Assessment of Seasonal Variations of Surface Water Quality in the Phong Watershed, Thailand

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Abstract

Variations of water quality parameters with seasonal changes in the Phong watershed were explored. Water quality parameters including turbidity, suspended solids (SS), total dissolved solids (TDS), nitrate, phosphate, alkalinity, conductivity and total coliform were directly measured on site or analyzed at a laboratory twice a year in January (dry season) and in July (wet season) for two years (2004 and 2005). The results revealed a significant influence of seasonal changes on the Phong water quality. It was significantly evident for the concentrations of turbidity, SS, NO_3^- and PO_4^{3-} between wet and dry seasons. In addition, the water turbidity had strong positive correlations with SS and Phosphate (PO_4^{3-}), especially during the wet season in both the upstream and downstream of the Phong watershed where human activities have a high influence on land use patterns. While the middle Phong watershed, a location of the Ubolratana Dam, turbidity had very weak correlation with SS (0.14) in the dry season. However, it had very strong correlation with SS (1.00) in the wet season indicating that the dam plays an important role of settling down SS. Moreover, the significant positive correlations of turbidity, SS and PO_4^{3-} especially in the wet season clearly indicated the phenomena of naturally occurred soil erosion with exacerbation by human induced soil erosion. This results in transformation of the forest land to the agricultural land which has been occupied in the Phong watershed. Therefore, these water quality parameters (turbidity, SS and PO_4^{3-}) should be focused on for monitoring human impacts on water quality in the Phong watershed.

Keywords: Phong watershed, Water quality, Seasonal change, Correlation

1. Introduction

Watershed refers to the geographic boundaries of a particular water body, its ecosystem and the land that drains to it. The river water quality in the watershed is therefore influenced by both natural and anthropogenic factors. According to Dunne and Leopold (1978) [5] and Winpenny (1991) [14], watersheds are threatened by a variety of human activities including encroachment of human settlements, livestock grazing, firewood collection, commercial logging, road construction, major civil engineering projects such as dams and highways, and the conversion of forest to plantations. The ecological consequences of poor watershed management and intensified agriculture throughout the watershed are amplified by increased development. This situation is also evident in the Phong watershed, Thailand.

In the past four decades, deforestation in Thailand has been obviously encountered. The forest land has been transformed into agricultural land, leading to the increased erosion in the watershed. Soil erosion from agricultural areas results in loss of not only productive soil, but also plant nutrients, and organic and inorganic matter causing reduction in soil fertility. Sediment, a product of soil erosion, becomes a pollutant in rivers. According to Arheimer and Liden, 2000 [2]; Johnson et al., 1997 [6]; Smart et al., 1998 [12], agricultural land use strongly influences stream water nitrogen, phosphorus and sediments. Babel *et al.*, 2004 [8] reports that according to the land development department, Thailand, some 33% of the 51.3 million hectares of the total geographical area, is moderately to severely eroded. Suspended sediments from all the watersheds in Thailand are estimated to be 27 million tons annually. Cropland expansion through exploitation of forested hilly regions in the North and the utilization of the marginal uplands in the East and Northeast, have been major contributors [8].

The issue of seasonal variations also gives rise to variation in land use and land cover analysis. Many authors have commented that the analysis should be conducted during the storm season, as it is during this time the landscape is most intimately connected with local waterways (Arthemier and Liden, 2000 [2]; Basnyat et al., 1999 [3]; Bolstad and Swank, 1997 [4]). Others have addressed this issue by analyzing stream chemistry during multiple seasons and conducting separate correlations with land use and land cover for each season (Johnson et al., 1997 [6]; Osborne and Wiley, 1988 [10]). The results indicate that season, land use and land cover have influence on water quality. Osborne and Wiley (1988) [10] noted that median nitrate concentrations are correlated with agricultural practices during the high flow in the spring period, but then became correlated with urban land cover during the low flow in summer and autumn.

The purpose of this study was to investigate the variations of water quality parameters at different sections of the Phong watershed (upstream, middle and downstream) with seasonal changes (dry and wet).

2. Methods of study

2.1 Study area

The Phong watershed (Figure 1) is the most important watershed in the upper northeast region of Thailand. The Phong River is a tributary of the Chi River system, which flows into the Mekong River. Its catchment covers 1,518,900 ha, extending to the five provinces of Chaiyaphum, Khon Kaen, Loei, Nong Bua Lumphu, and Petchaboon. The highest mean rainfall is in September. The southern part of the watershed has quite low mean annual rainfall (800 mm) compared to the northern part of the watershed (1,300 mm). The lowest mean rainfall in the Phong watershed is in January (3.86 mm), the dry season, compared to the highest one found in September (227.35 mm), the wet season. The highest amount of runoff is in September and October in the range of annual runoff from 46.7-68.5%. The range of annual specific rainfall yield per area is in between 4.24-10.09 l/sec-km^2 [7]. According to the water samplings data in January (the dry season) and in July (the wet season) 2006, the flow rate is very low in the dry season (mean 0.45 Mm^3/day) and very high in the wet season (mean 1.25 Mm^3/day).

The upstream watershed area consists of four main rivers, namely the Phrom, the Choen, the Phaneng, and the upstream Phong. These rivers run into the Ubolratana Dam located in the middle region of the Phong watershed. The downstream Phong River is divided into two river sections, from the Ubonratana Dam to Nong Wai irrigation weir and from the weir to Mahasarakam dam. The upstream Phong watershed occupies 79.59% of the total watershed area, consisting of 27.33% forest, 64.05% agriculture (mainly rain-fed paddy fields and plantations producing crops such as cassava, corn and sugarcane), and 8.62% other uses (Figure 1). The majority of the agricultural land has been transformed from forestland in the last few decades. This land transformation, together with farming practices without soil conservation, causes soil erosion and increased suspended solids in rivers, which silt up reservoirs, raise the riverbeds and affect water quality and water uses due to elevated turbidity levels in the rainy season. It has been learnt that the driving force for the land transformation is the government's land use and economic policies, intended to alleviate the poverty of people in the northeast of Thailand. Much infrastructure has been built in the Phong watershed to serve government land use and economic policies, for example the construction of Ubonratana Dam, Chulabhorn Dam and Hua Khum Dam. In addition, the government policies support the establishment of agro/food factories within the Phong watershed. There are many of these factories located in the Phong watershed. It is interesting to see that the type of agro/food factory established in the Phong watershed has a large influence on the type of crops in the countryside surrounding the factory. In addition to paddy fields, sugar cane, cassava and corn are the three other main crops planted in the area. Moreover, in information discussed with the officers of the Land Development Department Office Zone 6, Khon Kaen province, rubber trees plantations have been recently promoted by the government.

Land use from Ubolratana Dam to Nong Wai Irrigation weir consists of industry, community, agriculture and forestry. Industrial area covers 236 ha. There are two large factories within the area, which are a Pulp and Paper Mill and a Combined Cycle Thermal Power Plant. Significant communities in this sub-watershed are Ubolratana Sanitary District, Nam Phong Sanitary District and Ubolratana District. The agricultural area directly affecting the Phong river is 20,000 ha. Agricultural land consists of rain fed paddy field, upland crop and other vegetable areas. Typical crops cultivated include rice, cassava, sugarcane, jute, eucalyptus, watermelon and vegetables. Much of the forested areas have been transformed to agricultural and industrial areas (Figure 1).

Land use from Nong Wai Irrigation weir to Ban Na Piang, consists of large and medium scale factories as follows: sugar mill, paperboard mill, distillery mill and tapioca mill. Significant communities are Wang Chai Sanitary District, and Amphor Nam Phong. Concerning the agriculture, the area under irrigation is 31,880 ha. Rice cultivation is carried out in the rainy season. Some rice and vegetables are cultivated in the dry season. Other areas are used for seed production and cantaloupe cultivation (Figure 1).

Land use from Ban Na Piang to Mahasarakham weir, consists of communities and household industries are such as Khon Kaen Municipality, Thai rice noodle production, meat processing and brick production. Regarding the agriculture, a large irrigation area is provided by both the Nong Wai Irrigation Project and also by the Department of Energy Development and Promotion. There is the Mahasarakham Weir Project of the Department of Energy Development and Promotion.

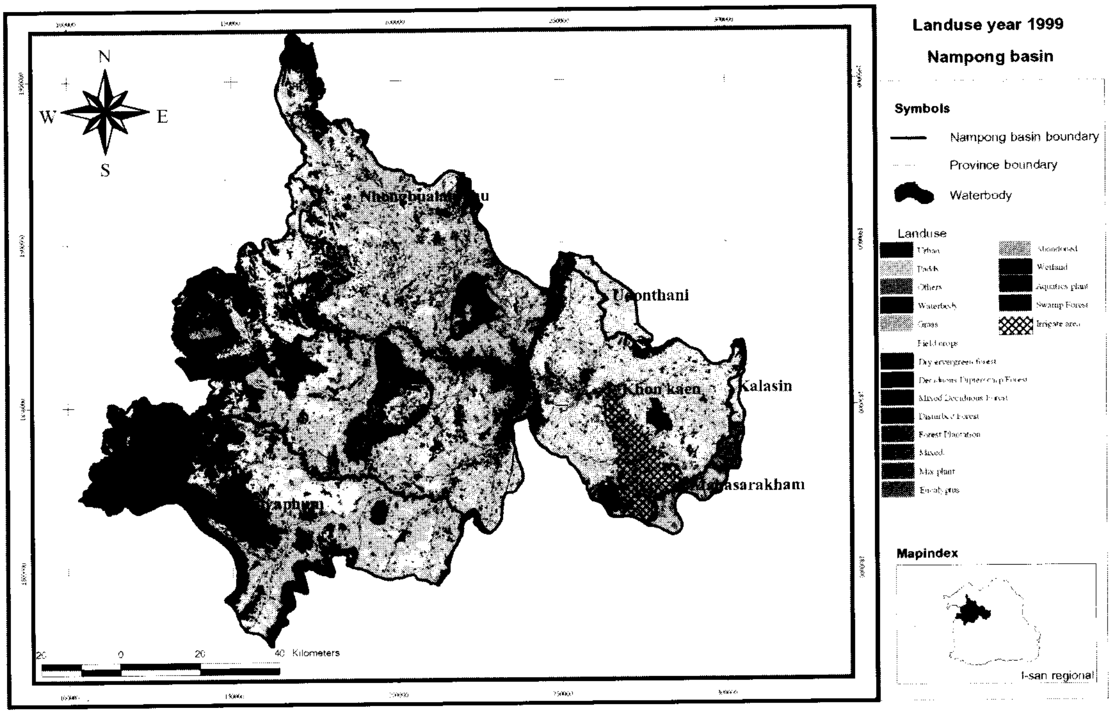

Figure 1. The land use map in 1999 of the Phong Watershed.

Table 1. Soil loss rates (tons/ha-year) and slope length and steepness of the Phong watershed classified by different types of land use [7]

Rivers	Soil loss rates (tons/ha-year)			Slope length and steepness		
	Forest	Crop	Paddy	Forest	Crop	Paddy
Choen	0.33-30.11	0.21-20.01	0.04-9.96	0.03-1.32	0.03-0.19	0.03-0.19
Phaneng	0.16-40.52	2.41-7.74	0.13-2.68	0.03-1.32	0.03-0.06	0.03-0.52
Phrom	0.33-28.94	0.22-6.56	0.04-10.69	0.03-1.32	0.03-0.52	0.03-1.32
Upstream Phong	0.39-17.38	1.81-63.33	0.16-13.82	0.03-1.32	0.03-0.52	0.03-1.32
Ubonratana Dam	0.56-17.91	0.04-2.63	0.13-2.36	0.03-0.60	0.03-0.06	0.03-0.19
Downstream Phong	0.39-17.85	0.59-73.46	0.16-2.36	0.03-0.60	0.03-0.52	0.03-0.06

Table 1 clearly indicates that the highest soil loss rates are in the upstream watershed, where there is the higher slope with deteriorated forest. Land transformation has been carried out by the crop plantations. Upland paddy fields can also be found in the high slope of forest areas, especially in the Prom and upstream and downstream Phong Rivers.

2.2 Collection and analysis of surface water samples

Surface water samples were collected by a grab sampling method for two years (2004 and 2005) in January (representing the dry period) and in July (representing the wet period). At the upstream section, 30 samples were taken from the Prom, the Choen, the Phaneng, and the upstream Phong rivers and from the Chulabhorn and Huakhum Dams. At the middile section, 8 samples were collected from the Ubonratana reservoir. At the downstream section, 12 samples were taken from the downstream Phong river, Jode stream, Tung Tuen lagoon, Phra Kreu stream and the confluence of the Phong and the Chi rivers. Water samples were collected in high density polyethylene bottles and kept cool in an icebox, and transported to a laboratory of Khon Kaen University. Water quality samples were analyzed for turbidity, suspended solids (SS), total dissolved solids (TDS), nitrate (NO_3^-), phosphate (PO_4^{3-}), alkalinity and total coliform (TC). Conductivity was measured at the time of sampling. Analysis of water quality followed the standard methods [1].

2.3 Data analysis

The Pearson's correlation coefficients were calculated to examine the strength and significant of the relationships among water quality parameters of the upstream, middle and downstream Phong watershed and between dry and wet seasons.

3. Results

3.1 Seasonal variations of water quality parameters

3.1.1 The upstream Phong watershed

The mean contents of turbidity, SS, and TC were evidently much higher in the wet season compared to the dry season: 316 NTU (wet), 8.87 NTU (dry); 175.88 mg/l (wet), 13.73 mg/l (dry) and 815 MPN/100ml (wet), 451.66 MPN/100ml (dry), respectively. In contrast, the mean contents of TDS, NO_3^-, PO_4^{3-}, alkalinity and conductivity were lower in the wet season than the dry season as follows; 149.88 mg/l (wet), 161.62 mg/l (dry); 0.47 mg/l (wet), 0.99 mg/l (dry); 0.09 mg/l (wet), 1.50 mg/l (dry); 83.73 mg/l as $CaCO_3$ (wet), 118.72 mg/l as $CaCO_3$ (dry); and 181.90 mS/cm (wet), 260.28 mS/cm (dry), respectively.

3.1.2 The middle Phong watershed

All mean contents except NO_3^- and PO_4^{3-} were higher in the wet season compared to the dry season. The means of turbidity, SS, TDS, TC, Alkalinity and conductivity in wet and dry seasons were as follows: 90.02 NTU (wet), 3.95 NTU (dry); 51.31 mg/l (wet), 7.88 mg/l (dry);

109.81 mg/l (wet), 90 mg/l (dry); 292.25 MPN/100ml (wet), 12.86 MPN/100ml (dry); 62.25 mg/l as $CaCO_3$ (wet), 59.31 mg/l as $CaCO_3$ (dry); and 177.30 mS/cm (wet), 149.90 mS/cm (dry); respectively. Means of NO_3^-, and PO_4^{3-} in the wet and dry seasons were as follows: 0.26 mg/l (wet), 0.44 mg/l (dry); and 0.05 mg/l (wet), 1.12 mg/l (dry), respectively.

3.1.3 The downstream Phong watershed

The mean contents of turbidity, SS, TDS and alkalinity were also higher in the wet season than the dry season; 127.49 NTU (wet), 14.20 NTU (dry); 103.33 mg/l (wet), 19 mg/l (dry); 129.29 mg/l (wet), 126 mg/l (dry); and 63.04 mg/l as CaCO3 (wet), 60.67 mg/l as CaCO3 (dry), respectively. However, means of NO_3^-, PO_4^{3-}, TC and conductivity were higher in the dry season than the wet season as follows: 0.37 mg/l (wet): 2.07 mg/l (dry); 0.08 mg/l (wet), 3.21 mg/l (dry); 612.46 MPN/100ml (wet), 1,404.79 MPN/100ml (dry); and 172.8 mg/l as $CaCO_3$ (wet), 205.20 mg/l as $CaCO_3$ (dry); respectively.

3.2 Seasonal correlation of water quality parameters

Correlation analyses were performed to identify the linear relationships of water quality parameters between two different seasons (wet and dry) and the upstream, middle and downstream of the Phong watershed occupied with different land use patterns (Table 2).

3.2.1 The upstream Phong watershed

Water quality that presented a strong positive correlation are as follows: turbidity and SS in both dry (0.87) and wet (0.76) seasons, turbidity and PO_4^{3-} in the wet season (0.79), SS and PO_4^{3-} in the wet season (0.87). Turbidity and SS showed a weak to negative correlation with other parameters. Evidently, TDS presented a strong positive correlation with alkalinity (0.97 and 0.83) and conductivity (0.99 and 0.86) in both dry and wet seasons, respectively, but the correlation with NO_3^- was less positive in the wet season (0.44). NO_3^- showed a low to medium positive correlation with alkalinity, in both dry (0.30) and wet (0.44) seasons and a low correlation with conductivity only in the wet season (0.30). Alkalinity had very strong positive correlations with conductivity in both dry (0.97) and wet (0.94) seasons.

3.2.2 The middle Phong watershed

Obviously, the correlation of turbidity and SS was very strong (1.00) in the wet season, but very weak (0.14) in the dry season. Moreover, the correlation of turbidity with TDS, (0.53: 0.75) and PO_4^{3-} (0.50: 0.86) were fair and strong in the dry and wet seasons, respectively. SS had strong correlations with TDS (0.73) and PO_4^{3-} (0.85) in the wet season. TDS had fair correlations with PO_4^{3-} in the wet season (0.68) and with alkalinity (0.54) in the dry season and very strong correlation with conductivity (0.96) also in the dry season. NO_3^- was significantly negatively correlated with PO_4^{3-} in the dry season (-0.63). Finally, alkalinity was positively significantiy correlated with conductivity in the dry season (0.56).

3.3.3 The downstream Phong watershed

Likewise, turbidity presented very strong correlations with SS in both dry (0.99) and wet (0.96) seasons, while presenting fair correlations with TDS (0.44), NO_3^- (0.54), PO_4^{3-} (0.58) and alkalinity (0.42) in the wet season. SS had fair correlations with NO_3^- (0.50), PO_4^{3-} (0.51) in the wet season. TDS was significantly positively correlated with PO_4^{3-} in the wet season (0.74) and with alkalinity (0.60; 0.68) and conductivity (0.98; 0.88) in both dry and wet seasons, respectively. PO_4^{3-} was significantly positive correlated with alkalinity (0.73) and conductivity (0.54) in the wet season. Alkalinity was positively significantly correlated with conductivity in both dry (0.65) and wet (0.64) seasons. Finally, TC was positively significantly correlated with PO_4^{3-} in the dry season (0.80).

4. Discussion

The significant differences in the amounts of rainfall between dry (mean 14.14 mm) and wet seasons (mean 171.24 mm) and the forestland transformation into agricultural land have considerably affected water quality in the Phong watershed. The problem becomes more severe in the wet season when the amount of rainfall could go up to the highest of 1,300 mm, especially in the upstream Phong watershed, with much higher slope lengths and steepness and intensive upland agricultures.

Table 2. Pearson's correlation of water quality parameters

Phong watershed	Turbidity		SS		TDS		NO_3^-		PO_4^{3-}		Alkalinity		Conductivity		Total Coliform	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Upstream																
Turbidity	1	1	0.87*	0.76*	0.01	-0.13	0.02	0.04	-0.02	0.79*	0.00	-0.20	0.05	-0.20	0.00	-0.07
SS			1	1	0.00	-0.29**	0.05	0.03	0.04	0.87*	-0.02	-0.25	0.01	-0.26**	0.17	-0.11
TDS					1	1	0.23	0.44*	-0.08	-0.13	0.97*	0.83*	0.99*	0.86*	0.27	0.04
NO_3^-							1	1	-0.23	0.00	0.30**	0.44*	0.21	0.30**	-0.06	-0.09
PO_4^{3-}									1	1	-0.15	-0.24	-0.06	-0.21	0.18	-0.14
Alkalinity											1	1	0.97*	0.94*	0.22	0.04
Conductivity													1	1	0.25	0.05
Total Coliform															1	1
Middle																
Turbidity	1	1	0.14	1.00*	0.53**	0.75*	-0.13	0.25	0.50**	0.86*	0.38	-0.45	0.58**	-0.13	0.12	0.01
SS			1	1	0.21	0.73*	0.30	0.26	-0.37	0.85*	0.36	-0.47	0.36	-0.11	0.22	0.03
TDS					1	1	0.17	0.24	-0.17	0.68*	0.54**	0.11	0.96*	-0.21	0.28	-0.39
NO_3^-							1	1	-0.63*	0.11	0.46	0.34	0.23	0.05	-0.43	0.31
PO_4^{3-}									1	1	-0.24	-0.36	-0.14	-0.19	0.12	-0.11
Alkalinity											1	1	0.56**	0.03	0.11	-0.31
Conductivity													1	1	0.24	-0.07
Total Coliform															1	1
Downstream																
Turbidity	1	1	0.99*	0.96*	0.12	0.44**	-0.14	0.54*	0.37	0.58*	-0.20	0.42**	0.01	0.11	-0.14	0.02
SS			1	1	0.14	0.36	-0.10	0.50**	0.32	0.51**	-0.17	0.35	0.03	0.01	-0.16	0.04
TDS					1	1	-0.15	0.39	-0.19	0.74*	0.60*	0.68*	0.98*	0.88*	-0.38	-0.15
NO_3^-							1	1	0.12	0.15	0.21	0.00	-0.12	0.28	0.33	-0.07
PO_4^{3-}									1	1	0.05	0.73*	-0.20	0.54*	0.80*	-0.07
Alkalinity											1	1	0.65*	0.64*	0.21	-0.13
Conductivity													1	1	-0.32	-0.11
Total Coliform															1	1

* Correlation is significant at the 0.01 level (2-tailed), ** Correlation is significant at the 0.05 level (2-tailed)

Strong positive correlations between turbidity, SS and PO_4^{3-} were found in the Phong watershed, especially in the wet season evidently indicating the potential impact of soil erosion on the Phong river water quality. This is in accordance with the water quality indicated by turbidity and SS which were considerably higher in the wet season. On the other hand, the strong positive correlations among mineral related parameters were found especially in the dry season including TDS, alkalinity and conductivity, indicating the concentration effect during the dry season.

According to the Office for Agricultural Economics, 2004 [9], human activities driven by economic development plan had caused the changes of land use in the Phong watershed. The agricultural lands increased between 1994-2002 in the provinces of Chaiyaphum, Nong Bua Lumphu, Khon Kaen and Petchaboon at mean annual rates of 0.77, 3.28, 4.71, and 10.66%, respectively. During 1988-1999, all forest areas in the provinces of Chaiyaphum, Nong Bua Lumphu, Khon Kaen, Petchaboon and Loei decreased at the mean annual rate of 0.84, 1.00, 2.34, 3.21, and 2.07%, respectively.

Agricultural practices, particularly the rapid expansion for cash crops utilizing the marginal uplands in the East and the Northeast, have been major contributors [8]. Widespread deforestation for commercial agriculture has caused not only increasing surplus runoff, soil erosion, siltation in rivers and reservoir, increasing rates of occurrence and severity of floods, drought, and other damaging downstream areas, but also water contamination from insecticides and fertilizer. Silva and Williams (2001) [11] reported that watershed study results showed a negative correlation of forested land cover with TSS in Ont., Canada. The characteristics of non-forested land cover can strongly influence the impact of reforestation. For example, Johnson et al.'s (1997) [6] positive relationship of forest area with TSS in a study of landscape influence on water chemistry in the Saginaw Bay watershed of central Michigan should be viewed in light of the significant extent of row crop agriculture in many regions of their study.

The Ubolratana Dam plays a major role in settling down turbidity and possible other mineral related water quality parameters. This can be distinctly seen by the mean contents of all water quality parameters except NO_3^- and PO_4^{3-} which were much higher in the wet season compared to the dry season. In addition, turbidity had very weak correlation with SS (0.14) in the dry season but had very strong correlation with SS (1.00) in the wet season. This solidly supports the role of the dam as a sedimentation tank, especially in the dry season when there is very little amount of rainfall available. According to KKU (2003) [7], the mean rainfall in the Phong watershed in January (the dry season) is 3.86 mm compared to 227.35 mm in September (the wet season). Furthermore, the Electricity Generation Authority of Thailand (EGAT) reported that the mean annual amount of siltation in the Ubolratana dam was 1.50 million tons/year during 1965-1990. It has decreased the water storage capacity by 32.90 million m^3, which is about 1.4% of its maximum storage capacity of 2,263 million m^3 (KKU, 2003).

This study is in accordance with Johnson et al., 1997; Osborne and Wiley's 1988 studies that a season, land use and land cover had a varying impact on water quality. The different land use patterns in the upstream Phong (mainly agriculture), the middle Phong (Ubolratana Dam) and the down stream (urban and industrial areas) deteriorate the status of Phong water quality and are source of water pollution. This can be explained by the considerable increase of turbidity as a result of soil on land being flushed into a river by heavy rainfall causing a significant increase of SS and nutrients in a river. The strong positive correlations among turbidity, SS, TDS, PO_4^{3-} in the wet season and in the upstream and downstream of the Phong watershed support this claim. Sthiannopkao et al. (2006) [13] reported that soil erosion in the upstream Phong River was estimated to increase the suspended solids in the river during the 30-year simulation period. This is in accordance with Arheimer and Liden, 2000; Johnson et al., 1997; Smart et al., 1998, stated that agricultural land use strongly influenced stream water nitrogen, phosphorus and sediments. Furthermore, correlation results suggested that turbidity, SS, TDS and PO_4^{3-} were useful water quality indicators that can be predicted directly by land use impacts and seasonal changes.

5. Conclusions

This study documented the strong variations of water quality parameters resulting from variations of both dry and wet seasons. Suspended solids and nutrients were found to increase with increasing turbidity as described by positively significant correlation in the wet season. In contrast, TDS was found to increase with increasing of alkalinity and conductivity in the dry season as described also by their strong positive correlations. This study also indicated the problem of human induced soil erosion occurring in the Phong watershed and suggested for using turbidity, SS, TDS and PO_4^{3-} as indicators for monitoring impacts of soil erosion at different seasons.

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