MJSIR
Mountain Journal of Science and Interdisciplinary Research
PRINT ISSN: 2619-7855
ONLINE ISSN: 2651-7744
January-June 2019 • 79 (1) : 17-30

Physico-Chemical Characteristics of Selected Tributaries of Didipio River, Eastern Nueva Vizcaya, Philippines

Ryan P. Manuel

College of Forestry, Nueva Vizcaya State University
** - corresponding author: nayrleunam@gmail.com*

Abstract

Didipio, known for its gold and copper resources, has developed into a mining-agricultural area. Conflicting interests over its resources, i.e., water and soil, necessitate information based management to inspire participation among stakeholders. This study aimed to assess the condition of water, soil and sediments of four major streams in Didipio and surrounding areas namely Alimit, Boulevard, Camgat-Surong and Dinauyan using 26 physical and chemical parameters. The research is part of a multi-pronged study and served as baseline for management purposes. For each stream, the up and downstream sections were sampled. Water, soil and sediment samples were brought to laboratory, and results were compared to water quality standards. Multivariate ANOVA (MANOVA), Tukey Honestly Significant Difference (HSD) test and t-test were employed to compare whether or not physico-chemical characteristics of the sites differ from one another. Results were also discussed in connection to most imminent anthropogenic factors present in the streams. Stream sections with highest level of contaminants are those adjacent to streambank slushing (small-scale mining) and those devoid of riparian cover and subject to soil disturbance. Least impaired channels are those away from such land-uses. As majority of contaminants fall within acceptable levels, the four studied streams can return to more pristine state, provided that proper management mechanisms would be implemented.

KEYWORDS

freshwater
impairment
water quality standards
Didipio

Introduction

The Philippine Development Plans 2010-2016 and 2017-2022 have identified freshwater bodies as important components for inclusive growth. Water-related resources are also part of the country's priority research and development areas [S&T Agenda for 2010-2016, Harmonized National R&D Agenda 2017-2022], whereby assessment and monitoring of water quality are encouraged to ensure sound management and secure sustainable quality water for human and ecological use.

People see rivers and streams as strategic sites for abode and livelihood (Guinumtad, 2007; Manuel, 2010) because of the inherent soil fertility brought about by their nutrient flow (McClain & Cossío, 2003). Many rural communities have thus situated themselves near or adjacent to freshwater bodies. One such river-dependent village is Barangay Didipio in the municipality of Kasibu, Nueva Vizcaya. It has a land area of

3,685.76 hectares comprising 4.50% of the municipality's total. As of 2015, the community's population was 748. Didipio and its adjacent barangays are situated along four large streams that primarily define the area's hydrology.

In the 1970s, migrant Ifugaos found that Didipio, particularly Didipio River, was abundant with alluvial gold (gold bits scattered along the river body). Verified deposits of gold and copper in the area prompted operation of small and large-scale mining entities. Aside from mining, present-day settlers in Didipio also depend upon rice farming, fruit, vegetable and livestock production.

Ometo et al. (2000) and Allan (2004) argue that land uses, when proximate to freshwater ecosystems, may cause organic pollution in streams. As land is altered by people in favor of certain resource uses, resulting perturbation in biochemical characteristics of water can cause weakened local ecological services (Zimmerman, 1993; Iwata et al., 2003; Heartsill-Scalley & Aide, 2003; FAO, 2006; Greenpeace, 2007; Sitzia et al., 2015). This disturbance may also affect resiliency of ecological processes to the rest of the river continuum (Vannote et al., 1980; Kondolf et al., 1996; Milner & Piorkowski, 2004; Chakrabarty & Das, 2005; Luke et al., 2007; Sabater et al., 2007; Shimabukuro & Henry, 2018; Dedieu et al., 2015).

Since stakeholders have overlapping interests in Didipio's resources, participatory management is a necessary approach to sustainable development considering the balance of environmental and economic concerns. Mining entities (small- and large-scale), farmers, residents, and local government need to understand that individual gains and progress should not always result to environmental degradation (Brosse et al., 2011). With science, anthropogenic impacts to nature can be properly addressed (Beder, 2006). The challenge then is how managers would bridge resource sustainability (protection-conservation) issues between high-end economic (e.g. mining operations) and grassroots sectors (Mudd, 2007). Scientific information must become an arbiter for varied interests in Didipio's resources. Thereafter, policies can be strategized to assure equity and shared responsibility for protection, conservation, rehabilitation and restoration. This assessment is one of such attempts to clarify the environmental scenario in Didipio towards more engaging and proactive management among its dependents and stakeholders.

The study aimed to characterize the physical and chemical characteristics of the four (4) tributaries of Didipio River. To fulfill this objective, the general condition of water and riparian environments of the 4 streams were observed; 26 physical and chemical parameters of water, soil and sediments in upstream and downstream sites of each stream were measured; the variability of selected physico-chemical parameters of upstream and downstream sites of each stream was analyzed; the relationships of the streams as a continuum, and of the parameters mainly affecting such relationships were described; and inferred the parameter values to present condition stream-riparian environments, citing possible impacts of major anthropogenic factors.

Methodology

The study focused on four (4) stream-riparian ecosystems (hereto referred as sampling stations) in Barangays Didipio and Alimit, Kasibu, Province of Nueva Vizcaya (Figure 1). Didipio is primarily known as a mining-impacted area, where both large- and small-scale community setups are in operation. However, there are also visible signs of environmental alteration by upland farming and clearing. The choice of streams for the purpose of this research was based on reports by Dumingyay Jr. (2012), AGHAM (2014) and UPLBFI (2015).

The methodology used for assessing the freshwater channels followed that of Manuel (2010) Manuel et al. (2016), after protocols devised by Hilsenhoff (1988), Zimmerman (1993), and United States Environmental Protection Agency (US-EPA, 1989). For each stream, two sampling stations representing upstream and downstream were established with maximum distance of 500 meters in between. Upstream channels are assumed to be less impacted than lower channels. Thus, such impacts were described when there is substantial change in conditions and assemblage between the two stations.

In each sampling station, 2L and 200ml water samples were gathered for physico-chemical analyses. One kilogram of soil and sediments were also collected on both riparian of the upstream and

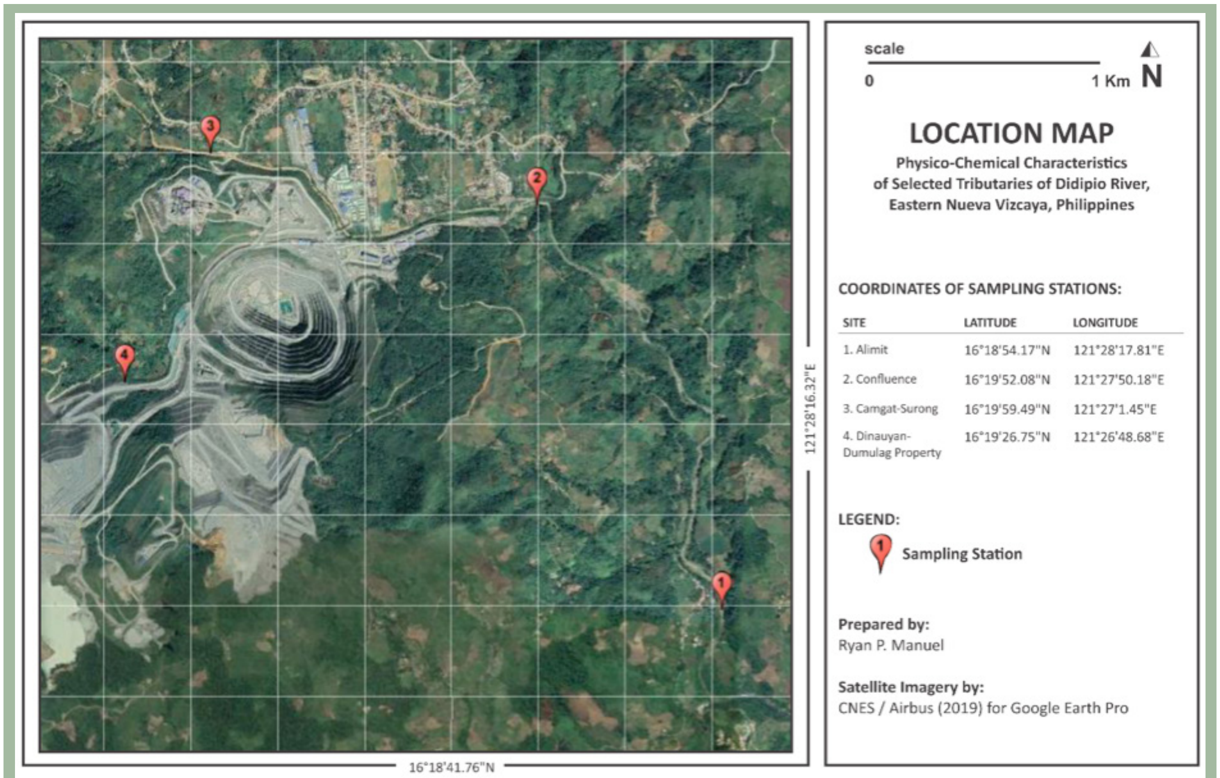

Figure 1. Location of sampling stations in Didipio, Kasibu, NV. By name of stream: 1) Alimit; 2) Boulevard; 3) Camgat-Surong; 4) Dinauyan.

downstream stations for laboratory analysis. Basic stream/habitat characteristics such as stream flow, average depth, width and elevation, and present condition were determined through observation and photo-documentation.

Water and sediment samples were sent to the University of The Philippines Los Baños (UPLB) Analytical Services Laboratory, and National Institute of Molecular Biology and Biotechnology for analyses. Results were compared to water quality standards (e.g. DAO 2016-08). This was to show if the streams are being impacted by various point-source and non-point source contaminants. For comparison of nutrient (N, P, K) and mercury loads, sediments were also sampled in the water treatment pond located in Dinauyan Laboratory. Other chemical parameters that were analyzed include pH, dissolved oxygen, biological and chemical oxygen demand, turbidity, total dissolved solids, salinity and heavy metals (copper, zinc, iron, manganese) for water. All measurements were done in three replicates.

The study used Multivariate ANOVA, or MANOVA to compare simultaneously the physico-chemical characteristics of water (excluding mercury), chemical parameters of the riparian soil, the metal contents of sediments in stream and the sediment of the Water Treatment Facility of the large-scale mining camp. To determine which site is the most significantly different, Tukey's Honestly Significant Difference was used as *post hoc* test for MANOVA. Meanwhile, *t*-test was used to compare differences in mercury levels in water.

Results and Discussion

Physical and Vegetation Characteristics of the Stream Channels and Riparian Zones

The freshwater continuum of Didipio (Figure 1) has a stream order of 2-3 (following Strahler's method). The stream network is fed by perennial creeks and smaller streams in Alimit, Camgat-Surong, and the Dinauyan channel. These drain to small rivers in Boulevard and downstream section of Alimit. The riparian zones of all streams, except Boulevard, contain at least one of the following land-uses: large-scale mining rehabilitation/ structures, small scale operations (active and/or abandoned), agriculture and small irrigation, and semi- to permanent structures (e.g., roads, bridges, residences).

Alimit (Station 1). The farthest from large-scale mining operations, the stream section at Alimit (610masl) is composed of two branches: the clean upstream headwater from secondary dipterocarp and lowland montane forest intertwining with farmlots, and the turbid downstream channel from Didipio community. The riparian zone of Alimit downstream is dominated by grasses like *Saccharum spontaneum, Pennisetum purpureum* and *Mischanthus floridulus*. With an estimated discharge of 13.07m³/s, average depth at Alimit is 0.805m but some parts are believed to reach depths greater than 2 meters.

Boulevard (Station 2). This part of the Didipio River (stream continuum; 674masl) is located at the entrance gate of the large-scale mining camp, and of the road leading to Didipio community. As the main entry to the village, residences, land clearing and permanent structures such as road, bridges are immediate to the water channel rendering its riparian area with little vegetative cover. Stacked boulders are the primary feature of engineered riparian sections. Grasses and weeds emerge within the greenline. Disturbance of surrounding area make waters in Boulevard section very turbid. This is an indication that substrate is gradually accumulating in the area. Stream discharge at Boulevard was measured at 5.19m³/s, while the surface water velocity was 0.98m/s - slowest among the sampled stations at the time.

Camgat-Surong (Station 3). This tributary of the river continuum is located at the northwestern part of Didipio community (704masl). The upstream channel is relatively clean, and used for irrigation. Downstream section, meanwhile, is heavily affected by slushing of active small scale mining operations; water was evidently turbid and heavily disturbed. Rice paddies with sparse trees and tree ferns (*Cyathea*) are general feature of the riparian zone. Average stream discharge was 6.65m³/s while effective width was 9.25m.

Dinauyan Stream (Station 4). The narrowest among the sampled stations, this part of the stream continuum is marked by the water treatment facility and rehabilitated slope of large-scale mining operations. On the north side of the stream, the riparian zone is lined with sloping farms. A small brook originating from the residential area connects to the main Dinauyan channel near a private lot. Visually, surrounding environment provides for good water quality. Effective width of the channel during the site visit was 5.21m, with average discharge of 5.36m³/s.

Chemical Parameters of Water

The water parameters measured in Didipio's streams are presented in Tables 1 and 2. On the average, the streams of Didipio River are slightly acidic (pH 6.69). Highest pH was found in Camgat-Surong channels (6.84 and 6.83) while the lowest was in Boulevard upstream (6.52). Along the Dinauyan-Boulevard-Alimit stream continuum, the pH of water near the treatment area (large-scale mining; pH=6.77) dipped in the Boulevard channels (downstream pH=6.63) then rose again at Alimit (where Boulevard drains to) as the water was agitated and met with 'clearer' waters. As a general indication of water quality, the pH levels obtained were indicative that the channels can support aquatic life. Fishes in the Philippines are known to thrive in waters with pH 6.50-8.50 (DENR, 2016) but fish can survive at pH ranging from 5 to 9. Exposed at a pH below 4 or higher than 11, the fish dies; at pH 4 in-between 5, no reproduction occurs; and at pH 5 in-between 6.5, the growth of fish is slow (Bestre et al., 2018). Additionally, the pH of the sampled streams are within the water quality standard.

It could be readily gleaned in Table 1 that abrupt changes in turbidity occur along the upstream-downstream interface suggesting that properties of other streams are carried over along downstream. Turbidity was highest in Camgat-Surong downstream channel (239.00NTU). This is most likely due to the small-scale mining by slushing in the area. Turbidity slightly settles as it passes Boulevard (125.00NTU upstream, 142.00NTU downstream). It further settles and greatly improve at Alimit upstream but then significantly rose again at Alimit downstream (94NTU). In Alimit downstream, physical disturbance is mainly due to people movement. According to Robillard et al. (2017), values of +5.00NTU already indicate water contamination, most likely by iron and manganese. Also, the NTU values in downstream of Camgat-Surong and

Alimit as well as the entire Boulevard stations are way above the water quality standard.

On the other hand, the total dissolved solids along the four streams are all within the water quality standard. TDS levels along Didipio streams were lower compared to the average TDS reported in Buhisan and Bulacao Rivers, Cebu Province (Maglangit et al., 2014) at 496.06 and 290.72mg/L, respectively. However, Addalam River, where Didipio River drains to, has lower average TDS of 99.875mg/L (Manuel et al., 2016).

Dissolved oxygen (DO) and biological oxygen demand (BOD). DO levels obtained from the study indicate that the areas can support aquatic fauna such as fish (Willamson & Carter, 2001). Dissolved oxygen of >5.00mg/L is needed by pollution-sensitive detritivores i.e., Ephemeroptera-Plecoptera-Trichoptera or EPT (Chadde, n.d.). Connoly et al. (2004) also reported that hypoxic waters are fatal to EPT.

The average DO in all Didipio streams was 7.65ppm. With the exemption of Camgat-Surong,

Table 1

General Water Chemical Measurements in Four Sampled Streams in Didipio. "ND" Means Not Detected (Below Detectable Limits). DENR Limits Used are for Class C Waters (Fisheries, Irrigation)

Parameters	Dinauyan		Camgat-Surong		Boulevard		Alimit		Average	DENR Limit
	Up	Down	Up	Down	Up	Down	Up	Down		
pH	6.69	6.77	6.84	6.83	6.52	6.63	6.55	6.72	6.69	6.50 – 9.00*
Turbidity, NTU	5	5	1	239	125	142	2	94	76.63	75*
Salinity, %	0.01	0.03	0	0	0.01	0.01	0	0	0.01	n/a
TDS, mg/L	255	247	67	69	285	241	130	156	181.25	(1000)**
DO, mg/L	7.9	7.53	7.53	7.58	7.65	7.4	8	7.6	7.65	5.00**
BOD, mg/L	0.43	0.05	0.15	0.12	0.62	0.17	0.52	0.39	0.31	7*
COD	ND	ND	ND	54	ND	ND	ND	9	31.50	100mg/L*

Within acceptable limits (unshaded) *Outside acceptable limits* (shaded: 239, 125, 142, 94, 76.63)

**per DENR Administrative Order 2016-08*
***per DENR Administrative Order 1990-34*

Table 2

Water Nutrient And Metal Content in Four Sampled Streams in Didipio. "ND" Means Not Detected (Below Detectable Limits). DENR Limits Used are for Class C Waters (Fisheries, Irrigation)

Parameters	Dinauyan		Camgat-Surong		Boulevard		Alimit		Average	DENR Limit
	Up	Down	Up	Down	Up	Down	Up	Down		
Acidity, $CaCO_3$/L	9.89	6.02	4.09	3.44	3.66	5.16	5.38	4.52	5.27	n/a
Phosphate, mg/L	0.04	0.02	ND	0.80	0.05	0.03	0.07	0.17	0.17	1.00*
Copper, mg/L	0.04	0.02	ND	2.08	0.28	0.29	0.00	0.22	0.42	.05**
Iron, mg/L	0.31	0.29	0.39	77.79	12.13	13.82	0.15	9.63	14.31	1.50*
Zinc, mg/L	0.01	0.01	ND	0.09	0.02	0.02	ND	0.02	0.03	2.00*
Mn, mg/L	0.06	0.03	0.15	1.85	0.34	0.48	0.05	0.32	0.41	0.20*

Within acceptable limits (unshaded) *Outside acceptable limits* (shaded: 2.08; 77.79, 12.13, 13.82, 14.31; 1.85, 0.34, 0.48, 0.32, 0.41)

**per DENR Administrative Order 2016-08*
***per DENR Administrative Order 1990-34*

all upstream stations contain higher DO than its downstream counterparts. DO of Camgat-Surong (7.53), while visually one of the cleanest sections, is the one with lowest values. It is most likely due to the water's relatively stagnant, very shallow flow and being exposed to sunlight. Murkier sections in Surong, Dinauyan, Alimit and Boulevard have more dissolved oxygen because water flow was agitated by the presence of rocks and slope in the area.

DO is critical to fish survival. The saturation concentration is a function of water temperature and atmospheric pressure which is determined by elevation. DO is directly related to atmospheric pressure and inversely related to water temperature (Bestre et al., 2018). The maximum amount of DO that water can hold is 14.7mg/L at sea level and 0ºC. Sources of DO include aeration brought by flow motion of the water and photosynthetic activity of aquatic plants. On the other hand, DO is depleted through respiration (from fish and aquatic plant), decay of organic matter, direct chemical oxidation and outflow of water (Thompson & Larsen, 2004).

In comparison, Addalam River had higher DO levels. Manuel et al. (2016) recorded an average DO of 8.76mg/L in various points in Kasibu (Nueva Vizcaya), Cabarroguis (Quirino) and Jones (Isabela Province). This suggests that impacts of land uses in Didipio is minimized as the water flows downstream into Addalam River. On the other hand, Aritao and Bambang Rivers in Nueva Vizcaya (Tabaquero et al., 2017) were reported to have lower values at 7.15 and 7.05 respectively. Even lower DO values were reported by Fajardo (2015) in nickel mining impacted bodies in Tubay, Agusan del Norte, with an average of 5.22mg/L.

Biological oxygen- and chemical oxygen demands (BOD, COD) in the studied streams were low, meaning more oxygen is available for aquatic life. The average BOD was 0.31mg/L. While six stations contain negligible COD levels, values in upstream Alimit (9.0) and downstream Camgat-Surong are high (54). These levels denote high contamination of non-biological matter in the sites. Nonetheless, The Bureau of Indian Standards contends that COD of <250ppm are within acceptable levels for most surface waters. Levels of BOD and COD in the four streams are also within limits, as per "Effluent Discharge Standards" of Food and Agriculture Organization (FAO, 2003) and by World Health Organization for Class V waters.

Nutrients and Metals Content. For phosphorus, zinc, and manganese, Camgat-Surong$_{up}$ had negligible levels or below detectable limits. However, highest nutrient levels among sites were observed in its downstream, ($P_{Camgat\text{-}Surong}$=0.798ppm; $Zn_{Camgat\text{-}Surong}$=0.09ppm; $Mn_{Camgat\text{-}Surong}$=1.85ppm) (see Table 2). By comparison, the average total phosphates and nitrate-nitrogen in Mananga River of Cebu Province (Flores and Zafaralla, 2012) was 2.15ppm and 2.78ppm.

Overall, copper levels in the four streams averaged at 0.42ppm, 70.80% of which was found in Camgat-Surong downstream (2.08ppm). However in Camgat-Surong upstream, Cu is below detectable limits (<0.002mg/L). Since natural copper pools are found in soil and softer parts of bedrock, the disturbance of the riparian soil may be the primary contributor to elevated Cu downstream. As Camgat-Surong drains to Boulevard, the Cu levels settled to low levels passing the water quality standard. Other areas with low Cu levels are found in upstream Alimit (0.002ppm), downstream Dinauyan (0.018ppm) and upstream Dinauyan (0.042ppm). According to the Pennsylvania State University Extension Service (Swistock et al., 2003), copper levels above 1.30mg/L may trigger severe stomach cramps and intestinal illnesses. Svobodova et al. (1993) reported that the permissible range of Cu in water for fish management is 0.001 to 0.01mg/L.

For iron, average content for all channels was 14.31ppm. Highest iron concentration (difference between site's loads) was also found in Camgat-Surong continuum at 77.79ppm. On the other hand, the lowest amount was in Alimit at 0.15. Similar to copper, the Fe levels in the Camgat-Surong may indicate that activities in the lower channel had greatly affected its heavy metal load. According to Kentuky's Water Watch (n.d.), aquatic life standard for iron is 1.00mg/L based on toxic effects. Only the upstream channels of Alimit and Camgat Surong and the Dinauyan channel are within acceptable limits for Fe. However, the WHO standards (2006, 2008) state that acceptable limits for Fe are 50mg/L in surface waters and 2mg/L for potable water.

Overall, the physico-chemical parameters at Camgat-Surong were the most significantly different compared to the other streams. In terms of salinity and calcium carbonate, the Dinauyan channel was significantly different among the rest of the sites. One plausible reason for this was the mixing of treated water from the adjacent treatment facility into the stream. Meanwhile, the high phosphorus measurements from Alimit versus other streams may be attributable to the farm inputs in nearby rice fields, vegetable farms and citrus orchards that dominate the riparian zone.

Based on the results of one-way MANOVA (Figure 2), there is a statistically significant difference in physico-chemical parameters among the four streams, $F(33, 118.551) = 25592.611$, $p < .0005$; Wilk's Lambda = 0.000.

Mercury in Water. While being regarded as an ordinary trace metal, mercury is regarded as an industrial biocide. For example, the Alken-Murray website states that Hg is "acutely toxic to marine organisms in the range of 3.5 to 1678ppm", and "may be toxic to marine organisms in the range of 0.1 to 2.0ppm". Mance (1987) reported that mercury

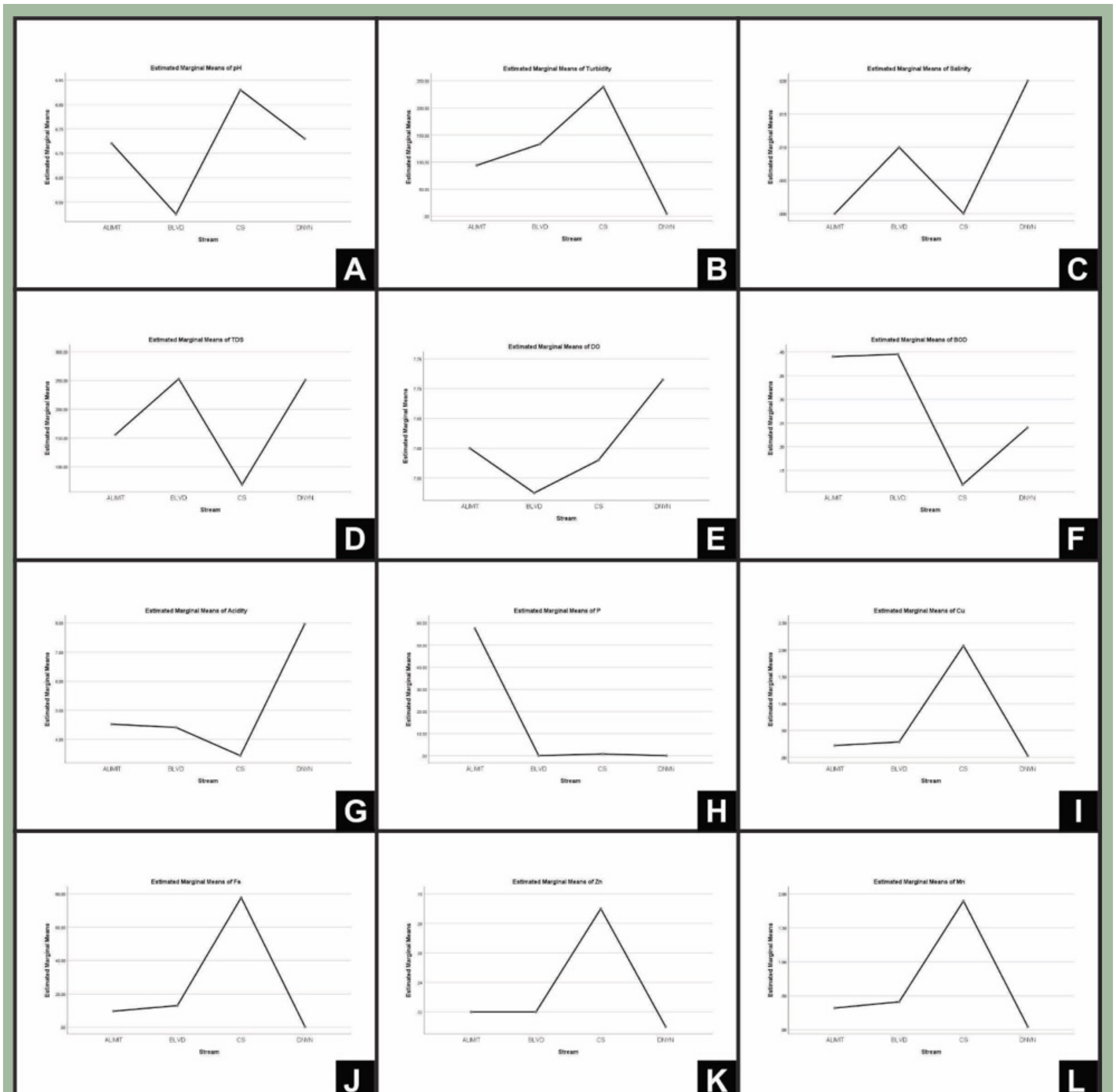

Figure 2. Visualization of Tukey HSD results as *post hoc* test for significant differences (one-way MANOVA) of Didipio streams' water physico-chemical analyte readings. A: pH; B: Turbidity; C: Salinity; D: Total Dissolved Solids; E: Dissolved Oxygen; F: Biological Oxygen Demand; G: Acidity, as $CaCO_3$; H: Phosphorus; I: Copper; J: Iron; K: Zinc; L: Manganese. MANOVA and Tukey HSD performed using SPSS v25.

poisoning on fish ranges at 1-30.00mg/L. Mercury (in water) measurements in the four streams are presented in Figure 3.

Levels of Hg in the four streams of Didipio ranged from 0.14 to 1.07 with the highest concentrations found in the upstream and downstream stations of Boulevard (Boulevard$_{down}$ =1.07pbb). However, the difference of 0.66 between the two sites (and given their proximity as sampling area) implies that discharge, sedimentation and other factors may have been contributing to the "sinking" of Hg as water flows downstream. Concentration of mercury further diminishes to about 0.26 pbb at Alimit$_{down}$. Lowest mercury levels were found in upstream channels of Alimit and Camgat-Surong.

Soil Characteristics

The riparian sections of Alimit contained the highest soil moisture, highest organic matter (OM=9.17%+5.38%), cation exchange capacity (CEC), and nitrogen (Table 3). These results may have been attributable to shade, forest/plant cover, as well as to the relatively stable and undisturbed streambank. The Camgat-Surong upstream, particularly the riparian area before stream branching, ranks next in terms of OM (OM$_{Camgat-Surong}$= 3.78%) and N (N$_{Camgat-Surong}$=0.17%). Of all the riparian zones, the upstream area of Camgat-Surong was most similar to Alimit especially on vegetation and physiognomy.

Cation exchange capacity is usually attributable to the soil's nutrient-holding capacity (e.g., K, Ca, Mg). In connection to the soil elements, CEC is predicated upon soil's clay and organic matter levels. Thus, clayey, undisturbed soils would have more CEC (and more minerals) than otherwise. According to an agricultural company, EcoChem (www.ecochem.com), CEC ranges from less than 5 to 35 meq/100g for agricultural type soils. In the four streams studied, Alimit riparian had higher CEC. The mean for Alimit was 36.93cmol/Kg compared to 15.5 cmol/Kg average of the other three streams. In consideration of CEC, assuming all other things equal, the disturbed riparian soils (by mining or agriculture regardless) could consequently lose its nutrient-holding capacity. The high CEC average in Alimit means that soils in streambanks are in a still-pristine state.

One-way MANOVA results indicate that there is a statistically significant difference in chemical characteristics of riparian soils among the four sites, F 21, 178.581) = 470.837, $p < .0005$; Wilk's Lambda = 0.000. *Post hoc* test (Tukey HSD) suggests that such characteristics (Figure 4) may be attributable to the general land use in the area. In almost all parameters, Alimit – a low-disturbed site for mining – is different from the highly disturbed areas (Boulevard and Camgat-Surong), as well as from mining-agricultural riparian zone of Dinauyan. Further, riparian soils directly affected by soil disturbance tend to be similar chemically.

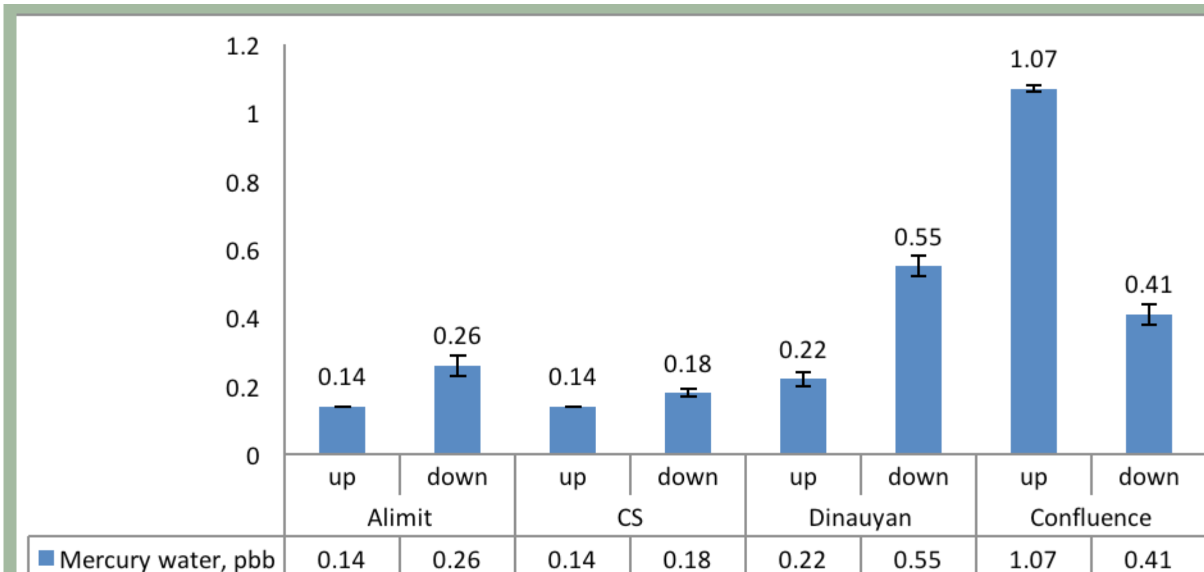

Figure 3. Mercury levels (March 2015) in four streams in Didipio. Error bars expressed as SD (max= ±0.38; min=±0.07).

Table 3

Soil Analyses in Four Sampled Riparian Sections in Didipio.

Parameters	Dinauyan		Camgat-Surong		Boulevard		Alimit	
	Up	Down	Up	Down	Up	Down	Up	Down
pH	7.23	6.77	6.30	6.44	6.76	6.04	5.47	5.55
Moisture, %	28.36	18.48	19.94	15.70	24.34	24.73	47.25	38.87
Available S, mg/Kg	142.29	97.39	51.86	3.91	15.74	29.24	25.48	7.72
CEC, cmol/Kg	17.88	12.12	14.66	14.59	18.71	15.04	39.66	34.20
TKN, (w/w)%	0.09	0.02	0.17	0.01	0.02	0.01	0.36	0.24
OM, (w/w)%	2.76	1.31	3.78	0.18	0.37	0.20	9.17	5.38
Water Soluble Chloride, meq/100g	0.11	0.16	0.44	0.19	0.24	0.11	0.56	0.22

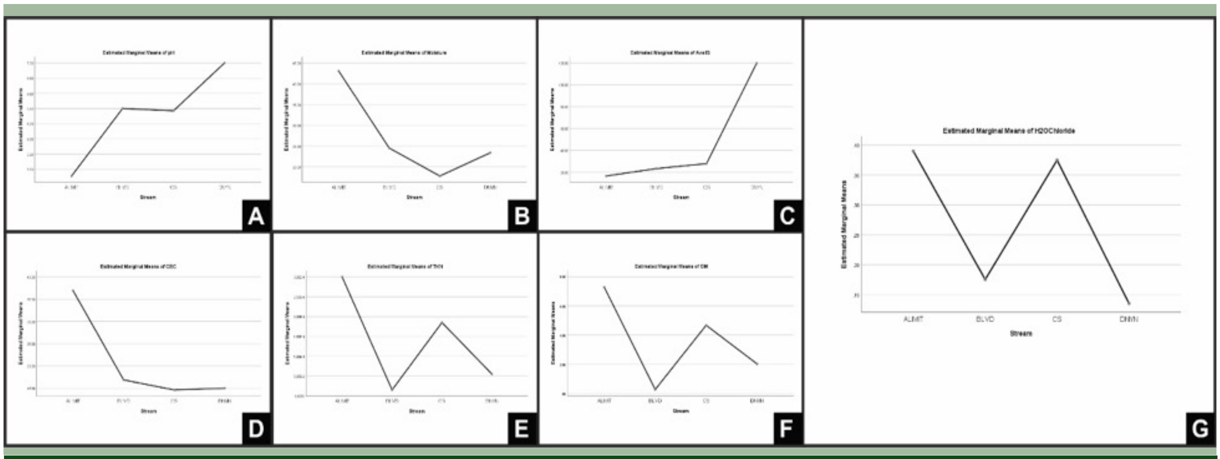

Figure 4. Visualization of Tukey HSD results as *post hoc* test for significant differences (one-way MANOVA) of Didipio streams' soil chemical analyte readings. A: pH; B: Moisture; C: Available Sulfur; D: Cation Exchange Capacity; E: Total Kjedahl Nitrogen; F: Organic Matter; G: H2O Chloride. MANOVA and Tukey HSD performed using SPSS v25.

Chemical Parameters of Sediment

The chemical parameters for sediments sampled in Didipio are presented in Table 4. Sediment iron and calcium were found to be the most abundant minerals, averaging 1,846.38 and 2,822.00mg/kg, respectively. Highest Fe loads in all upstream sites were recorded in Boulevard (4,087mg/Kg) while Dinauyan for downstream (1,897mg/Kg). For Ca, highest readings were found in Alimit (4,406mg/kg) and Dinauyan (4,663mg/kg). Half of Dinauyan's riparian zone (right side facing downstream) is a rehabilitated slope composed of settled boulders but atop it (especially at Dinauyan sample site), a set of open ponds which catches treated water is visible. This pond can readily spill into the Dinauyan stream during occasional overflows due to heavy rains. Given the high Fe and Ca values in the sediments at downstream Dinauyan, it can be argued that pond spillage may be the only element of large-scale mining (not the mining extraction per se) having a direct impact to the streams and its riparian areas.

In comparison, Fe, Cu, Zn, Mn, Ca and Na concentrations of substrate sampled in the water treatment area (large-scale mining property, part of Dinauyan) exceeded those of all other sites by an average of 51.12%. It had the lowest magnesium compared to the four streams (793.33%).

Table 4

Readings of Sediment Samples Taken From Four Streams And Riparian Sections in Didipio, Kasibu. "Pond" Refers to Open Treated Water Catchment at Water Treatment Facility of Large-Scale Mining Company in Didipio. Analysis Performed by University of the Philippines Los Baños Institute of Chemistry – Analytical Services Laboratory.

Metal (mg/kg)	Dinauyan		Camgat-Surong		Boulevard		Alimit		Pond (WTF)	Average
	Up	Down	Up	Down	Up	Down	Up	Down		
Fe	2250.00	1897.00	543.00	1413.00	4087.0	914.00	2532.0	1135.0	2535.00	1922.89
Cu	223.00	223.00	6.86	12.20	32.40	32.30	205.00	32.80	159.00	102.95
Zn	5.24	5.86	1.52	2.63	5.07	2.07	6.87	4.96	11.25	5.05
Mn	44.00	308.00	71.90	145.00	581.00	134.00	256.00	144.00	325.00	223.21
Ca	1334.0	4663.0	655.00	1700.0	2384.0	4334.0	4406.0	2650.0	9839.00	3551.67
Na	59.00	233.00	114.00	46.10	201.00	390.00	83.40	97.10	390.00	179.29
Mg	60.5	50.1	198	248	82	27	749	179	27	180.07

One-way MANOVA results showed that metal contents of streams' sediments are significantly different from one another, F (28, 286.261) = 632.669, p < .0005; Wilk's Lambda = 0.000. *Post hoc* test (Tukey HSD; Figure 5) suggests that Fe, Cu, Mn, and Mg content in Pond and Camgat-Surong sediments are generally different from rest of the sites. Specific to calcium and sodium, contents found in the Pond area are high compared to that of stream sediments since the Water Treatment Facility (where pond sediment comes from) reduces the acidity of the water used in gold separation (a process used by the company instead of conventional cyanide method), prior to release to the river.

Bio-available sulfur was highest in the Dinauyan stream, the upstream site with 142.29mg/kg and lowest in Camgat-Surong$_{down}$ (3.91mg/Kg). The average for all sites was 46.93mg/kg. On the other hand, water soluble chlorine was high in upstream stations in Alimit and Camgat-Surong. As a micronutrient at normal levels, the values of Cl- in the said sites, and the low concentration in the rest of streams may be interpreted in two ways. First, the current chlorine levels in these sites are due to agricultural reasons; and second, the chlorine levels are an indication that the riparian sections of streams adjacent to mining and residences have been altered.

Since there are no existing Philippine standards for soil minerals as contaminants, and given that no major reports of crop diseased by excess minerals in the area, it can be assumed that the sediment loads were still in tolerable levels for agriculture purposes.

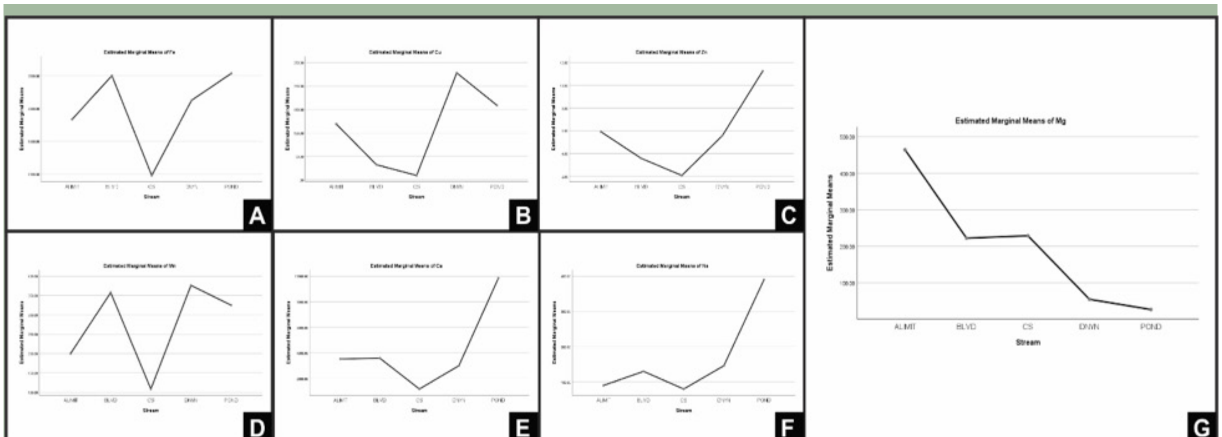

Figure 5. Visualization of Tukey HSD results as *post hoc* test for significant differences (one-way MANOVA) of metal content of sediments taken from four Didipio streams and the treated water pond at large-scale company operating in the area. A: Iron (Fe); B: Copper (Cu); C: Zinc (Zn); D: Manganese (Mn); E: Calcium (Ca); F: Sodium (Na); G: Magnesium (Mg). MANOVA and Tukey HSD performed using SPSS v25.

Interestingly, Hg in Alimit's soils is higher than the disturbed sites (except Boulevard), including the pond at water treatment area (Table 5). Hg levels was highest in Boulevard$_{down}$ while Alimit$_{down}$ had the second-highest. Camgat Surong$_{upstream}$ and treatment pond have lowest values at 134.84 and 142.02ppb, respectively. These result indicate the following: 1) that a highly efficient physical feature in the stream-riparian environment caused the arrest of sediments further downstream; 2) the pond area / water treatment facility had small impact on mercury levels in Dinauyan; and, 3) mercury levels in sediments along Dinauyan-Camgat-Boulevard-Alimit continuum may be coming from channels other than the Dinauyan section.

Like in water Hg, mercury in sediments/ soil may pose lethal effects. In particular, Hg is reported to be detrimental to the functioning of benthic organisms, spurring biomagnification and/or ecological backlash. Jaagumagi (1988) and Jaagumagi et al. (1989) have linked the decline of Gastropoda and Chironomidae in Ontario, Canada to Hg concentrations. In said studies, mercury levels exceeded Canada's freshwater Interim Sediment Quality Guideline by 500%.

Conclusions

Based on the parameters examined in this study, it can be deduced that the streams of Didipio are subject to varying degrees of contamination. The levels of physical, organic, and nutrient-type parameters suggest that presence of contaminants have been due to various anthropogenic factors nearby.

It was also observed that contaminants in upper portions of the stream continuum did not only converge/remain at the Boulevard (Didipio River) channel, but was also carried towards downstream in Alimit. Given the distance between Boulevard and Alimit, and the strong correlation between these sites, it is also plausible that there is other strong presence of contaminants in "unseen" parts of the stream channel.

Generally, waters from these streams are not advisable for human consumption. The least impaired waters are found in upstream sections of Alimit and Camgat-Surong, whereby only agriculture and land conversion are most evident human activities. While most soil and water parameters are generally below the toxic/lethal levels, the most affected stream was in downstream of Camgat-Surong. The strong presence of contaminants can be attributed to prevalence of riparian damage by slushing. Interestingly, direct impacts of large-scale mine extraction (i.e., tunneling, wastewater disposal) are not reflected in the most immediate water body (Dinauyan). Water treatment facility may still bring forth considerable adulteration of the stream especially during heavy downpour.

Nevertheless, in consideration of general morphology of the stream-riparian environments, the four streams studied can still be seen resilient to impacts of various land-uses. This is manifested in the normal DO, low mercury and undetected heavy metals. Proper rehabilitation of riparian channels and modification of land-uses can bring the waters to more pristine state.

Table 5

Mercury Levels of Stream Sediments Sampled in Didipio. Hg Level of Pond in Water Treatment Area Also Analyzed for General Comparison. SD Refers to Standard Deviation of Replicates (3).

Sampling Stations	Concentration, ppb				Average (per stream)
	Upstream	SD	Downstream	SD	
Dinauyan	239.22	25.47	184.22	8.81	211.72
Camgat Surong	134.84	9.08	317.27	16.19	226.055
Boulevard	217.71	19.88	445.2	13.5	331.455
Alimit	243.05	13.18	426.95	5.33	335.00
Pond (WTA)	142.02	2.34			
Average	**208.705**		**343.41**		**276.06**
Grand Average (w/o pond)	**231.23**		**Grand Average**		**242.38**

Acknowledgment

This study was part of author's Dissertation (PhD by Research Work - Forestry) supported financially by OceanaGold Philippines, Commission on Higher Education, and NVSU-Faculty and Staff Development Program. The author deeply extends gratitude to the following: Dr. Ramil Rodriguez and Dr. Marcelino Razalan Jr of NVSU-College of Forestry; Dr. Jesus Pozo, Dr. Arturo Elosegui and Dr. Aingeru Martinez of the University of the Basque Country (Vizcaya, Spain); the people of Didipio, Kasibu, NV; and BSU-REPO and this paper's reviewers.

References

AGHAM. (2014). Environmental Investigation Mission on the Impacts of Large Scale Mining in Nueva Vizcaya.

Allan, J.D. (2004). Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. Annual Review of Ecology, Evolution, and Systematics, 35(1), 257–284. http://doi.org/10.1146/annurev.ecolsys.35.120202.110122

Beder, S. (2006). Environmental Principles and Policies: an Interdisciplinary Introduction. University of New South Wales Press Ltd.

Bestre, E.C., Lumiquio, A.M., & Napaldet, J.T. (2018). Water Quality Assessment of Major River Systems in Benguet Province, Philippines. *Journal of Wetland Biodiversity* 8: 19-38.

Brosse, S., Grenouillet, G., Gevrey, M., Khazraie, K., & Tudesque, L. (2011). Small-scale gold mining erodes fish assemblage structure in small neotropical streams. *Biodiversity and Conservation*, 20(5), 1013–1026. doi:10.1007/s10531-011-0011-6

Chadde, J.S. (undated). Macroinvertebrates as Bioindicators of Stream Health. Lecture material for Michigan Technological University. Accessed at https://www.researchgate.net/file.PostFileLoader.html?id=55261832ef971370628b4581&assetKey=AS%3A273753366302735%401442279297014

Chakrabarty, D., & Das, S.K. (2006). Alteration of macroinvertebrate community in tropical aquatic systems in relation to sediment redox potential and overlaying water quality. *Int. J. Environ. Sci. Technol*. 2, 327–334 (2006) doi:10.1007/BF03325893.

Connolly, N. M., Crossland, M. R., & Pearson, R.G. (2004). Effect of low dissolved oxygen on survival, emergence, and drift of tropical stream macroinvertebrates. *Journal of the North American Benthological Society* 23(2): 251–270.

Dedieu, N., Rhone, M., Vigouroux, R., & Céréghino, R. (2015). Assessing the impact of gold mining in headwater streams of Eastern Amazonia using Ephemeroptera assemblages and biological traits. *Ecological Indicators* 52: 332–340. https://doi.org/10.1016/j.ecolind.2014.12.012

Department of Environment and Natural Resources. (1990). 34. Water Quality Standards. Administrative Order

Department of Environment and Natural Resources. (2016). Water Quality Guidelines and General Effluent Standards of 2016. Administrative Order 08.

Dumingyay, Jr. A.D. (2012). *Assessment of Mercury and Lead Contamination at Didipio River, Kasibu, Nueva Vizcaya*. Unpublished undergraduate thesis.

Fajardo, D.R.M., Seronay, R.A., & Jumawan, J.C. (2015). Aquatic macroinvertebrate diversity and physicochemical characteristics of freshwater bodies in Tubay, Agusan Del Norte, Philippines. *Journal of Entomology and Zoology Studies* 2015 3(5): 440-446.

FAO. (2003). Standards for Effluent Discharge Regulations. Effluent Discharge Standards. General Notice No. 44. of 2003. Accessed in: http://faolex.fao.org/docs/texts/mat52519.doc

Flores, M.J.L. & Zafaralla, M. T. (2012). Macroinvertebrate Composition, Diversity and Richness in Relation to the Water Quality Status of Mananga River, Cebu, Philippines. *Philippine Science Letters*. 5 (2)

GREENPEACE. (2007). The State of Water Resources in The Philippines.

Guinumtad, R.L. (2011). Assessment of the Stewardship Agreement Between the Provincial Government of Nueva Vizcaya and Land Managers of the Barobbob Watershed. *Meristem* 10(1): 22-32.

Heartsill-Scalley, T. & Aide, T.M. (2003). Riparian vegetation and stream condition in a tropical agriculture-secondary forest mosaic.*Ecological Applications* 13(1): 225–234. doi:10.1890/1051-0761(2003)013[0225:RVASCI]2.0.CO;2

Hilsenhoff, W.L. (1988). Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society* 7(1): 65-68. JSTOR.doi:10.2307/146 7832

Iwata, T., Nakano, S. & Inoue, M. (2003). Impacts of past riparian deforestation on stream communities in a tropical rain forest in Borneo. *Ecological Applications* 13(2): 461–473. doi:10.1890/1051-0761(2003)013[0461:IOPRD O]2.0.CO;2

Jaagumagi, R. (1988). The in-place pollutants program. Volume V, Part B. Benthic invertebrates studies results. Ontario Ministry of the Environment, Water Resources Branch, Aquatic Biology Section, Toronto.

Jaagumagi, R., Persaud, D. & Lomas, T. (1989). The in-place pollutants program. Volume V, Part A. A synthesis of benthic invertebrate studies. Ontario Ministry of the Environment, Water Resources Branch, Aquatic Biology Section. Toronto.

Kentuky Water Watch. (undated). Important Water Quality Measurements–Water Quality Parameters. Accessed in: http://www.state.ky.us/nrepc/water /wcparint.htm

Kondolf, G.M., Kattelmann, R., Embury, M., & Erman, D.C. (1996). Status of riparian habitat. In Sierra Nevada Ecosystem Project Final report to Congress: Vol. II, Assess (pp. 1009–1030). Retrieved from http://www.sierraforestlegacy.org/Resources/Conservation/FireForestEcology/ThreatenedHabitats/Aquatic/AquaticRiparian-Kondolf96.pdf

Luke, S.H., Luckai, N.J., Burke, J.M., & Prepas, E.E. (2007). Riparian areas in the Canadian boreal forest and linkages with water quality in streams. *Environmental Reviews* 15: 79–97. https://doi.org/10.1139/A07-001

Maglangit, F.F., Galapate, R.P., & Bensig, E.O. (2014). Physicochemical-assessment of the water quality of Bulacao River, Cebu, Philippines. *Journal of Biodiversity and Environmental Sciences*. 5(2): 518-525.

Maglangit, F.F., Galapate, R.P., & Bensig, E.O. (2014). Physicochemical-assessment of the Water Quality of Buhisan River, Cebu, Philippines. *International Journal of Research in Environmental Science and Technology*. Universal Research Publications. Available online at http://www.urpjournals.com

Mance, G. (1987). Pollution Threat of Heavy Metals in Aquatic Environments. London: Elsevier.

Manuel, R.P. (2010). Aquatic Macroinvertebrates as Indicators of Pollution in Barobbob and Nagsabaran Streams of Nueva Vizcaya Using Hilsenhoff Family-Level Biotic Index. *NVSU Research Journal*. 17(1&2).

Manuel, R.P., Bansuan, A.M., Pascua, R.L., Labatos Jr, B.V., Pasion, G.L., Managuelod, J., Cuidno, F.C., & Equiz, M.M. (2016). Biophysical Resources Assessment of the Addalam River System (Cagayan Valley Region), Philippines. International River Foundation (Philippines). Terminal Report.

McClain, M.E., & Cossío, R.E. (2003). The use of riparian environments in the rural Peruvian Amazon. *Environmental Conservation* 30(3): 242–248. https://doi.org/10.1017/S0376892903000237

Milner, A.M. & Piorkowski, R.J. (2004). Macroinvertebrate assemblages in streams of interior Alaska following alluvial gold mining. *River Research and Applications* 20(6): 719–731. https://doi.org/10.1002/rra.786

Mudd, G.M. (2007). Global trends in gold mining: Towards quantifying environmental and resource sustainability. *Resources Policy* 32(1-2): 42–56. doi:10.1016/j.resourpol.2007.05.002

National Economic Development Authority. (2010). Chapter 10 – Conservation, Protection and Rehabilitation of the Environment and Natural

Resources. Philippine Development Plan 2011-2016.

National Economic Development Authority. (2016). Philippine Development Plan 2017-2022

Ometo, J.P.H.B., Martinelli, L.A., Ballester, M.V., Gessner, A., Krusche, A.V., Victoria, R.L., & Williams, M. (2000). The effects of land use on water chemistry and macroinvertebrates rates in two streams of the Piracicaba river basin South-east Brazil. *Freshwater Biology* 44: 327-337. http://dx.doi.org/10.1046/j.1365-2427.2000.00557.x

Robillard, P.D., Sharpe, W.E., & Swistock, B.R. (2017). Water Tests: What Do the Numbers Mean? Extension Material. Pennsylvania State University Extension Service.

Sabater, S., Elosegi, A., Acuña, V., Basaguren, A., Muñoz, I. & Pozo, J. (2008). Effect of climate on the trophic structure of temperate forested streams. A comparison of Mediterranean and Atlantic streams. *The Science of the total environment* 390: 475-84. 10.1016/j.scitotenv.2007.10.030.

Shimabukuro, E. & Henry, R. (2018). Benthic distribution in small tropical lakes: The presence of macrophytes matters. *Tropical Ecology*. 59.

Sitzia, T., Picco, L., Ravazzolo, D., Comiti, F., Mao, L. & Lenzi, M. (2015). Relationships between woody vegetation and geomorphological patterns in three gravel-bed rivers with different intensities of anthropogenic disturbance. *Advances in Water Resources* 93. 10.1016/j.advwatres.2015.11.016.

Svobodová, Z.; Lloyd, R.; Máchová, J.; Vykusová, B. (1993). Water quality and fish health. EIFAC Technical Paper. No. 54. Rome, FAO. 59 p.

Swistock, B., Sharpe, W.E. & Clark, J. (2003). Water Tests: What Do the Numbers Mean? University Park, Pa.: The Pennsylvania State University.

Tabaquero, A.L., Del Rosario, F.Y.G., Addauan Jr, J.P.A., Villanueva, H.T., Balonquita, M.C., Saludarez, M.U. (2017). Physico-Chemical, Biological and Anthropogenic Related Attributes of Cagayan River Sub-tributaries in Nueva Vizcaya, Philippines. *International Journal of Scientific Engineering and Research*. 5(2): 89-95.

Thompson, L.C. & Larsen, R. (2004). Fish Habitat in Freshwater Streams. Reference Sheet (Publication 8112). University of California - Division of Agriculture and Natural Resources

United States Environmental Protection Agency (U.S. EPA). (1989). Overview of selected EPA regulations and guidance affecting POTW management. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA 440/69-89/008.

UPLBFI. (2015). Ecological Assessment and Monitoring of Biodiversity in Terrestrial and Aquatic Ecosystems in Didipio Gold-Copper Project, Nueva Vizcaya, Philippines

Vannote, R.L., Minshall, G.W. Cummins, K.W., Sedell, J.,& Cushing, C.E. (1980). The River Continuum Concept.(N.R. Andersen & B. J. Zahuranec, Eds.) *Canadian Journal of Fisheries and Aquatic Sciences* 37(1): 130-137. NRC Resaerch Press. Doi:101139/f80-917

Williamson, J.E., & Carter, J.M. (2001). Water quality characteristics in the Black Hills area, South Dakota: U.S. Geological Survey Water-Resources Investigations Report 01-4194, 196 p. accessed in: https://pubs.usgs.gov/wri/wri014194/pdf/wri014194.pdf

World Health Organization (WHO). (2006). Guidelines for drinking-water quality [electronic resource] : incorporating first addendum. Vol. 1, Recommendations. – 3rd ed.

World Health Organization (WHO). (2008). Guidelines for drinking-water quality [electronic resource]: incorporating 1st and 2nd addenda, Vol.1, Recommendations. – 3rd. ed. Geneva. Accessed in: http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf and http://www.who.int/water_sanitation_health/dwq/fulltext.pdf

Zimmerman, M.C. (1993). The use of the biotic index as an indication of water quality. Pages 85-98, in Tested studies for laboratory teaching, Volume 5 (C.A. Goldman, P.L.Hauta, M.A. O'Donnell, S.E. Andrews, and R. van der Heiden, Editors).