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Preliminary assessment of selected physico-chemical properties of peat water in relation to land use conversion in the Leyte Sab-a Basin Peatland,Philippines

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ABSTRACT

Tropical peatlands are unique wetland ecosystems that provide various ecosystem services such as carbon and water storage. However, these ecosystems have been significantly altered by anthropogenic activities. In this study, the impact of land use conversion on the selected physico-chemical properties of surface water in the Leyte Sab-a Basin Peatland was investigated. Surface peat water was collected from peat swamp forest, peatland converted to grassland and peatland under cultivation. The surface peat water temperature was measured on-site and the collected water samples were analyzed for turbidity, pH, dissolved oxygen (DO), nitrate (NO_3-N), phosphate (PO_4), and total dissolved solids (TDS). It was found that the physico-chemical properties of water such as temperature, pH, and TDS were significantly higher in disturbed land use (cultivation) areas. The direct relationship between the temperature of surface peat water to both phosphate and TDS suggests that increasing temperature brought by peatland conversion may directly lead to increasing phosphate and total dissolved solids concentration in water. Strong relationships were also found between TDS and

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phosphates as well as between pH and dissolved oxygen. Finally, the increasing trend of values of the examined peat water physico-chemical properties with land use disturbance (cultivation) indicates peatland degradation.

Keywords: Grassland, peat swamp forest, pH, phosphate, tropical peatlands

INTRODUCTION

Peatland is an accumulation of 100% of pure organic material (Salimin et al 2010) and forms a distinct habitat characterized by water logging, poor nutrition levels, and low dissolved oxygen levels in acidic water (Rosli et al 2010). Due to their waterlogged and acidic condition, peatlands are the top long-term carbon reserves in the terrestrial biosphere (Alibo & Lasco 2012). Peatland does not only serve as carbon storage but also provides other benefits including water storage and resources, groundwater absorption, and flood mitigation (United Nations Development Programme 2006).

Peat swamp forests are being lost due to the conversion of these forests to agricultural lands (Koh et al 2011, Decena et al 2021). For the growing of crops, drainage canals are used to lower the water table which subsequently negatively affects peatland hydrology and hydrochemistry (Hamilton 2005, Lundin et al 2017). For example, the removal of trees and reduction of canopy cover in the peat swamp forest can result in higher peat water temperature (Rosli et al 2010). Most importantly, the conversion and drainage of peat swamp forest also results in changes to the chemical properties of the peat water particularly pH (Rosli et al 2010, Miyamoto et al 2009, Aribal & Fernando 2018). Under drained conditions, peat water pH usually increases (Ramberg 1981) as the result of organic matter decomposition and leaching of mineral soil groundwater (Lundin et al 2017). In terms of nitrogen species in peat water, it changes from being dominated by the organic fraction to inorganic nitrogen due to peat decomposition and oxidation (Lundin 1988). Likewise, disturbance and drainage of peatland results in an increase in fluvial organic carbon (Moore et al 2013).

The Leyte Sab-a Basin Peatland (LSBP) is the second largest peatland in the Philippines, but it has been deforested and drained for conversion into other land uses such as grassland and peatland with cultivation, which has resulted in a decline of peat forest cover. In 2018, out of a total area of about 3,088.00ha, the remaining unutilized peatland or peat swamp forest was only 1,288.00ha (ASEAN Peatland Forests Projects 2018). The LSBP provides various ecological services, specifically water regulation and supply, however, due to ongoing various anthropogenic activities, primarily clearing and draining of the peatland for agricultural purposes, these ecological functions are probably significantly altered. For example, the cultivation and drainage of the peatland can alter the properties of water in terms of acidity and nutrient concentrations that might have a deleterious effect on the receiving downstream aquatic ecosystems.

The impact of land use conversion on the carbon stock and physicochemical properties of the peat soil in the LSBP has already been studied (Decena et al 2022), but knowledge about the influence of conversion on the peat water quality is unknown. In addition, to the best knowledge of the authors, this is the first study evaluating the influence of land use conversion on surface water quality in peatlands in the Philippines. This study aimed to (a) determine the selected physico-chemical properties of peat water in terms of temperature, turbidity, pH, dissolved oxygen (DO), nitrate (NO_3-N), phosphate (PO_4), and total dissolved solids (TDS) across the different land use types in the LSBP; (b) compare the physico-chemical properties of peat water between land use types; and (c) evaluate the interrelationships between the physico-chemical properties of peat water using regression analysis and principal component analysis (PCA).

MATERIALS AND METHODS

Study Area

The LSBP is situated in the northeastern portion of Leyte Island covering the municipalities of Alangalang, Sta Fe, and San Miguel. It was formed by the presence of metamorphic hills where some parts of the rocks have been downthrown, resulting in a graben that has now become the LSBP (ADB 2000). The previously known area of the peatland was 3,088.00ha (ASEAN Peatland Forests Projects 2018), but recent estimates suggest that the peatland now has an area of about 2,108ha (Garcia et al 2021). The peatland appears to be a minerotrophic tropical peatland having the second most significant peat soil deposit in the Philippines, second to the Caimpugan peat swamp forest within the Agusan marsh in Mindanao (Figure 1). Based on observations, the peat in the LSBP is typically woody and herbaceous peat. The maximum peat depth exceeds 10m, especially in the peat swamp forest areas (Decena et al 2021), however, the overall average depth of the peatland is only about 2.71m (Baldesco et al 2021).

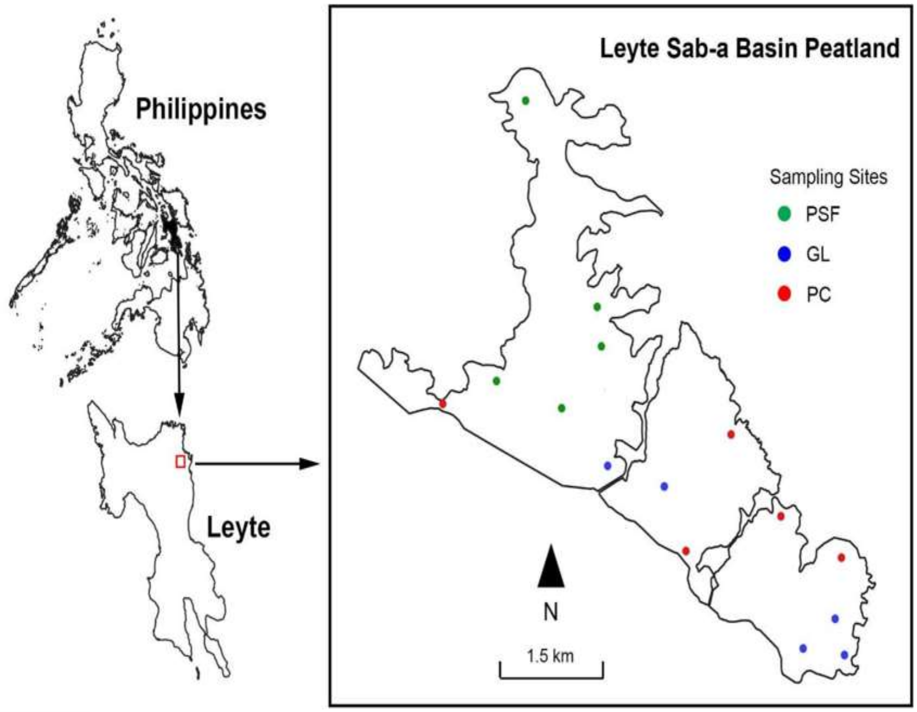

Figure 1. Map of the Leyte Sab-a Basin Peatland (LSBP) and locations of sampling stations in Northeastern Leyte, Philippines (adapted from Decena et al 2021). PSF–peat swamp forest, GL–grassland, PC–cultivation

On the eastern border, ultramafic outcrops known as the Tacloban Ophiolite Complex (TOC) surround the LSBP. The alluvial deposits derived from ultramafic rocks and sedimentary sequences compose the underlying sediments of the peatland (Suerte et al 2005).One of the primary sources of water that feed the peatland is surface runoff, since the peatland is formed in a depression and is bordered by metamorphic hills, surface runoff from the surrounding hills and uplands tend to collect in the peatland. Moreover, there are two major river systems, namely the Bangon and Mainit Rivers which are significant sources as well as outlets of water from the peatland. Tributaries from these river systems traverse the middle or along the edges of the peatland where water is observed to flow or overflow towards it during rainy periods and flow in the reverse direction during periods of low precipitation.

During the 1970s, the Philippine government initiated a project funded by the National Food Authority and the Philippine Coconut Authority to drain the LSBP for agricultural development along with provisions for land ownership. The project involved the clearing of the original peat swamp forest and the construction of canals and an artificial water outlet for drainage purposes. However, poor yield in these areas caused its abandonment, and now extensive sedges and grasses dominated the peatland ecosystem. These activities have resulted in a significant reduction of forest cover and probably the degradation of the peatland. The remaining unutilized peatland of 1,288.00ha in the northern part of the basin consists of small remnant areas of swamp forest (ASEAN Peatland Forests Projects 2018).

The climate in the LSBP area is characterized as equatorial rainforest, fully humid (Kottek et al 2006).The study area has no dry season and has more or less evenly distributed rainfall throughout the year.The warmest month is April with a mean annual temperature of 27°C and pronounced wetness occurring in the months of November, December, and January with annual total precipitation of 2293mm (Quiñones & Asio 2015, Marteleira 2019).

Study Sites

Peat Swamp Forest

The remaining forested portions of the peatland are in the northern part, which represents the primary peat swamp forest (Figure 2A). Although peat swamp forest areas had no history of clear-cutting and draining, these have already been subjected to some minor disturbances for activities such as the collection of wood for construction and fuel, fishing, and wildlife poaching. It is characterized by the presence of medium-sized trees with an average height of 6m, often covered by very thick vines, and dominated by the tree species *Ilex cymosa* Hassk. Whereas the understorey layer is usually dominated by the sedge species *Mapania sumatrana* (Miq.) Benth. and *Scleria scrobiculata* Nees and Meyen, including a climbing fern species *Stenochlaena palustris* (NL Burm.) Bedd. In addition, these areas still harbor some important wildlife species such as wild pigs and species of giant fruit bat.

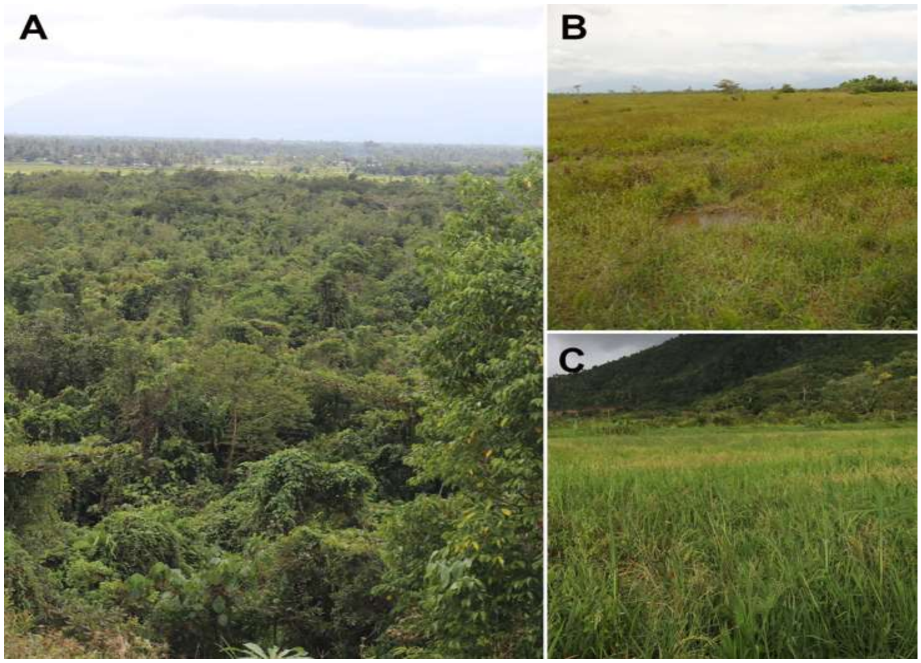

Figure 2. The land use types sampled in LSBP. A) Peat swamp forest, B) Grassland, and C) Cultivation

Grassland

The extensive grasslands in the LSBP are actually abandoned croplands (Figure 2B) and are now dominated by sedges such as *S. scrobiculata* and *Fimbristylis globulosa* (Retz.) Kunth. With occasional trees of the species *Nauclea orientalis* (L.). These areas were previously cleared and drained for rice production and other agricultural crops but abandoned later due to poor yield. Previously, there were large and small canals that could still be observed, however, these are already covered with vegetation, which probably stopped the process of draining.These grasslands are subjected to fire disturbance, with the vegetation being burned during the drier periods of the year. Compacted peat soils can be observed, indicating decomposition and mineralization.

Cultivation

Peatlands with cultivation considered in this study were predominantly productive rice fields located along the edges of the peatland (Figure 2C).These rice field areas are cultivated at least once a year and receive fertilization such as nitrogen, phosphorus, and potassium. In some instances, remnants of logged or cut trees could still be observed. These are characterized by the presence of canals ranging from 1.30 to 1.70m wide and 0.25 to 0.80m deep, which were constructed to lower the water table and for irrigation purposes. These rice field areas tend to be maintained with sufficient water for most of the year.

Site Establishment and Water Sampling

Reconnaissance surveys were conducted first to identify sampling stations before collecting the water samples. A total of 15 different sampling locations were randomly selected, with 5 locations from each land use type (peat swamp forest, grassland, and cultivation).The sampling stations were separated by a distance of at least 500m to ensure sampling independence. The geographic location of each sampling station was determined using a handheld GPS (Model etrex).

At each sampling location in the different land use types, 3.79L (1 gallon) of surface peat water in the acrotelm layer was collected by the grab sampling method. Water samples were collected gently and carefully to avoid disturbing the substrate which might unnecessarily alter the properties of the peat water. A maximum of 2 samples were collected in a day following the protocols for sampling surface waters by Musselman (2012). Water samples were placed in an ice box and transported to the laboratory (Water Laboratory, University of San Carlos, Cebu) within 24h for further analysis. All the sampling campaigns were done in April 2021.
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Peat Water Analyses

The temperature of the water was measured *in situ* using a glass thermometer. The measurements for temperature were performed thrice at each sampling location with a couple of minutes intervals between each measurement. In each sampling campaign, a maximum only of two sampling locations could be measured for temperature due to the considerable distance between locations and the difficulty in walking/trekking, but the measurements took place between 9:30AM and 3:00PM. The sampling and temperature measurements in all locations were carried out in sunny weather conditions.

Peat water samples were analyzed for all other selected physical and chemical properties in the laboratory. The water samples were analyzed for turbidity (nephelometric method), pH (potentiometric method), dissolved oxygen (DO) (Wrinkler method), nitrate (NO_3-N) (Brucine treatment and colorimetric method), phosphate (PO_4) (ascorbic acid and colorimetric method), and total dissolved solids (gravimetric method). Testing of water samples followed the APHA, AWWA, and WEF Standard Methods for the Examination of Water and Wastewater, 22nd ed., USA (American Public Health Association 2012).

Data Analyses

All the data were tested for normality using the Kolmogorov-Smirnov test.The difference in peat water physico-chemical properties (temperature, turbidity, pH, DO, NO_3-N, PO_4, and TDS) between land use types (peat swamp forest, grassland, and cultivation) was analyzed using one-way ANOVA.Tukey's post-hoc tests were performed whenever there were significant variations at $p \leq 0.05$.The relationships among peat water physico-chemical properties across the different land use types were examined using regression analyses.Principal Component Analysis (PCA) was also applied, to further evaluate the relationships between peat water properties and land use types.PCA was performed with Z-score transformed data (Z score = $(X_i - X_{avg})/X_{std}$; where X_i is a given value of a variable in a sample, X_{avg} is the average of that variable and X_{std} is its standard deviation).Analyses such as one-way ANOVA and regression were carried out in SPSS version 20.0 for Windows, and the PCA was performed using PAST 3.22 (Hammer et al 2001).

RESULTS AND DISCUSSION

Changes in Peat Water Physico-chemical Properties

Water temperature differed significantly between land use types with the highest reading in peatlands with cultivation (30.54±1.23°C), and the lowest in peat swamp forest areas (25.76±0.25°C) (Table 1, Figure 3A).The recorded water temperature in the cultivated peatland in the study area was comparable to the temperature range (27.69–30.07°C) for peat water in small rivers and irrigation canals in peat swamp forests converted to oil palm plantations in Sarawak, Malaysia (Rosli et al 2010). In addition, the increasing trend in peat water temperature from less disturbed (peat swamp forest) to disturbed land use (cultivation) in this study area was also observed in Brunei from intact peat swamp forest to burnt peatland (Lupascu et al 2020).Anthropogenic activities such as logging and agriculture, along with the drainage of peat swamp forests have negative implications on hydro-chemistry (Hamilton 2005) such as water temperature. The presence of forests plays a role in maintaining the surface temperatures, therefore the removal of trees and reduction/loss of canopy cover results in higher peat water temperature (Rosli et al 2010).

The same pattern was observed for peat water pH with a significantly higher value in cultivation (7.06±0.27) and lower in peat swamp forest (6.26±0.17) (Table 1, Figure 3C). The recorded pH in the LSBP for all three land use types was higher than the reported values by other authors for water pH in oil palm and sago plantations (3.68–4.00) (Rosli et al 2010, Miyamoto et al 2009) and peat swamp forests (3.60–4.56) (Aribal & Fernando 2018, Page et al 1999). Decena et al (2021) reported that water pH in the same study area was found to be higher than the surface peat soil (5.51–5.63). The same observation was made by Page et al (1999) in peat swamp forests in Kalimantan, Indonesia. The relatively high surface water pH in the peat swamp forest can be possibly caused by the presence of human activities in the adjacent landscape. For example, deforestation, cultivation, and weathering can enhance inputs of other substances (eg, carbonate minerals) through surface or subsurface runoff that counteracts pH limitations (Klemme et al 2022). The increasing trend in changes in water pH from pristine to disturbed land uses indicates peatland degradation (Lupascu et al 2020, Anshari et al 2010). For example, the cultivation and drainage, fertilizer application, and burning of peat in the study area could increase pH, which is consistent with the previous findings of Frank et al (2014) and Lupascu et al (2020). Specifically, the latter disturbances and activities result in the decomposition of organic matter that, in turn, decreases protons in the leachate leading to a rise in pH (Ramberg 1981, Lundin et al 2017). Also, an increase in water pH in coastal peat swamp forests has been associated with the inflow of seawater during high tide (Miyamoto et al 2009). In addition, with respect to agricultural production, the relatively lower water pH compared to mineral soils may explain the lower productivity of rice fields in the area.

Table 1. Results of the one-way ANOVA on the physico-chemical properties of peat water in the Leyte Sab-a Basin Peatland

Variable	df	SumSqs	MeanSqs	F	*p*
Temperature					
Land use	2	57.68	28.84	7.08	0.009
Residuals	12	48.86	4.07		
Turbidity					
Land use	2	103300.45	51650.22	3.27	0.074
Residuals	12	189736.74	15811.40		
pH					
Land use	2	1.86	0.93	4.74	0.030
Residuals	12	2.36	0.20		
DO					
Land use	2	17.86	8.93	1.00	0.398
Residuals	12	107.73	8.98		
NO_3-N					
Land use	2	0.29	0.14	0.12	0.888
Residuals	12	14.31	1.19		
PO_4					
Land use	2	0.06	0.03	3.79	0.053
Residuals	12	0.10	0.01		
TDS					
Land use	2	35827.60	17913.80	9.80	0.003
Residuals	12	21932.00	1827.67		

Total dissolved solids refer to any salts, minerals, metals, cations, or anions and small amounts of organic matter that are dissolved in water (Corwin & Yemoto 2017, Irvine et al 2013). In the study area, land use conversion also resulted in changes in total dissolved solids which were higher in the cultivation area (200.00±30.74mg L^{-1}) than in the peat swamp forest (104.60±9.43mg L^{-1}) and grassland (90.00±7.91mg L^{-1}) (Table 1, Figure 3G). The total dissolved solids recorded in the peat swamp forest of the LSBP was lower than the average total dissolved solids (143–246mg L^{-1}) in the peat swamp forest of Caimpugan Peatland, Mindanao, Philippines (Aribal & Fernando 2018). Basically, the increase in total dissolved solids in peat water in the cultivation areas of the peatland can be attributed to agricultural and irrigation activities (Chen & He 2003). However, peat water normally has quite high total dissolved solids such as heavy metals (eg, Fe and Mn), which is indicated by the red and brown color of peat water (Rusdianasari et al 2018).

On the other hand, the rest of the parameters such as turbidity, dissolved oxygen, nitrate, and phosphate did not differ significantly between the different land use types (Table 1, Figure 3B and D-E). The recorded average turbidity of the surface water in the study area ranged from 67.26±39.91 to 250.42±46.56 NTU, which were very high compared to the turbidity of peat water in small river and irrigation canals (1.27–5.33 NTU) reported by Rosli et al (2010). The higher levels of turbidity act as an important indicator of organic pollution, and the run-off of suspended material and heavy rainfall (Yisa & Jimoh 2010).

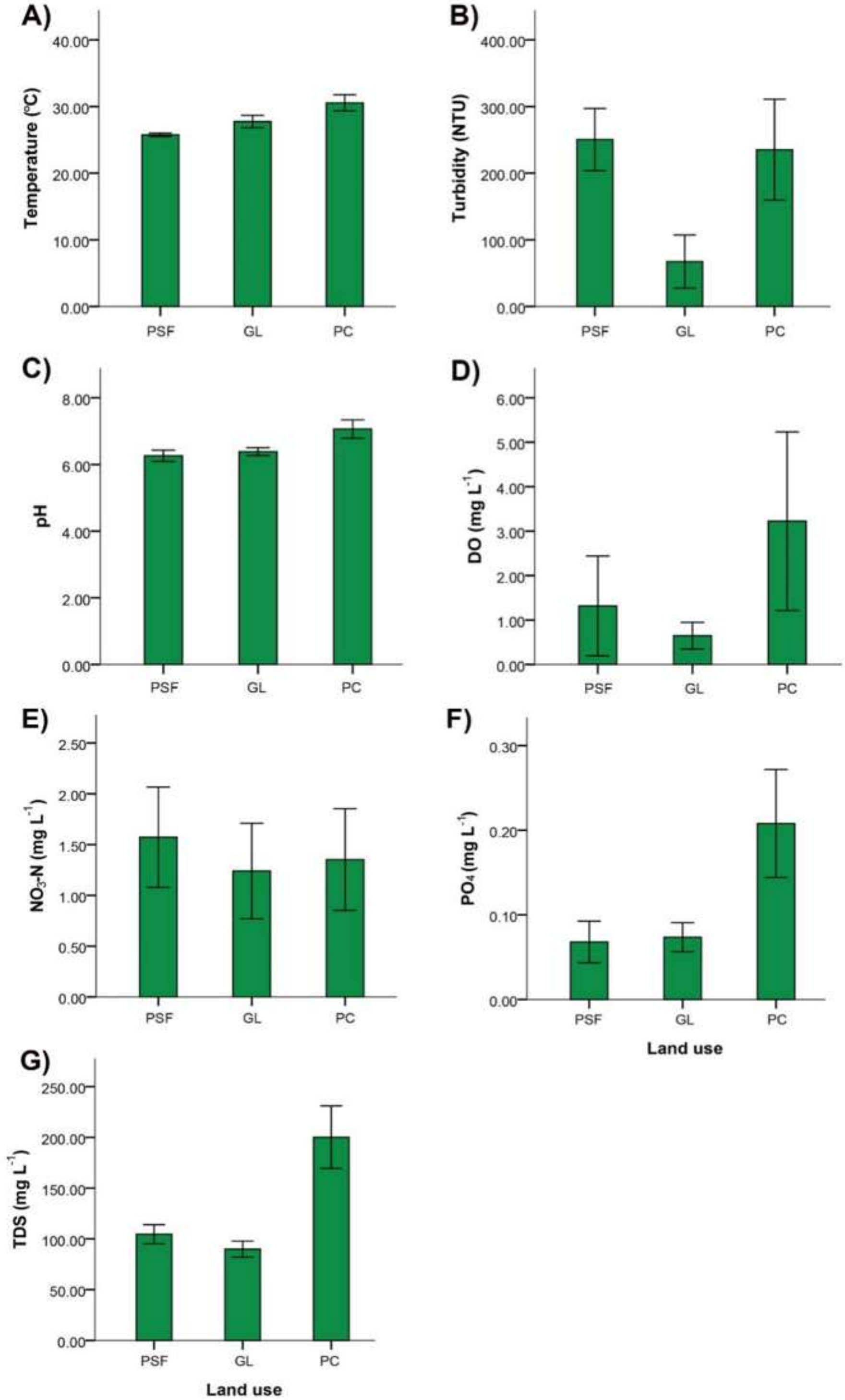

Figure 3. The difference in A) temperature, B) turbidity, C) pH, D) dissolved oxygen (DO), E) nitrate (NO_3-N), F) phosphate (PO_4), and G) total dissolved solids (TDS). PSF–peat swamp forest, GL–grassland, PC–cultivation

The overall average dissolved oxygen of surface peat water in the peatland (1.73±0.77mg L^{-1}) was higher than the reported value by Irvine et al (2013) in peat swamp forests (0.31mg L^{-1}) but lower than with one recorded by Rosli et al (2010) in peat waters around oil palm plantation areas (3.02–4.34 L^{-1}). Though no significant variation was detected for dissolved oxygen, Irvine et al (2013) reported an increasing pattern of dissolved oxygen from peat swamp forests through the agricultural areas. For aquatic life, the dissolved oxygen levels in water should be high enough (>5mg L^{-1}) to ensure survival (Rosli et al 2010). Lastly, nitrate and phosphates in the study area were higher in the peat swamp forests and cultivation with a value of 1.57±0.49 and 0.21±0.06mg L^{-1}, respectively. These measured values, compared to values recorded in the surface waters of peat swamp forests in Caimpugan peatland, Mindanao, were comparable for nitrate, recorded at (1.07–2.23mg L^{-1}), but very low compared to the phosphate level (9.32–15.57mg L^{-1}) (Aribal & Fernando 2018). Frank et al (2014) noted that the long-term drainage of peatland can increase the concentration of nutrients such as nitrate in peat water which indicates peatland degradation. In addition, the excess of these nutrients/ions in aquatic ecosystems results in the overgrowth of water plants leading to the formation of algal blooms, eventually resulting in the lowering of dissolved oxygen in the water (Isiuku & Enyoh 2020).

Interrelationships Between Peat Water Properties and Land Use

The regression analysis showed a direct relationship between the temperature of surface peat water to both phosphate and total dissolved solids (Figure 4A & B). Temperature is very important as it largely influences water chemistry. For example, the higher water temperature can result in more minerals or ions such as phosphates being dissolved in water from the surrounding sediments thereby increasing their concentrations in water (Shoukat et al 2020). In addition, Li et al (2013) and Koerselman et al (1993) have shown that phosphorus or phosphate released in water or at the water and sediment interface is enhanced by higher temperatures.

In the peatland, phosphorus or phosphate availability to plants is limited, however, increase in surface water temperature, coupled with drainage resulting in organic matter decomposition may increase these ions (Frank et al 2014). A strong relationship was also found between total dissolved solids and phosphates (Figure 4C), and between pH and dissolved oxygen (Figure 4D). In contrast to the results of the present study, Irvine et al (2013) found an inverse association between water pH and dissolved oxygen in peat swamp forests. Nevertheless, Boto and Bunt (1981) demonstrated a high positive correlation between pH and dissolved oxygen in wetland waters, which is likely influenced by the presence of dissolved organic matter. In this study, pH and dissolved oxygen both increased in the disturbed land use (cultivation), where disturbance is associated with peat destabilization and more dissolved organic matter or carbon in peat water (Moore et al 2013).

Further, PCA was applied to explore the associations between surface peat water physico-chemical properties and land use. The relationships between peat water physico-chemical properties and land use are shown in the PCA biplot (Figure 5) with two principal components explaining 71.43% of the total variance. The first principal component accounted for 44.95% of the total variance with higher positive loadings for temperature (0.47), turbidity (0.43), phosphate (0.51), and total dissolved solids (0.53). In addition, the second principal component accounted for 26.48% of the total variance with positive loadings for pH (0.68), dissolved oxygen (0.70), and nitrate (0.14). The high positive loadings for all the peat water physico-chemical properties except for nitrate indicated strong associations with and increases towards peatlands with cultivation. Specifically, again, the elevated peat water temperature in the peatlands with cultivation is the direct result of the removal of forest vegetation and canopy cover (Rosli et al 2010). Agricultural activities in the peatland could increase dissolved solids (eg, metals, ions, organic materials) and suspended materials (eg, silt and fine organic materials) which result in increased total dissolved solids and turbidity, respectively (Pullanikkatil et al 2015, Corwin & Yemoto 2017). Likewise, a higher concentration of nutrients specifically phosphate in the cultivated peatland can be associated with the application of fertilizers (Khan et al 2018). Moreover, the notable increase of peat water pH with cultivation land use can be the result of organic matter release and decomposition (Lundin et al 2017). Finally, such a pattern of changing peat water properties with disturbed land use indicates peatland degradation.

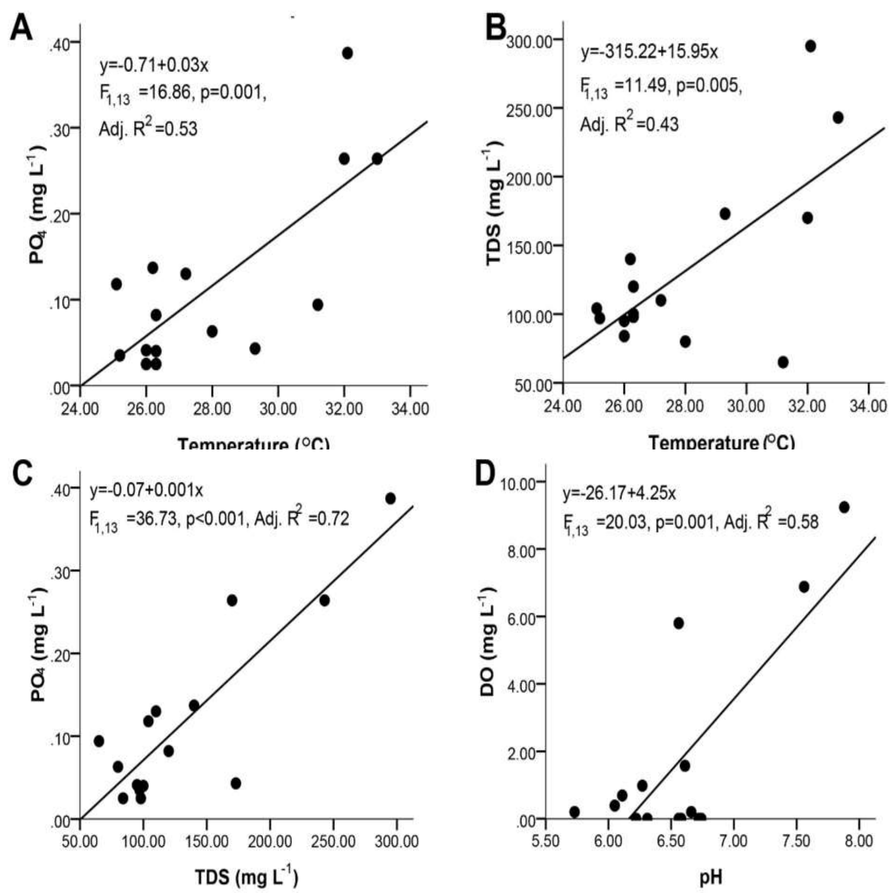

Figure 4. The relationships between A) temperature and phosphate (PO_4), B) temperature and total dissolved solids (TDS), C) total dissolved solids and phosphate (PO_4), and D) pH and dissolved oxygen. The significant regression lines and their equations, R^2, F and p-values are presented

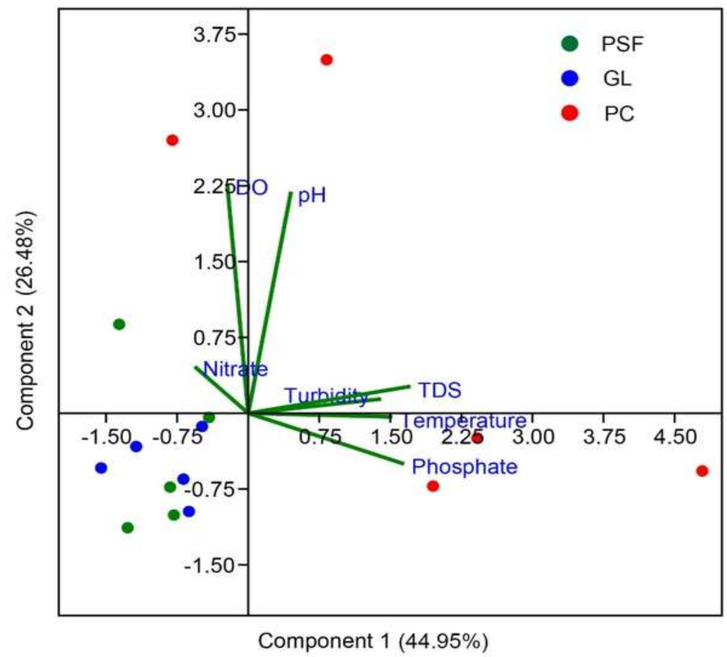

Figure 5. Principal Component Analysis (PCA) biplot showing the relationships between surface peat water physico-chemical properties and land use classes. PSF–peat swamp forest, GL–grassland, PC–cultivation, DO–dissolved oxygen, TDS–total dissolved solids

CONCLUSION

Tropical peatlands play a very important role in the hydrological cycle.The present study provided a glimpse into the effect of the conversion of pristine peat swamp forests into other land uses such as cultivation, which resulted in the alteration of some physico-chemical properties of the surface peat water. It was found that peat water properties such as temperature, pH, and total dissolved solids were higher in the cultivated peatland.The elevated surface temperature is associated with increasing concentrations of phosphates and total dissolved solids, and similarly, the increase in pH is associated with increasing dissolved oxygen, all of which signal peat water characteristics deterioration.Finally, the increasing trend of the physico-chemical properties of the examined surface peat water with land use disturbance (cultivation) indicates peatland degradation.

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AUTHOR CONTRIBUTIONS

All the authors contributed significantly to the development of the manuscript. SSS, SCPD, and MSA designed the study. All the authors (SSS, SCPD, MSA, AOA, LLR) performed the field data collection and analyses. SSS, SCPD, and AOA prepared the initial draft of the manuscript, and all authors commented on previous versions. All authors read and approved the final manuscript.

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AVAILABILITY OF DATA AND MATERIALS

The raw data associated with this study is available from the corresponding author upon reasonable request.

ETHICAL CONSIDERATION

Ethics approval is not applicable.

COMPETING INTEREST

There are no competing interests to disclose.

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