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Spatial Variation of Stream Water Quality within Upper Bilu Catchment, Inle Lake, Myanmar

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List of Abbreviations

EC	Electrical Conductivity
F^-	Fluoride (F^-) ion
Cl^-	Chloride (Cl^-) ion
NO_2^-	Nitrite (NO_2^-) ion
Br^-	Bromide (Br^-) ion
NO_3^-	Nitrate (NO_3^-) ion
PO_4^{3-}	Phosphate (PO_4^{3-}) ion
SO_4^{2-}	Sulphate (SO_4^{2-}) ion
Li^+	Lithium (Li^+) ion
Na^+	Sodium (Na^+) ion
K^+	Potassium (K^+) ion
Mg^{2+}	Magnesium (Mg^{2+}) ion
Ca^{2+}	Calcium (Ca^{2+}) ion
NH_4^+	Ammonium ion
HCO_3^-	Bicarbonate (HCO_3^-) ion
CO_3^{2-}	Carbonate (CO_3^{2-}) ion
TN	Total Nitrogen
NPOC	Total Organic Carbon
LULC	Land Use and Land Cover
mmol L^{-1}	Milli Mole per Liter
mg L^{-1}	Milligram per Liter
UBLU	Upper Bilu

Spatial Variation of Stream Water Quality within Upper Bilu Catchment, Inle Lake, Myanmar

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Abstract

The degradation in physical and chemical water quality due to human activities is mostly slow and gradual. Subtle adaptations by the aquatic ecosystems to such degradation cannot readily be detected. Temporal and spatial variation of water chemistry, and relationship with land use were investigated within the catchment of Upper Bilu stream, one of the four major streams flowing into Inle Lake. Stream water samples were collected two times during wet (September) and dry seasons (February). Physicochemical properties of stream water (pH, Electrical Conductivity, Total Nitrogen, Total Organic Carbon, dissolved ions (F^-, Cl^-, NO_2^-, Br^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+})) were measured at Kyoto University. SRTM-DEM and Sentinel 2A data for 2019 were used to delineate sub-catchment boundaries and to generate land use map of the study area, respectively. There was a significant higher concentration of water quality parameters during the dry season compared to wet season except pH. Four clusters of similar water chemistry could be identified across the study area. The cluster with the highest concentration of EC, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, and TN was found in sub-catchments with average highest proportion of settlement and cropland. The lowest concentration was found in water samples from steep slope and high elevation areas where most of the land is dominated by forests. Most of the samples which were spatially closer to Inle lake exhibited significant high concentration of Cl^-, NO_3^-, and TN and these high concentrations of nutrients might be transported into the lake. A positive relationship between land uses including settlement, cropland and grassland and water quality parameters was found during the study. In contrast, negative association existed between water chemistry and forested areas within the catchment.

Keywords: Water chemistry; Spatial; Land use; Catchment

အင်းလေးကန်၊ အထက်ဘီလူးချောင်းရေဝေရေလဲ ဒေသအတွင်းချောင်းရေ၏ အရည်အသွေးများ နေရာအလိုက်ပြောင်းလဲမှုကို လေ့လာခြင်း

နွေးနွေးအောင်၊ တောအုပ်ကြီး
သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်း

ရေအရင်းအမြစ်များ၏ ဓာတုရူပဆိုင်ရာ အရည်အသွေးများ ယုတ်လျော့လာမှုဖြစ်စဉ်သည် အများအားဖြင့် တဖြည်းဖြည်းချင်း ဖြစ်ပေါ်လေ့ရှိသည်။ ယင်းယုတ်လျော့မှုများအား ရေနေဂေဟစနစ်မှ တုန့်ပြန်မှုများသည်လည်း အလွန်သိမ်မွေ့ပြီး ဂေဟစနစ်အတွင်း သိသာထင်ရှားသည့် ပြောင်းလဲမှုတစ်ခု မဖြစ်မချင်း အလွယ်တကူ မတွေ့ရှိနိုင်ပါ။ ရာသီအလိုက်နှင့် နေရာအလိုက် ရေ၏ဓာတုရူပဆိုင်ရာ ဂုဏ်သတ္တိများ ပြောင်းလဲမှုနှင့် မြေအသုံးချမှု အခြေအနေများအကြား ဆက်စပ်မှုကို အင်းလေးကန်အတွင်း အဓိက စီးဝင်လျက်ရှိသော ချောင်း (၄) ခု အတွင်းမှတစ်ခုဖြစ် သော အထက်ဘီလူးချောင်းရေဝေရေလဲဒေသအတွင်း ဆောင်ရွက်ခဲ့ပါသည်။ ရေနမူနာများကို စိုစွတ်သည့်ရာသီ (စက်တင်ဘာလ)နှင့် ခြောက်သွေ့ရာသီ (ဖေဖော်ဝါရီလ) နှစ်ကြိမ်ကောက်ယူခဲ့ပါသည်။ ရေ၏ဓာတုရူပဆိုင်ရာ ဂုဏ်သတ္တိများ (pH, Electrical Conductivity, Total Nitrogen, Total Organic Carbon, dissolved ions (F^-, Cl^-, NO_2^-, Br^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}) ကိုလည်း ကျိုတိုတက္ကသိုလ်တွင် တိုင်းတာခဲ့ပါသည်။ SRTM-DEM နှင့် ၂၀၁၉ ခုနှစ်အတွက် Sentinel 2A data များကို sub-catchment နယ်နိမိတ်များနှင့် မြေအသုံးချမှု အမျိုး အစား ခွဲနိုင်ရန်အတွက် အသုံးပြုခဲ့ပါသည်။ အထက်ဘီလူး ချောင်းရေအတွင်း pH တန်ဖိုးမှအပ အခြားဂုဏ်သတ္တိများသည် ခြောက်သွေ့ ရာသီတွင် ပါဝင်နှုန်း ပိုများသည်ကို တွေ့ရှိရပါသည်။ ရေနမူနာများအားလုံးကို ဂုဏ်သတ္တိ တူညီသည့် အုပ်စု (၄) ခု အဖြစ် ဖွဲ့စည်းနိုင်ကြောင်း တွေ့ရှိခဲ့ ရပါသည်။ EC, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+} နှင့် TN တန်ဖိုးအများဆုံးနမူနာများကို ပျမ်းမျှမြို့ပြနှင့် စိုက်ပျိုးရေယာ အများဆုံး sub-catchment များတွင် တွေ့ရှိရပါသည်။ တန်ဖိုး အနည်းဆုံး နမူနာများမှာ သစ်ပင်ဖုံးလွှမ်းလျှက်ရှိသော မြင့်မားသော ပျမ်းမျှမတ်စောက်မှု ပမာဏ အများဆုံးနေရာများ တွင်တွေ့ရှိရပါသည်။ အင်းလေးကန်နှင့် အနီးစပ်ဆုံးနေရာများရှိရေနမူနာ များတွင် Cl^-, NO_3^- နှင့် TN တန်ဖိုးများ သိသိသာသာများနေသောကြောင့် ကန်အတွင်း ရောက်ရှိနိုင်သည့် အလားအလာများ တွေ့ရှိရပါသည်။ အထက်ဘီလူးချောင်း ရေဝေရေလဲ ဒေသ

အတွင်းရေ၏ ဓာတုဂုဏ်သတ္တိဆိုင်ရာညွှန်းကိန်းများနှင့် မြို့ပြလူနေအိမ်များ၊စိုက်ပျိုး မြေများ နှင့် မြက်ခင်း ပြင်ကြီးများသည့် အပေါင်းလက္ခဏာဆောင်သည့် ဆက်စပ်မှုများ တွေ့ရှိ ရပြီး သစ်တော ဖုံးလွှမ်းမြေများနှင့်မှု အနုတ်လက္ခဏာဆောင်သည့် ဆက်စပ်မှုကို တွေ့ရှိရပါ သည်။

Spatial Variation of Stream Water Quality within Upper Bilu Catchment, Inle Lake, Myanmar

1. Introduction

Less than 0.3% of the world's fresh water is contained in rivers, lakes and the atmosphere and it is estimated that around 70% of fresh water is used in agriculture. Increasing world population demanded high-quality water more for domestic purposes and economic activities in the face of climate change which resulted in unpredictable rainfall patterns. Water quality is a function of natural influences and human activities either severally or collectively. The degradation in physical and chemical water quality due to human activities is mostly slow and gradual. Moreover, subtle adaptations by the aquatic ecosystems to such degradation are not readily detected unless a notable shift takes place in the ecosystem (Khatri and Tyagi 2015).

Unsustainable land use and improper tillage and soil management in agriculture are increasing erosion and sediment runoff into rivers, lakes and reservoirs and global rate of erosion in croplands is estimated at 10.5 megagrams (Mg) per ha per year, which corresponds to 193 kilograms of soil organic carbon per ha per year. Overgrazing in pasturelands, inappropriate ploughing on steep slopes, deforestation, land clearing and the degradation of riverine vegetation can accelerate erosion and sedimentation into water courses (FAO & IWMI 2017).

In most high-income countries and many emerging economies, agricultural pollution is a major concern in the degradation of inland and coastal waters (e.g. eutrophication) while in low-income countries, the large loads of untreated municipal and industrial wastewater are major concerns followed by agricultural pollution through increased sediment runoff and groundwater salinization (FAO & IWMI 2017).

Inle lake which is a major tourist attraction site in Myanmar is now facing the problem of eutrophication as a result of population pressure, floating agriculture, increase in hotel accommodation, and local businesses inside the lake which has been aggravated by sedimentation due to deforestation in the upland watershed areas. Most silt loads come from four main inlet streams namely Nam let (Nant Latt) Chaung, Negya (Ye Pae) Chaung, Kalaw (Ka Law) Chaung, and Upper Bilu (Indain, Nam Bilu) Chaung (NIVA 2017). Sedimentation from upland catchments indicated that an improper land management, carelessness of the environment, and water quality deterioration is also happening in these areas.

The drastic need in restoration of Inle lake and its watershed areas has been recognized and a watershed approach for conservation and sustainable development of the lake and its watershed areas by dividing sub-watersheds of each stream which will be further divided into "Micro-Watersheds" based on the catchment areas of their feeder streams is suggested through Inle lake Long Term Restoration & Conservation Plan (MOECAF 2014). Basic information regarding water quality of inflowing streams and land use situation for each micro-watershed is important in order to achieve those management goals.

Several studies focused on the water quality inside Inle lake which needs to be managed through monitoring and water treatment especially for agricultural activities and sewage from the residents (Akaishi et al. 2006). Water quality of major inflowing streams into the lake is rarely known despite its importance not only for the livelihood of local communities within the watershed but for its contribution to the sustainability of the lake itself.

Extension of agriculture area occurred in the whole watershed area especially in western and northwestern part of the lake as paddy being the main crop and different kinds of cash crops (Himiyama 2018). Agricultural activities within Upper Bilu sub-watershed depended mainly on rainfall during the wet season and stream water during the dry season according to Agriculture Department, Pinlaung Township. Upper Bilu stream is also an important source for domestic water use to all the local ethnic communities across the catchment apart from agricultural activities. Understanding the current water quality situation and how it changed throughout the watershed can contribute to management activities for the sustainability of not only the stream itself but also Inle lake. The objectives of this study are

- to assess overall ionic composition of stream and lake water
- to analyze temporal and spatial variation of stream water quality, current land use conditions within Upper Bilu catchment of Inle Lake, Myanmar
- to identify the relationship between current physicochemical stream water quality and land use.

2. Description of study area

This study is conducted within the Upper Bilu Stream (also known as Nam Bilu or Indain Chaung) which is one of four major streams flowing into the Inle Lake of Southern Shan State, Myanmar. UBLU stream occupy the second largest catchment area after Nam Let stream and contributed the highest silt load of 121 t/ yr/ km^2 into the delta, marshes, and inside the lake (NIVA 2017). The stream itself is now rising popularity as tourist destination in Pinalung township. UBLU catchment receives the highest annual rainfall compared to other locations within the catchment (Takahisa Furuichi 2008). UBLU occupies 835.1027 km^2 comprising most parts of Pinlaung township with some areas in Kalaw and Nyaungshwe townships.

It flows into the Inle lake from south western part which then connected to Saga Lake, Mobye` Reservoir and ultimately into the Than Lwin River (MOECAF 2014). UBLU catchment is composed of Kalaw south mountains in the westernmost part, Lonpo Plain in the middle and Pinlaung range at the closet part of Inle lake. The mean annual rainfall of Pinlaung township ranges from 1688 mm to 2594 mm per year (between 2010 – 2019) with the highest rainy days occurring between June to October over 10-year period. The mean annual temperature ranges from 7°C - 32°C between 2010 – 2019 (https://www.worldweatheronline.com/pinlaung-weather-averages/ shan-state/mm.aspx) with extreme cases going down as low as 1°C to -1°C. Limestone, dolomite and sandstone comprises the main bed rock components in the watershed with mountainous brown and yellow brown soils classified as Cambisol and Ferrasols according to FAO classification (NIVA 2017).

3. Materials and Method

3.1 Data Collection

During the raining season of September 2019, altogether 21 stream water samples along Upper Bilu stream and its tributaries comprising one sample located beside the village closet to the Inle lake, three samples from western mountainous areas surrounding the lake, twelve samples from the flat plains where extensive lowland agriculture dominates, and five samples from highland agricultural regions were collected.

In order to identify seasonal and spatial variation of water quality parameters within the sub-catchment, 84 sampling points including 21 locations from the wet season were selected to gather samples for the dry season. The location of 84 sampling points was used as pour points to delineate sub-basin boundaries for further analyses. Moreover, 8 water sampling sites covering floating garden sites, weaving area, inlets, outlet, tourism site and center of the lake were also selected for analyzing the ionic composition of Inle lake compared to UBLU sub-watershed (Fig 2.1).

Electrical Conductivity and pH were measured in situ with conductivity meter Satotec Data Logger Conductivity Meter 17 SD and LAQUAact pH meter D-73 respectively. Water samples were collected approximately from the center of the stream below water surface using 1L plastic bottles. After being filtrated by 0.45-μm (HP045AN) membrane filter, the samples were transferred into 30-mL polyethylene bottles, labelled and stored with liquid ice packs for further chemical analyses. Water quality parameters including major cations and anions, total nitrogen (TN) and total organic carbon (NPOC) are then analyzed at the Laboratory of Field Science Education and Research Centre, Kyoto University after completing each field trip.

Locations for specific land cover types are also recorded during both field trips to use as accuracy assessment points for resulted land cover map.

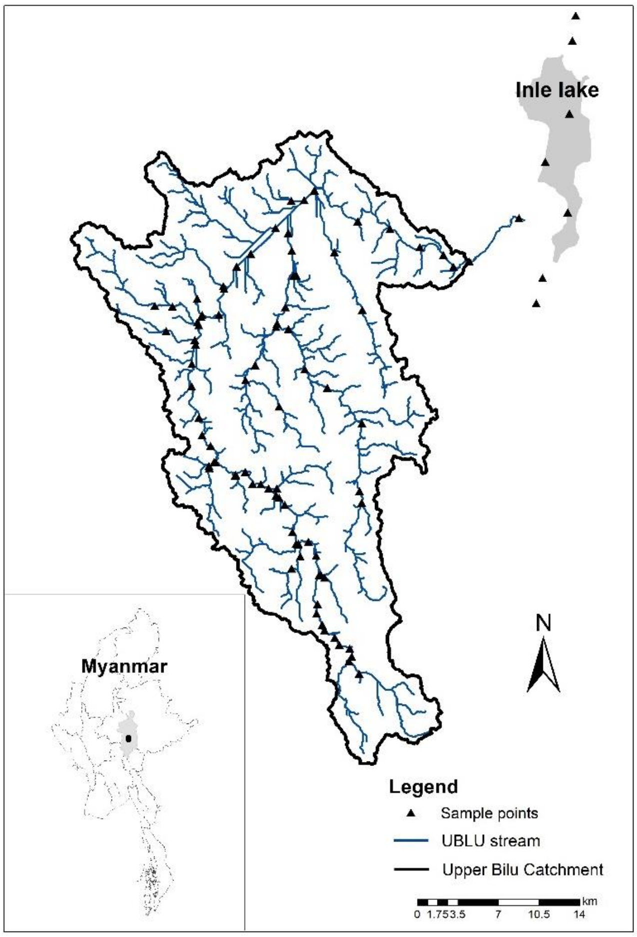


Figure 2.1 Location of UBLU catchment and water sampling points

3.2 Laboratory Analysis

Major cations (Li^+, Na^+, NH_4^-, K^+, Mg^{2+}, Ca^{2+} and anions (F^-, Cl^-, NO_2^-, Br^-, NO_3^-, PO_4^{3-}, and SO_4^{2-}) were analyzed by DIONEX ICS-1100 Ion Chromatography system. TN and NPOC were determined through NC Analyzer (Sumigraph NC 22A, Sumika Chemical Analysis Service).

The following equation was used to calculate the alkalinity (HCO_3–CO_3) of study area in milliequivalents per Liter (meq L^{-1}) (Akaishi et al. 2006).

$$[\text{Alkalinity/ANC}] = (2[Ca^{2+}] + 2[Mg^{2+}] + [Na^+] + [K^+]) - (2[SO_4^{2-}] + [NO_3^-] + [Cl^-])$$

Piper's trilinear diagram was produced using smwrGraphs package (Dave Lorenz 2016) in R version (4.0.2) with the concentrations in milli equivalent per liter of 8 major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-}) by grouping Na^+ with K^+ and alkalinity as CO_3^{2-} with HCO_3^-.

3.3 Land use/land cover classification

For LULC classification and watershed delineation of UBLU catchment, 10-m resolution bands of Sentinel 2- A image for 2019/01/03 (47QKC) and Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global data were downloaded from Earth Explorer website (https://earthexplorer.usgs.gov/) respectively.

Pixel-based image classification was done using Semi-automatic Classification Plugin provided in Quantum GIS (https://semiautomaticclassificationmanual-v5.readthedocs.io/en/latest/_tutorial_2.html). Regions of Interest (ROIs) for five land cover classes (Table 2.1) were selected based on different combinations of Band 2,3,4 and 8. Built-in Maximum Likelihood Algorithm was applied to produce a classified image for 2019. Example-based Feature extraction tool (ENVI 5.5) was used to extract settlement areas (Scale Level – 30, Merge Level – 95) with KNN classification algorithm over the study site. The resulted settlement polygons are then merged into pixel-based classified map. Delineation of sub basins through SRTM is done using Hydrology toolbox under Spatial Analyst tools provided by ArcMap 10.7.1.

Table 2.1 Description of LULC classes

LULC	Description
Forest	Low to high density woodland.
Cropland	Upland and Lowland crops.
Grassland	Rangeland with isolated trees and shrubs.
Water	Streams and lakes.
Settlement	Cities and small villages, roads and industrial facilities.

3.4 Data Analysis

Temporal variation of stream water quality was analyzed using 21 samples collected in September 2019 and February 2020. Parametric paired t-test and Wilcoxon signed rank test for nonnormally distributed data were used to understand seasonal variation of water quality parameters.

Ten water quality variables (Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, NPOC, TN, EC) were used to perform hierarchical agglomerative cluster analysis in R version (4.0.2) using hclust function (https://stat.ethz.ch/R-manual/R-devel/library/stats/html/hclust.html) (The R Stats Package) by Ward’s method and Euclidean distances as measure of similarity (Kändler et al. 2017).

The resulted clusters were then compared through Welch’s ANOVA and Games Howell post Host test to reflect the samples’ nature of heteroscedasticity in R version (4.0.2) using rstatix package. The slope (percent-rise) of the study area was calculated with SRTM data using slope tool of Spatial Analyst Toolbox in ArcMap 10.7.1. Average proportion of land use, slope and elevation were extracted based on sub-catchment boundaries for each water sample.

Principal component analysis (PCA) was used to identify the relationship between water quality parameters (Dry season) and LULC percentages (2019 LULC) across the study area and how it changed based on each cluster. Log-transformation ($y' = \log10 (y + 1)$) was done for water quality variables (Kändler et al. 2017). PCA was based on correlation matrix as Scale=TRUE command was used in prcomp function (The R Stats Package) of R version 4.0.2.

4. Results and Discussion

4.1 Hydro chemical Facies

Piper's trilinear diagram of surface water chemistry for Inle Lake and UBLU (wet and dry) stream was generated to understand the chemical relationships among water samples based on the concept of hydro-geochemical facies. The relative concentrations of cations and anions are plotted in the lower triangles and the resulting two points are extended into the central field to represent the total ion concentrations Figure (3.1) (Amadi et al. 2014). Both stream and lake water fall under Ca^{2+}_Mg^{2+}_HCO_3^- type illustrating temporary hardness of surface water. The plot also demonstrated the dominance of alkaline earths over alkali ($Ca^{2+} + Mg^{2+} > Na^+ + K^+$), and weak acids ($CO_3^{2-} + HCO_3^-$) exceed strong acids ($SO_4^{2-}+ Cl^-$) in all the samples. Overall, CO_3^{2-} _ HCO_3^- and $Ca^{2+} + Mg^{2+}$ type according to diamond-shaped field showed temporary hardness of surface water. Similar facies in both lake and stream water implied that as there were no significant difference the mineralization processes occurring in both wet and dry season across the study area (Abendong et al. 2019). The hydrochemistry of UBLU stream and lake water might be the result of dissolution of limestones and dolomite within the catchment area. Overall, there was no change in the hydro chemical properties and the factors affecting the hydrochemistry inside and outside the lake.

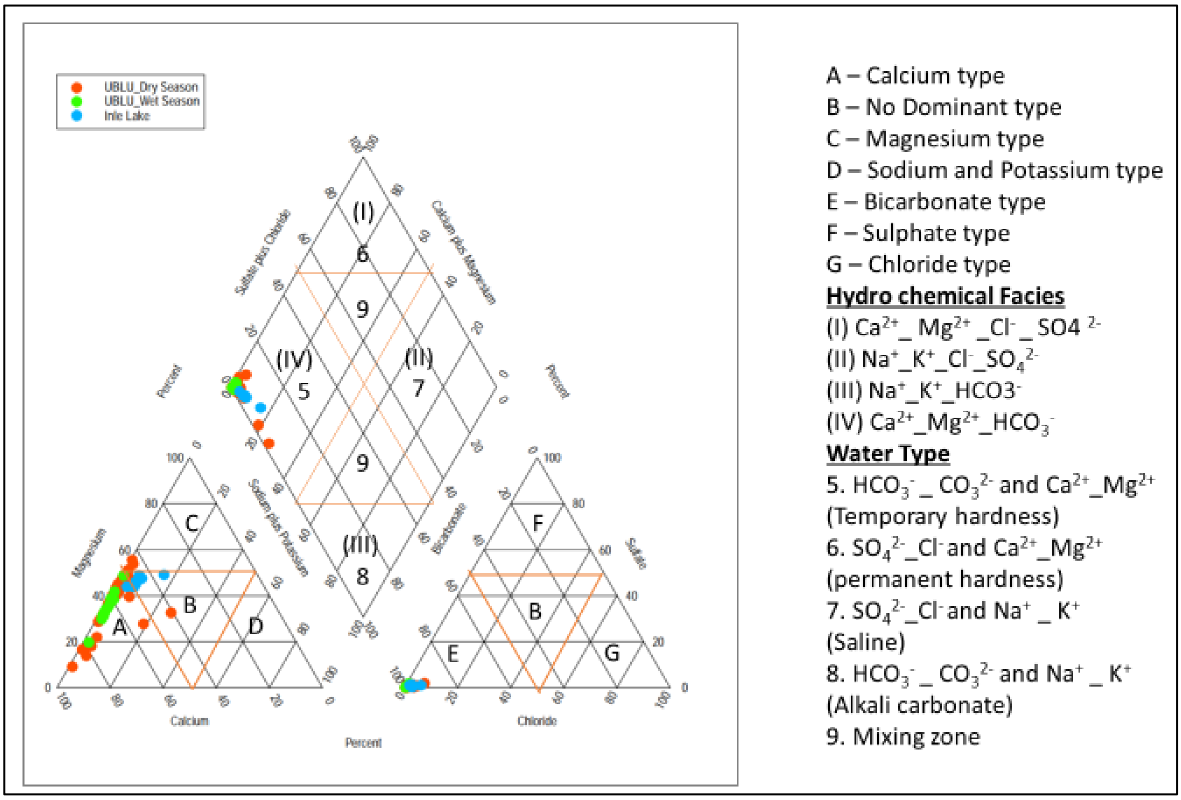
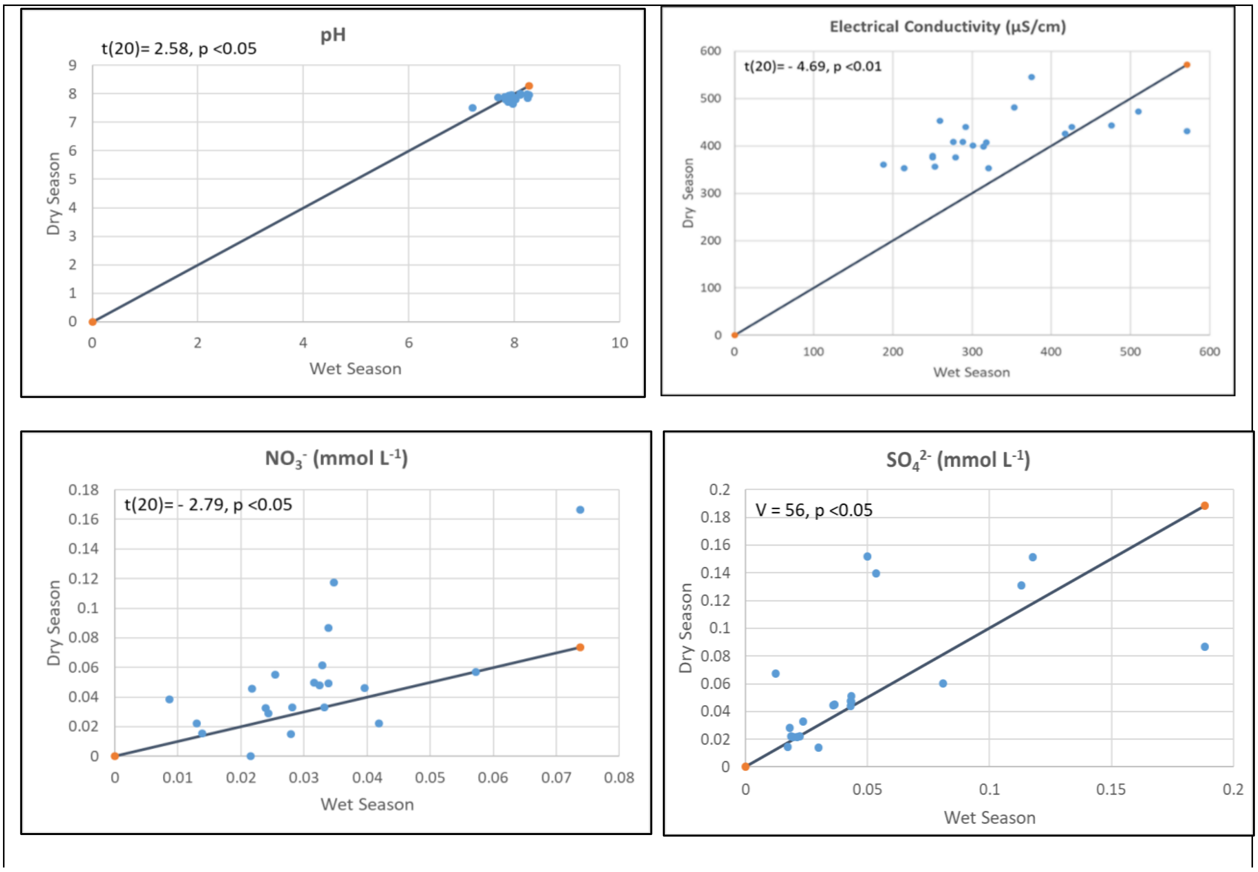


Figure 3.1 Surface water samples illustrated in Piper's trilinear diagram (%meq L^{-1})

4.2 Seasonal Variation of Water Quality Parameters

Unlike wet season, additional ions including F^-, NO_2^-, Br^-, Li^+ were also detected in small concentrations in all sampling points during the dry season. There was a significant higher mean concentration of EC, NO_3^-, Ca^{2+}, Mg^{2+} during the dry season except pH which showed a significant higher value during the wet season. The mean value pH was 7.94 during the wet season and 7.85 during the dry season which can be assumed that the limestone around the area contributed to its alkaline nature (Akaishi et al. 2006). Higher pH values during wet season may be related to environmental factors variations such as flow rate, water temperature, aquatic plant growth, etc. and further research is still needed as the reasons are complex (Chen and Lu 2014). pH value of UBLU stream fell within the range of 6.0 to 9.0 despite the season which appears to provide protection for the life of freshwater fish and bottom dwelling invertebrates in canals (Boman, Wilson, and Ontermaa 2012). Higher values of EC could be found during the dry season which could be the result of its negative relationship with discharge volume (Hamid, Bhat, and Jehangir 2020) which is relatively low compared to rainy season.

The chloride concentration didn't show any significant differences between the two seasons ($p > 0.01$) as it changed from 0.02 - 0.17 during the wet season to 0.03 - 0.36 mmol L^{-1} in the dry season. According to the results of Wilcoxon signed rank test, the median concentration of SO_4^{2-}, Na^+, K^+, NPOC and TN during the dry season were statistically significantly higher than the scores during the wet season. Similarity of concentration between the two seasons was again illustrated by closeness of data to x=y line (Helsel and Hirsch 1992) in (Figure 3.2).



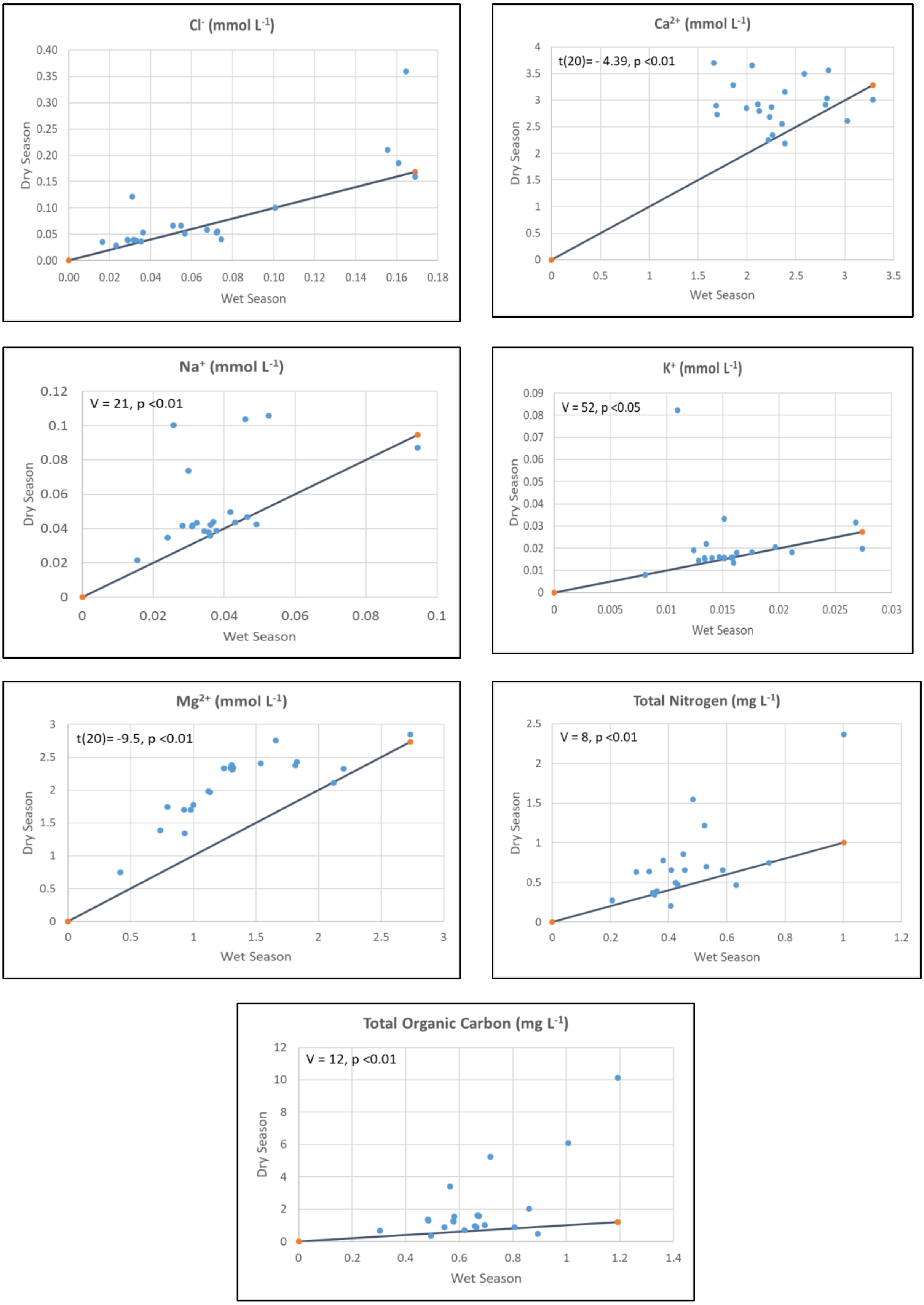


Figure 3.2 The relationship of water chemistry between dry and wet seasons (X axis being wet and Y axis being dry season).

4.3 Spatial Variation of Water Quality Parameters

4.3.1 Water quality groups (Clusters) and dominant land uses

Hierarchical cluster analysis resulted four groups of water quality parameters (EC, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+}, TN, NPOC) as illustrated in Figure 3.3. Cluster 1 and 3 comprises 23 and 32 samples which existed mainly along the UBLU stream whereas cluster 2 and cluster 4 formed 16 samples and 13 samples respectively. The distribution of land use percentages for each sample was demonstrated in Figure 3.4.

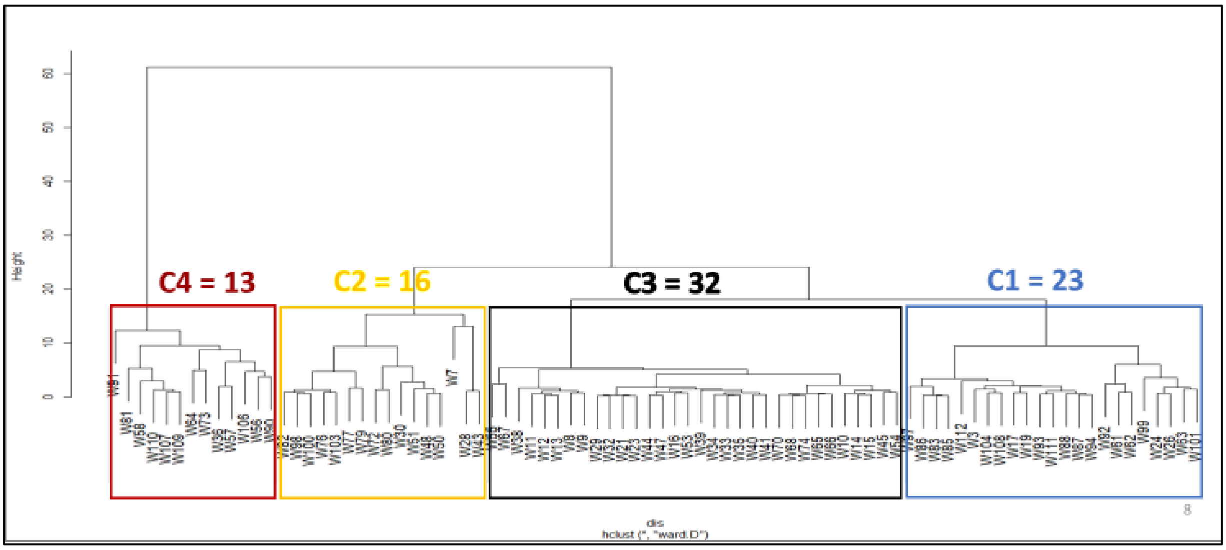


Figure 3.3 Cluster dendrogram based on water quality parameters (n=84)

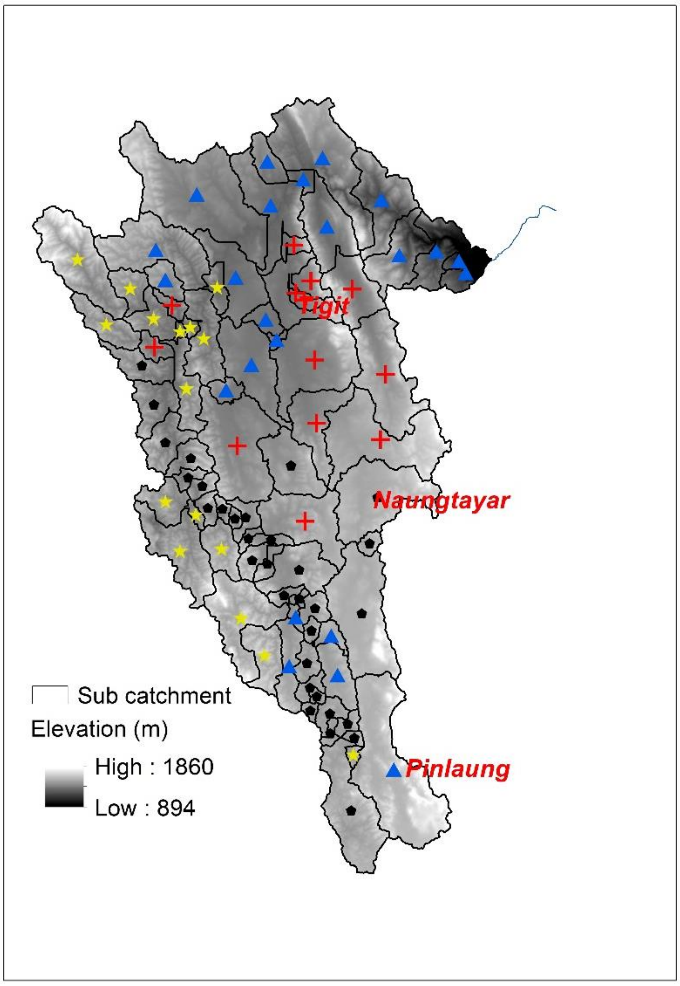


Figure 3.4 Distribution of Water quality clusters throughout UBLU catchment

Table 3.1 summarizes average percentages of land use and topographic characteristics within each cluster. Land use within Cluster 1 was dominated by agriculture and grassland with the least percentage of forested areas compared to other clusters accompanied by second highest proportion of settlements. Samples inside cluster 2 existed in very steep slope areas where most of them is covered by the forests whilst samples of cluster 4 exhibited mainly in the flat plain where coal-mining industry and commercial agriculture dominates.

Cluster 3 samples exhibited the highest elevation of 1424.09 m with agricultural crops as dominant land use accompanied by forested areas as second most abundant one. The average slope percent of Cluster 1, 2, 3 and 4 were 16.55, 27.46, 21.9, and 17.78 respectively whereas Cluster 2 comprised samples with the steepest slope of all clusters across the entire sub-watershed.

Table 3.1 Average percentage of land use and topographic variables for each cluster (C = Cluster)

C	Settlement	Water	Forest	Crop	Grassland	Slope	Elevation (m)
1	4.64	0.25	20.12	62.06	13.02	16.55	1321.96
2	1.8	0.23	57.04	40.23	0.74	27.46	1397.13
3	1.77	0.03	39.65	56.56	1.97	21.9	1424.09
4	5.4	0.1	21.69	69.77	2.89	17.78	1380.88

4.3.2 Variation among Clusters

Table 3.2 revealed that there was a significant difference in EC of all clusters except 1 and 3, most of which lied along the UBLU stream. Significant lower concentrations of Cl^- and NO_3^- could be found in Cluster 2 and 3 compared to the rest two clusters. The lowest mean concentration of Cl was found in Cluster 2 where forested land use mostly dominated whilst NO_3^- was seemed to be the lowest in Cluster 3. TN values showed the same pattern of significance with NO_3^-. SO_4^{2-} values showed significant difference in all Clusters except between 1 and 2. The highest concentration of SO_4^{2-} could be found in Cluster 4. Cluster 3 exhibited the significant lowest K^+ value against other three groups. There was a significant highest Ca concentration in Cluster 4 compared to others. There was a significance lowest value of Mg^{2+} in Cluster 2 against other groups while Cluster 4 samples being highly concentrated in Cluster 4. NPOC and Na^+ didn't show any significant difference in the mean concentration of all clusters throughout the study area.

Table 3.2 Water quality parameters at different clusters. C = Clusters, EC in µs cm^{-1}, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+}, TN and NPOC in mg L^{-1}. Values are (Mean ± SE)

C	n	EC	Cl^-	NO_3^-	SO_4^{2-}	Na^+	K^+	Ca^{2+}	Mg^{2+}	TN	NPOC
1	23	422.17 ± 6.41^{a}	2.68 ± 0.26^{a}	2.5 ± 0.2^{a}	2.12 ± 0.32^{a}	1.18 ± 0.1$^{n.s}$	0.87 ± 0.12^{a}	54.53 ± 1.49^{a}	26.3 ± 0.66^{a}	0.59 ± 0.03^{a}	1.99 ± 0.46$^{n.s}$
2	16	299.83 ± 25.81^{b}	1.29 ± 0.15^{b}	1.31 ± 0.31^{b}	1.72 ± 0.31^{a}	1.39 ± 0.19$^{n.s}$	0.93 ± 0.12^{a}	46.94 ± 4.87^{a}	11.45 ± 1.69^{b}	0.33 ± 0.06^{b}	6.24 ± 4.07$^{n.s}$
3	32	408.41 ± 5.11^{a}	1.57 ± 0.1^{b}	0.92 ± 0.09^{b}	0.75 ± 0.05^{b}	0.85 ± 0.06$^{n.s}$	0.46 ± 0.02^{b}	51.03 ± 0.96^{a}	24.77 ± 0.27^{a}	0.24 ± 0.02^{b}	3.03 ± 0.77$^{n.s}$
4	13	526.08 ± 25.48^{c}	10.91 ± 1.64^{c}	5.75 ± 0.69^{c}	5.68 ± 0.67^{c}	2.58 ± 0.64$^{n.s}$	1.77 ± 0.31^{a}	68.94 ± 2.27^{b}	29.91 ± 2.02^{a}	1.33 ± 0.14^{c}	2.29 ± 0.5$^{n.s}$

The different letters within the same column indicate significant difference according to Games Howell post Host test of Welch's ANOVA at 5% significant level. 'n.s' means no significance.

The lower EC values in Cluster 2 and 3 might also be contributed by the decrease in weathering rates at higher elevations and the water flow through thinner, less mature soils generating more dilute soil water and hence more dilute stream flow (Moore, Richards, and Story 2008). The lowest mean values of EC, Cl^-, Ca^{2+}, and Mg^{2+} were found within Cluster 2 where the influence of settlement is relatively low and sloping agricultural fields were left fellow during the dry season for Cluster 2. Similar situation was found in Cao-E River basin in East China (Chen and Lu 2014) where concentration of nutrients were negatively correlated with mean slope% and elevation areas where forest was the primary land cover.

The highest value of NPOC was found in Cluster 2 which could be the result of terrestrial organic carbon compounds from decaying organic material such as fallen leaves and crop residues (Watershed and County 1990). But NPOC and Na^+ values didn't show any significant difference within Clusters although the highest concentrations could be found in Cluster 2 and Cluster 4 respectively. Being occupied by mosaic of horticulture including orange, pear, avocado, coffee and tea plantations with annual crops followed by higher percentage of forest area mediated an increase in the loads of NO_3^-, SO_4^{2-}, Na^+, K^+, TN into stream water within Cluster 3.

The highest mean concentration of EC, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+}, and TN was found within Cluster 4. The value of EC showed highest which has been affected by concentrations of Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+} within Cluster 4 samples (Boman, Wilson, and Ontermaa 2012). Cluster 4 consisted of water samples around Tigit village tract where coal mining industry was established with extensive agricultural fields. Direct discharge of water into the stream from coal mining industry might also be the main source of higher ionic concentrations within Cluster 4. This stream water was then used by local people for domestic and agricultural purposes although there were some reported skin problems related with the water use (NRC 2019). Fertilizers or manure nitrogen which is not completely absorbed by the crops could be discharged into ground water, river, lake and coastal water through runoff and sub-surface drainage (Jiang et al. 2006). This might contribute to the contents of NO_3 and TN within Cluster 4. The concentration of Cl, NO_3, and TN was significantly high in samples of Cluster 1 whose sub-watersheds were dominated by crop land, settlement and grassland. These nutrients might be transported into Inle lake given their proximity to the lake itself.

4.4 Land use and land cover types of the study area

According to the resulted maps for 2019, the percentage of land covered by each LULC classes was described in (Table 3.3). According to the results of LULC classification, more than half of the area of catchment is covered by croplands followed by forested areas and settlement areas (Figure 3.5). Agricultural activities mainly based on rain and river water growing rice, potato, maize, garlic, chili pepper, pulses, ginger, turmeric, sunflower, cabbage, cauliflower, mustard, etc. as seasonal crops and tea, avocado, coffee, banana, pear, orange, mango, etc. as horticultural crops. Double cropping during the wet monsoon seasons within flat valley (e.g. lowland rice followed by potato or tomato or chickpea), growing of wheat, potato or niger during the dry season, and cultivation of potato (sown April) followed by upland rice (sown late June) in sloping fields which are left fellow during the dry season are also practiced (FAO 1999). Besides, extensive tea plantations of Pinlaung township of around 1,500 meters above sea level used chemicals very little and were used as rival crops with poppy cultivation based on the price (ILO 2019). Major forest types of Taunggyi district are Moist Upper Mixed Deciduous Forest, Dry Upper Mixed Deciduous Forest, Evergreen Forest, Dry Hill forest, Indaing forest and Pine forest. Commercial land use projects and infrastructural development such as mining and transportation development could affect forest health resulting in forest loss (Sharma, Thapa, and Matin 2020).

Table 3.3 Proportion of LULC classes within UBLU stream catchment

LULC	Area (km^2)	%Area
Settlement	28.9	3.5
Water	0.5	0.1
Forest	263.6	31.6
Grassland	42.2	5.1
Crop	499.9	59.9

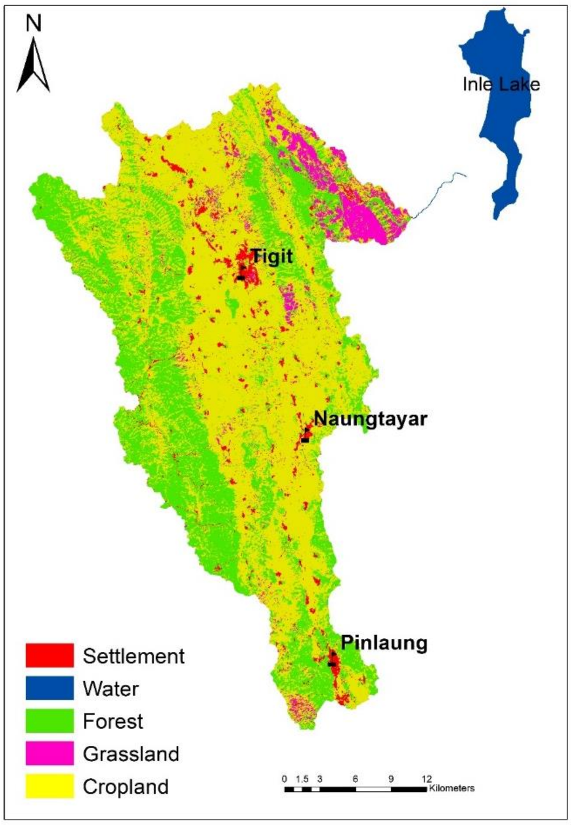


Figure 3.5 LULC Situation in 2019

Stratified random samples for each LULC classes were defined using Create Accuracy Assessment Points tool from ArcMap 10.7.1. Area of 10m^2 square polygons were laid based on point locations to reflect the actual pixel size of classified map. The land cover situation of these square polygons was then checked in Google Earth Pro software which provide different time series of fine resolution images. Altogether 255 accuracy assessment points including 42 ground control points are then used to construct Accuracy Assessment Matrix with Commission and Omission Error, User's and Producer's accuracy (Table 3.4). Overall Accuracy of 82.75% with 0.7152 kappa coefficient were achieved.

Table 3.4 Accuracy Assessment Matrix for 2019 LULC Map

	Settlement	**Water**	**Forest**	**Grassland**	**Crop**	**Total**	**Commission Error_%**	**User's Accuracy %**
Settlement	**13**	0	3	0	2	18	27.8	72.2
Water	0	**10**	0	0	1	11	9.1	90.9
Forest	0	0	**57**	4	9	70	18.6	81.4
Grassland	0	0	2	**8**	0	10	20.0	80.0
Crop	6	0	14	3	**123**	146	15.8	84.2
Grand Total	19	10	76	15	135	**255**		
Omission Error_%	31.6	0	25	46.7	8.9			
Producer's Accuracy%	68.4	100	75	53.3	91.1			

4.5 Relationship between current land use and water quality parameters

Principal Component Analysis was used to display the pattern of similarity between land use and water quality parameters through the loading values. The proportions of LULC (2019) for each sample were calculated based on the area of sub-catchment derived from SRTM data with 30-m resolution.

Variance explained (%) and eigenvalues are normally used to determine the principal components (Zeinalzadeh and Rezaei 2017). Table 3.5 showed that the eigenvalues remained stable after axis 3 and first three principal components could explain 61.69% of total variation. Therefore, the first three components were used for further analyses.

Table 3.5 Eigenvalues, percentage of variance and cumulative variance for each principal component

	Principal Component (Dimensions)				
	1	2	3	4	5
Eigenvalues	5.08	2.63	1.55	1.13	1.09
Variance (%)	33.84	17.53	10.32	7.56	7.3
Cumulative variance (%)	33.84	51.37	61.69	69.25	76.54

The first and second principal components with eigenvalues greater than 1 could explain 51.37% of total variance according to (Table 3.5). The first component explained 33.84% of total variance within the data and was characterized by strong positive coefficients for Cl^-, NO_3^-, SO_4^{2-}, K^+, Mg^{2+}, Ca^{2+}, TN, EC, settlement and crop variables and strong negative coefficient for forest land (Table 3.6). Correlation coefficients (factor loadings) values of >0.75 is classified as “strong”, values between 0.75 and 0.50 is classified as “moderate”, and value between 0.50 and 0.30 is classified as “weak” (Baluch, Hashmi, and Yu 2019).

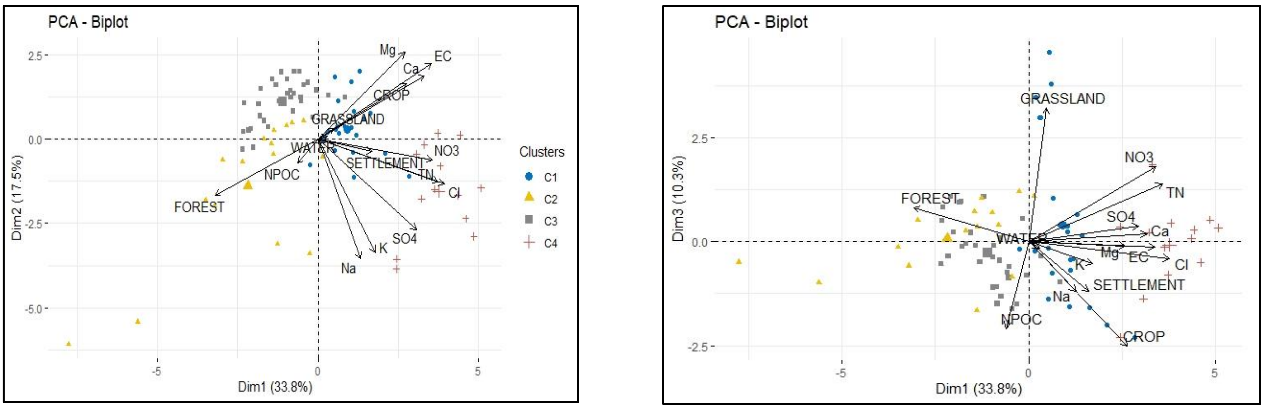
The second axis with 17.53% variance showed positive correlations with crop land and Mg, Ca, EC and negative correlations with forest land with SO_4^{2-}, Na^+, and K^+. There was a positive relationship between grassland and NO_3^- over the study area whilst cropland and NPOC values exhibited negative relationships according to coefficients as shown in Table (3.6). The third component explained 10.32% of total variation demonstrating strong positive associations between NO_3^- and grassland within the dataset.

Table 3.6 Correlation coefficients between the principal components (dimensions) and land use and ion concentrations

	Dim.1	Dim.2	Dim.3
Cl^-	0.8508681	-0.28736	-0.09066
NO_3^-	0.7688154	-0.13042	0.407335
SO_4^{2-}	0.6614876	-0.58189	0.086981
Na^+	0.2845523	-0.76733	-0.27178
K^+	0.3857809	-0.72613	-0.12072
Mg^{2+}	0.5839222	0.556934	-0.0225

Ca^{2+}	0.7144486	0.407786	0.04291
NPOC	-0.13871	-0.15335	-0.47029
TN	0.8089589	-0.27212	0.316276
EC	0.7622006	0.483986	-0.02887
Settlement	0.361956	-0.08066	-0.26912
Water	0.0659105	0.017976	-0.03519
Forest	-0.695415	-0.35865	0.18486
Grassland	0.1091007	0.070115	0.72573
Cropland	0.5967408	0.356157	-0.565

According to Figure 3.6 (a), Cluster 1 samples were positively affected by settlements and croplands among all land uses and Ca, Mg and EC among water quality variables. Cluster 2 and 3 were negatively affected by physicochemical and nutrient parameters which exhibited the importance of forests in steep slope areas. Cluster 4 samples were strongly and positively associated with nutrient and chemical parameters. Coal mining areas, infrastructure development together with extensive agricultural areas near Tigit village tract may affect water quality within Cluster 4. Ca^{2+}, Mg^{2+} and EC showed higher positive influence in Dim.2 which was negatively affected by nutrient and other chemical parameters. Dim.2 underlined the importance of Ca^{2+}, Mg^{2+} and EC resulting from intensive agricultural areas within Cluster 1. Mountainous areas covered by grassland mostly fall within Cluster 1 and Dim.3 (Figure 3.6 (b)) showed the positive relationship with grasslands, NO_3 and TN within the study site.



(a) (b)

Figure 3.6 Coordinates of principal component axis (dimensions) based on the water quality and land use variables

As Cluster 1 and Cluster 4 samples were spatially closer to the lake (Lompo plain around Tigit village tract and downstream areas of UBLU stream after Tigit), diffuse pollution through fertilizer application of off-season lowland agriculture and human activities could contribute to lake eutrophication which was the major problem affecting the sustainability of the lake itself (Akaishi et al. 2006). Takahisa Furuichi (2008) also stated that Lonpo catchment and downstream areas of UBLU stream including Palin catchment should be targeted for control of surface erosion and gully erosion as sediments in the lake and delta are overwhelmingly from these areas.

PC1 demonstrated negative relationship of forest land use with water quality parameters in Cluster 2 and 3 samples highlighting the importance of forests within the sub catchment of sloping areas. PC2 demonstrated positive relationships in Ca^{2+}, Mg^{2+}, EC being Ca^{2+} and Mg^{2+} the main contributing ions for higher EC which then have positive relationship with cropland percentage.

4.6 Implications of future land use on water chemistry

Natural weathering of rocks and anthropogenic activities pose a combined influence on water chemistry. Higher elevation and rugged topography within the study area created favorable condition for forests which in turn indicated less polluted stream water in these areas. However, various development projects, growth in foreign trade and population density favoring expansion of road network may have adverse impact on the forests through higher human accessibility and chances of forest encroachment (Sharma, Thapa, and Matin 2020). This might affect the current water quality conditions of UBLU stream in less accessible, sloping areas of Cluster 2 and Cluster 3. Disturbance of areas containing steep slopes can trigger erosion and sedimentation, resulting in the loss of topsoil, loss of habitat quality, degradation of surface water quality, silting of wetlands, and alteration of drainage patterns (David K. Maski, PP, AICP 2012).

Sharma et al., also projected that Pinlaung township was likely to be the future most deforested area among the townships of Taunggyi District. The higher deforestation rate would reflect agricultural, rural, urban and industrial expansion which would affect adversely on water chemistry as indicated by higher concentration of NO_3^-, Cl^- and SO_4^{2-} within Cluster 4. Furthermore, nonpoint source pollution from upland catchment could aggravate water quality issues of Inle Lake.

The use of agricultural chemicals could degrade water quality through direct runoff together with disposal of industrial waste into the stream. Although local people aware the degradation of water quality and quantity, the insights for sustainable land use and water management was still limited. Riparian vegetation should be conserved along the stream to achieve buffering effect of pollutant removal nutrients are intercepted, to varying degrees, as runoff passes through managed and natural riparian zones (National Research Council 2002). Furthermore, these areas could provide habitat for a variety of animal species and support terrestrial and aquatic food webs through deposition of woody debris (David K. Maski, PP, AICP 2012). Monitoring of industrial waste and reduced utilization of agricultural fertilizers and pesticides should be practiced. Land use and water management interventions should be implemented with the consent of local communities through recognition of their traditional knowledge and values.

5. Conclusion

Being limestone the dominant bed rock across the watershed, HCO_3^- – CO_3^{2-} and Ca^{2+} – Mg^{2+} type of stream water indicated temporary hardness across the study area. Significant higher concentrations of EC, NO_3^-, Mg^{2+}, Ca^{2+}, Na^+, K^+, SO_4^{2-}, NPOC and TN were found during the dry season compared to wet season. This might be related to natural processes including lower discharge volume, evapotranspiration and the deposition of dust and salt by wind, rural and urban anthropogenic sources (Khatri and Tyagi 2015). Possible anthropogenic sources within UBLU catchment include mainly of agricultural activities and extractive industries. Deciduous nature of trees and agricultural residues could also be contributing factor affecting higher NPOC concentration in stream water during the dry season. The cluster with second highest concentrations exhibited in areas where surface and gully erosion are the main concern. There were strong positive correlations between crop land, settlement and water quality parameters whilst negative relationships existed with forested land. Although forests only existed on very steep slope areas and high elevation sub-catchments, their contributions for sustaining good water quality could be seen within the study area.

Most crop land in the UBLU catchment existed on both sides of the stream affected by direct runoff from the fields. Being Inle Lake a popular tourist destination in Myanmar, UBLU stream also attracted local and international travelers with its unique natural beauties. Sustainability of UBLU stream is important also for Inle lake which is now encountering problems of eutrophication with excess loads of pollutants. Water quality within the watershed of the rest three main inflowing streams, how it changed spatially and combined effect on lake water quality is also worth observing in future studies.

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