IMPACT OF LAND USE CHANGE ON STREAM WATER QUALITY: A REVIEW OF MODELLING APPROACHES

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Abstract

It is a fact that stream water quality in a watershed depends on land use in that watershed. To better understand the relationship, a number of previous studies is reviewed in this paper and found that water quality variables are correlated with land use and land cover change. Expansion of agricultural land is one of the major cause of stream water pollution. Pollutant load in stream is quite low in dry season and very high in wet season. Concentration of diffuse pollutants in stream varies with the spatiotemporal variation of land use and land cover. Besides types of vegetation and climate of the watershed also found to be responsible for changing stream water quality. Water quality models reviewed here simulates part of hydrological process. Therefore, a combination of hydrodynamic model, sediment model and a biogeochemical model is recommended for future studies.

Key Words : Land use change, land cover change, water pollution, water quality modelling

1. Introduction

Over the last few decades, the world is experiencing rapid population growth. Between 1990 and 2008, global population living in cities increased from 10% to 50% and is expected to reach 60% by 2030 [1]. Consequently, agricultural, forest, grass and wet lands have been converted to urban areas to accommodate excess population. Urban expansion increases impervious surface on land that can alter natural hydrologic cycle [2] and poses direct and indirect threats to the integrity of streams and watersheds [3]. Land use change not only affect stream water quality; it also affects stream water quantity [4]. Currently, land use and land cover change are one of the major cause of global environment change [5].

The main purpose of this paper is to review various studies related to land use change and its consequence on stream water quality. For better understanding their relationship, studies from all continents are selected since each continent has different hydrologic and climatic condition. The outcomes of this review are expected to improve the knowledge of current understanding of land use change and water quality relationship that can be utilized to manage stream water pollution.

The next sections of this paper describe various studies related to land use change and water quality, key findings from these studies, current knowledge gap in water quality modelling and future directions, etc. Some conclusions are drawn in the last section.

2. Land use/ Land cover relationship with water quality

Land use refers to human activities carried on over the land and land cover refers to vegetation, water bodies, snow, rock, forest, or any other covers on the land [6]. Water quality is defined by the world health organization (WHO) as the chemical, physical and biological properties of water that are required for safe use. These characteristics are measured in terms of ingredients present in water such as, biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), total dissolved solids (TDS) and E. coli, etc. It is found that concentrations of these ingredients vary in water coming from different land. For instance, Sarukkalgilge et al. [7] analyzed stormwater samples from residential, commercial and industrial land areas in the town of Victoria park in Western Australia and found that stormwater from commercial land has the lowest turbidity (1.164 NTU) whereas stormwater from residential land has the highest turbidity (1.9 NTU). Their study proves that land use has effect on stream water quality.

Several studies have been undertaken from the last few decades to identify different factors that affects stream water quality. Some of these studies reported that water quality is strongly affected by the type of land use [8, 9, 7]. Some researchers found that streams receiving water from agricultural land has high nutrient concentration than streams receiving water from forested land [8, 10, 11]. These various studies are site specific and the result

from a study cannot be applied to other regions because of different hydrologic and climatic conditions. Thus, we need to look at studies from other regions having different hydrologic and climatic setup.

3. Approaches to identify the impact of land use on water quality

land-based pollution of water considers two main sources of pollution: point and non-point sources. A point source of pollution comes from a single source which is easily identifiable whereas non-point sources of pollution generates from multiple sources and are not easily identifiable [12]. The nature underlying these two causes vary with complexities. Some researchers reported that diffuse pollutant in water vary with spatial scale and they used a shorter spatial scale (sub-catchment scale) while others used whole watershed approach. Some used statistical analysis with the help of geographical information system (GIS) and remote sensing (RS) whereas others used computerized water quality modelling tools to evaluate land use and water quality relationship. These various approaches are described below.

3.1 Land use change and water quality study in a subcatchment scale

According to many researcher including Sliva and Williams [13], the influences of land-use on water quality becomes more significant within a shorter distance from the receiving water body. This was verified by Chu et al. [14] who studied the land use and water quality relationship in Tseng-Weng reservoir watershed, Taiwan. They used high resolution satellite image which was quantified by normalized difference vegetation index (NDVI) method to identify land use changes between 2001 to 2010. They found that average NDVI values were positively correlated with NO_3^- concentrations ($r = 0.687$, $p < 0.05$) within 3 km buffer zone and negatively correlated with suspended solids ($r = -0.577$, $p < 0.05$) in the entire watershed. While these studies consider whole catchment as well as a small buffer area, Kibena et al. [10] used a subcatchment scale approach. Their study was conducted in the Manyame river upstream catchment in Zimbabwe and found that between 1995 and 2012, forest, grassland and bare land area decreased by 24%, 22.6% and 31.7% respectively whereas urbanization and agricultural activities increased by 41.6% and 24.4% respectively. This land use change increased total phosphorus (TP) load from 130 kg/day to 376 kg/day and total nitrogen (TN) load from 290 kg/day to 494 kg/day at the outlet.

3.2 Land use change and water quality study in a catchment scale

Apart from sub-catchment scale study, some studies used whole catchment approach. For instance, Salajegheh et al. [15] studied water quality in Karkheh watershed in West Iran and found that between 1988 and 2002, urban land in the watershed increased from 19051 hectares to 27794 hectares which increased total dissolved solids (TDS) in water from 1200 mg/L to 1900 mg/L at some points. Hatt et al. [16] found a similar result that extension of urban land has a direct relationship with the water body and it increases TDS in river water. Muñoz et al. [11] found that between 1998 and 2006, 53% forest land converted to cropping and pasture land in lake Rupanco basin, Chile which increased nitrogen in the lake water from 33 kg TN/km²/y to 621 kg TN/km²/y. The study conducted by Khare et al. [17] in the Alafia river watershed in Florida, USA, claimed that increasing urban area and decreasing agricultural land improves water quality. They concluded that between 1974 and 2007, urban and residential land in the watershed increased from 10 to 21%, whereas agricultural land decreased from 36 to 19% and forest reduction from 13 to 8%. This land use change decreased total nitrogen (TN) in stream water at some points from 2 mg/l to 1.5 mg/l. A more recent study was conducted by Ding et al. [8] in the Dongjiang river basin, Southeastern China. They found that total nitrogen (TN) in stream water is negatively correlated with forest land ($r = -0.23$, $p < 0.05$) whereas positively correlated with urban land ($r = 0.36$, $p < 0.05$). They concluded that “Although we did not reach a conclusion on a cause-effect relationship, there is sufficient evidence for effectively explaining variations in stream chemistry in relation to land use”.

3.3 Land use change and water quality study using statistical analysis, GIS and RS

Many researchers utilized geographical information system (GIS) and remote sensing (RS) in their studies to interpret spatial data [9, 14]. Some of these studies confirmed that integrating GIS and RS in the model is useful to improve the controlling strategy of diffuse pollution [18] and to develop advance decision-making supporting system. Integrating GIS and RS, Gyawali et al. [19] developed a multiple regression model for U-Tapao river basin in Thailand. They found that urban land in the watershed showed significant positive correlation with TEMP, SS and DS ($r = 0.50, 0.48 \text{ \& } 0.72$, $p < 0.05$) and negative correlation with pH ($r = -0.26$, $p < 0.05$). Similarly, agriculture land showed significant positive correlation with SS and DS ($r = 0.47 \text{ \& } 0.69$, $p < 0.05$) and negative correlation with TEMP and DO ($r = -0.44 \text{ \& } -0.21$, $p < 0.05$). Using statistical analysis, Huang et al. [11] studied stream water quality in Chaohu lake basin, China. Their statistical model showed that between 2000 and 2008, built up land in the basin was positively correlated with most of the water quality variables whereas forest, grassland and water bodies were negatively correlated with most of the variables

3.4 Land use change and water quality study using computerized models

Nowadays computerized modelling tools are becoming popular to simulate and predict the water environment. Some of these water quality models are BASINS (Better Assessment Science Integrating Point and Nonpoint Sources), L-THIA (Long-Term Hydrological Impact Assessment), QUAL (developed by US EPA), SWAT (Soil and Water Assessment Tool), SWMM (Storm Water Management Model) and WASP (Water Quality Analysis and Simulation Program). Some of these models application in water quality studies are discussed below.

SWAT is a catchment scale model, developed by the United States Department of Agriculture (USDA). It is capable of simulating groundwater flow, surface runoff, nutrient and pesticide loading, crop growth and irrigation, etc. Using SWAT model, Wu and Chen [20] studied the impact of point and diffuse sources of pollution on the quality of water in the East river in southern China. They found that diffuse pollution has the dominant contribution (>94%) to nutrient loads. Lin et al. [21] found that types of crops cultivated on a land have significant impact on water quality. They developed a SWAT model for the Red river basin in USA. The model was calibrated using observed streamflow, suspended sediments, and nutrients during 2006 to 2013. Result showed that during 2006-2013, corn and soybean cultivation in the basin area increased by 62% and 18% whereas cultivation of spring wheat, forest, and pasture decreased by 30%, 18%, and 50%. This changes in cultivation increased sediment load at the basin's outlet by 2.6%, total phosphorus (TP) by 14.1%, nitrate (NO₃-) by 5.9% and total nitrogen (TN) by 9.1%. While SWAT is proving an effective tool for water quality modelling, some researchers including Benaman et al. [22] pointed that SWAT does not simulate sediment and flood routing in detail and during the winter and spring periods it has difficulties in modelling snowmelt erosion and floodplain erosion.

Apart from SWAT model, L-THIA model is increasingly used in recent times for water quality and land use change studies. The L-THIA model was developed by the Purdue university. It evaluates average long-term hydrologic impacts of land use change on surface runoff, groundwater infiltration and water quality variables. Using L-THIA model, Wilson and Weng [23] found that during 1992 to 2001, residential land increased by 37.3% in lake Calumet, Chicago, USA which increased nitrite concentration within residential land by 200%. A different combined modelling approach was done by Tang et al. [2] who used a land transformation model (LTM) to predict land use changes between 1978 to 2040 in the Muskegon river watershed in Michigan, USA. The LTM simulated data was applied to L-THIA model to predict hydrologic changes within that period. They found that by 2040, urban land will be expanded from 4.2 to 11.5% which will increase average runoff volume by

5% and nitrogen by 3%. However, the L-THIA model simulation is reported to have some limitation: it focuses on long term average impact rather than a particular storm event and it does not account the snowfall contribution to precipitation.

The use of BASINS and SWMM is gaining popularity nowadays for modelling stormwater quality. Using BASIN model, Tong and Chen [24] studied the quality of water receiving from various land uses in the East Fork Little Miami river basin. They found a significant relationship between land use and concentration of phosphorus (P) in the river water. Their study showed that agricultural land use produced more than 10 times phosphorus than urban land use, 20 times than forest land use, and 154 times more than barren land use. On the other hand, using SWMM model, Chen [25] claimed that there is a linear inverse relationship between mean sediment discharge and percentage of urban land use in the Big Darby Creek watershed, Ohio, USA. Apart from land use change and water quality studies, these models are used in developing water pollution control strategies. For instance, Chuersuwan et al. [29] used WASP model to develop pollution control strategy in the Lamtakhong river basin, Thailand. The water quality in the basin had various issues including very low dissolved oxygen. Their model predicts that a reduction in 5-20% household pollution will improve the quality of water.

4. Key findings and discussion

The research articles reviewed here clearly shows that land use change has significant impact on water quality (section 3.1-3.4). Apart from this, one of the major finding is that decreasing agricultural land improves water quality [9, 17]. This can be explained as agricultural land contains a high level of nutrients because of fertilizer usage. When stormwater flows over the agricultural land as overland flow, more nutrients are added to stormwater compared to other lands. Therefore, reducing agricultural land will add less nutrients to stormwater which improves stormwater quality.

Another key finding in this review come from the study of Sliva and Williams [13] that the influence of a particular land use on water quality is more significant within a shorter distance from the land. This can be explained as water within a shorter distance from the land reflect the land characteristics much more compared to water at relatively longer distance. As water flows over the land, more and more pollutant mixes up with water from different lands and water characteristics therefore reflect whole catchment rather than a particular portion of the catchment.

On the basis of the study by Wilson and Weng[23], it can be said that land use and land cover are responsible for soil erosion. This is because a significant portion of pollutant can be transported from one place to another by

wind or water. For a land with small vegetation cover such as agricultural land, the amount of erosion is high. On the other hand, land with dense cover such as forest, soil erosion by wind and water is low because the erosion is greatly reduced by the dense land cover.

In this review, it is found that the types of crops cultivated on land have significant impact on water quality [21]. This can be explained as different vegetation consumes different level of nutrients from the soil. Therefore, they change the level of nutrients in soil which affect the concentration of nutrients in surrounding water.

At present many countries in the world are experiencing water quality issues such as rising salinity, high nutrient level, low dissolved oxygen and cold water pollution. High nutrient level in water may accelerate harmful algal bloom. In 1878, the blue-green algae named *Nodularia spumigena* bloomed in Lake Alexandrina in South Australia causing death of animals that drank from that water [27]. Therefore, in order to maintain the aquatic life and a healthy ecosystem, stream water must be protected from pollution and land use change should be managed.

5. Recommendations

Some researchers including Chu et al. [14] and Sliva and Williams [13] used sub-catchment approach in their study. It is recommended to use whole catchment approach because the whole catchment approach is more appropriate to develop pollution control measures and effective land use policy. Some researchers used multiple regression method in their study. This should be verified with other methods since multiple regression method is based on a number of assumptions. Modelling time step is another important factor affecting pollutant loading. It is recommended to use sub-daily data if available.

One of the major challenges in water quality modelling is that data are often recorded at point stations which often do not coincide with the study area. The traditional method to deal with this problem is to obtain data from nearby gauge stations or using spatial estimation technique such as Theissen polygon method or Isohytal method. But these methods may lead sometimes inaccurate estimation. To overcome this issue, sufficient water quality monitoring stations should be installed.

Since land use is found to have significant impact on water quality, the authority should introduce effective land use plan and pollution control strategy. Agricultural activities should be closely monitored during the wet season to reduce the pollution of water by fertilizers. A number of wastewater treatment plant should be installed in the watershed.

6. Knowledge gap and future directions

The research articles reviewed here does not explain sediment routing and wind erosion. Further research in this area is necessary to fulfil the knowledge gap. A few

studies reported to be found relationship between types of crops cultivated on a watershed and stream water quality. However, more research needs to be done in this area.

It has been found that an individual water quality model cannot simulate all the process involved in water quality modelling. Therefore, a combined model including climate model, land transformation model, hydrodynamic model, sediment transport model and a biogeochemical model should be considered in future studies. Besides 3S technology along with artificial intelligence should be incorporated with next generation water quality models. 3S is a combination of geographical information system (GIS), remote sensing (RS) and global positioning system (GPS) that is capable of acquiring high quality data. Artificial intelligence will give the model freedom to select its parameters rather than running with predefined fixed parameters.

7. Limitations of the review

The statistics presented here from various research articles considered that water quality changes because of land use change. Actually, there are other factors including geology of the watershed, climate condition, soil types, population characteristics, average precipitation and other physical and biological factors that also responsible for water quality changes. The results presented here is caused by all these combined effect. The individual impact of land use change on water quality must be different than the results presented here.

8. Conclusion

A review has been done to evaluate the relationship between land use change and stream water quality. This review found that stream water quality changes with land use practices. Expansion of agricultural land is one of the major cause of stream water pollution. Apart from land use practices, it is seen that types of crops cultivated on agricultural land also affect water quality. The integration of geographical information system (GIS) and remote sensing (RS) with water quality models is found very effective to improve water quality models output. All the studies reviewed here did not account sediment routing and wind erosion effect. More research need to done in this area. Land use related policies should be developed to improve the quality of stream water and to keep functioning the ecosystem properly.

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