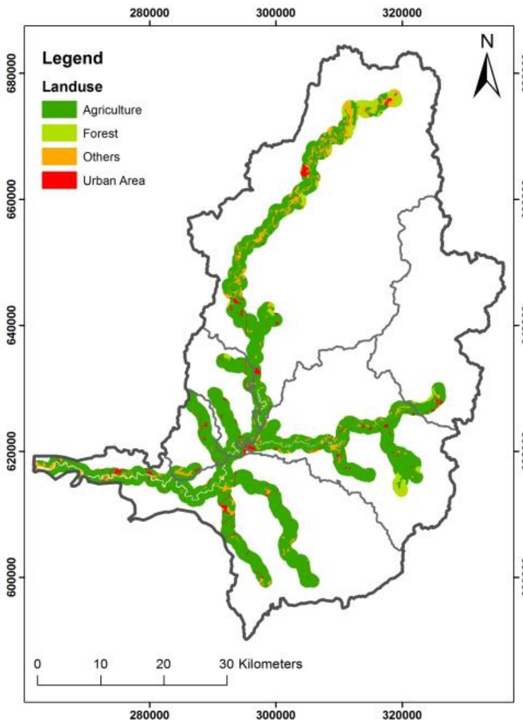

Figure 6 1000 m buffer zone, 1998

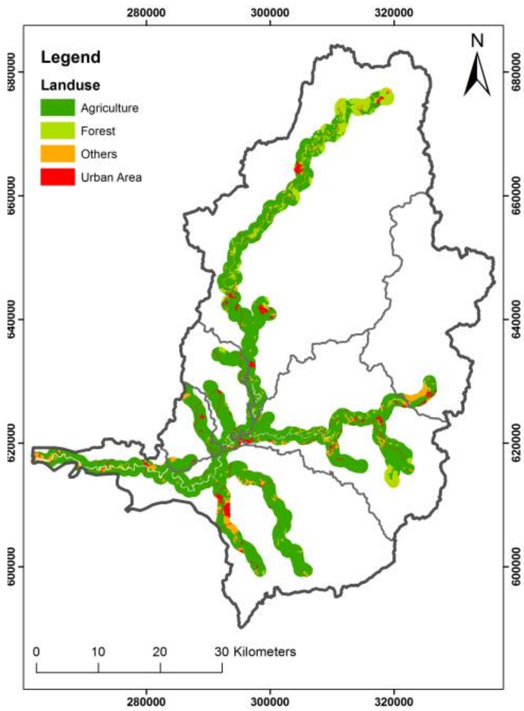

Figure 7 1000 m buffer zone, 2007

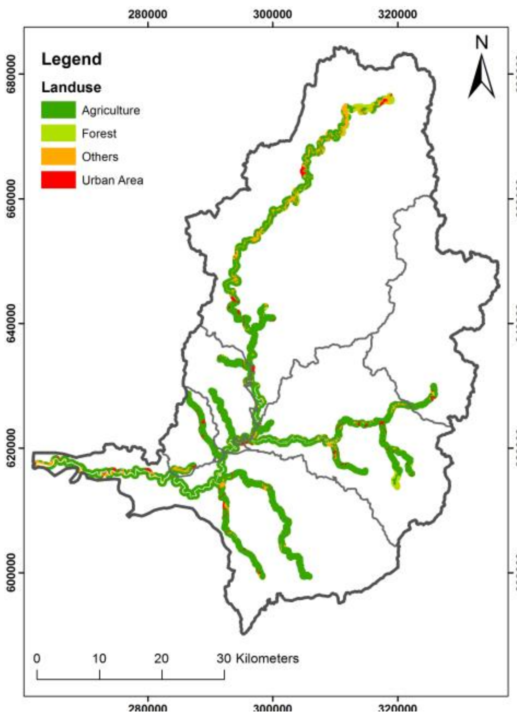

Figure 8 500 m buffer zone, 1998

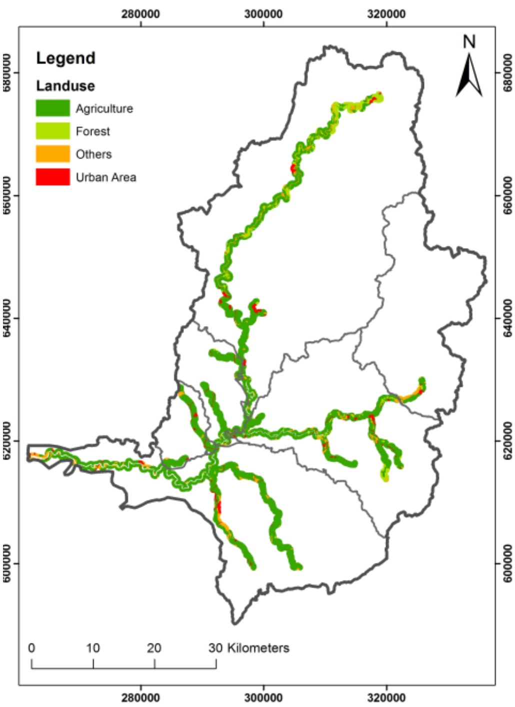

Figure 9 500 m buffer zone, 2007

Water Quality Descriptive Statistics

Table 4 shows descriptive statistics for the water quality data involving 22 WQV from the year 1998-2007. The lowest mean water quality index (WQI) value (56.75) was reported for MD02 while the other monitoring stations (MD01, and MD03-MD09) had a mean WQI value in the range of 81.00-91.00. The water quality classifications set by the Department of Environment Malaysia based on values of the WQI, the water quality of station MD02 falls within Class III while the other stations (MD01 and MD03-MD09) comply with Class II. Table 4 also shows that the highest values of EC and Sal; concentrations of BOD, COD, NH_3-N, DS, TS, PO_4-P, K, Mg, and Na; and counts of *E.Coli* and Coli were reported at station MD02. The SS, Temp, Turb, and Fe were high in four stations: MD01, MD04, MD05, and MD06. The lowest pH reading and the highest concentration of NO_3-N were found at MD03. Whereas, MD09 had the highest concentration of Ca.

Relationships between Water Quality Variables and Land Uses

MLR modelling was conducted to determine the river water quality that is associated with various effects of land use (agriculture, forestry, and urban areas). Out of 88 regression models examined (22 WQV x 4 buffer zone), only eight significant models were obtained (Table 5). The regression analysis only indicates a weak association between the water quality and land use for NO_3-N and Ca (p <0.05) within all the investigated buffer zones. On the other hand, no significant correlations (p >0.05) were observed between all land use classes and others WQV such as Turb, EC, pH, Temp, Sal, *E. coli*, Coliform, DO, BOD, COD, SS, NH_3-N, Cl, PO_4-P, Fe, K, Mg, Na, DS, and TS.

Regression analysis of the water quality and land uses showed that NO_3-N is weakly influenced by increases in the agricultural land use area and it decreases under the forest cover ($0.08< R^2 <0.14$, $p< 0.05$), consistent within all the buffer areas examined. The result is in line with previous findings which suggested that the percentage of agriculture at the watershed scale is the primary predictor of nitrogen [10,11] whereas, lower levels of NH_3–N and NO_3–N were associated with the forest areas [28]. The use of fertilizers in agriculture activities contributes to the increase of NO_3-N in the MRB agricultural land use areas [40]. While, analysis of the effect of forest area on Ca in stream water uncovered that there is a positive and low in strength association between forests and Ca within the 2000 m buffer width ($0.10 <R^2< 0.17$, $p< 0.05$). The presence of Ca in the river water in MRB is a result of the natural carbonate dissolution process from the limestone hills near the forest area [40].

Table 4 Mean values for the WQV in the water quality dataset of Muda River from the year 1998-2007

	Monitoring station								
Variable	**MD01**	**MD02**	**MD03**	**MD04**	**MD05**	**MD06**	**MD07**	**MD08**	**MD09**
DO (mg/L)	6.44	4.01	4.95	5.57	5.24	6.05	7.14	6.47	7.34
BOD (mg/L)	1.75	14.40	1.74	1.55	1.32	1.53	1.25	2.56	1.50
COD (mg/L)	18.72	57.75	19.71	19.54	18.31	18.34	17.31	21.26	19.59
SS (mg/L)	61.97	43.65	17.21	91.08	64.74	63.60	11.02	26.03	59.78
pH	6.63	6.79	6.15	6.77	6.67	6.83	6.69	6.69	7.23
NH_3-N (mg/L)	0.11	15.05	0.31	0.11	0.12	0.22	0.09	1.31	0.13
Temp (^{o}C)	28.39	27.28	26.91	27.70	28.27	27.74	25.27	25.28	26.03
EC (μS/cm)	57.18	317.14	64.04	63.08	55.72	50.70	34.71	69.62	108.82
Sal (%)	0.02	0.14	0.02	0.02	0.02	0.02	0.01	0.02	0.04
Turb (NTU)	110.35	100.87	37.18	145.16	155.70	113.81	32.86	43.63	67.77
DS (mg/L)	27.81	59.36	59.65	23.83	34.19	20.75	17.90	28.58	47.18
TS (mg/L)	89.19	199.82	76.88	117.58	98.94	84.35	29.00	54.60	106.95
NO_3-N (mg/L)	0.44	0.36	3.09	0.36	0.38	0.34	0.27	0.43	0.24
Cl (mg/L)	2.89	3.57	2.84	1.50	3.49	1.67	0.78	1.32	1.91
PO_4-P (mg/L)	0.05	6.50	0.09	0.18	0.11	0.11	0.13	0.34	0.16
Ca (mg/L)	3.45	4.91	2.97	3.27	2.11	1.98	1.56	2.27	10.75
Fe (mg/L)	1.03	0.52	0.48	0.92	1.01	1.02	0.32	0.49	0.54
K (mg/L)	2.61	25.14	2.18	2.08	4.61	1.98	1.47	2.99	2.38
Mg (mg/L)	0.80	3.58	0.74	0.66	0.93	0.62	0.41	0.62	1.18
Na (mg/L)	2.76	5.39	2.25	2.66	3.18	3.17	2.31	2.69	3.47
E.Coli[a]	4.59×10^3	5.17×10^4	1.98×10^3	2.88×10^3	1.95×10^3	1.84×10^3	1.61×10^3	3.50×10^3	2.77×10^4
Coliform[a]	2.23×10^4	1.22×10^5	2.46×10^4	1.63×10^4	1.80×10^4	4.34×10^4	1.42×10^4	2.49×10^4	8.51×10^4

[a]per 100 mL

Table 5 MLR models of the relationships between WQV and land use at five buffer zones

Buffer zone	Equation of the regression model	*F-test*	*p-value*	R^2
2000 m	NO_3-N=0.25 +0.000897x_1 – 0.000913x_2	4.21	0.02	0.13
2000 m	Ca=4.79 + 0.07x_2 -0.13x_4	3.26	0.04	0.10
1500 m	NO_3-N=0.25 +0.00162x_1 – 0.00651x_2	4.08	0.02	0.12
1500 m	Ca=4.77 + 0.10x_2 -0.15x_4	3.57	0.03	0.11
1000 m	NO_3-N=0.30 +0.00376x_1 – 0.00724x_2	2.74	0.04	0.08
1000 m	Ca=4.81 + 0.17x_2 -0.20 x_4	4.75	0.01	0.14
500 m	NO_3-N=0.27 +0.007326x_1 – 0.13x_2	3.87	0.02	0.12
500 m	Ca=4.62 + 0.42x_2 -0.29 x_4	5.73	0.00	0.17

where x_1 = Agriculture; x_2 = Forest; x_3 = Urban; x_4 = Others

The watersheds with natural forests are almost always characterized by better water quality [22,23,24] due to an extensive root network and an excellent ability to generate porously and filtering soils [45,46]. The riparian forest root and plant systems have a filtering role and they trap nutrient elements such as phosphorus, potassium, and nitrogen, as well as some toxic elements [47]. Therefore, forest areas can lower the impact of agricultural nutrients on water quality [48].

The forest around streams is beneficial for nitrate and phosphorous load reductions [49]. Besides that, agricultural nutrients and chemicals on surface water were reduced by the forest buffer zone [50]. Thus, in most areas worldwide, reforestation is actively carried out to address surface water pollution [50,51,52,53]. In MRB, the forest areas are well administered by the authorities, where the reduction of forest areas are only 5.89 % from the year 1998 to 2007 [40].

Uncontrolled rapid urbanization can lead to declining water quality [18,20,54] and worsened if the low percentage of forests around urban areas [7]. In the case of MRB, urban areas covered 2.24% of the total water catchment area in 1998 and slightly increased around 3.68% in 2007. Apart from low urban areas, the existence of extensive forests of about 35% of the entire basin supports maintaining water quality in the study area.

Overall, the land use factor could not explain much of the variability in WQV in this study. In principle, the period of data sufficient and should not be the problem to address the effects of land uses on river water quality even though the land use and water quality data involved limited temporally to the period 1998-2007. The WQI at MRB in 2007 was 82.15 [55] while in 2013 was 81.30 [42] indicates that there is no significant change in land use in the study area that could change the water quality of the river differently from the year 1998-2013.

CONCLUSION

The association between land use and water quality is unique and inconsistent for diverse regions. Overall, the findings revealed that the river water quality is not significantly affected by the land use within all the investigated zones due to the root system from the plants acting as a shield that can trap the pollutant from entering the river. The results only show a weak negative association between the water quality and land use for nitrates even though the basin is covered by 55 % of agricultural land. Hence, the results provide new perspectives on the associations of river water quality and land use in the areas dominated by agricultural activities.

This research presents an example of an approach to spatial analysis and assessment of river water quality that combines the strengths of the GIS and multivariate analysis. It integrates catchment-scale investigations with zonal analysis to provide an in-depth understanding of the sophisticated river water quality interactions with land uses and supports current knowledge about these interactions at several buffer areas.

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