EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 15(2) 2022 75-85
DOI 10.14456/ea.2022.35
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Relationships between Land Use Patterns and Water Quality in the Pong River Basin, Northeast Thailand

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Received: January 26, 2022; Revised: March 8, 2022; Accepted: April 2, 2022

Abstract

Land use affects stream water quality as pollutant sources, while preventing runoffs and purifying water (e.g., riparian forests and marshes). Water characteristics were measured in 15 Pong River's tributaries in summer 2021. Surrounding land uses were identified and classified into forests, farmlands, residential areas, water body and others, using field observation and panoramic photography. Water characteristics are within Thailand's water quality standard (WQS), except biochemical oxygen demand at all sites (avg. = 5.0 mg/L > the 2.0 mg/L standard) and fecal coliform bacteria at Mo tributary in Nong Bua Lamphu (avg. = 4,900 MPN/100 mL > the 4,000 MPN/100 mL standard). Major land uses include farmlands, followed by forests and residential areas, water body and other land uses (e.g., patches of *Mimosa pigra,* fish-cage aquaculture and bare ground). One-way analyses of variance show a significant difference of dissolve oxygen: DO (p-value = 0.03) among different major land use types, but only a marginal difference for nitrate (p = 0.055). Amounts of DO were significantly higher in tributaries surrounded by forests as the major land use (avg. = 10.0 mg/L, SD = 2.00).

Keywords: Land use; Water quality; Pong River Basin

1. Introduction

Land use patterns such as agriculture, residential areas, industrial plants and vegetated areas influence environmental conditions, including stream water quality (Schoonover and Lockaby, 2006; Cunha *et al.,* 2010; Bu *et al.* 2014). For example, agricultural expansion and urbanization were reported as major drivers of deforestation and biodiversity loss (Vázquez *et al.,* 2011; Jenkins and Schaap, 2018). Impervious pavements cause flash flood and runoff, leading to water pollution in rivers, lakes and estuaries (Chakravarty, 2012; Barrios, 2020). Land use patterns also affect eutrophication and water quality (Jordan *et al.,* 1997; Cunha *et al.,* 2010). A case study from Brazil reported that a river basin with large amounts of forestlands obtained better water quality with little eutrophication, while basins with high numbers of industrial plants showed great water contamination and eutrophication (Cunha *et al.,* 2010).

Forest ecosystems provide goods and services, including water purification (Ferrier *et al.,* 2001; Cunha *et al.,* 2010; Jenkins and Schaap, 2018; Camara *et al.,* 2019). Marsh lands, riparian buffers and forest meadows filtrate and absorb waste sediments before reaching rivers or lakes. Trees slow down runoff and trap debris, while plant roots sieve small particles and pollutants. Aquatic plants help remove total ammonia, nitrate and phosphorus from water (Wang *et al.,* 2017), keeping the water clean. Thus, decreases in forest areas can result in impaired water purification service (Mello *et al.,* 2018).

Pong River Basin (PRB) in northeast Thailand has experienced a great decline in forest areas. Kaewchampa (2015) recorded land use changes in the PRB during 1999-2008. Approximately, 1.22% of forests disappeared, while 0.94% of farmlands and 0.27% of residential areas increased. Pong River was also reported as one of Thailand's most polluted rivers, specifically in 1992, due to industrial and farm discharge (Mekong River Commission Secretariat, 2001). One question arose whether deteriorating water quality in the PRB was to some extent due to decreasing forest areas and water purification service. In this preliminary stage of the study, relationships between land use patterns and water quality in 15 tributaries of the Pong River were examined. Following this section includes study sites, study methods, results, discussion and conclusions.

2. Methodology

2.1 Study site

The PRB is located in northeast Thailand, consisting of 32 tributaries (Department of Water Resources, 2006a). The PRB is classified into upper and lower basins, flowing through four provinces from the watershed in Loei to Nong Bua Lamphu and Khon Kaen before merging the Chi River in Mahasarakham province (Figure 1). The PRB covers areas of approximately 15,190 km² (Department of Water Resources, 2006a). The Pong River length is about 335 km where Ubolratana Dam, the northeast's largest dam, is located. The upper basin in Loei consists of mountainous areas, steep terrains with dense vegetation in Phu Kradung Mountain. The lower basin covers slight slope topography and floodplains. Moreover, at least six industrial plants (e.g., sugar and pulp paper production) are located at a lower portion of the Pong River near the river bank (Mekong River Commission, 2001). Using Google Earth satellite imagery, 15 tributaries in the upper and lower basins with similar lengths but varying forest coverage from low to high were selected. Nine tributaries are located in the upper PRB with average length of 199 km in Loei, Nongbua Lamphu and Khon Kaen. Meanwhile, six streams are situated in the lower PRB with average length of 136 km.

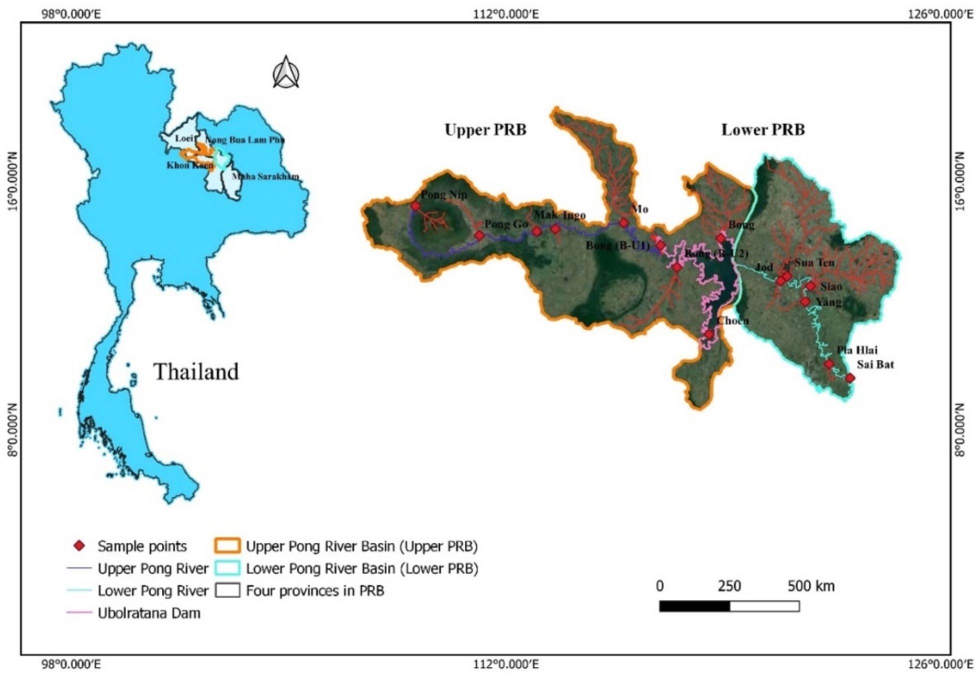

Figure 1. The study area in the PRB and sampling points in the 15 tributaries

2.2 Water sampling and measurement

One water sample from each of the 15 tributaries was collected near an outlet point up to approximately 500 m from the Pong River, and about two to five meters from a stream bank during March to April 2021 (Figure 2). A grab sampling method (Pollution Control Department: PCD, 2006) was used for water sample collection. According to Thailand's WQS (PCD, 1994; Suttibak *et al.,* 2010), eight parameters representing physical, chemical and biological properties of water were measured. On-site measurements were conducted for pH and dissolve oxygen (DO) using METTLE TELEDO IP 67 and YSI 550A probes, respectively. Biochemical oxygen demand (BOD), total solid (TS), total suspended solid (TSS), nitrate (NO_3^-), phosphate (PO_4^{3-}) and fecal coliform bacteria (FCB) were measured in laboratory. All water samples were preserved in 4 °C before laboratory tests, following the American Public Health; while TS and TSS were determined by 103-105 °C in a dry air oven. Azide modification at 20 °C with 5-day incubation was used to measure BOD. Hydrazine and vanadomolybdate methods were used to measure amounts of NO_3^- and PO_4^{3-}.

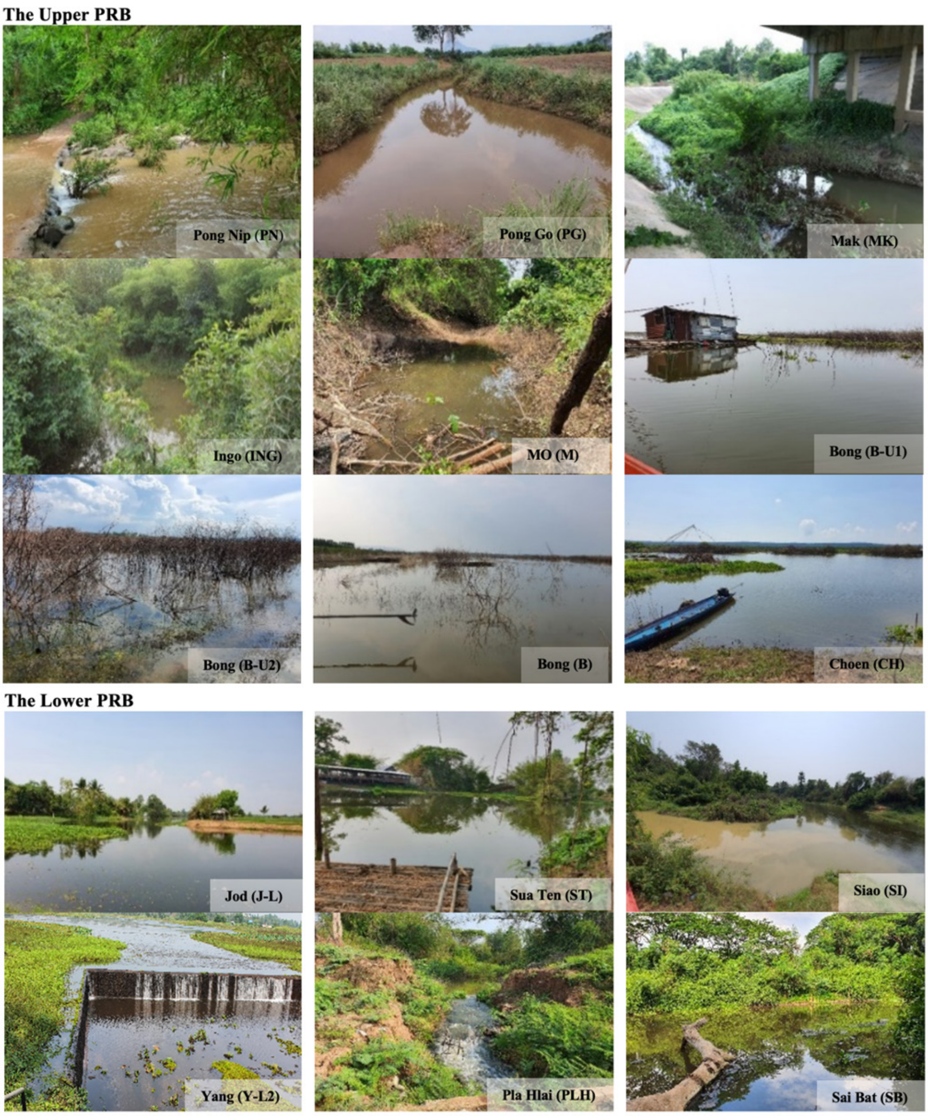

Figure 2. Surrounding environments at each of the 15 sampling points

2.3 Land use identification and classification

Land use patterns were identified by visual interpretation using topographic maps (scale 1: 50,000) and Google Earth satellite imagery, together with on-site observation and panoramic photography where images within a 180-degree angle and up to 1,000 m distance from each of the sampling points were captured (Figure 3). Types of land use, namely forests, farmlands, water body, residential zones and other areas, were classified according to the Department of Water Resources (2006a and 2006b). In this initial step, only rough quantification of land use patterns was conducted in which each land use type was proportionated (%) to the entire observed area and classified as low (0 - 40%), medium (41 - 70%) and high (71 - 100%). Vegetation types and dominant species, plantation patterns, human activities and surrounding environments were also recorded.

2.4 Statistical analysis

Descriptive statistics (i.e., mean, standard deviation and percentage) were used to describe water characteristics and surrounding land uses. All the estimated water parameters were compared against Thailand's WQS (1994). In this initial stage of the study, one-way analyses of variance (one-way ANOVA) were conducted to examine differences of water quality among different land use patterns. All the statistical tests were run using SPSS 28 from IBM License (IBM, 2021).

3. Results and Discussion

3.1 Land use patterns

Table 1 summarizes land use patterns in the study area. Farmlands are the major land use in which 11 out of 15 tributaries (n = 11) were identified having farmlands (e.g., rice paddies, sugarcane and cassava plantations) as the number one land use type that surrounds the sampling locations with average 62% of area covers in the upper PRB and approximately 43% in the lower PRB. Forests (i.e., riparian and freshwater swamp) were identified as the most important land use at two tributaries i.e., Pong Nip (~ 85% vegetative cover) and Siao (~65% vegetative cover), located in the upper and lower PRB, respectively. Similarly, residential areas are the major land use at two sampling tributaries, and both are located in the lower basin (i.e., Sua Ten and Sai Bat) with slight-slope undulating plains and close to big cities i.e., Nam Pong and the City of Khon Kaen. Figure 4a-4c depict overall surroundings in some of the sampling locations.

Water body and other land uses (e.g., patches of *Mimosa pigra*, fish-cage aquaculture, barren lands and dump sites) were accounted only small proportion at all locations. All the streams are covered by aquatic plants, especially water hyacinths (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*) and lesser duckweed (*Lemna minor*). This vegetative coverage is more evident in downstream tributaries such as

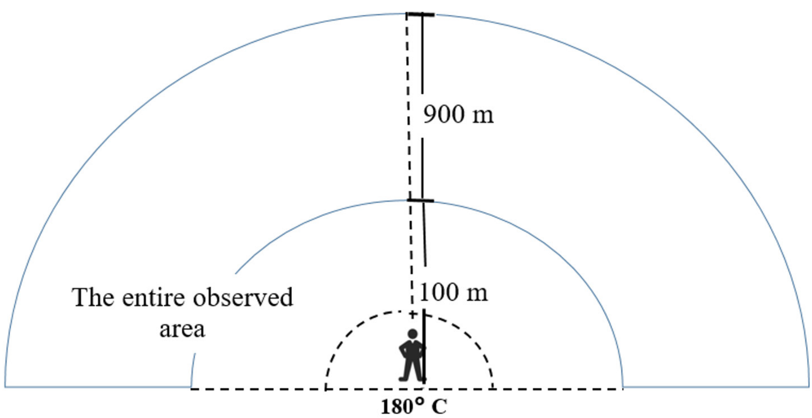

Figure 3. Panoramic photography and quantification diagram. Land use types were identified and proportionated to the entire observed area.

Jod, Yang and Sai Bat. Perhaps, this is due to small-sized weir construction (Figure 5) that alters stream flow and creates a reservoir with favorable environmental factors (e.g., still and persistent water) for those aquatic plants. All the stream banks are covered by plants both native and invasive species, including *Mimosa pigra*, *Typha angustifolia*, and bamboo. Key dominant trees and shrubs include *Samanea saman*, *Dipterocarpus alatus* and *Leucaena leucocephala*. Moreover, some land development activities such as digging and grading were presented during field data collection in Jod and Yang tributaries.

Figure 4. Examples of some panoramic photographs depicting three major land use patterns: a) vegetated areas at Pong Nip and Siao; b) agricultural lands around Pong Go, Choen and Jod; and c) residential areas – bridge, buildings and a dump site at Sue Ten and Sai Bat.

Table 1. Land use patterns at 15 tributaries in the Pong River Basin.

Point No.	Stream name	Forests (%)		Total	Farmlands (%)					Total	Residential areas (%)		Total	Water body (%)	Others (%)			Total
		RR	FS		RP	SG	CN	CS	VG		HS	R			MS	FC	W	
Upper Pong																		
1	PN	85	-	**85**	-	-	-	5	-	5	3	2	5	5	-	-	-	0
2	PG	5	-	5	-	30	25	30	-	**85**	-	5	5	5	-	-	-	0
3	MK	15	-	15	-	25	25	20	-	70	5	5	10	5	-	-	-	0
4	ING	10	-	10	-	25	25	30	-	**80**	2	3	5	5	-	-	-	0
5	M	10	-	10	20	20	20	20	-	**80**	-	5	5	5	-	-	-	0
6	B-U1	15	-	15	-	-	-	-	55	55	5	5	10	15	5	-	-	5
7	B-U2	10	-	10	-	-	-	-	55	55	5	5	10	20	5	-	-	5
8	B	5	-	5	50	-	-	-	10	60	5	5	10	20	5	-	-	5
9	CH	5	-	5	70	-	-	-	-	70	5	5	10	15	-	-	-	0
Avg % and level of coverage			**18 (L)**				**62 (M)**					**8 (L)**		**11(L)**		**2 (L)**		
Lower Pong																		
10	J-L	5	-	5	65	5	5	-	-	**75**	-	5	5	10	-	-	5	**5**
11	ST	5	-	5	20	-	-	-	5	25	50	5	**55**	10	-	5	-	**5**
12	SI	65	-	**65**	5	5	5	-	-	15	5	5	10	10	-	-	-	0
13	Y-L2	5	5	10	50	5	5	-	5	65	5	5	10	10	-	-	5	**5**
14	PLH	5	-	5	70	5	-	-	-	**75**	5	5	10	5	-	-	5	**5**
15	SB	5	-	5	-	-	-	-	-	0	75	15	**90**	5	-	-	-	0
Avg % and level of coverage			**16 (L)**				**43 (M)**					**30 (L)**		**8 (L)**		**3 (L)**		

Note: 1. Stream names: the upper PRB -- Pong Nip (PN), Pong Go (PG), Mak (MK), Ingo (ING), Mo (M), Bong (B-U1), Bong (B-U2), Bong (B) and Choen (CH) and the lower PRB -- Jod (J-L), Sua Ten (ST), Siao (SI), Yang (Y-L2), Pla Hlai (PLH) and Sai Bat (SB); **2. Level of area coverage**: Low (<40%) = L, Medium (40-70%) = M and High (>70%) = H; **3. Forests:** Riparian (RR) and Freshwater Swamp (FS); **4. Farmlands:** Rice paddy (RP), Sugarcane plantation (SG), Corn field (CN), Cassava plantation (CS) and Vegetable plots (VG); **5. Residential areas:** Household (HS) and Road & Bridge (R) and **6. Others:** *Mimosa pigra* (MS), Fish-cage aquaculture (FC) and Weir (W)

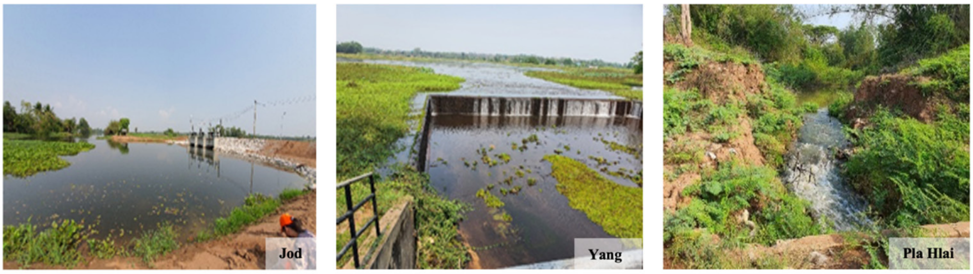

Figure 5. Small weirs and surrounding land cover and land use in the lower PRB.

3.2 Water quality characteristics

Figure 6a)-6h) depict water characteristics at all study sites. Overall, they are within Thailand's WQS (PCD, 1994), except BOD and FCB, similar to what reported by Kanchak and Pasukphun (2021) where BOD values (3.55 - 4.48 mg/L) were higher than the standard. Amounts of BOD at all sites were higher than the WQS with average 5.0 mg/L (> the 2.0 mg/L standard), especially in Mo, Bong and Sai Bat. This is possibly due to surrounding land use activities, including farming, cattle grazing, fish-cage aquaculture and household activities, that discharged wastewater and runoff with agricultural chemicals to the streams (Khatri and Tyagi, 2015). FCB was measured 4,900 MPN/100 mL at Mo tributary in Nong Bua Lamphu, higher than the WQS (4,000 MPN/100 mL). Land development activities (i.e., canal digging and pond cleanup), cattle grazing and fish-cage aquaculture were observed near the sampling site.

All tributaries reveal pH values within the WQS (pH = 5 - 9), the highest pH value was recorded in the lower PRB where the major land uses are farmlands and residential areas. All the streams with high DO are located in the upper basin. It is due to sufficient amounts of oxygen in water caused by strong flow at Pong Nip and a low water level with constant flow at Choen tributary. High amounts of TSS and NO_3^- were measured in upstream tributaries. Leaf-litter from trees and surrounding forests, animal remains are among the main sources of nitrate through decomposition processes and leaches (Lappalainen *et al.,* 2016). Meanwhile, downstream tributaries reveal higher PO_4^{3-} than streams in the upper basin. Possibly, it is due to strong water flowing through irrigation weirs, causing riverbank erosion and sediments from road construction near the sampling locations. Phosphorus mineral bonded in soil and sediment in PO_4^{3-}forms: an internal source of phosphorus, activities such as digging and streambed clean-up could trigger PO_4^{3-} leaching into the stream water (Wang *et al.,* 2017). In addition, Cunha *et al.* (2010) indicated that residential areas were positively correlated with PO_4^{3-}. Streams near roads received dust precipitation and collapsed soil. Fiquepron *et al.* (2013) reported that wetlands nearby residential areas revealed high levels of total phosphorus, five times higher than the levels measured in other land use types.

3.3 Relationships between land use and water quality in the Pong River Basin

Forest ecosystems, including woodland and riparian, influence water quality. Trees and shrubs intercept rain water, allowing infiltration and preventing runoff. Riparian and aquatic plants purify water through their root systems (Fiquepron *et al.,* 2013; Jenkins and Schaap, 2018). To examine water purification service from forest ecosystems in the PRB, in this initial stage of the study one-away ANOVA were conducted if any significant differences of water parameters occur among different land use types.

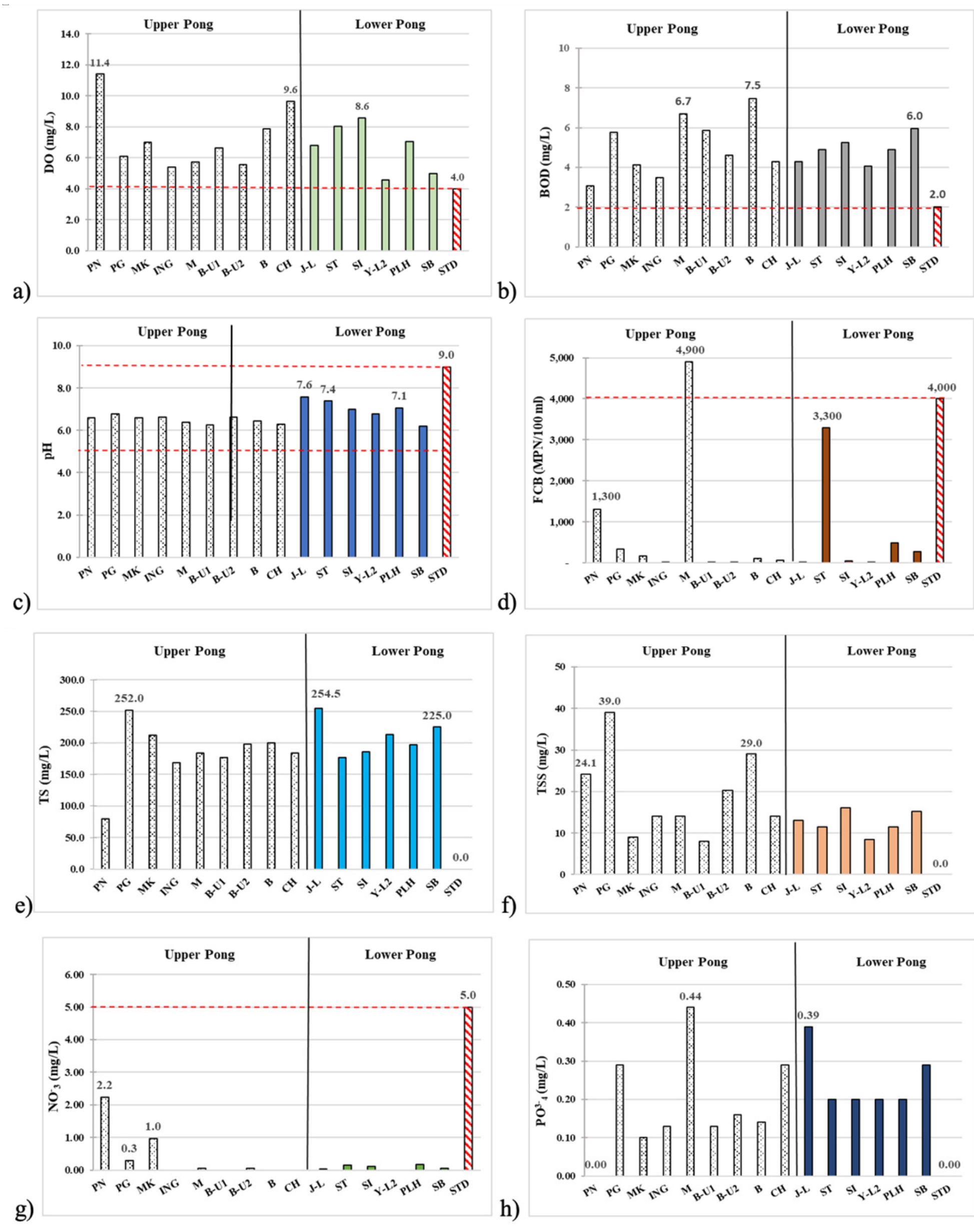

Figure 6. Water quality parameters in all 15 tributaries in summer 2021: a) DO, b) BOD, c) pH, d) FCB, e) TS, f) TSS, g) NO^-_3 and h) PO^{3-}_4. The red dash-lines present Thailand's WQS (PCD, 1994).

No statistical significances for most of the parameters were observed, except amounts of DO (p-value = 0.03). The highest level of DO (average 10.0 mg/L) was recorded in tributaries where riparian vegetation was identified as the major land use type, and was significantly higher than DO levels in tributaries adjacent to farmlands (Table 2). Presumably, it is due to mountainous terrain and riparian vegetation, allowing strong flow and sufficient oxygen diffusion from the ambient atmosphere (Correll and Weller, 1986; Nyssen and Prokofieva, 2014). A similar finding was reported in the Taizi River basin in China where amounts of vegetation and DO were positively correlated ($p < 0.01$) (Bu *et al.,* 2014). A marginal significance was observed for NO^-_3 values (p-value = 0.055). The highest amount was recorded in streams mainly surrounded by riparian forests – a key source of organic nitrogen from plant materials, manure and urine (Lappalainen *et al.,* 2016). They are mineralized to inorganic nitrogen primarily by ammonification into NH_4^+. The mineralization process is primarily carried out by heterotrophic microorganisms that prefer aerobic conditions. The NH_4^+ is then nitrified by nitrifying bacteria into NO_2^- and then quickly to NO_3^-, which is the form of inorganic nitrogen that is readily leached (Boyer and Neel, 2010). Fall leaves from riparian forests supplied the plant material resulting in high levels of NH_4^+ and then NO_3^-, but only with a marginal difference due to clumps of aquatic plants, trees and shrubs on the banks of streams surrounded by farmlands and residential areas.

High concentrations of FCB (average 1790 MPN/100 mL) were measured in streams surrounded by residential areas. *Escherichia coli,* commonly found in the gut of humans and warm-blooded animals, is the primary species, making up FCB. Boyer and Neel (2010) documented that *E. coli* concentrations were typically accounted for 95 - 100% of the measured FCB concentrations in their study. Primary sources of *E. coli* are undercooked ground meat products, raw milk, fecal contamination of vegetables and feces directly discharged into water bodies. These *E. coli* sources link to human activities in residential areas, including food hygiene, household sanitation and sewage system. Meanwhile, low concentrations of FCB were recorded in streams surrounded by farmlands and forests. Dougherty *et al.* (2009) suggested that microbiological activity associated with tree roots might have a detrimental effect on *E. coli* survival. Pathogenic bacteria are known to colonize the rhizosphere (Berg *et al.,* 2005), but *E. coli* usually dies off to a small population (Stoddard *et al.,* 1998). Vegetative buffers along surface streams might provide effective barriers to fecal bacterial contamination from farmlands where overland flow is minimized (Boyer and Neel, 2010).

4. Conclusions

This study reveals one of the forest ecosystem services – water purification in the PRB, northeast Thailand. In this initial stage, water characteristics were measured together with rough quantification of surrounding land uses at 15 tributaries of the Pong River in summer 2021. Most of the water characteristics are within Thailand's water quality standard, except BOD and FCB. The most frequently recorded major land use is farmlands, followed by forests and residential areas. A significant difference of DO among different major land use types was observed where the highest level was recorded in tributaries surrounded by riparian forests. Moreover, all the streams with high DO are located in the upper basin with larger amounts of vegetative coverage. A marginal difference was also observed for NO_3^- values where the highest amount was recorded in streams mainly surrounded by riparian forests.

Table 2. Analyses of variance of water parameters among different land uses in the PRB.

Water Quality Parameters	Forest (n=2)		Farmlands (n=11)		Residential areas (n=2)		Mean	p-value
	Mean	SD	Mean	SD	Mean	SD		
pH	6.8	0.28	**6.7**	0.38	6.8	0.85	6.7	0.90
DO (mg/L)	**10.0**[a]	2.00	6.6[b]	1.38	6.5[ab]	2.16	7.0	**0.03**
BOD (mg/L)	4.2	1.54	5.1	1.24	**5.4**	0.73	5.0	0.57
TS (mg/L)	133.0	74.95	**203.7**	28.02	201.0	33.94	194.0	0.06
TSS (mg/L)	**20.1**	5.64	16.3	9.64	13.4	2.64	16.4	0.75
NO^-_3 (mg/L)	**1.2**	1.49	0.1	0.29	0.8	0.11	0.3	**0.055**
PO^{3-}_4 (mg/L)	0.1	0.14	0.2	0.11	**0.3**	0.05	0.2	0.33
FCB (MPN/100 mL)	675	885.6	558	1448.3	**1790**	2135.5	738	0.57

Note: Letter [a] and [b] depict mean differences between land use types from the Post Hoc analysis (Tukey's test). The values with different letters indicate significant difference ($p < 0.05$), while the same letter represents insignificant differences between the mean values.

These findings suggest possible water purification service provided by forest ecosystems. Thus, forest protection and restoration in the PRB need to be prioritized for effective implementation and participation. Especially, international attentions on restoration of degraded forests have been heightened in recent decades, exemplified by the UN declaration on the Decade of Ecological Restoration (2021-2030). To deepen our findings on the water purification service from forest ecosystems, further studies to be conducted include: 1) all-year water quality measurements, 2) land cover and land use classification using QGIS to quantify amounts of forest areas and other land use types and 3) correlation analyses to determine relationships between land use patterns, especially forest areas, and water characteristics.

Acknowledgements

This research was funded by the National Science and Technology Development Agency (NSTDA), Ministry of Higher Education, Science, Research and Innovation. We greatly appreciate their financial support. We also want to thank the Integrated Water Resource Management Research and Development Center in Northeast Thailand, Khon Kaen University for useful feedback about the study design and water quality measurement. Finally, big thanks go to all the research assistants who made our field data collections productive and joyful.

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