

# THE POTENTIAL OF FOREST BUFFER TO PREVENT STREAM FROM WATER POLLUTANTS: A CASE STUDY IN GROJOKAN SEWU SUB-WATERSHED, KARANGANYAR DISTRICT, CENTRAL JAVA

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## ABSTRACT

Population growth leads to water scarcity in terms of both quality and quantity. Agricultural and urban watersheds potentially produce more pollutants than forested area. It is considered that forested area has potential in storing and protecting water supply in such a way that water distribution and quality can be guaranteed. The objective of the study was to determine the relationship between the percentages of forested area in a watershed with the water quality. The study was conducted in 2010 in Grojokan Sewu Sub-watershed, Karanganyar District, Central Java. Using GIS (Geographic Information System), this sub-watershed was divided into four sub-sub-watersheds with different percentages of forested areas. Water samples were collected in each sub-sub-watershed to find out the relationship between the forested area and the total dissolved solids, turbidity, sodium, nitrite, nitrate, sulfate and organic matters. The statistical analysis indicates relationships in quadratic form between sodium, nitrite, TDS, sulfate and organic matters with the percentage of forested area ( $R^2=0.99$ ,  $R^2=0.99$ ,  $R^2=0.98$ ,  $R^2=0.95$  and  $R^2=0.77$ , respectively). The relationships are different from those of turbidity and nitrate that have low  $R^2$  ( $R^2=0.28$  and  $R^2=0.36$ ) values. It implies that the forested area is capable to reduce sodium, nitrite, TDS, sulfate and organic matters, and thus water pollutants can be reduced by forest formation as it can filter water through retention of sediments and nutrients.

Keywords: Forest, water quality, watershed, land use

## I. INTRODUCTION

Demand for water is rising rapidly in line with world's population growth. Water scarcity for drinking water as well as for agriculture is increasing. On the other hand ground water is being depleted as ecosystems are becoming polluted and degraded (Rosegrant *et al.*, 2002). The water use is related to the consumption of the people. The water consumption of a country is defined as the volume of water needed for the production of the goods and the services consumed by the inhabitants of the country. USA appears to have an average water consumption of 2480m<sup>3</sup>/cap/yr, while China has 700m<sup>3</sup>/cap/yr. The global average water consumption is

1240m<sup>3</sup>/cap/yr (Hoekstra and Chapagain, 2007).

A wide range of construction and development activities can adversely affect the world's water supplies in terms of both quality and quantity. These conditions are also affected by land use formations. It is widely known that watershed hydrology depends on many factors, including land use, climate, and soil conditions. (Tong, 2002) Agricultural and urban watersheds potentially produce more pollutants than forested areas (Lenat and Crawford, 1994; Dauer *et al.*, 2000; Fisher *et al.*, 2000; Wang, 2001). It maybe the result of high concentration of fertilizers (Mattikalli and Richards, 1996) and municipal wastes (Fisher *et al.*, 2000). Moreover, conversion of forested lands to agriculture and/or urban/ residential areas has been associated with declines in stream and lake water quality (Houlahan and Findlay, 2004). Therefore, forest is expected to be effective in maintaining water quality by reducing any

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pollutant into the river. By intercepting rain, a forest canopy reduces the impact of heavy rainfall on the forest floor and decreases soil disturbance. Leaves and natural debris on the forest floor may slow down the rate of water runoff and trap soil washing away from surrounding fields. Consequently, it reduces soil loss which potentially brings nutrient to the stream (Zisheng *et al.*, 2011; Foltz, 2012).

Forest condition that manages to regulate water is the forest which has multilayers, such as natural forest (Tíscar and Linares, 2011) or agroforestry system (Suryanto and Putra, 2012). Natural forest which consists of trees at different stages of growth, such as seedlings, saplings, poles and mature trees creates canopy layers (Tíscar and Linares, 2011). This multilayer can also be found in agroforestry in which trees or shrubs are grown in association with agricultural crops (Suryanto and Putra, 2012). Based on that, characteristic of forested area acts as water filter and thus protects soil from erosion and surface run off (Wentai *et al.*, 2011; Singh and Mishra, 2012), as well as supplies ground water discharge which provides oxygen to the stream (Núñez *et al.*, 2006). Hairiah *et al.* (2012) reported that forest conversion to coffee-based agroforestry initially led to a decrease in the rate of litter fall and the accumulated litter layer covering the soil, replenishment of soil organic matter (SOM), and likely related to a reduction in soil macro porosity. On sloping land, a reduction of macro porosity and soil cover will increase overland flow and erosion (Hairiah *et al.*, 2012). It indicates that the type of trees used as shade trees to the coffee can influence directly the physical conditions of the soil through their rooting pattern. A combination of trees with slowly decomposing litter, that help to protect the soil surface, and trees with deep root systems that directly create macro porosity is probably the best for securing soil conditions that meet the requirements of low surface runoff and erosion rates.

Based on the important effect of forested area on water quality, the study was aimed to determine the relationship between land use type composition (the percentage of forest cover) and water quality parameters, i.e. total dissolved solids (TDS), sodium (Na), sulfate ( $\text{SO}_4$ ), nitrite ( $\text{NO}_2\text{-N}$ ), nitrate ( $\text{NO}_3\text{-N}$ ) and organic matters in a

watershed. To achieve the goal of the study, observation of water quality was conducted in four sub-watersheds which have different percentages of forested areas.

## II. MATERIAL AND METHOD

### A. Location

This research has been conducted in Grojokan Sewu Sub-watershed in Karanganyar District, Central Java. Geographically, which is located between  $7^{\circ}41'24.10''$ - $7^{\circ}37'32.48''$ S and  $111^{\circ}07'27.07''$ - $111^{\circ}07'19.01''$ E. Grojokan Sewu Sub-watershed was divided into four sub-sub-watersheds: Grojokan Sewu, Blumbang, Gondosuli 1 and Gondosuli 2.

Grojokan Sewu Sub-watershed is dominated by undulating topography. This area was selected because there are extensive agricultural activities on steep slopes using intensive fertilizer (Prasetyo, 2013) which may lead to erosion and water pollution.

### B. Land cover classification

Land cover map was generated from Quick-Bird image of September 29, 2006 which was downloaded from Google Earth in 2010. Arc-Map 9.3 was used in image processing, such as geo referencing and digitizing. Geo referencing process utilized the coordinate system of WGS 84 based on images coordinates of Google Earth. On-screen digitizing was done by delineating similar patterns seen in the image, such as color and texture of the objects. Land cover types were divided into four types, i.e. vegetable garden, settlement, forest and shrub.

Ground checking survey was conducted in the same year as the image downloading. Survey was based on land cover map by matching the present type in the field with the map. To determine forest density, tree measurement was conducted to obtain parameters such as tree species, diameter at breast height (DBH), tree height and number of trees in the  $30\text{ m} \times 30\text{ m}$  sample plots (sample intensity was approximately 10%). These plots were considered as training samples used to complete the image classification.

Finally, land covers were classified into six classes such as vegetable crops, settlement, sparse plantation forest, moderately dense plantation forest, dense natural forest and shrubs. Cover story and under story were also analyzed in order to find out their effect on water filtering.

**C. Water sample analysis**

Water samples were collected in 2009 during the rainy season from each sub-subwatershed with different percentages of forested area. The samples (4 samples) were taken simultaneously. Each sample consisted of 1500 ml water and it was analyzed in the Indonesian Ministry of Health's Laboratory, Yogyakarta. Parameters analyzed were turbidity, TDS, natrium, sulfate, nitrite, nitrate and organic matters. The standard methods used were SNI 06-6989.25-2005; SNI 06-6989.1-200; APHA2012, Section 3500-Na; SNI 6989.20-2009; SNI 06-6989.9-2004; APHA 2012, Section 4500- NO<sub>3</sub> and SNI 066989.22-2004, respectively. Regression method was used to develop the relationship between forested area and each water quality parameter.

**III. RESULT AND DISCUSSION**

**1. Land cover types**

Based on image analysis there were six land cover classes in the study area, i.e. vegetable crops, settlement, sparse plantation forest, moderately dense plantation forest, dense natural forest and shrubs. The distribution of land cover types is presented in Figure 1.

Settlements are generally situated in flat areas, while vegetable gardens, forests and shrubs are found in areas with steeper slopes, in areas with slope of more than 45%. Based on the map, Grojokan Sewu Sub-watershed is dominantly covered by forests (55%) (Table 1). Table 1 shows the percentage of forested area in each sub-watershed, namely Gondosuli 2 (88%), Gondosuli 1 (72%), Blumbang (64%) and Grojokan Sewu (55%). The forest cover type was divided into three classes based on density levels, i.e. (1) sparse plantation forest, (2) moderately dense plantation forest, and (3) dense natural forest. The forest density is influenced by the type of plant, tree density per ha, canopy closure, understory plants and diameter (Table 2).

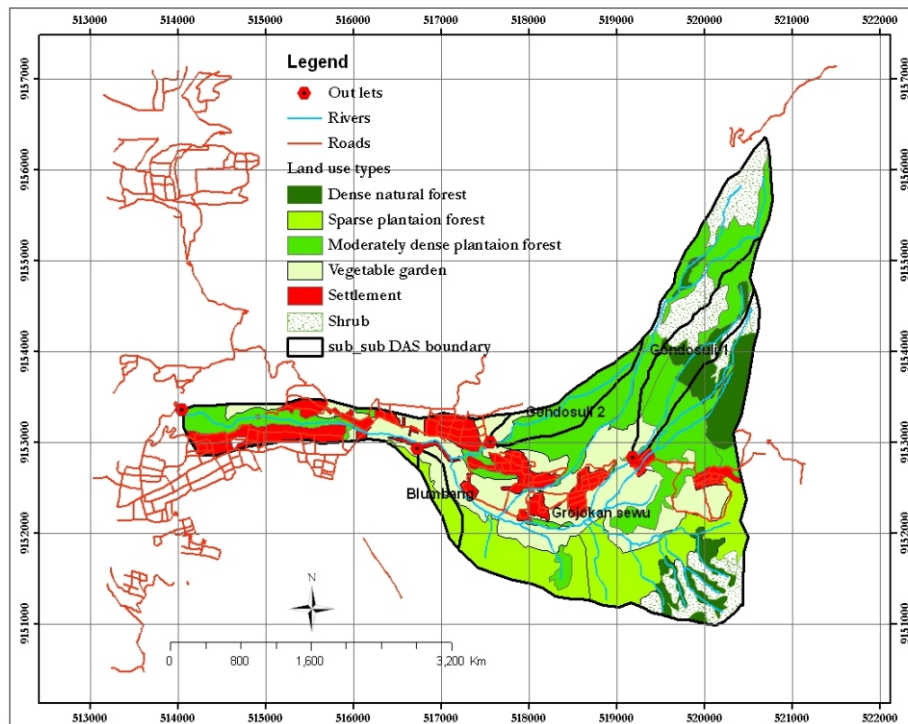


Figure 1. Land cover map of Grojokan Sewu Sub-watershed

Table 1. Distribution of land cover types in each sub-watershed

Land cover types	Sub-watersheds							
	Blumbang		Gondosuli 1		Gondosuli 2		Grojokan Sewu	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Vegetable garden	7.99	36.27	5.80	5.91	6.23	11.95	249.37	22.05
Settlement	-	-	0.53	0.54	-	-	125.50	11.10
Sparse plantation forest	14.04	63.73	-	-	-	-	182.88	16.17
Moderately dense plantation forest	-	-	49.57	50.47	45.91	88.05	334.15	29.55
Dense natural forest	-	-	20.77	21.15	-	-	102.70	9.08
Shrubs	-	-	21.53	21.93	-	-	136.17	12.04
Total	2.03	100.0	98.21	100.0	52.14	100.0	1130.77	100.0

Table 2. Forest condition and density of Grojokan Sewu Sub-watershed

Land cover type	Species	Density of			Average DBH (cm)	Area	
		Forest canopy (%)	Understory plant (shrubs)	Trees per ha		(ha)	(%)
Sparse plantation forest	<i>Pinus merkusii</i> , <i>Acacia decurrens</i>	26.7	Sparse-moderate	675.0	9.0	182.88	16.17
Moderately dense plantation forest	<i>Pinus merkusii</i> , Jungh, <i>Acacia decurrens</i>	61.0	Moderate-dense	835.0	15.3	334.15	29.55
Dense natural forest	Mixed species	86.7	Uniformly Dense	1033.3	-	102.70	9.08

Natural forests are densely populated by mixed species of trees and shrubs. Species of shrubs found in the area were *Gleichenia linearis*, *Eupatorium odoratum*, *Nephrolepis falcata*, *Mimosa pudica*, *Centotheca lappacea*, *Echinocloa colonum*, *Aristolochia tagala*, *Dicranopteris linearis*, *Cyperus rotundus*, and *Imperata cylindrica*.

## 2. Water quality

The statistical analysis indicates a relationship in quadratic form between Sodium, Nitrite, TDS, Sulfate and organic matters with the percentage of forested area whereas this relationship is not

found between turbidity and nitrate and the percentage of forested area (Table 3).

These relationships between the forested area with TDS, turbidity and other chemical materials are graphed in Figure 2 and Figure 3.

The relationship between TDS and other chemical contents with the percentage of forested area are in line with the fact that primary sources for TDS and other chemical contents in waters are agricultural and residential runoffs, leaching of contaminated soil and point source water pollution discharge from industrial or sewage treatment plants. Runoff may contain chemical materials such as sulfate, nitrites, nitrates, sodium,



and organic matters. In agriculture (non-forested) area the application of inorganic fertilizers tends to deliver high concentration of nitrates. In addition the well-drained area contained the highest concentration of nitrates (Hamilton and Helsel, 1995; Coulter *et al.*, 2004). Moreover, water from forested catchments has lower nitrates content compared to those from farmland, and residential areas (Ngoye and Machiwa, 2004).

The relationship between turbidity and forested area is similar to the research found by Coulter *et al.* (2004). They concluded that turbidity is generally higher in the urban and mixed watersheds. Intensive agriculture in the study area by applying intensive tillage and sewage from settlement might be the source of pollutants. These pollutants are delivered to the rivers through runoff and erosion. Surface-runoff, stream flow and overland flow also increase the turbidity level of the water. Turbidity will further influence the other water quality parameters such as TDS. Tillage erosivity increases exponentially with tillage depth. Therefore reducing tillage

depth can be considered as an effective soil conservation strategy (Oost *et al.*, 2006).

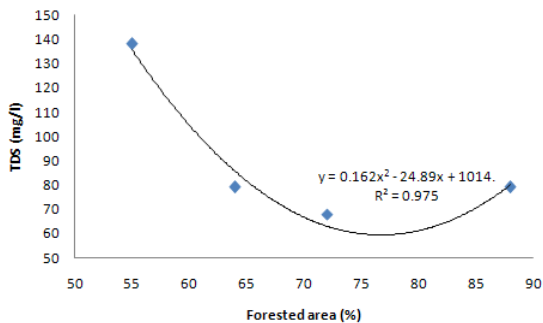
The forested area reduces pollutants by taking up nutrients and, especially in saturated riparian areas, creating conditions (anaerobic soil conditions and energy source of organic material) for de-nitrification (reduction of nitrite and nitrate to N<sub>2</sub> gas). Moreover, higher nitrate-N concentrations were found in streams with adjacent forest cover (Ice and Binkley, 2003; Messer *et al.*, 2012). Forested area e.g. riparian forest has also a function of maintaining water quality by protecting land from runoff and erosion. Riparian forest can reduce the carbon export to water bodies and forest buffers are effective in protecting water quality and aquatic life, particularly when it is wider than 40 m (Gundersen *et al.*, 2010). Furthermore, riparian forests are highly valued for maintaining water quality through the retention of sediments and nutrients. In addition increases in land development will likely lead to greater erosion and sediment deposition in these areas (Jolley *et al.*,

Table 3. Relationship of water quality parameters with the percentage of forested area

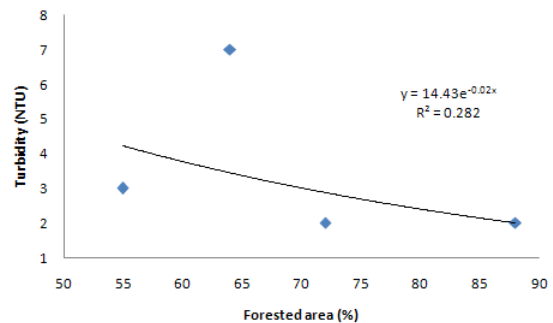
Parameters	Equations	R <sup>2</sup>	Adj. R <sup>2</sup>	SEE	Sig.
Sodium (mg/l)	$Y = 0.0317X^2 - 4.7236X + 186.98$	0.99	0.93	0.54	0.065**
NO <sub>2</sub> -N (mg/l)	$Y = 2E-06X^2 - 0.0004X + 0.0161$	1	1	0	0*
TDS (mg/l)	$Y = 0.1623X^2 - 24.898X + 1014.3$	0.98	0.93	8.62	0.15 <sup>ns</sup>
SO <sub>4</sub> (mg/l)	$Y = 0.0472X^2 - 6.875X + 250.59$	0.95	0.85	2.68	0.22 <sup>ns</sup>
Organic Matters (mg/l)	$Y = -0.0078X^2 + 1.0495X - 28.767$	0.77	0.32	1.39	0.47 <sup>ns</sup>
Turbidity (NTU)	$Y = 14.435e^{-0.022X}$	0.28	-0.77	0.61	0.46 <sup>ns</sup>
NO <sub>3</sub> -N (mg/l)	$Y = 5.6564e^{-0.065X}$	0.36	-0.97	1.5	0.40 <sup>ns</sup>

Remarks: Y = water quality  
X = percentage of forested area (%)

ns = not significant  
\*\*= significant at 0.1  
\*= significant at 0.05



(a)



(b)

Figure 2. The relationship between forested area with TDS and turbidity of Grojokan Sewu Sub-watershed

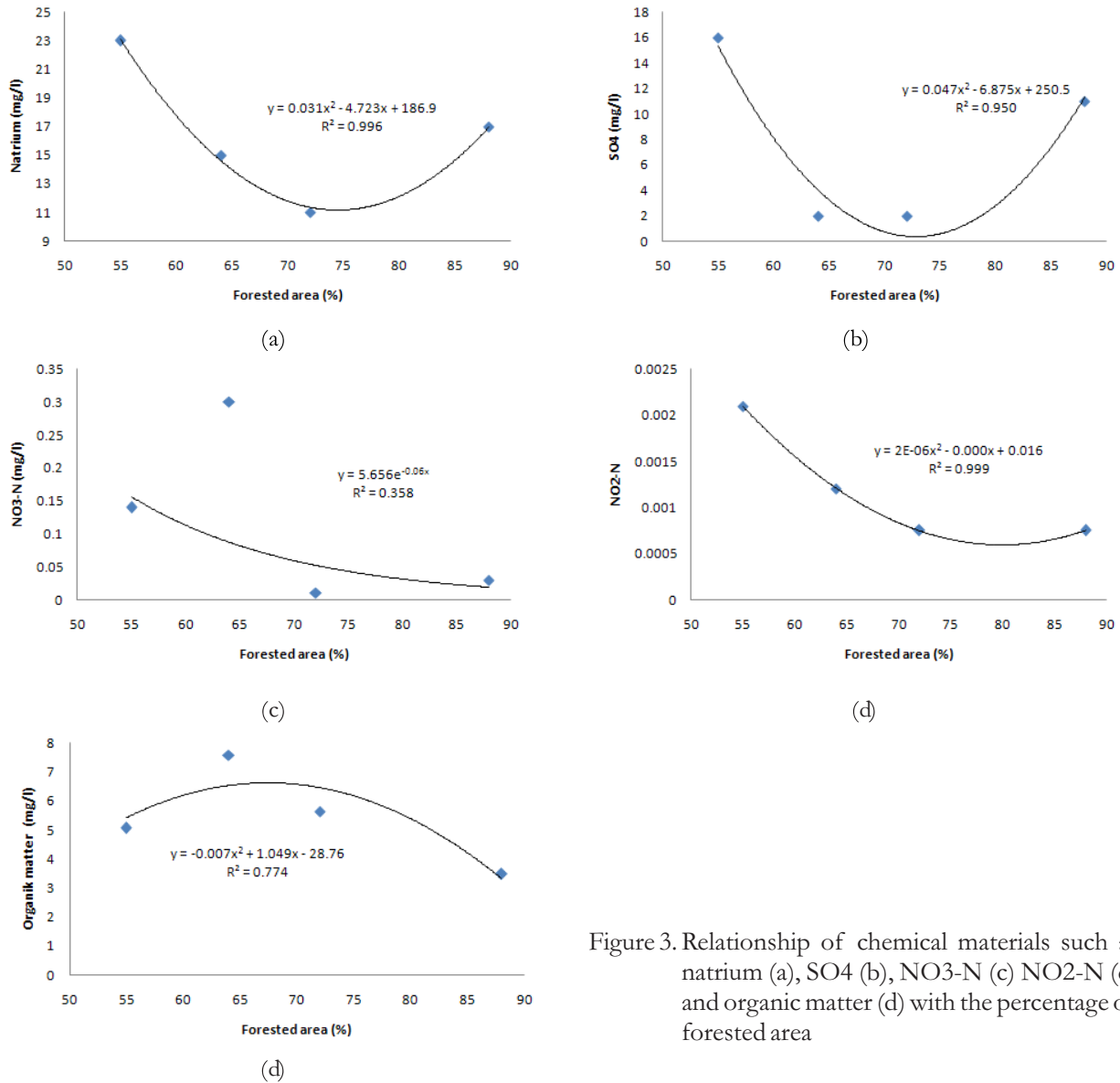


Figure 3. Relationship of chemical materials such as natrium (a), SO4 (b), NO3-N (c) NO2-N (d) and organic matter (e) with the percentage of forested area

2010).

Fragment size, or length and width of riparian forest and vegetation type, and fragment location in the catchment may have critical roles in enabling forest fragments to reduce the negative impacts of agriculture. The characteristics of fragments have important consequences for stream remediation. Moreover, small forest fragments can mitigate upstream agricultural effects on water quality (Harding *et al.*, 2006). Therefore, forestry practices e.g. urban forest can be functioned as a buffer region in urbanizing watershed to protect and to improve water quality (Matteo *et al.*, 2006; Vyas *et al.*, 2012). The urban forest cover substantially is a benefit to water quality and water quantity at a watershed scale. It was observed that previous cover reduced the

problem of non point source pollution from sediment and nutrient entering into urban watershed systems. Combining riparian and roadside buffers for urban forestry can provide substantial improvements in water quality. In addition, runoff decreased under these spatial policies, thus mitigating storm water problems. Nutrient loss is reduced through tree uptake and reduction in sediment loading (Matteo *et al.*, 2006).

Existence of forest increases precipitation and water availability. Progressive deforestation, land conversion from forest to agriculture and urbanization has potentially negative consequences on global precipitation. Therefore, forest ecosystems are fundamental for providing and maintaining freshwater resources, maintaining human health, agricultural production and economic activity

(Ellison *et al.*, 2011).

On the other hand, forest may act also as the source of chemical elements resulting from the decomposition of litter (Congyan *et al.*, 2012) such as lignin, Nitrate, Carbon and Phosphorus (Mitchell *et al.*, 2011; Moore *et al.*, 2011). Congyan *et al.* (2012) concluded that high temperature and intensive precipitation may lead to an accelerated decomposition of litter of conifer and also of broad leaf forest in the tropics. Both the litter and forest floor material favor decomposition and nutrient mineralization processes (Laganiere *et al.*, 2010). Moreover, microbial community composition also plays an important role in decomposition (Powers *et al.*, 2009; Bray *et al.*, 2012).

Based on the fact that water pollutants can be reduced by forest formation, it is recommended to build forest buffer strips for trapping non point-source pollutants and protecting surface water quality (Endreny, 2002). In this regard there are three aspects that should be considered: (1) the likelihood for excess pollutant on a watershed site is a function of the land cover type or use, (2) the likelihood for run off to leave a watershed site is a function of the size of the upslope contributing area and the slope, and (3) the likelihood for polluted runoff to enter a surface water body is a function of the opportunities for pollution filtering within the runoff dispersal area.

#### IV. CONCLUSION

The percentage of forested area has relationships with Sodium, Nitrite, TDS, Sulfate and organic matters in quadratic forms. It implies that forested area may reduce Sodium, Nitrite, TDS, Sulfate and organic matters, and water pollutants can be reduced by forest formation as it can filter water through retention of sediments and nutrients.

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