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**Working Paper**

## Case studies on the water use of large scale mining in the Philippines

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## UP School of Economics Discussion Papers

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### **Case Studies on the Water Use of Large Scale Mining in the Philippines**

by

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## Case Studies on the Water Use of Large Scale Mining in the Philippines\*

C. Magno<sup>†</sup> and J. Morillo<sup>††</sup>

### Abstract

Water use is one of the most critical sustainability issues of the mining sector. It is important in each stage of the mining life cycle. The water use of the mine can introduce significant ecological changes. It can compete with the water use of households living in the community and other economic activities in the area. We look at the water use of two large scale mining companies and communities in Didipio, Nueva Viscaya and Taganito, Surigao del Norte. We compare water extraction with various factors such as mineral production, land use, rehabilitation, mine development, and environmental concerns. Based on our initial findings, the rate of water extraction of the two mines is significantly correlated with the level of mine development, rehabilitation and pollution control. In both cases, household consumption plays a minimal role in driving the demand for water.

JEL Codes: Q56, Q58, Q59

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\* The production of this paper was supported by the Natural Resource Governance Institute (NRGI). The views and opinions expressed here are those of the authors and do not in any way represent the views of the NRGI or the UP School of Economics.

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# Case Studies on the Water Use of Large Scale Mining in the Philippines\*

C. Magno<sup>†</sup> and J. Morillo<sup>††</sup>

## Introduction

Water resources play a vital role in the economic activity of local communities. It is also an essential input to mining. Water use is one of the most critical sustainability issues of the mining sector (Bridge, 2004). It is important in each phase of the mining operation life cycle (Australian Centre for Sustainable Mining Practices, 2011). Water is used for processing and transport of ore and waste, minerals separation, dust suppression, washing of equipment and human consumption (Kemp, Bond, Franks, & Cote, 2010). The industry makes significant investment in water infrastructure (Ossa-Moreno et al., 2018).

At the same time, the water use of the mine can introduce significant ecological changes. Kemp et al. (2010) identified the following impacts based on existing literature. The high demand for surface and underground water competes for access with other water users including households and other industries. This can happen even in areas that benefit from high average rainfall due to local and punctual water scarcity. Failure of waste and wastewater dams and direct disposal into water bodies can have devastating effects on local water endowments of communities. Landscape transformation due to mining can also affect waterways and ground water. Acid and metalliferous drainage can also affect water endowments when minerals associated with ore bodies decompose in the surficial environment. Mining operation can interrupt natural water cycles.

Mining activities operate in a variety of circumstances that benchmarking for efficient water use becomes very challenging (Northey, Mudd, Werner, Haque, & Yellishetty, 2019). The acceptable level of water use is influenced by many factors such as the hydrological and climate context, the physical and geochemical nature of the ore being mined, topography and the regulatory environments, among others (Northey et al., 2019). For example, declining ore grade is associated with higher water use for production (Mudd, 2008). With declining quality of ore, the impact of mining on water resources and sustainability is significant (Mudd, 2008).

The significant impacts of water use not just in mining operation but to communities and other industries necessitate the correct measures of costs and benefits of water use in their operation (Ossa-Moreno et al., 2018).

This study aims to estimate the impact of water utilization of two operating large-scale mining companies in the Philippines to the host communities. The biggest user of water in the country is the hydropower sector, followed by irrigation, industry and municipal use (Alikpala & Ilagan, 2018 citing National Water Resources Board). However, most studies focus on the impact of irrigation and agricultural sector on water. There are limited studies on the impact of mining on water resources, particularly the supply of water. We model the impact of water consumption of mining companies based on the rate of extraction and replenishment, identify areas affected by water consumption using existing climate and land use data and its short term and long term impact to the water use of local communities, as well the local industrial and agriculture sectors. The study utilized data that are publicly available.

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## Regulation of water use in the Philippines with respect to Mining<sup>1</sup>

The Water Code of the Philippines (Presidential Decree 1067, as amended), governs the appropriation and utilization of waters in the country ("Water Code of the Philippines," 2005). The Code allows for the use of water for industrial purposes including mining. Water permits are acquired from the National Water Resources Board. Mining being an environmentally critical project is required to submit an Environmental Compliance Certificate (ECC) to apply for water permit for industrial use.<sup>2</sup>

Applications for water permit need to pay a filing fee which currently is Php 7,200 (about USD 140.70) for industrial use. The water charges for industrial use are as follows (NWRB, 2015):

Withdrawal Cost/LPS (in PhP)				
Base Cost	Not more than 10 lps	More than 10 lps but not exceeding 50 lps	More than 50 lps but not exceeding 7,000 lps	more than 7,000 lps
5,000 (97.71 USD)	12.30 (0.24 USD)	18.95 (0.37 USD)	24.55 (0.48 USD)	30.55 (0.60)

The Code allows the board to revise the water fees or charges or impose special water rates given the following consideration:

- Intended use of water
- Quantity/rate of water withdrawal vis-à-vis other users taking into account the water bearing potential of the source;
- Environmental effects;
- Extent to which water withdrawal will affect the source; and
- Development cost of bringing water from the source.

The regulatory board may also decide to impose raw water charges based on the maximum volume of water that may be withdrawn using the facilities installed or on the actual volume withdrawn as reflected in the water abstraction meter in lieu of the existing water extraction charges.

The law specifies conditions that are attached to the permit. With respect to monitoring, the permittee is required to allow the Board inspectors/investigators access to the source at any time upon notice to

<sup>1</sup> This section does not cover the regulation of water discharge

<sup>2</sup> The permit for industrial use requires the following:

- Proof of land ownership of, legal title to, or right to use, the property on which the water source is situated;
- Certificate of registration from relevant agencies;
- Vicinity Map/location plan with scale 1:10,000 or 1:50,000 showing the exact location of the point of diversion;
- Brief description of the project stating among others, how water will be used, amount of water needed, etc.
- Well drilling data (in case of existing groundwater source);
- Environmental Compliance Certificate (for projects considered as Environmentally Critical Projects or projects located in Environmentally Critical Areas) or Certificate of Non-Coverage from DENR-Regional Office;
- Such other documents that may be required by the Board.

monitor compliance with the terms and conditions imposed in the permit. The permittee is also required to submit to the Board quarterly records of water withdrawal from the source.

Water recycling is not required for mining operations. There are no currently no data disclosure from the government on the water use of mines.

### Background

This study investigates the impact of mining activity on water resources in two operating large-scale metallic mines. The first study area is the Didipio Mine of the Oceana Gold Philippines Incorporated (OGPI, a subsidiary of the Oceana Gold Corporation), a copper-gold mine located in the disputed Barangay Didipio in Kasibu, Province of Nueva Vizcaya (Figure 1). This is in the northern part of the island of Luzon. The second study area is the Taganito Mine of the Taganito Mining Corporation (TMC, a subsidiary of Nickel Asia Corporation), a nickel-laterite mine situated at Barangay Taganito, Claver, Surigao del Norte (Figure 2a,b). This is in the southern part of the Philippines.

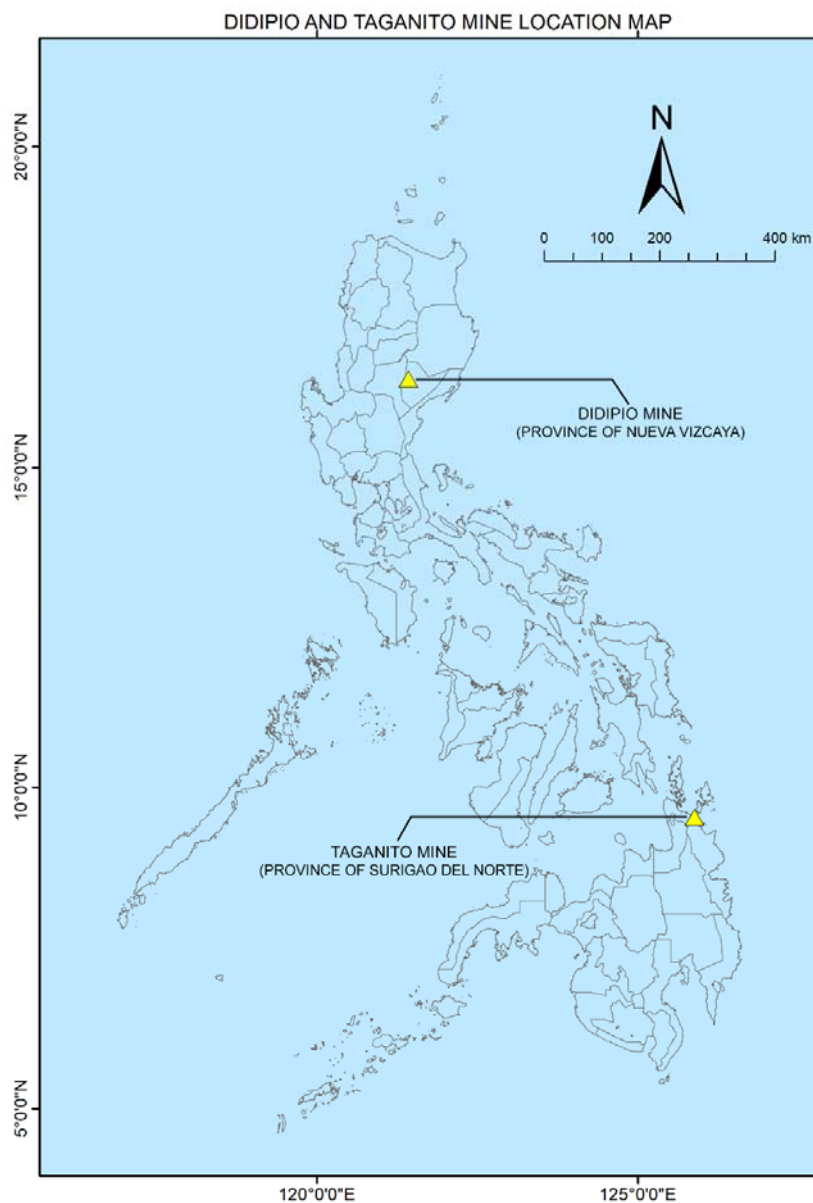


Figure 1. Location of the Didipio and Taganito mines

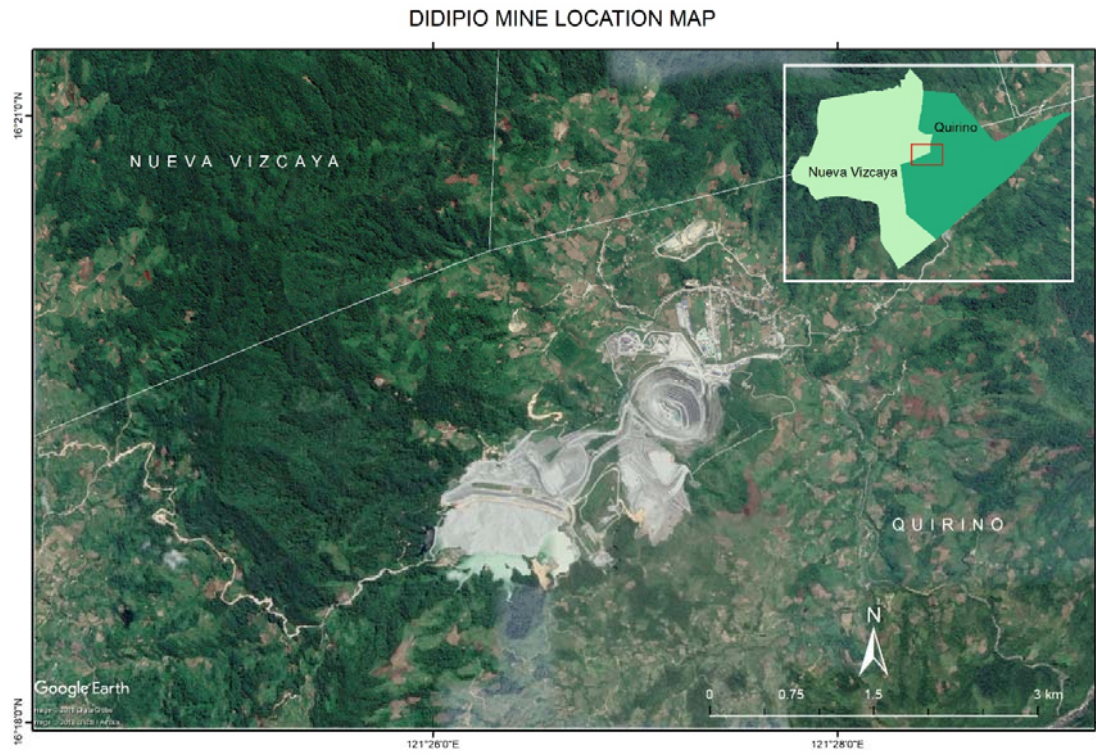


Figure 2a. The Oceana Gold copper-gold mine in Barangay Didipio, Nueva Vizcaya. Source: Google Earth

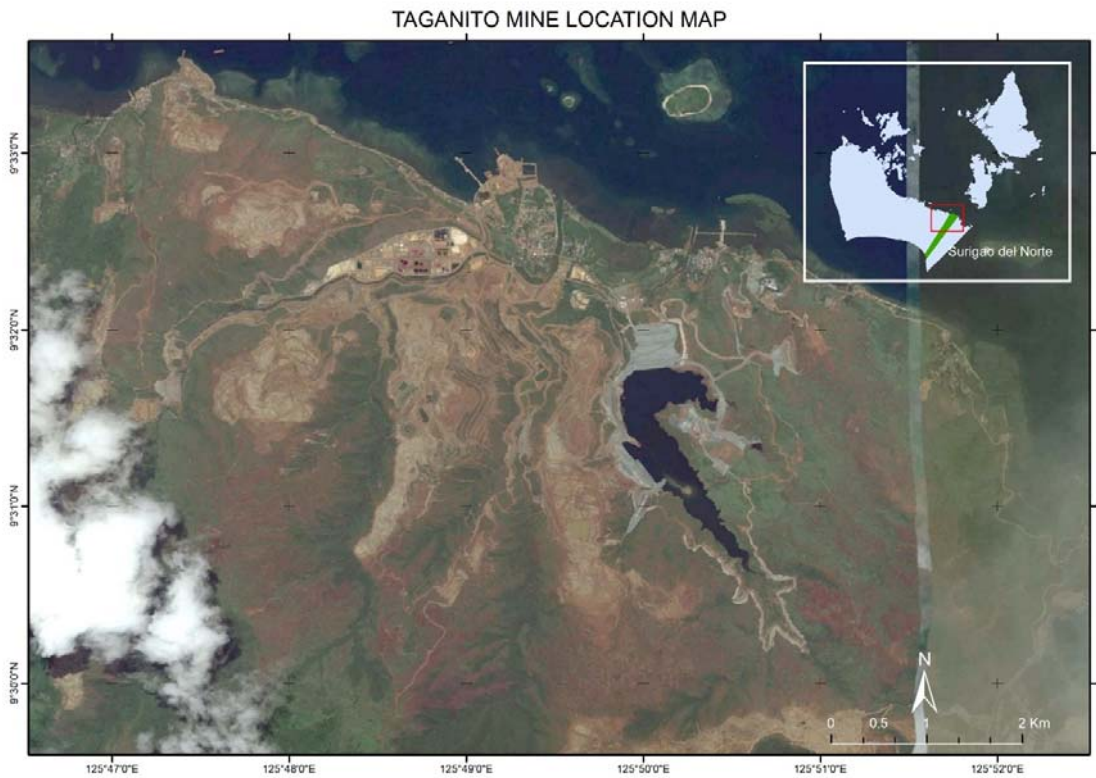


Figure 2b. The Taganito Mine in Claver, Surigao del Norte. Source: Google Earth

The Didipio Mine is a 11,500- hectare copper-gold mine operating under a Financial or Technical Assistance Agreement (FTAA)<sup>3</sup>. Acquired by OGPI in 1994, the mine began full-swing development in 2011. The company reported its first commercial gold production in April 2013, and in 2017 it shifted from open-pit to underground mining (long hole open stoping with cemented paste backfill). The disturbed area currently stands at 393.5 hectares and its life is expected to end by 2032 (Oceana Gold Corporation (OGC), 2017a)

The Taganito Mining Corporation (TMC), on the other hand, is a 4,900- hectare open pit nickel laterite mine within the Taganito Special Economic Zone. It is a subsidiary of the Nickel Asia Corporation (65% owned) and has been governed by the terms of a Mineral Processing and Sharing Agreement (MPSA)<sup>4</sup> since 2008 (Nickel Asia Corporation (NAC), 2016).<sup>5</sup> The disturbed area is currently at 2,079 hectares and mine life is expected to last until 2034 when its MPSA also expires (Nickel Asia Corporation (NAC), 2014, 2017).

### *Water supply in the Philippines*

The Philippines' annual total renewable freshwater available per year is about 146 billion cubic meters of which 86 percent is surface run-off and the remainder is below the ground (Alikpala & Ilagan, 2018 citing the National Water Resources Board). The water resources across regions are uneven, with some regions enjoying more water resources than others. The water availability per capita is about 1,553 m<sup>3</sup>/year, which is below the international "water stress" threshold of 1,700m<sup>3</sup>/year and nearing the "water scarcity" threshold of 1,000 m<sup>3</sup>/year (Alikpala & Ilagan, 2018). Alikpala and Ilagan (2018 citing a JICA study) that projected four of the 12 water resource regions to experience water deficits. These include Regions 2, 3, 4, and 7. Region 2 hosts 2 large scale mining projects including the Didipio Mine.

### *Climate and Geology*

The climate of the Philippines is typical of a tropical, near-equatorial region. It is dominated by interchanging wet and dry seasons heavily influenced by ocean currents and trade winds. Its climate and weather systems are affected by prevailing conditions in the West Pacific Ocean. Annually, the Philippines experiences an average of 20 typhoons, monsoon winds from the northeast (Amihan) and southwest (Habagat) as well as seasons of drought (El Nino) and deluge (La Nina) which dictate the country's hydrologic cycle (Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA), undated).

The Modified Coronas classification (Figure 3) is a regional index used by PAGASA to segregate regions in the country into four climate types based on the average amount of rainfall received over a period (PAGASA, undated b). The figure below shows the differences between each of the climate types based on the Modified Coronas classification. The provinces of Nueva Vizcaya and Surigao del Norte belong to climate types 3 and 2, respectively. The differences in climate type are reflected by the rate and amount of available surface and groundwater resources at the Didipio and Taganito Mines, as will be shown later.

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<sup>3</sup> This agreement allows 100 percent foreign equity participation/ownership. The FTAA's require the approval of the President while the other types of contracts may be approved by the Secretary of the Department of Environment and Natural Resources.

<sup>4</sup> The Government grants the contractor exclusive right to conduct mining operations within a contract area and share in the gross output. The contractor provides the financing, technology, management and personnel necessary for the implementation of this agreement. Foreign ownership cannot exceed 40 percent under this agreement.

<sup>5</sup> The activity of TMC is limited to mining the nickel ore. Nickel ore extraction and processing is conducted by the Taganito High-Pressure Acid Leaching Plant (THNC), a separate subsidiary of the Nickel Asia Corporation.



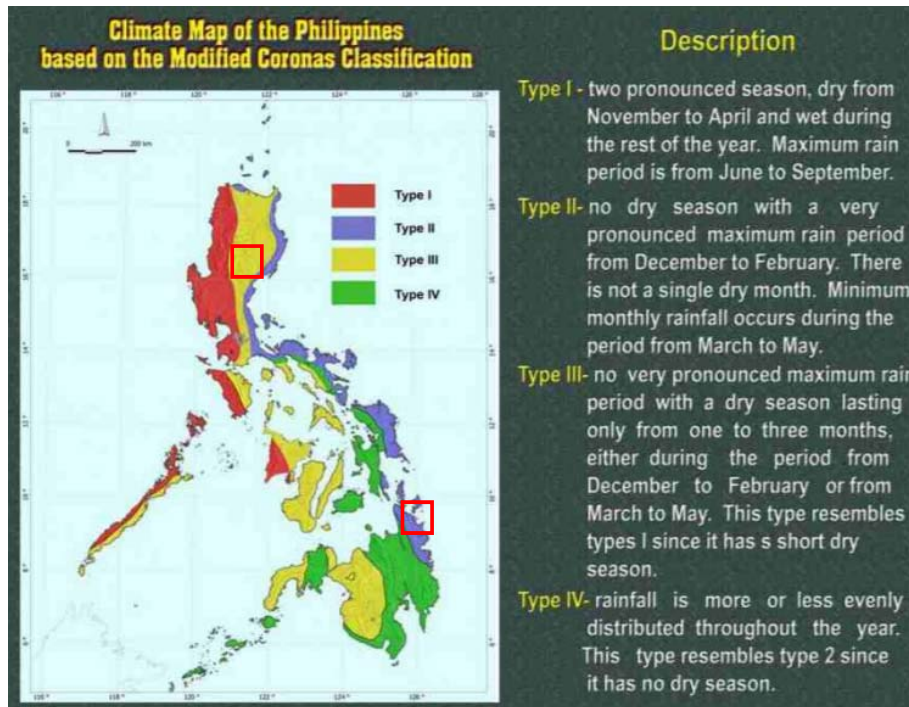


Figure 3. The Modified Coronas Classification of Philippine Climate, showing the locations of the study areas (red boxes). Figure taken from PAGASA.

Apart from prevailing climate conditions, the geology of an area influences the availability of surface and groundwater. Certain rock types such as sedimentary units (e.g. sandstones, limestones, volcanic breccia) are generally permeable, and hence allow easy recharge of groundwater. On the other hand, crystalline and compacted rocks such as volcanic, plutonic, and metamorphic rocks are nearly impermeable and obstruct groundwater recharge, permits more water to flow on the surface as runoff.

Water flow through soil, on the other hand, is mainly controlled by the grain size of each soil particle. Groundwater recharge is generally more favorable with coarse (sandy-gravelly) and permeable soils, while runoff is dominant with clayey and silty soils (Scesi & Gattinoni, 2009).

The geology at the Didipio Mine consists of volcanic rocks and breccia (sedimentary) intruded by alkalic rocks which are responsible for the gold and copper mineralization (Oceana Gold Corporation (OGC), 2017a). These types of rocks are generally moderately to poorly permeable, making groundwater recharge and movement difficult. The presence of fractures within rocks increases the permeability with fractures serving as conduits for groundwater recharge and discharge that usually take the form of springs (Scesi & Gattinoni, 2009).

Nickel laterites, on the other hand, are associated with the weathering of ultramafic rocks formed within the Earth's lower crust to the upper mantle, several tens to hundreds of kilometers deep within the oceans. Nickel enrichment in the soil (laterite) profile is a result of downward migration of nickel towards the bed rock (Evans, 1993).

### Scope and Limitations

Analyzing the impact of mining activity on water resources requires an estimation of water resources in the two study areas. Using publicly available climate from PAGASA and the Japan Meteorological Agency (JMA) and stream gauging data from the Department of Public Works and Highways, we calculate the potential amount of water available by estimating the amount of precipitation, evapotranspiration, runoff, and groundwater recharge in the watersheds where the mines are located.

Once an estimate of the amount (volume) of water resources is available, we compare water extraction<sup>6</sup> patterns between the two mining areas to determine factors that influence the mines' water extraction, and if these adversely affect the water supply in host communities. We consider several mining-intrinsic variables that potentially affect water extraction, such as production, mine development (disturbed areas), environmental spills, pollution control, and expenditure for rehabilitation environmental protection. Meanwhile, population growth and annual water extraction per capita are modeled to determine whether water supply for local households are threatened.

Data availability, resolution, and consistency are the primary limitations of the study. Due to lack of public disclosure and accessibility of data particularly on climate, land use, and water consumption by host communities, some of the raw data are estimated or obtained from international agencies (such as the JMA and NASA) and poses problems related to the resolution. Likewise, data accessibility and consistency of reports from private companies also pose additional challenges on the study.

The scope of analyses on the possible effects of water extraction is limited to watersheds within the host communities (i.e. Barangay Didipio and Barangay Taganito). Hence, the results are geared towards developing policies specific for mine-hosted communities. However, results may also serve as guide to improve existing national policies on water resources conservation and management.

The analyses are also limited to the local population but may be extended to other sectors, especially agriculture which is largely dependent on irrigation.

The water discharge of the mines and their effects on water quality and ecology are also not discussed as these require strategic and long-term monitoring as well as careful sampling and laboratory analyses.

### Data and Methods

To determine whether mining causes over-extraction or permanent depletion of water, the study estimates available surface and groundwater, as well as water lost by evaporation and plant transpiration (collectively evapotranspiration). The river basin approach was used to estimate surface and groundwater availability. The approach calculates the water balance in watersheds belonging to the same climate type under the assumption that climate patterns are consistent (Fetter, 2001; Ly, Charles, & Degre, 2013; Nwaogazie, Ologhadien, Uba, & Bovwe, 2018). Equation 1 describes water balance equation:

$$P_{it} = R_{it} + G_{it} + E_{it} \quad (1)$$

Where

$P_{it}$	Average precipitation in area $i$ in year $t$ ( $m^3/year$ )
$R_{it}$	Runoff or stream water volume of area $i$ in year $t$ ( $m^3/year$ )
$G_{it}$	Groundwater recharge of area $i$ in year $t$ ( $m^3/year$ )
$E_{it}$	Evapotranspiration rate ( $m^3/year$ ), combined amount of water absorbed by plants and the water

<sup>6</sup> "Water extraction" refers to the volume of water taken from either surface or groundwater sources, which may have been either used or discarded by the company.

that goes back to the atmosphere as water vapor

A watershed and drainage network model of the study areas were generated from a Digital Elevation Model (DEM) processed using the ArcMap 10.4 application. Using the area measuring tool of ArcMap 10.4, we find that the area of watershed in Didipio Mine is 119.56 km<sup>2</sup>, while the area of the watershed in Taganito Mine is 33.57 km<sup>2</sup>

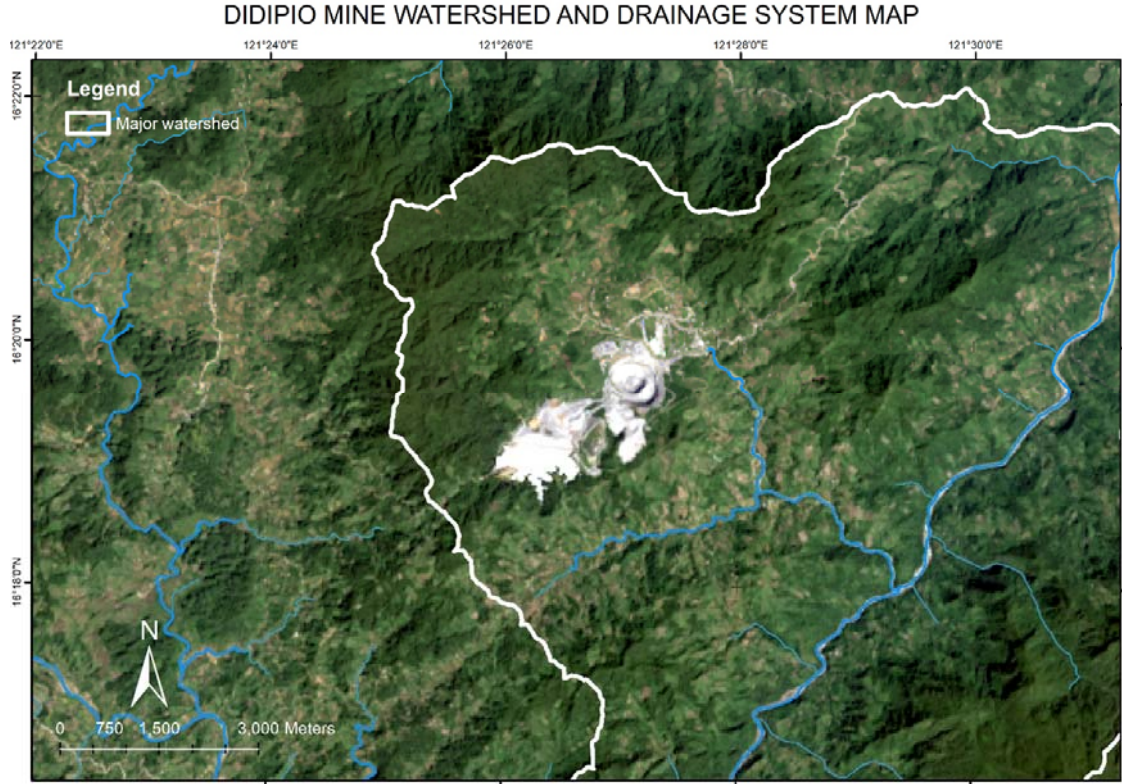




Figure 3. Watershed and drainage network model for (a) Didipio Mine and (b) Taganito Mine. Source: NASA Landsat 8

*Estimation of Water Resources*

We calculate average annual precipitation using the sum of 10 to 30-year monthly average rainfall from the JMA and PAGASA published through the US National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration (NOAA), 2019). In the absence of a weather station in the study area, we rely on data from the closest weather station. The figures below show the monthly rainfall averages for the stations located in Barangay Didipio, Nueva Vizcaya (2009-2018 JMA data) and at Surigao City (2000-2018 PAGASA). The sum of the monthly averages is 2041 mm for Didipio and 2804 mm for Surigao City.

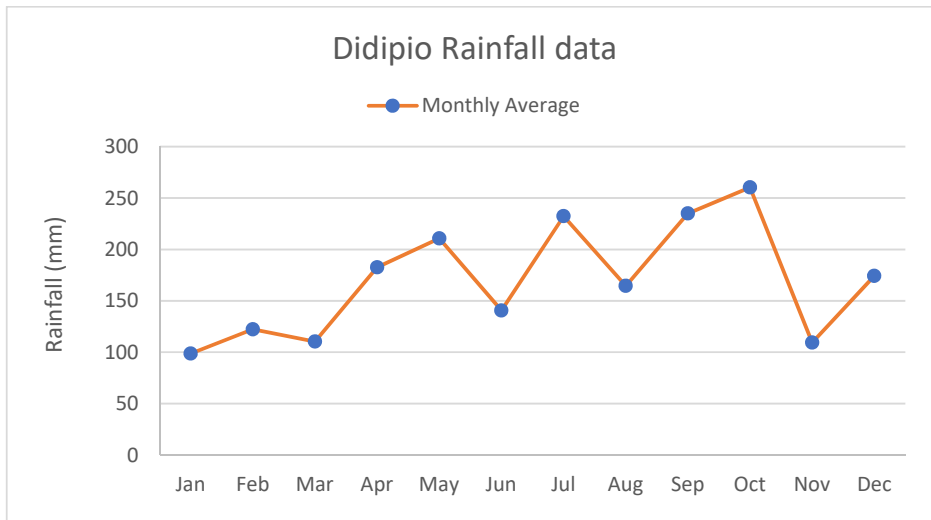


Figure 4. Monthly rainfall averages for (a) Barangay Didipio, Kasibu, Nueva Vizcaya. Source: PAGASA

Source:

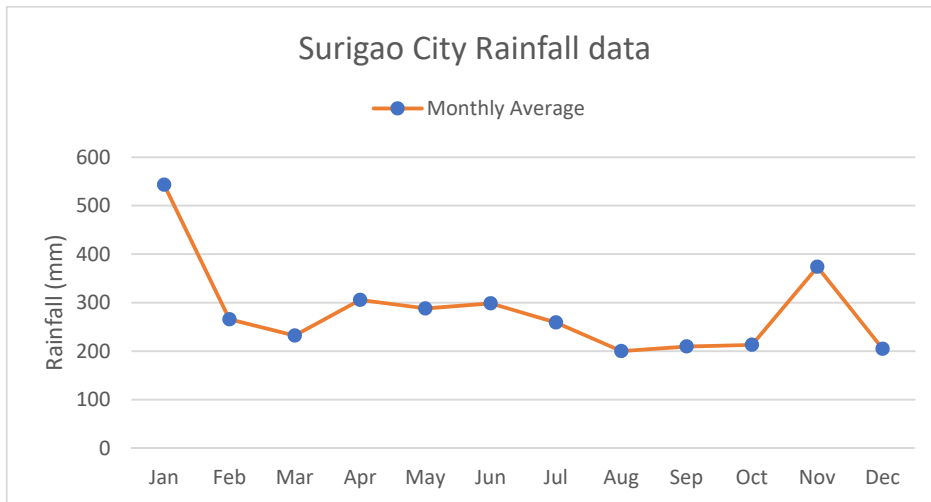


Figure 5. Monthly rainfall averages for Surigao City, Surigao del Norte. Source: PAGASA

The total precipitation a watershed receives in a year is then calculated as the product of the average annual precipitation and the area of the watershed (Fetter, 2001):

$$P_{it} = \frac{mm}{year} \times \frac{1m}{1000mm} \times 119,561,511.472 m^2 = 244,025,044.91 \frac{m^3}{year} \text{ for Didipio Mine } (2)$$

Applying the same equation for Taganito Mine, we obtain a figure of 93,996,000.00 m<sup>3</sup>/year in precipitation.

We determine surface runoff, the water that goes to streams, using discharge records from nearby stream gages<sup>7</sup>(Department of Public Works and Highways (DPWH), 2016). Mean monthly discharge data are ranked (with the highest entry at rank 1 and the lowest rank n) and the Annual Exceedance Probability (AEP) was calculated using Equation 3:

<sup>7</sup> Stream discharge records are taken from the Baluarte River (2010-2017) and Surigao River (1990-2010) gaging stations of the Department of Public Works and Highways.

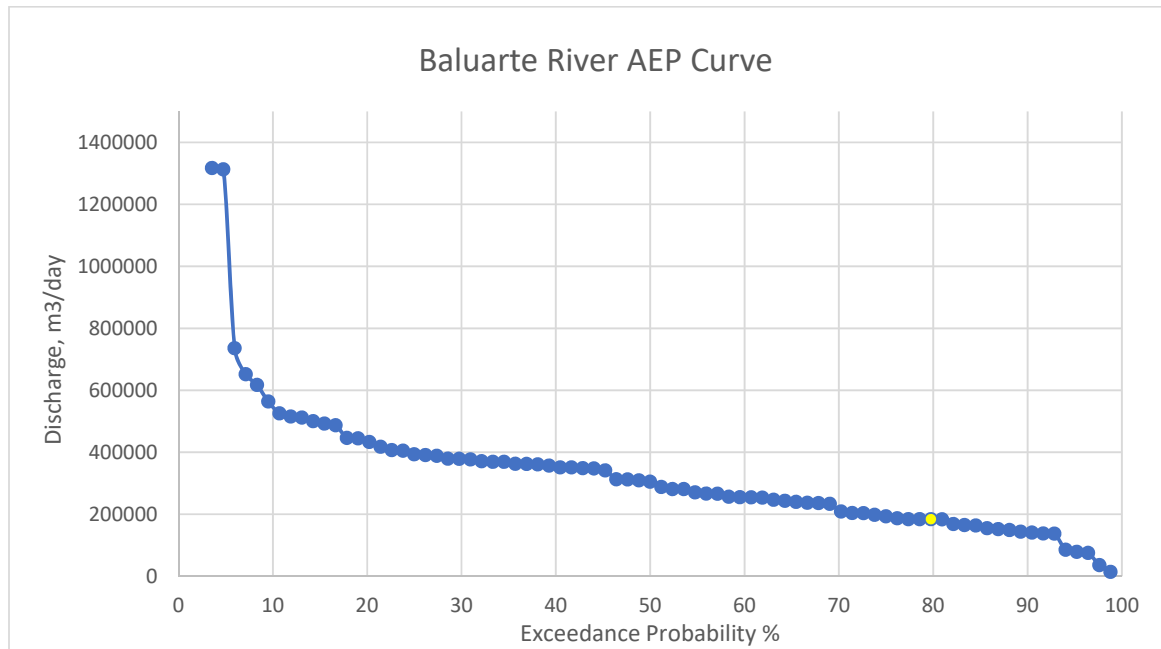
$$AEP = \left(\frac{m}{n+1}\right) * 100 \quad (3)$$

Where:

<i>m</i>	Rank of the discharge event in n records
<i>n</i>	Total number of discharge records

The AEP is a measure of the probability that rainfall or a discharge event may occur and be surpassed within one year (McCuen & Levy, 2000; Nwaogazie et al., 2018; Painter, Heimann, & Lanning-Rush, 2017). Furthermore, the corresponding discharge value to an AEP is called the *dependable flow*, or the volume of water by which a certain AEP value may exceed. As a standing policy of the National Water Resources Board<sup>8</sup>, a requirement of at least 80% dependable flow is needed to ensure that the extraction or use of stream water does not adversely affect the environment (National Water Resources Board (NWRB), 2013).

In the absence of a stream gage data, a proxy site (belonging to the same climate type) is used to calculate for a stream’s AEP and dependable flow. The watershed transposition method utilizes the discharge data of one stream. The AEP and the dependable flow is calculated by rationalizing the size of the proxy watershed to the watershed of interest (McCuen & Levy, 2000; Nwaogazie et al., 2018; Painter et al., 2017)The figures below show the AEP curves for two proxy streams: the Baluarte River watershed in Carranglan, Nueva Ecija (proxy for Didipio Mine) with an area of 419 km<sup>2</sup> and Surigao River watershed in Surigao City, Surigao del Norte (proxy for Taganito Mine) with an area of 85 km<sup>2</sup>.



<sup>8</sup> National Water Resources Board Resolution no. 030613, Sections 3 a-c

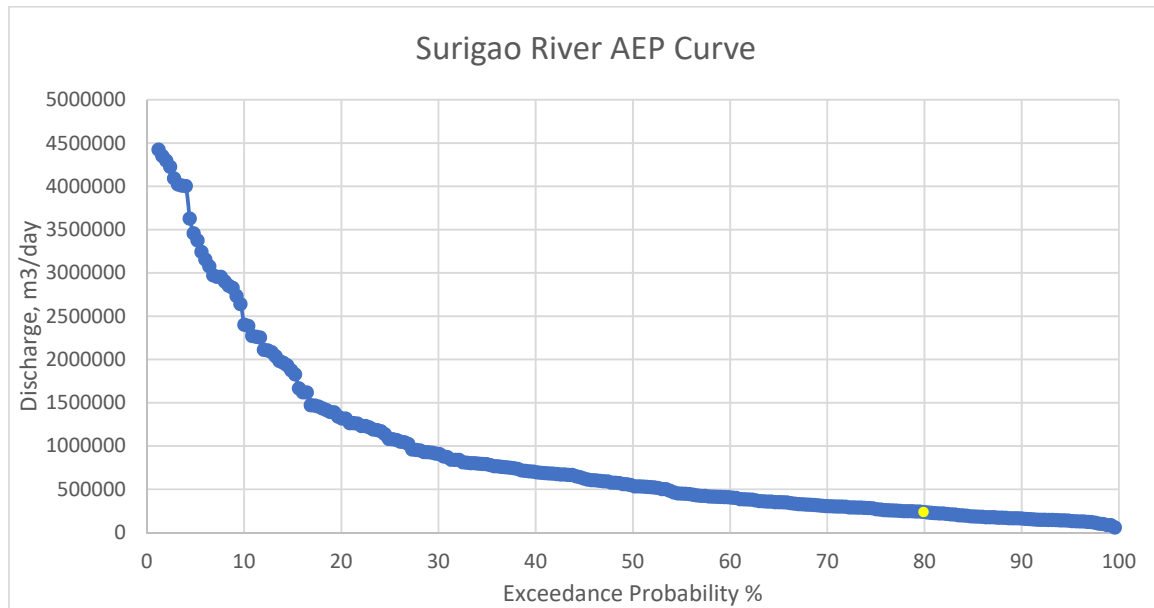


Figure 5. Annual Exceedance Probability curves showing AEP 80 for (a) Baluarte River in Carranglan, Nueva Ecija and (b) Surigao River, Surigao City, Surigao del Norte. Stream gaging data obtained from Department of Public Works and Highways.

Using the watershed area for the Didipio Mine (119 km<sup>2</sup>) and the dependable flow at AEP 80 for Baluarte River (183,168 m<sup>3</sup>/day), we obtain Equation 4:

$$R_{it} = \frac{119 \text{ km}^2}{419 \text{ km}^2} \times 183,168 \frac{\text{m}^3}{\text{day}} \times \frac{365 \text{ days}}{1 \text{ year}} = 19,077,187.64 \frac{\text{m}^3}{\text{year}} \quad (4)$$

The same method was applied to Taganito Mine watershed with an area of 33.57 km<sup>2</sup>. Using the AEP 80 for Surigao River with a dependable flow of 230,256 m<sup>3</sup>/day and an area of 85 km<sup>2</sup>, we obtain 33,192,215.07 m<sup>3</sup>/year.

For groundwater recharge computation, the Meyboom Method is employed (Fetter, 2001). This method uses weekly or monthly average stream discharge of at least two consecutive years to determine periods of baseflow recessions. These periods signify periods when summer stream levels drop below the water table and ends when the first storm flood is recorded. A dashed line is drawn at the base of the first recession to the base of the last recession prior to storm flood (Figure 6).

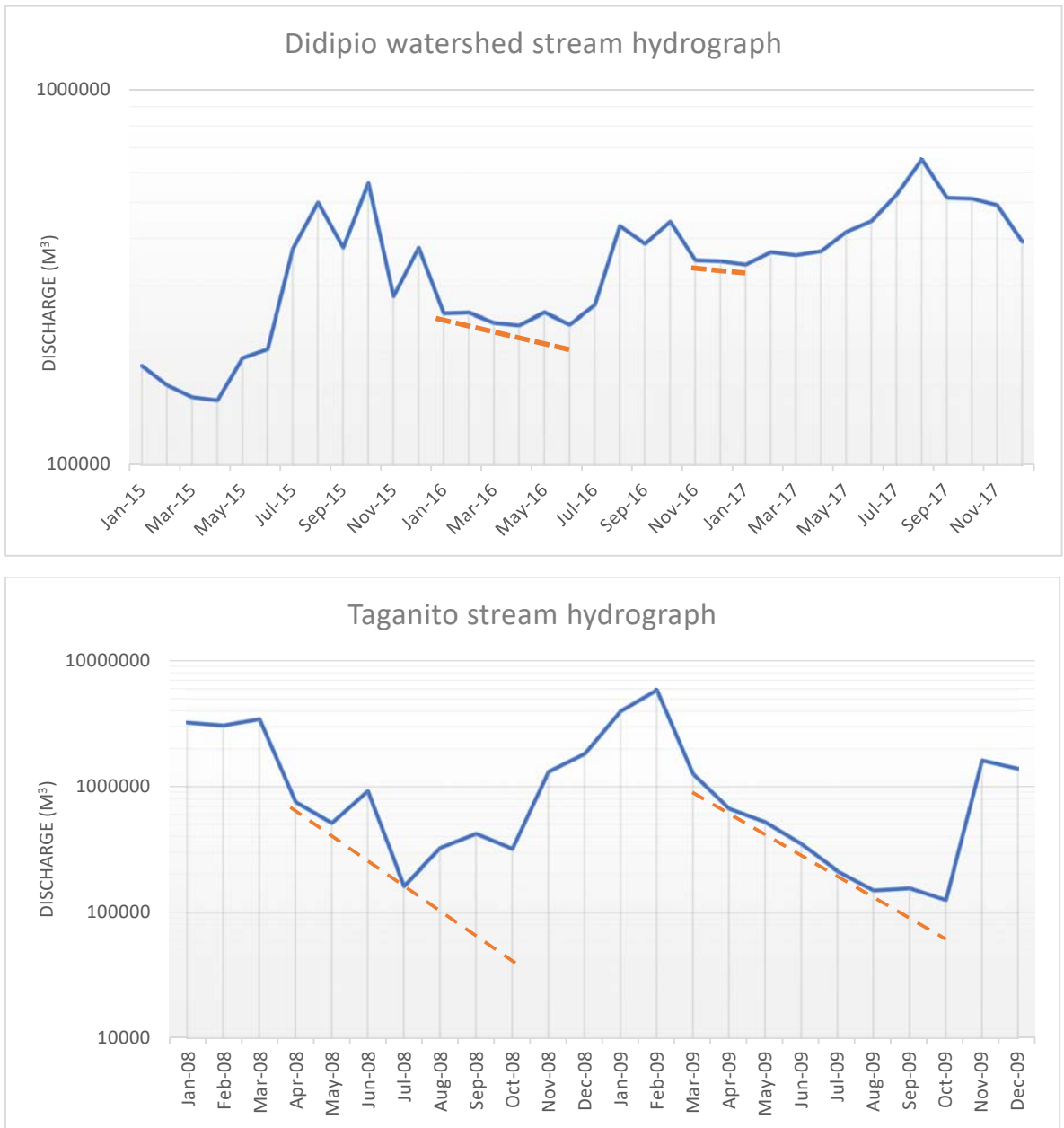


Figure 6. Semilogarithmic stream hydrograph showing baseflow recessions for (a) Didipio watershed and (b) Taganito watershed

The potential stream discharge for one recession is calculated using:

$$V_{tp} = \frac{Q_0 t_1}{2.3026} \quad (5)$$

Where

$V_{tp}$	Volume of the potential groundwater discharge (m <sup>3</sup> )
$Q_0$	Baseflow at the start of the recession (m <sup>3</sup> /s)
$t_1$	Time it takes to go from $Q_0$ to $0.1Q_0$

The amount of potential baseflow  $V$  after some time  $t$  since the recession starts is depicted by:



$$V_t = \frac{V_{tp}}{10^t/t1} \quad (6)$$

The amount of groundwater recharge is then calculated as the difference between  $V_t$  and the  $V_p$  of the succeeding recession cycle (Fetter, 2001). For the Didipio watershed, the groundwater volume is estimated at 29,505,249.70 m<sup>3</sup>/year while for the Taganito watershed, the volume is estimated to be 25,500,030.92 m<sup>3</sup>/year.

Referring to the water balance equation (Equation 1), we obtain the amount of evapotranspiration by subtracting the runoff and groundwater recharge from the precipitation. Table 1 shows the water balance at the Didipio and Taganito watersheds:

	Watershed area km <sup>2</sup>	Precipitation (m <sup>3</sup> /year)	Runoff/surface water (m <sup>3</sup> /year)	Groundwater (m <sup>3</sup> /year)	Evapotranspiration (m <sup>3</sup> /year)	Available water supply (GW + SW, m <sup>3</sup> /year)
Didipio Mine	119	244,025,044.91	19,077,187.64	29,505,249.70	195,442,607.58	48,582,437.34
Taganito Mine	33.57	93,996,000.00	33,192,215.07	30,045,213.20	30,758,571.73	63,237,428.27

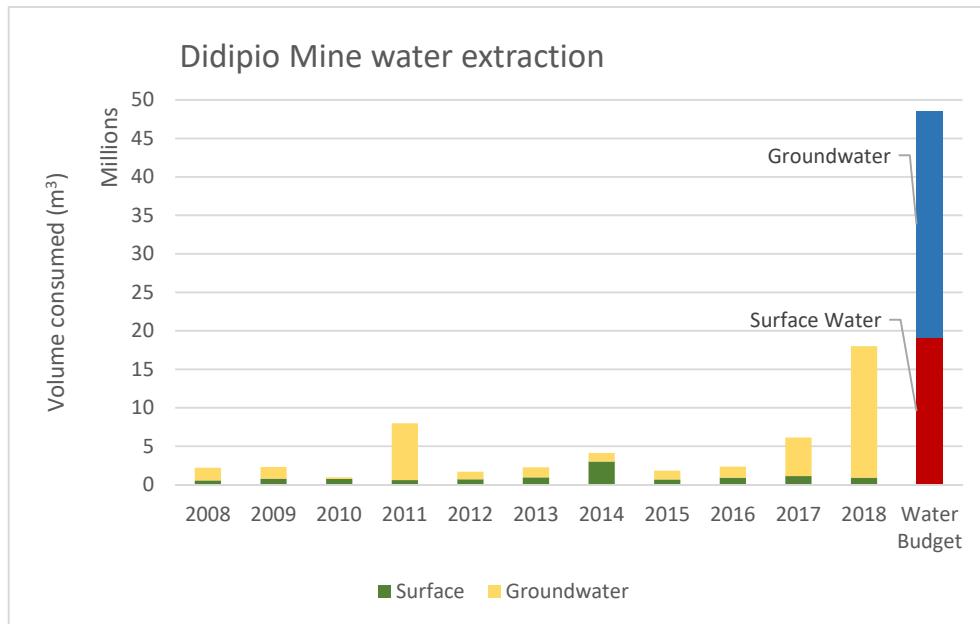
Table 1. Water balance equation for the Didipio Mine and Taganito Mine

## Results and Discussion

### *Comparative analysis between water supply and consumption of two large-scale operating mines*

We first look at the water extraction of each mine (Figure 7) from their respective Sustainability Reports published between 2010 and 2018. Didipio Mine's consumption ranges between 2% to 37% (Average: 9.8%) of the predicted available water supply in its area. Except for 2014, Didipio Mine sources the bulk of its water supplies from groundwater. In 2013, OGPI installed a water recycling facility that can recycle 75% of its water to date. In 2018, however, it extracted more than 17,000,000 m<sup>3</sup> from groundwater, or almost 58% of the predicted groundwater supply in the area due to its dewatering activity as part of its construction of decline and production boreholes for its underground operations. While dewatering is recognized as a necessary procedure for underground mine development, an abrupt decrease in groundwater from aquifers implies lower water pressure, requiring a deeper well and higher costs of pumping for households. Therefore, it is highly recommended that OGPI builds facilities for groundwater management and discharging.

Water extraction at the Taganito Mine ranges from 0.11% to 0.50% (Average: 0.30%) of the predicted available water supply in the area. While its sustainability reports do not indicate the exact volume extracted from surface and groundwater, it specifies that its major water source is the Taganito River.



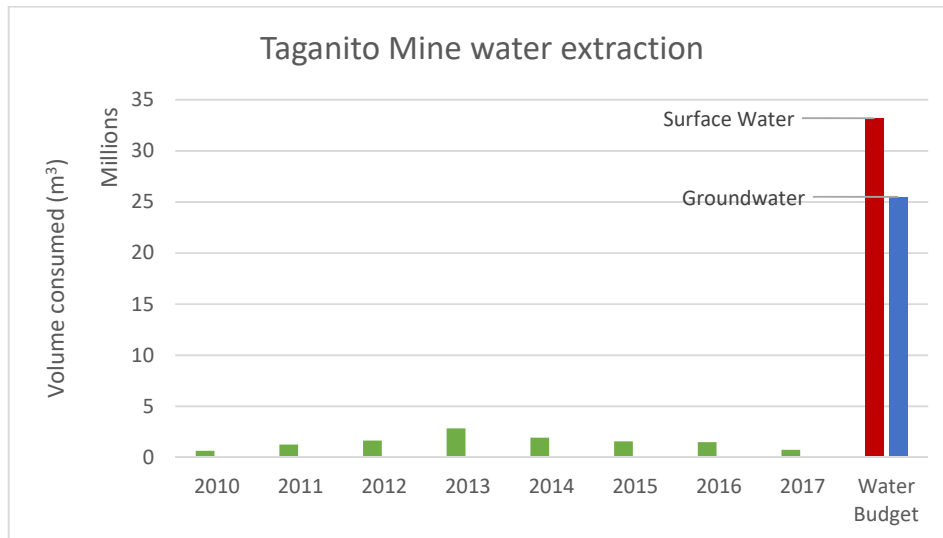


Figure 7. Temporal consumption patterns of large-scale mines. (a) Didipio Mine, Nueva Vizcaya and (b) Taganito Mine, Surigao Del Norte. Data from OGC and NAC Sustainability reports 2009-2018.

We analyze several variables such as population, disturbed and rehabilitated areas within the mine, and production and compare these to water extraction. Population is specifically included as a proxy to reflect economic and social activities of households outside of mining activity which demand water use.

Agriculture on the other hand is excluded from the analyses due to absence of public data on irrigation, but agricultural lands (i.e. Didipio Mine), are plotted to show how agricultural activity may be impacted by water supply distribution in mine-hosted communities.

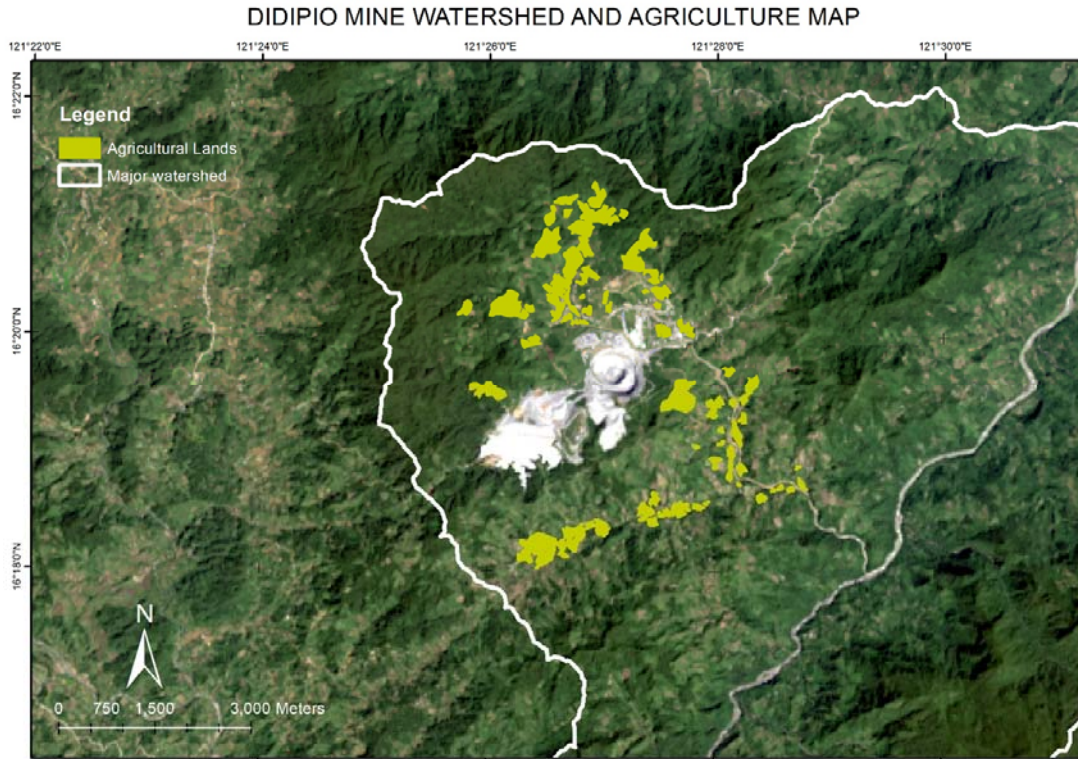


Figure 8. Agricultural lands near the Didipio mine.

The following figures show the temporal variations of several parameters in two large-scale operating mines. The projections and models were generated using non-linear regression of data from various sources.

Population growth (Figure 9) in Didipio and Taganito is expected to nearly double from 2010 to 2020. In both Didipio and Taganito, the highest population bracket is represented by children 1-4 years of age, comprising 13% and 11.5% respectively of the total population in 2015. Meanwhile, the population bracket with the least number belongs to the age group 70-74 in Didipio and > 80 in Taganito, comprising 0.31% and 0.38%, respectively (PhilAtlas, undated-a, undated-b).

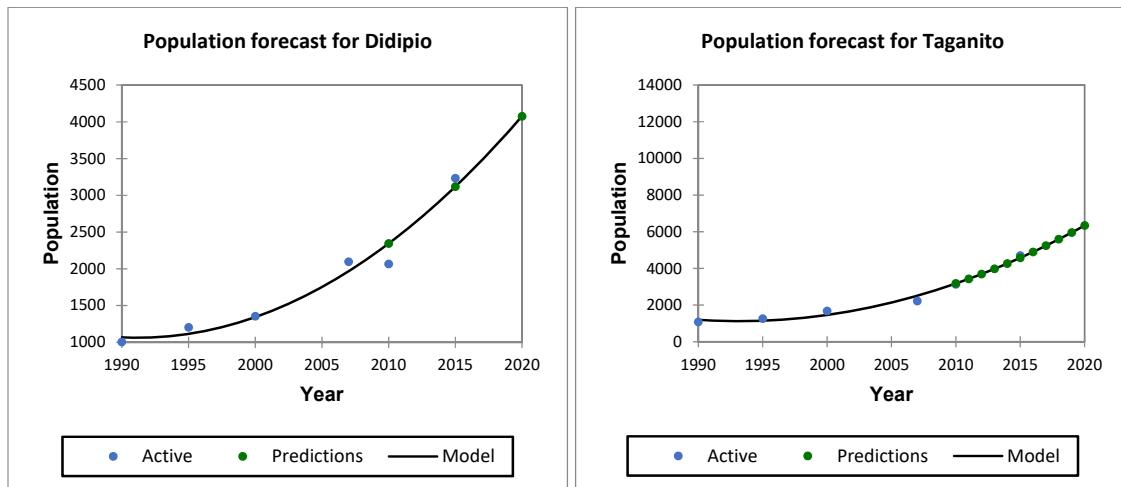


Figure 9. Projected population growth for (a) Didipio, Nueva Vizcaya and (b) Taganito, Surigao del Norte based on five-year census data from the Philippine Statistics Authority from 1990-2015 taken from PhilAtlas. The population for Didipio and Taganito is expected to nearly double from 2010 through 2020.

Land use for both mines is represented by the figures below (Figure 10). At the Didipio Mine, land has been converted from forest to mine since the start of its mine development and commercial production from 2011 until 2014. In 2015, however, OGPI commenced its first mine rehabilitation program and is progressively increasing the areas previously mined out by reforestation (Oceana Gold Corporation (OGC), 2017b). By the end of 2018, the mine has reached 230 hectares of rehabilitated lands in Didipio(Oceana Gold Corporation (OGC), 2018).

The Taganito Mine on the other hand has employed a different rehabilitation strategy. The mine has maintained a nearly fixed ratio of disturbed to rehabilitated lands, indicating immediate rehabilitation of mined-out lands (Nickel Asia Corporation (NAC), 2017).

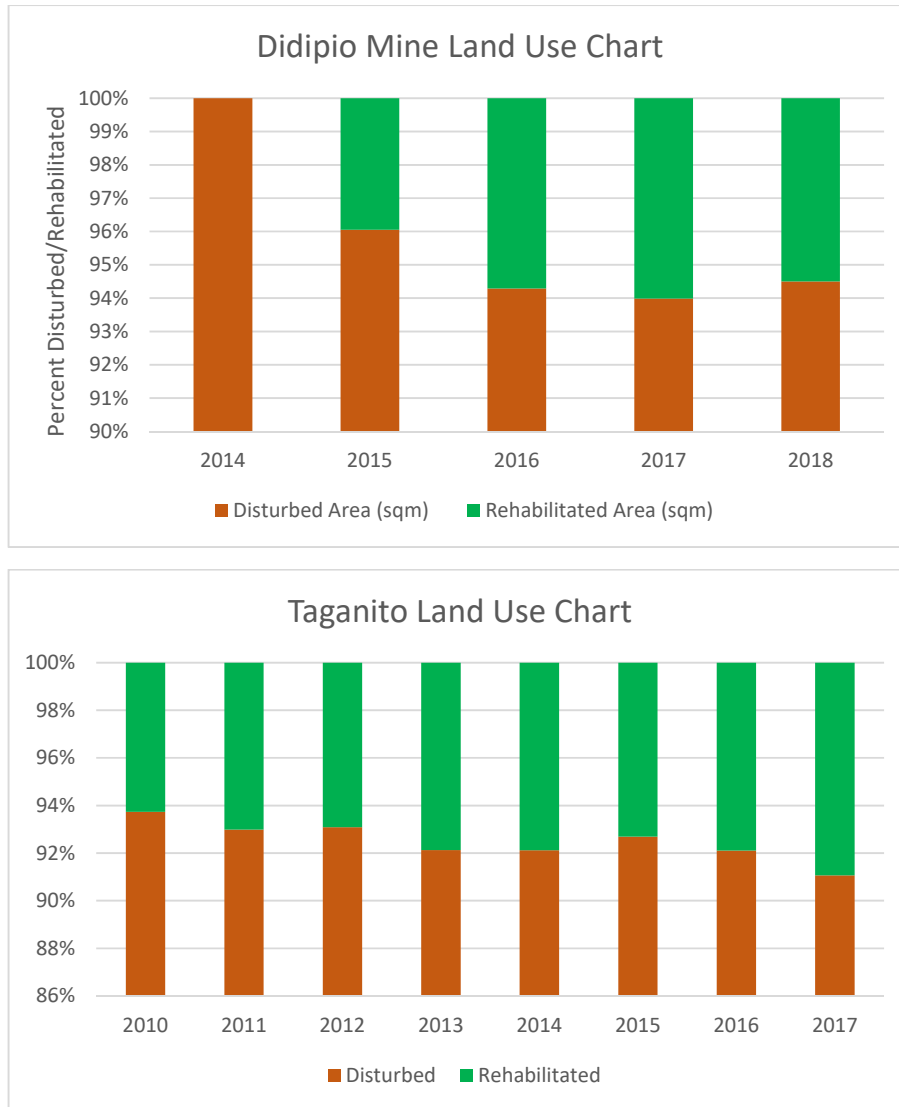
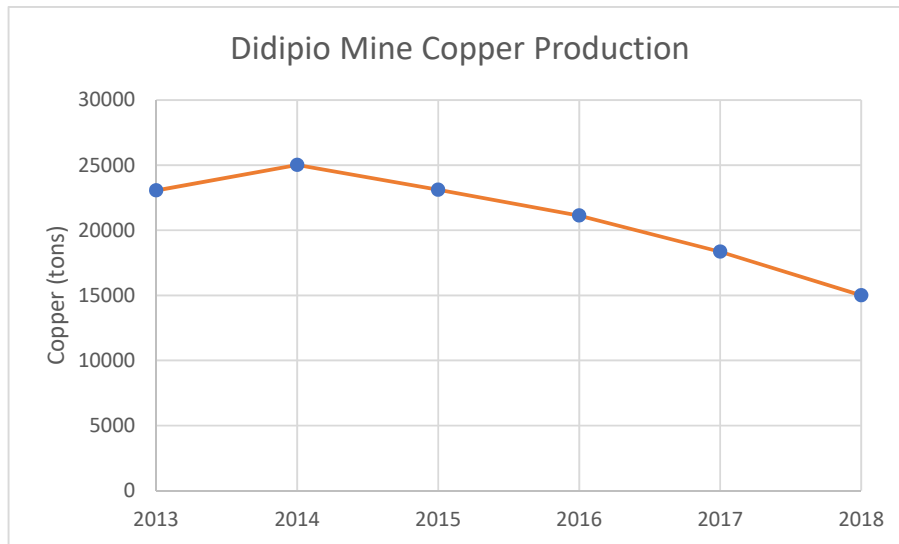
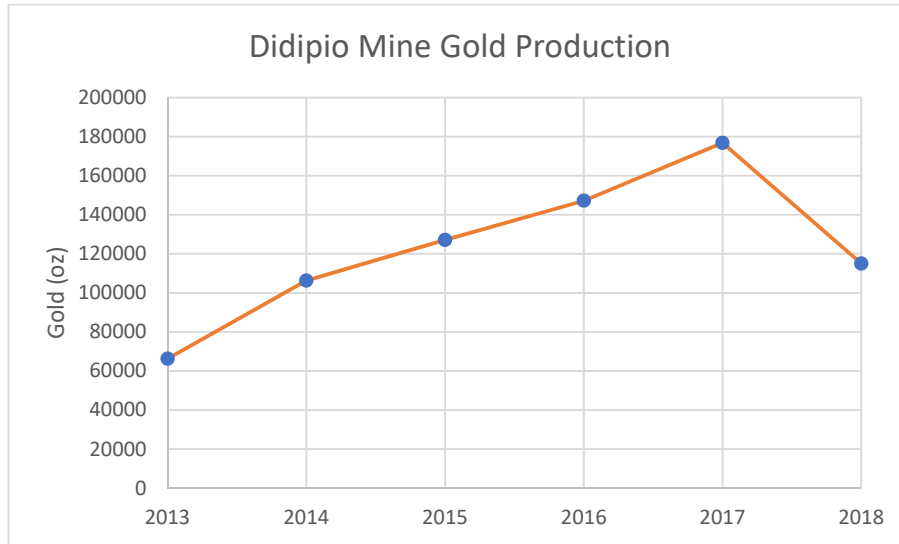


Figure 10. Percent land cover disturbed vs rehabilitated for (a) Didipio Mine and (b) Taganito Mine. Both mines show a range of 5-8% rehabilitated area from 2010 to 2018. Data from OGC and NAC Sustainability reports 2009-2018.

Mineral production<sup>9</sup> in both mines saw a generally increasing trend. In Didipio, gold production went up from 66,000 ounces in 2011 to almost 180,000 ounces in 2017 albeit a steady drop in copper production over the last 6 years. This can be attributed to the mine's shift in operation to underground in 2015, wherein gold is the more principally produced commodity (Oceana Gold Corporation (OGC), 2017a). In Taganito Mine, nickel production saw an increase beginning 2014 despite the drop in global nickel prices (Nickel Asia Corporation (NAC), 2014).



<sup>9</sup> Mineral production refers to the final commodity produced which is ready for trading. The mineral production process includes mineral processing and recovery, which may be conducted by the same company

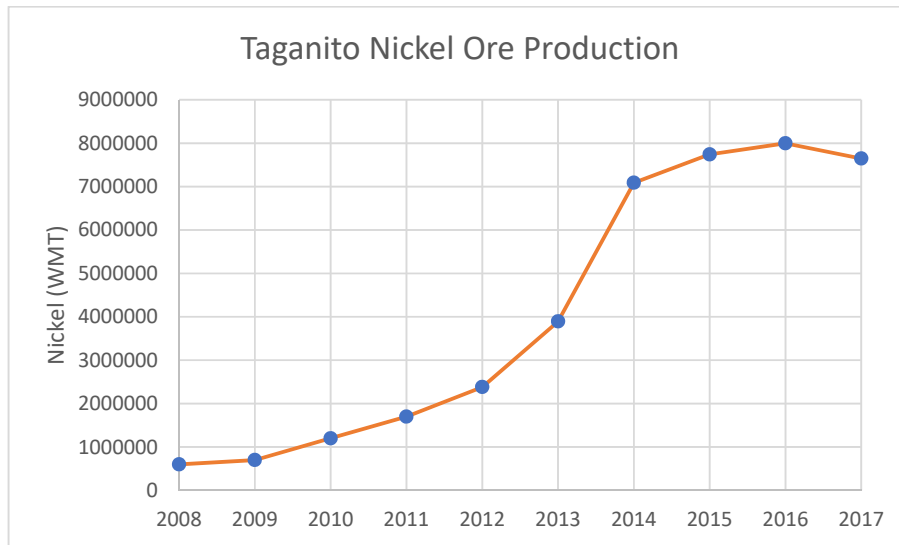


Figure 11. Commodity production patterns for (a) Gold, Didipio Mine (b) Copper, Didipio Mine and (c) Nickel, Taganito Mine. Didipio's gold production steadily increased beginning 2013, peaking in 2017 before abruptly falling in 2018. Its copper production peaked in 2014 and has been on the decline. Nickel production in the Taganito mine steadily rose from 2008 to 2017. Data from OGC and NAC Sustainability reports 2009-2018

### *Principal Component Analysis (PCA)*

To determine the relationship of each variable to the water extraction patterns of large-scale operating mines, we implement a Principal Component Analysis (PCA) using XLSTAT<sup>10</sup>. PCA enables a visual representation of correlations across multiple variables through lines and points plotted on a 2-dimensional map called the biplot (Abdi & Williams, 2010; Wold, 1987).

### *Interpreting the PCA biplot*

The biplot consists of two elements: the correlation circle and the observations plotted on a two-dimensional map which can be interpreted separately. The x- and y- axes correspond to factors, linear combinations of each of the variables that form the dimensions from where the variables can be best observed. The axes are uncorrelated with each other (perpendicular) and are associated with a percent variability which determines the contribution of the axes to data presentation. Ideally, the two factors with the highest percent variability are chosen, but other factors may also be selected if a specific relationship between variables is sought.

The correlation circle is represented by red lines that correspond to the variables examined. It is interpreted based on the lengths of the lines from the center of the axes and on the angles that each line forms with another. The variables are *significant and positively correlated* if the lines are long (far from the center), and close to each other, forming an acute angle. The variables are significant and negatively correlated if the lines are far from each other, forming an obtuse angle. *No correlation exists* between the variables if the lines are perpendicular. If the lines are short and closer to the center, interpretation needs to be done using a different factor (axis).

The observations, on the other hand (here, represented by years of data observation), represent points containing information about the variables. The observations plot is useful for cluster analysis (XLSTAT, 2017).

<sup>10</sup> XLSTAT is a statistical software developed by Addinsoft and is a plugin for Microsoft Excel.

*Didipio PCA Biplot*

The Didipio biplot (Figure 12) shows the relative position of seven variables: year, total water extraction (cubic meters), population, disturbed area (sqm), rehabilitated area (sqm), copper production (tons), and gold production (ounces) with respect to factors F1 and F2 with a total variability of 89.18%. The observations, which contain the data of the variables beginning 2009 to 2018 is also plotted for cluster analysis.

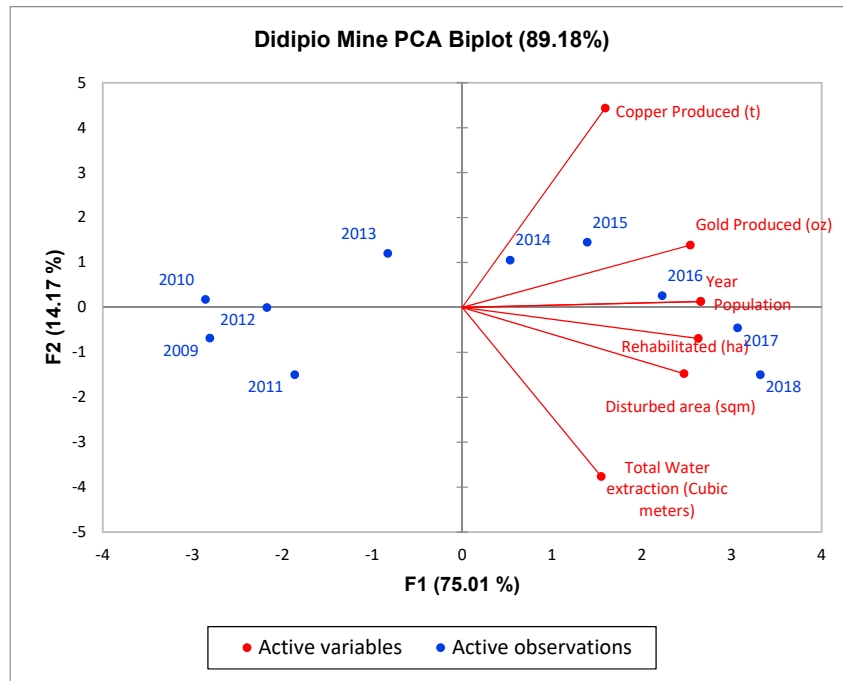


Figure 12. The Didipio PCA biplot

All seven variables have a positive correlation with respect to each other, except for copper production and water extraction being nearly orthogonal. Data clustering can also be seen between 2009-2012 and 2015-2018, which marks the pre- and post- commercial production in Didipio Mine. 2013 and 2014 meanwhile, marks a “transition” between the two clusters.

There is no fixed trend increase or decrease in water extraction pattern with respect to year, but water extraction generally increased from 2009 to 2018.

Looking at the correlation between population and water use, we can see that there has been an increase in water extraction vis-à-vis the increase in population of Didipio. By 2020, the projected population in Didipio reaches 4,000. According to the World Bank, the water extraction per capita per day is approximately 50 liters (World Bank, 2003). Based on our models, Didipio households are expected to spend 73,000,000 liters or 73,000 m<sup>3</sup> of water per annum by 2020. This is roughly 0.4% of the total water extraction by the Didipio Mine operations in 2018 and barely 0.15% of the total projected water budget in the Didipio watershed. Hence, while a significant positive correlation can be seen between water extraction and population, households still have a relatively less significant consumption compared with the operations of Didipio Mine.

The most significant positive correlation with water use is the disturbed area. Disturbed area refers to altered land cover by the mine due to operations or mine development such as construction of



facilities and roads, tunnels, and removal of rocks from the surface. Increased demand for water may be attributed to commercial production which began in 2013 and the expansion of operations to underground mining in 2014. It is noteworthy that water extraction increased almost tenfold from 2010 to 2011(Oceana Gold Corporation (OGC), 2010, 2011, 2012) when full-swing mine development was commencing. Water extraction also doubled from 2013 to 2014 during the time when OGPI was starting its underground operations and environmental spills were recorded (Oceana Gold Corporation (OGC), 2014, 2015).

The correlation between water extraction and rehabilitation is not as high compared with operations-related activities, but still significant<sup>11</sup> due to water demands in reforestation. It is also important to note the correlation that exists between disturbed area and rehabilitation is nearly in unison. This implies the continuous rehabilitation effort alongside the mine's operations.

While the correlation with disturbed areas is the most significant, copper and gold productions do not seem to correlate as significantly as the other variables with water extraction. This might be because the first gold production only began in late 2012 and was only commercialized by April of 2013. While gold production has consistently (but slowly) risen since 2013, water extraction has fluctuated during this time. Meanwhile, copper production has been nearly stable, or at times dropped.

Population and year, while (graphically) seemingly correlated with the Didipio Mine's water extraction, are not significant indicators compared with the amount of disturbed and rehabilitated areas. However, at times when mine development commences or a significant environmental spill is recorded, a major increase in water extraction arises. On the other hand, while gold and copper production maintained a nearly stable pattern, these did not necessarily transform to an increased water extraction (compared with mine development or during an environmental spill), possibly because fresh water is not much used during recovery processes.

Overall, we observe that water consumption at the Didipio Mine is mainly driven by operational expansion, mine development, and occurrence of environmental spills. These activities may present a certain level of threat to the communities relying on groundwater as source of potable water. The use of recycled water by OGPI helps reduce the impact of its operation on the water source of the area. The current extent of water recycling at the Didipio mines is almost 75% at present (Oceana Gold Corporation (OGC), 2017b, 2018).

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<sup>11</sup> Table 2A as depicted by Spearman's correlation value

*Taganito PCA Biplot*

The Taganito biplot shows the relative position of eight variables: Year, total water extraction (cubic meters), population, disturbed area (sqm), rehabilitated area (sqm) Nickel production (tons), silt collected (tons), and total spending for Environmental Protection and Enhancement Program (EPEP) with respect to factors F1 and F2 with a total variability of 94.01%. The observations, which contain data from variables beginning 2010 to 2017 is also plotted for cluster analysis.

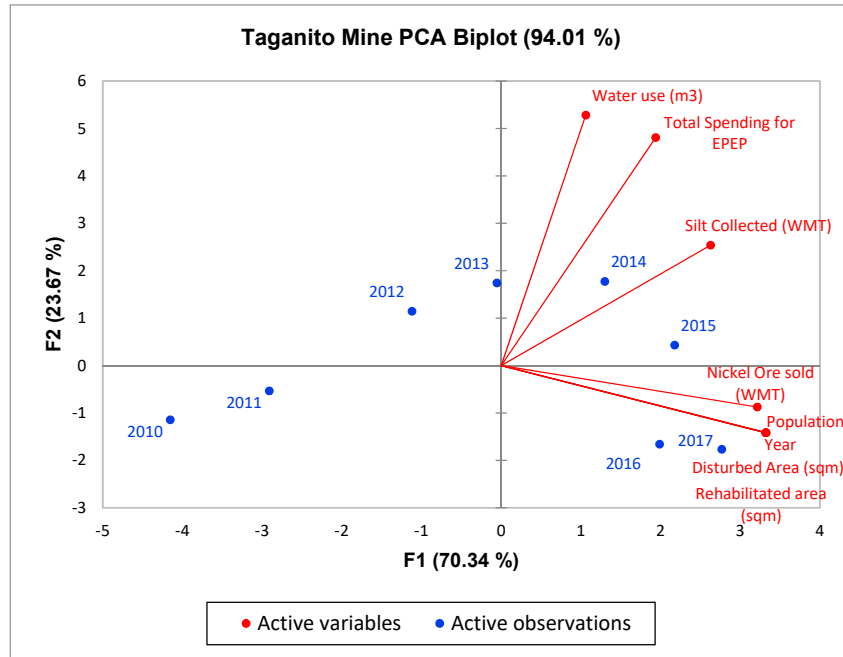


Figure 13. The Taganito Mine PCA biplot

All variables have a positive correlation with respect to each other, with the most significant correlation between total spending for EPEP and volume of silt collected while least for year, population, and rehabilitated and disturbed areas (Table 2B). Nickel ore sold (WMT) is also positively correlated with total water extraction but has a relatively lower correlation constant. Data clustering is not outright, but observations may be divided between 2010 to 2013 and 2014 to 2017, which represent periods of low and high nickel production, decrease in water extraction, and increase both in disturbed and rehabilitated areas.

There is a general increase in water extraction at the Taganito Mine from 2010-2013 and a decline of usage from 2014 to 2017.

The most significant positive correlations are with total spending for EPEP and silt collection. In nickel mines, dust control is a primary problem in operations. Dust particulates in air eventually end up in siltation dams, rivers, and even on the road. Road watering is the most common method to immobilize silt particles and easily capture, so bulk of the water use at the Taganito Mine goes to dust control and building facilities (hence, high EPEP expenditure) to minimize impact of dust to the surrounding communities (Nickel Asia Corporation (NAC), 2011).

Nickel production and sales on the other hand, is moderately positively correlated with water extraction. Intuitively, increasing the mine’s operation and production would result in higher water

extraction. However, because there is no nickel processing and extraction facility in TMC, increasing the operation is not necessarily tantamount to and increased water consumption as nickel mining is rather just a straightforward removal of lateritic soil. Furthermore, there is a separate facility operated by THNC (the HPAL) for nickel extraction and recovery, which is a different company and is not incorporated in this study.

Lastly, population, disturbed and rehabilitated (reforested) areas are weakly correlated with water extraction. This might be because the magnitude of water extraction for environmental measures such as dust and silt control outweigh the water demand for mine development and rehabilitation. This not only requires a large chunk of the water budget, but also monetary aspect due to the requirement in the maintenance facilities.

The 2017 population data for Taganito shows a population of 5,240. The population would require a water supply of approximately 95,630,000 liters or 95,630 m<sup>3</sup> of water. This is much higher than the reported usage of Taganito Mine in 2017, which is roughly 75,000 m<sup>3</sup> of water or approximately 0.13% of the available water supply at the Taganito watershed. The population variable is almost uncorrelated possibly due to the presence of abundant water supply from a Level II/ district water supplier (Source: LWUA), which means that water supply for the households is unthreatened by mining.

There is no imminent threat to water supply, but water quality should be ensured due to increasing discharge of silt to the rivers (and eventually to the sea) and reports on the presence of traces of hexavalent chromium at the tributaries of the Taganito River (Friends of the Earth Japan (FoE), 2018).

#### *Limitations of the PCA biplot*

While graphical representation using the PCA biplot offers a tempting straightforward interpretation, it still has its limitations such as the possibility of false correlation between two variables and misrepresentation of a variable in a factor (axis). To avoid this, the Spearman correlation coefficients are also presented. The Spearman correlation coefficient is a measure of the strength and direction (either positive or negative) of association between two or more measured, non-linear variables.

Table 2A. Spearman's correlation matrix for various parameters for Didipio Mine.

Variables	Year	Total Water extraction (Cubic meters)	Population	Disturbed area (sqm)	Rehabilitated area (sqm)	Gold Produced (oz)	Copper Produced (t)
Year	<b>1</b>	<b>0.515</b>	<b>1.000</b>	<b>0.937</b>	<b>0.888</b>	<b>0.894</b>	<b>0.569</b>
Total Water extraction (Cubic meters)	<b>0.515</b>	<b>1</b>	<b>0.515</b>	<b>0.562</b>	<b>0.498</b>	<b>0.375</b>	<b>0.113</b>
Population	<b>1.000</b>	<b>0.515</b>	<b>1</b>	<b>0.937</b>	<b>0.888</b>	<b>0.894</b>	<b>0.569</b>
Disturbed area (sqm)	<b>0.937</b>	<b>0.562</b>	<b>0.937</b>	<b>1</b>	<b>0.947</b>	<b>0.887</b>	<b>0.460</b>
Rehabilitated area (sqm)	<b>0.888</b>	<b>0.498</b>	<b>0.888</b>	<b>0.947</b>	<b>1</b>	<b>0.831</b>	<b>0.261</b>
Gold Produced (oz)	<b>0.894</b>	<b>0.375</b>	<b>0.894</b>	<b>0.887</b>	<b>0.831</b>	<b>1</b>	<b>0.677</b>
Copper Produced (t)	<b>0.569</b>	<b>0.113</b>	<b>0.569</b>	<b>0.460</b>	<b>0.261</b>	<b>0.677</b>	<b>1</b>

Values in bold are different from 0 with a significance level  $\alpha=0.95$

Table 2B. Spearman's correlation matrix for various parameters for Taganito Mine.

Variables	Year	Total Water extraction (Cubic meters)	Population	Nickel Ore sold (WMT)	Disturbed Area (ha)	Rehabilitated area within the mine (ha)	Silt Collected (WMT)	Total Spending for EPEP
Year	<b>1</b>	<b>0.095</b>	<b>1.000</b>	<b>0.929</b>	<b>1.000</b>	<b>1.000</b>	<b>0.619</b>	<b>0.357</b>
Water use (m3)	<b>0.095</b>	<b>1</b>	<b>0.095</b>	<b>0.214</b>	<b>0.095</b>	<b>0.095</b>	<b>0.476</b>	<b>0.881</b>
Population	<b>1.000</b>	<b>0.095</b>	<b>1</b>	<b>0.929</b>	<b>1.000</b>	<b>1.000</b>	<b>0.619</b>	<b>0.357</b>
Nickel Ore sold (WMT)	<b>0.929</b>	<b>0.214</b>	<b>0.929</b>	<b>1</b>	<b>0.929</b>	<b>0.929</b>	<b>0.595</b>	<b>0.381</b>
Disturbed Area (ha)	<b>1.000</b>	<b>0.095</b>	<b>1.000</b>	<b>0.929</b>	<b>1</b>	<b>1.000</b>	<b>0.619</b>	<b>0.357</b>
Rehabilitated area within the mine (ha)	<b>1.000</b>	<b>0.095</b>	<b>1.000</b>	<b>0.929</b>	<b>1.000</b>	<b>1</b>	<b>0.619</b>	<b>0.357</b>
Silt Collected (WMT)	<b>0.619</b>	<b>0.476</b>	<b>0.619</b>	<b>0.595</b>	<b>0.619</b>	<b>0.619</b>	<b>1</b>	<b>0.786</b>
Total Spending for EPEP	<b>0.357</b>	<b>0.881</b>	<b>0.357</b>	<b>0.381</b>	<b>0.357</b>	<b>0.357</b>	<b>0.786</b>	<b>1</b>

### Moving forward

Climate change poses a serious risk to water supply in the country. Between 2020 and 2050, PAGASA forecasts increasing frequency of heavy rainfalls such as storm events and lengthening the period of dry days. Even in rural areas, rapid urbanization threatens watershed conditions and hence water supply and quality ((PAGASA), undated a).

In both study areas, population is expected to exponentially grow and more than double from 2018 to 2035. With more people demanding water to sustain their activities, it is inevitable that water extraction also exponentially rises along with population growth.

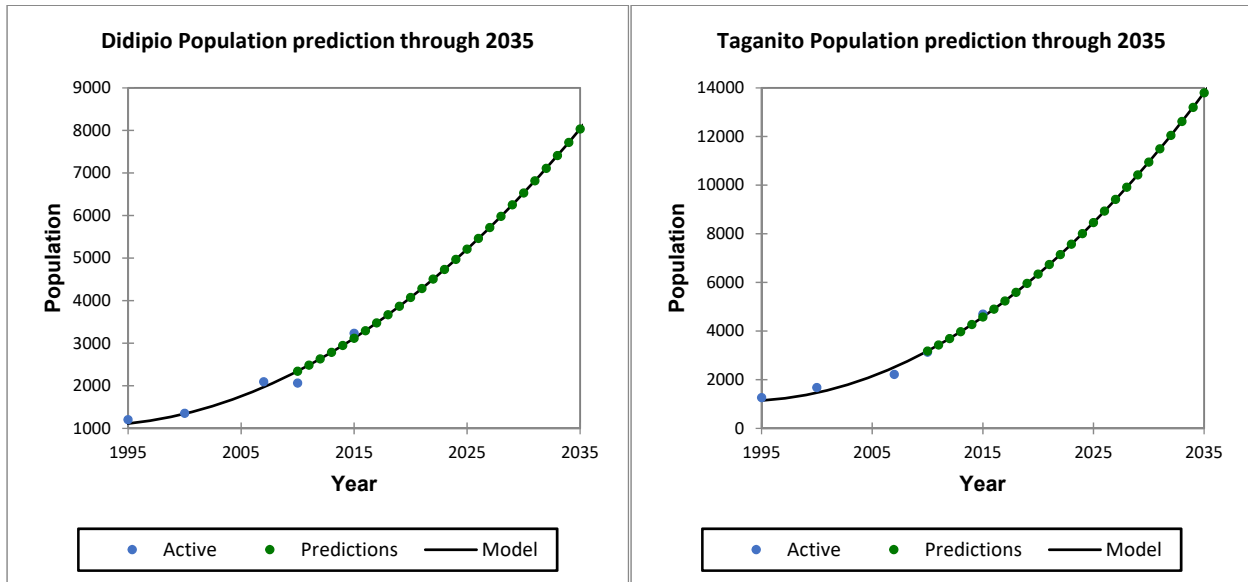


Figure 13. Population projection until 2035. (a) Didipio (b) Taganito. In both cases, population is seen to more than double within two decades.

We project the possible scenarios of water extraction of the Didipio and Taganito Mines under normal and extreme conditions (Figure 14).

Water usage at the Didipio Mine is expected to increase from its current state until its target mine life in 2034. This is mainly due to increased water demand for mine development, progressive rehabilitation, and increased population.

We also included a prediction<sup>12</sup> for when events that would require much water use such as environmental spills will take place (Figure 14). Near the end of the mine life of Didipio, the expected water demand could rise to up to 52% of the projected water resources. As such, the role of water recycling facilities will play a big role in water resources management and conservation. It is thus important to maintain the integrity of environmental facilities of the mine to avoid spills and consequently, increase water extraction. More so, significant increase in water demand by the mine could mean that households and agriculture may be adversely affected and may have to extract water from a deeper groundwater source or elsewhere, thereby increasing costs for water extraction. Over-extraction also poses a threat to groundwater as this can permanently deplete the groundwater level and cause geohazards such as subsidence (Lutgens and Tarbuck, 2011).

<sup>12</sup> Projections are done using non-linear regression with a significance level of 95% in XLSTAT

On the other hand, normal water extraction for Taganito Mine is expected to rise by approximately 15-20% from its current average consumption until the end of the mine life in 2034, or roughly 0.4% - 0.6% of the total water supply at the Taganito River watershed. Increased amounts of dust pollution will be the largest contributor to water extraction, which could drive water use to 17-25% of its current water usage or around 0.5%-0.7% of the total water supply.

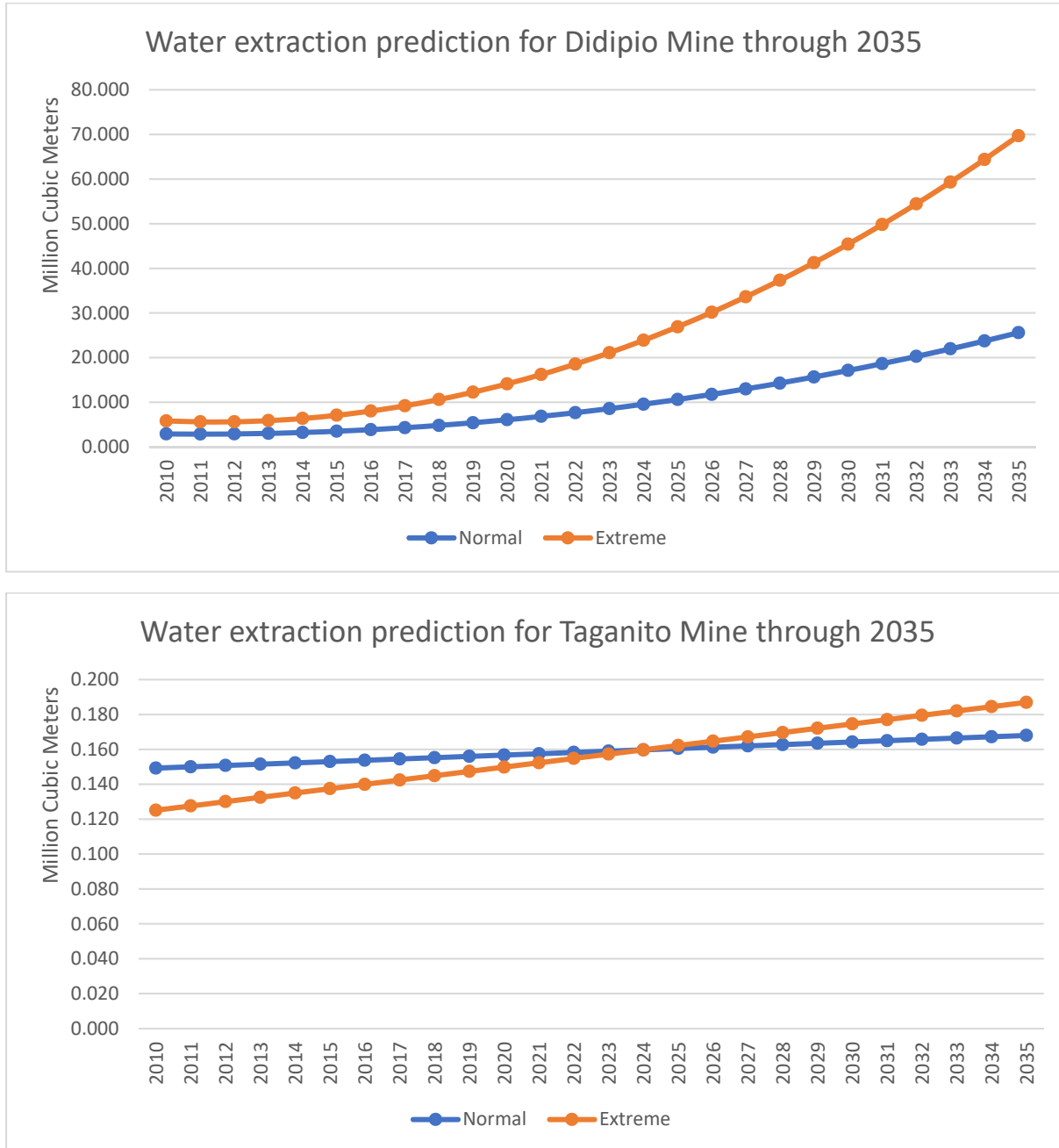


Figure 14. Water extraction prediction under normal and extreme usage for (a) Didipio Mine and (b) Taganito Mine

## **Conclusions**

Water is an important aspect in mine operations. While supply varies geographically, the main factors that control water availability are climate and geology. In areas where rainfall is more abundant and catchment basins are composed of permeable rock units, groundwater storage is favored, as in the case of the Didipio Mine. In areas with thick clayey soil cover, surface runoff is more prominent as in Taganito Mine.

We also look at the water extraction by communities in both study areas. In both cases, household consumption plays a minimal role in driving the demand for water. However, we also find that communities are vulnerable to changes in water supply and availability.

Moreover, we compared water extraction with various factors such as mineral production and profit, land use, rehabilitation, mine development, and environmental concerns. As it turns out, water extraction of mines has little to do with the size of its operation relative to the nature of commodity and environment the mine is operating in. Didipio Mine, a copper and gold mine, tends to use more water for mine development and rehabilitation, while Taganito Mine, a nickel mine, tends to use more water for pollution control. It is important to note, however, that the Taganito Mine does not involve ore processing. Taking into account mineral processing done by the separate subsidiary of Nickel Asia might result in a different water use profile for the company.

## **Recommendation and Policy Implications**

If mining is to be promoted as a pillar for economic development in the Philippines, it is important to develop a clear framework on the water use of mines in the context of sustainable development (van Berkel, 2007). The literature has highlighted the disconnection between technical, scientific and engineering-based approaches to water management and human rights perspective on water. Recognizing the intersection between water and human rights in the water management of mining companies is important from a sustainable development perspective (Kemp et al., 2010).

Water monitoring and regulation is weak. Water extraction should be carefully monitored, especially groundwater. Significant withdrawal might have a negative impact to households. It can result in less water pressure which would require tapping deeper wells and higher energy costs to pump out water. In extreme cases, groundwater withdrawal may also lead to land subsidence, especially if the bed rock and aquifers are composed of fine-grained, weakly-compacted rocks.

There are very limited information and data available on water use. The data that were used in this study came from the sustainability reports of the mining companies. For the purposes of conducting an impact analysis of water use, at the very least, the following data should be made readily available to the public: comprehensive land use and conversion plan, detailed ground and surface water usage (annual or monthly), and water recycling technologies and infrastructure of companies. There is also a need for more disclosure and accessibility of public data such as climate, local population, stream gaging data, and well inventory from government agencies.

A water accounting system should be developed to improve the availability and quality of water information. Regulatory reporting of water use of mining companies should be strengthened and aligned with a water accounting system (Garstone et al., 2017). The data should be publicly available. The Extractives Industry Transparency Initiative (EITI) has recently added environmental disclosures in the 2019 EITI Standard. The EITI can contribute in the standardization of reporting of water use. The

development of industry specific water accounting schemes contributes to the transparent, consistent and quality disclosure of the sector's water use (Northey et al., 2019). The Water Accounting Framework for the Minerals Industry (WAFMI) of the Minerals Council of Australia (MCA) and the guidance notes on assessing and reporting local water risks by the International Council of Mining & Metals (ICMM) as examples of this standardization (Northey et al., 2019).

Policies on recycling of water for mine use should be put in place. Water provision for household and industrial uses can be part of the social and community investment strategies of mining companies (Kemp et al., 2010).

Lastly, we recommend that succeeding studies assess the impact of water used by large-scale mining operations on the water quality and quantity available for the agricultural sector.



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## Annexes

### Annex A. Results of principal component analysis of Didipio Mine

Summary statistics (Quantitative data):

Variable	Observations	Obs. With missing data	Obs. Without missing data	Minimum	Maximum	Mean	Std. deviation
Year	10	0	10	2009.000	2018.000	2013.500	3.028
Total Water Consumption (Cubic meters)	10	0	10	945000.000	18009549.000	4764611.300	5153109.333
Population	10	0	10	2243.000	3424.000	2796.100	404.325
Disturbed area (sqm)	10	0	10	0.000	3935193.040	1653081.528	1761779.704
Rehabilitated (ha)	10	0	10	0.000	228836.640	76714.200	102345.536
Gold Produced (oz)	10	0	10	0.000	176790.000	73855.900	69457.994
Copper Produced (t)	10	0	10	0.000	25010.000	12565.200	11157.167

Correlation matrix (Spearman (n)):

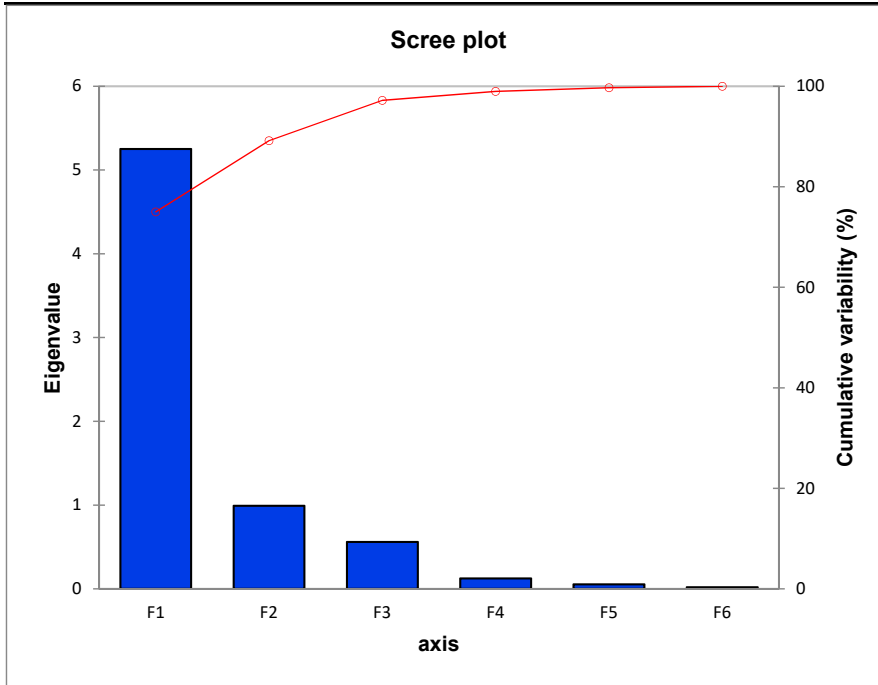
Variables	Year	Total Water Consumption (Cubic meters)	Population	Disturbed area (sqm)	Rehabilitated (ha)
Year	<b>1</b>	<b>0.515</b>	<b>1.000</b>	<b>0.937</b>	<b>0.888</b>
Total Water Consumption (Cubic meters)	<b>0.515</b>	<b>1</b>	<b>0.515</b>	<b>0.562</b>	<b>0.498</b>
Population	<b>1.000</b>	<b>0.515</b>	<b>1</b>	<b>0.937</b>	<b>0.888</b>
Disturbed area (sqm)	<b>0.937</b>	<b>0.562</b>	<b>0.937</b>	<b>1</b>	<b>0.947</b>
Rehabilitated (ha)	<b>0.888</b>	<b>0.498</b>	<b>0.888</b>	<b>0.947</b>	<b>1</b>
Gold Produced (oz)	<b>0.894</b>	<b>0.375</b>	<b>0.894</b>	<b>0.887</b>	<b>0.831</b>
Copper Produced (t)	<b>0.569</b>	<b>0.113</b>	<b>0.569</b>	<b>0.460</b>	<b>0.261</b>

*Values in bold are different from 0 with a significance level alpha=0.95*

### Principal Component Analysis:

Eigenvalues:

	F1	F2	F3	F4	F5	F6
Eigenvalue	5.251	0.992	0.560	0.125	0.053	0.019
Variability (%)	75.008	14.167	8.004	1.787	0.755	0.278
Cumulative %	75.008	89.175	97.179	98.967	99.722	100.000



Eigenvectors:

	F1	F2	F3	F4	F5	F6
Year	0.428	0.021	-0.062	-0.517	-0.202	-0.066
Total Water Consumption (Cubic meters)	0.249	-0.607	0.739	0.115	-0.078	0.064
Population	0.428	0.021	-0.062	-0.517	-0.202	-0.066
Disturbed area (sqm)	0.424	-0.112	-0.141	0.163	0.687	-0.538
Rehabilitated (ha)	0.398	-0.238	-0.409	0.211	0.161	0.739
Gold Produced (oz)	0.409	0.224	-0.090	0.617	-0.576	-0.249
Copper Produced (t)	0.257	0.715	0.501	0.031	0.287	0.298

Factor loadings:

	F1	F2	F3	F4	F5	F6
Year	0.981	0.021	-0.047	-0.183	-0.047	-0.009
Total Water Consumption (Cubic meters)	0.572	-0.604	0.553	0.041	-0.018	0.009
Population	0.981	0.021	-0.047	-0.183	-0.047	-0.009
Disturbed area (sqm)	0.971	-0.111	-0.106	0.058	0.158	-0.075
Rehabilitated (ha)	0.912	-0.237	-0.306	0.075	0.037	0.103
Gold Produced (oz)	0.938	0.223	-0.067	0.218	-0.132	-0.035

Copper Produced (t)	0.588	0.712	0.375	0.011	0.066	0.042
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Correlations between variables and factors:

	F1	F2	F3	F4	F5	F6
Year	0.981	0.021	-0.047	-0.183	-0.047	-0.009
Total Water Consumption (Cubic meters)	0.572	-0.604	0.553	0.041	-0.018	0.009
Population	0.981	0.021	-0.047	-0.183	-0.047	-0.009
Disturbed area (sqm)	0.971	-0.111	-0.106	0.058	0.158	-0.075
Rehabilitated (ha)	0.912	-0.237	-0.306	0.075	0.037	0.103
Gold Produced (oz)	0.938	0.223	-0.067	0.218	-0.132	-0.035
Copper Produced (t)	0.588	0.712	0.375	0.011	0.066	0.042

Contribution of the variables (%):

	F1	F2	F3	F4	F5	F6
Year	18.316	0.045	0.389	26.717	4.093	0.441
Total Water Consumption (Cubic meters)	6.221	36.844	54.604	1.317	0.610	0.405
Population	18.316	0.045	0.389	26.717	4.093	0.441
Disturbed area (sqm)	17.952	1.246	1.992	2.672	47.192	28.947
Rehabilitated (ha)	15.853	5.659	16.757	4.471	2.577	54.683
Gold Produced (oz)	16.752	5.002	0.803	38.010	33.222	6.211
Copper Produced (t)	6.590	51.158	25.066	0.098	8.214	8.873

Squared cosines of the variables:

	F1	F2	F3	F4	F5	F6
Year	<b>0.962</b>	0.000	0.002	0.033	0.002	0.000
Total Water Consumption (Cubic meters)	0.327	<b>0.365</b>	0.306	0.002	0.000	0.000
Population	<b>0.962</b>	0.000	0.002	0.033	0.002	0.000
Disturbed area (sqm)	<b>0.943</b>	0.012	0.011	0.003	0.025	0.006
Rehabilitated (ha)	<b>0.832</b>	0.056	0.094	0.006	0.001	0.011
Gold Produced (oz)	<b>0.880</b>	0.050	0.005	0.048	0.018	0.001
Copper Produced (t)	0.346	<b>0.507</b>	0.140	0.000	0.004	0.002

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Factor scores:

	F1	F2	F3	F4	F5	F6
Obs1	-2.808	-0.683	0.076	0.584	0.196	0.064
Obs2	-2.857	0.177	-0.997	0.064	0.164	-0.071
Obs3	-1.865	-1.498	1.018	0.024	-0.194	0.060
Obs4	-2.174	-0.004	-0.826	-0.616	-0.145	-0.141
Obs5	-0.828	1.202	0.554	-0.280	-0.292	0.222
Obs6	0.534	1.053	1.452	-0.094	0.250	-0.233
Obs7	1.391	1.449	-0.479	0.169	0.177	0.161
Obs8	2.225	0.261	-0.355	0.271	-0.141	-0.032
Obs9	3.065	-0.458	-0.309	0.345	-0.328	-0.140
Obs10	3.317	-1.499	-0.134	-0.467	0.313	0.110

Contribution of the observations (%):

	F1	F2	F3	F4	F5	F6
Obs1	15.016	4.700	0.103	27.251	7.273	2.096
Obs2	15.548	0.318	17.725	0.330	5.086	2.583
Obs3	6.621	22.637	18.503	0.046	7.158	1.853
Obs4	9.005	0.000	12.180	30.292	3.980	10.236

Obs5	1.306	14.568	5.472	6.278	16.098	25.204
Obs6	0.543	11.173	37.646	0.711	11.847	27.896
Obs7	3.682	21.158	4.091	2.273	5.899	13.361
Obs8	9.430	0.688	2.253	5.880	3.750	0.516
Obs9	17.894	2.115	1.706	9.519	20.352	10.048
Obs10	20.956	22.644	0.322	17.419	18.557	6.207

Squared cosines of the observations:

	F1	F2	F3	F4	F5	F6
Obs1	<b>0.902</b>	0.053	0.001	0.039	0.004	0.000
Obs2	<b>0.885</b>	0.003	0.108	0.000	0.003	0.001
Obs3	<b>0.511</b>	0.330	0.152	0.000	0.006	0.001
Obs4	<b>0.811</b>	0.000	0.117	0.065	0.004	0.003
Obs5	0.259	<b>0.545</b>	0.116	0.030	0.032	0.019
Obs6	0.079	0.305	<b>0.581</b>	0.002	0.017	0.015
Obs7	0.445	<b>0.483</b>	0.053	0.007	0.007	0.006
Obs8	<b>0.945</b>	0.013	0.024	0.014	0.004	0.000
Obs9	<b>0.945</b>	0.021	0.010	0.012	0.011	0.002
Obs10	<b>0.809</b>	0.165	0.001	0.016	0.007	0.001

*Values in bold correspond for each observation to the factor for which the squared cosine is the largest*



## Annex B. Results of principal component analysis of Taganito Mine

Summary statistics (Quantitative data):

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Year	8	0	8	2010.000	2017.000	2013.500	2.449
Water use (m3)	8	0	8	65689.000	284989.060	151874.008	69522.365
Population	8	0	8	16577.000	24331.000	20045.375	2749.371
Nickel Ore sold (WMT)	8	0	8	1200000.000	7997000.000	4955626.625	2957892.869
Disturbed Area (ha)	8	0	8	1032.000	2079.000	1396.553	384.405
Rehabilitated area within the mine (ha)	8	0	8	69.000	204.000	116.110	44.921
Silt Collected (WMT)	8	0	8	181000.000	631760.000	448331.408	182099.122
Total Spending for EPEP	8	0	8	29177742.810	345100000.000	195192961.091	104025403.247

Correlation matrix (Spearman (n)):

Variables	Year	Water use (m3)	Population	Nickel Ore sold (WMT)	Disturbed Area (ha)	Rehabilitated area within the mine (ha)	Silt Collected (WMT)
Year	<b>1</b>	<b>0.095</b>	<b>1.000</b>	<b>0.929</b>	<b>1.000</b>	<b>1.000</b>	<b>0.619</b>
Water use (m3)	<b>0.095</b>	<b>1</b>	<b>0.095</b>	<b>0.214</b>	<b>0.095</b>	<b>0.095</b>	<b>0.476</b>
Population	<b>1.000</b>	<b>0.095</b>	<b>1</b>	<b>0.929</b>	<b>1.000</b>	<b>1.000</b>	<b>0.619</b>
Nickel Ore sold (WMT)	<b>0.929</b>	<b>0.214</b>	<b>0.929</b>	<b>1</b>	<b>0.929</b>	<b>0.929</b>	<b>0.595</b>
Disturbed Area (ha)	<b>1.000</b>	<b>0.095</b>	<b>1.000</b>	<b>0.929</b>	<b>1</b>	<b>1.000</b>	<b>0.619</b>
Rehabilitated area within the mine (ha)	<b>1.000</b>	<b>0.095</b>	<b>1.000</b>	<b>0.929</b>	<b>1.000</b>	<b>1</b>	<b>0.619</b>
Silt Collected (WMT)	<b>0.619</b>	<b>0.476</b>	<b>0.619</b>	<b>0.595</b>	<b>0.619</b>	<b>0.619</b>	<b>1</b>
Total Spending for EPEP	<b>0.357</b>	<b>0.881</b>	<b>0.357</b>	<b>0.381</b>	<b>0.357</b>	<b>0.357</b>	<b>0.786</b>

*Values in bold are different from 0 with a significance level alpha=0.95*

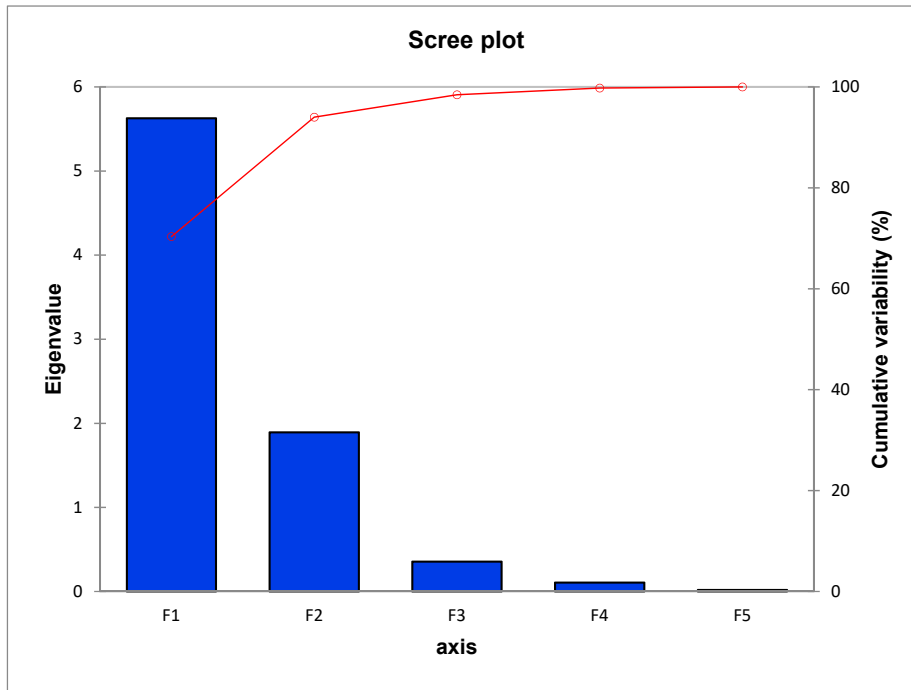
Ranks matrix:

	Year	Water use (m3)	Population	Nickel Ore sold (WMT)	Disturbed Area (ha)	Rehabilitated area within the mine (ha)	Silt Collected (WMT)
Obs1	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Obs2	2.000	3.000	2.000	2.000	2.000	2.000	2.000
Obs3	3.000	6.000	3.000	3.000	3.000	3.000	5.000
Obs4	4.000	8.000	4.000	4.000	4.000	4.000	4.000
Obs5	5.000	7.000	5.000	5.000	5.000	5.000	7.000
Obs6	6.000	5.000	6.000	7.000	6.000	6.000	8.000
Obs7	7.000	4.000	7.000	8.000	7.000	7.000	3.000
Obs8	8.000	2.000	8.000	6.000	8.000	8.000	6.000

**Principal Component Analysis:**

Eigenvalues:

	F1	F2	F3	F4	F5
Eigenvalue	5.627	1.893	0.355	0.106	0.018
Variability (%)	70.340	23.666	4.437	1.329	0.228
Cumulative %	70.340	94.006	98.443	99.772	100.000



Eigenvectors:

	F1	F2	F3	F4	F5
Year	0.408	-0.174	-0.049	-0.212	-0.078
Water use (m3)	0.130	0.649	-0.535	0.036	-0.524
Population	0.408	-0.174	-0.049	-0.212	-0.078
Nickel Ore sold (WMT)	0.395	-0.107	-0.297	0.800	0.324
Disturbed Area (ha)	0.408	-0.174	-0.049	-0.212	-0.078
Rehabilitated area within the mine (ha)	0.408	-0.174	-0.049	-0.212	-0.078
Silt Collected (WMT)	0.323	0.312	0.782	0.299	-0.311

Total Spending for EPEP	0.238	0.591	0.063	-0.301	0.707
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Factor loadings:

	F1	F2	F3	F4	F5
Year	0.968	-0.239	-0.029	-0.069	-0.011
Water use (m3)	0.309	0.893	-0.319	0.012	-0.071
Population	0.968	-0.239	-0.029	-0.069	-0.011
Nickel Ore sold (WMT)	0.936	-0.148	-0.177	0.261	0.044
Disturbed Area (ha)	0.968	-0.239	-0.029	-0.069	-0.011
Rehabilitated area within the mine (ha)	0.968	-0.239	-0.029	-0.069	-0.011
Silt Collected (WMT)	0.766	0.429	0.466	0.098	-0.042
Total Spending for EPEP	0.565	0.813	0.037	-0.098	0.095

Correlations between variables and factors:

	F1	F2	F3	F4	F5
Year	0.968	-0.239	-0.029	-0.069	-0.011
Water use (m3)	0.309	0.893	-0.319	0.012	-0.071
Population	0.968	-0.239	-0.029	-0.069	-0.011
Nickel Ore sold (WMT)	0.936	-0.148	-0.177	0.261	0.044
Disturbed Area (ha)	0.968	-0.239	-0.029	-0.069	-0.011
Rehabilitated area within the mine (ha)	0.968	-0.239	-0.029	-0.069	-0.011
Silt Collected (WMT)	0.766	0.429	0.466	0.098	-0.042
Total Spending for EPEP	0.565	0.813	0.037	-0.098	0.095

Contribution of the variables (%):

	F1	F2	F3	F4	F5
Year	16.652	3.023	0.243	4.474	0.608
Water use (m3)	1.702	42.123	28.622	0.130	27.424
Population	16.652	3.023	0.243	4.474	0.608
Nickel Ore sold (WMT)	15.584	1.153	8.828	63.949	10.486
Disturbed Area (ha)	16.652	3.023	0.243	4.474	0.608
Rehabilitated area within the mine (ha)	16.652	3.023	0.243	4.474	0.608
Silt Collected (WMT)	10.434	9.739	61.187	8.949	9.692
Total Spending for EPEP	5.673	34.895	0.391	9.077	49.965

Squared cosines of the variables:

	F1	F2	F3	F4	F5
Year	<b>0.937</b>	0.057	0.001	0.005	0.000
Water use (m3)	0.096	<b>0.798</b>	0.102	0.000	0.005
Population	<b>0.937</b>	0.057	0.001	0.005	0.000
Nickel Ore sold (WMT)	<b>0.877</b>	0.022	0.031	0.068	0.002
Disturbed Area (ha)	<b>0.937</b>	0.057	0.001	0.005	0.000
Rehabilitated area within the mine (ha)	<b>0.937</b>	0.057	0.001	0.005	0.000
Silt Collected (WMT)	<b>0.587</b>	0.184	0.217	0.010	0.002
Total Spending for EPEP	0.319	<b>0.661</b>	0.001	0.010	0.009

*Values in bold correspond for each variable to the factor for which the squared cosine is the largest*

Factor scores:

	F1	F2	F3	F4	F5
Obs1	-4.153	-1.144	0.282	0.019	0.178
Obs2	-2.909	-0.534	-0.032	0.029	-0.102
Obs3	-1.119	1.147	0.158	0.053	-0.264
Obs4	-0.054	1.743	-0.812	-0.329	0.037
Obs5	1.301	1.776	0.257	-0.105	0.171
Obs6	2.177	0.433	0.666	0.586	0.022
Obs7	1.988	-1.655	-1.105	0.292	0.010
Obs8	2.769	-1.765	0.586	-0.547	-0.051

Contribution of the observations (%):

	F1	F2	F3	F4	F5
Obs1	38.310	8.642	2.800	0.043	21.666
Obs2	18.803	1.882	0.036	0.101	7.101
Obs3	2.782	8.693	0.876	0.336	47.963
Obs4	0.006	20.058	23.211	12.712	0.923
Obs5	3.760	20.820	2.333	1.287	20.149
Obs6	10.529	1.236	15.609	40.390	0.333
Obs7	8.780	18.093	43.024	10.017	0.063
Obs8	17.031	20.576	12.111	35.114	1.802

Squared cosines of the observations:

	F1	F2	F3	F4	F5
Obs1	<b>0.924</b>	0.070	0.004	0.000	0.002
Obs2	<b>0.966</b>	0.033	0.000	0.000	0.001
Obs3	0.470	<b>0.494</b>	0.009	0.001	0.026
Obs4	0.001	<b>0.797</b>	0.173	0.028	0.000
Obs5	0.342	<b>0.637</b>	0.013	0.002	0.006

Obs6	<b>0.829</b>	0.033	0.078	0.060	0.000
Obs7	<b>0.494</b>	0.343	0.153	0.011	0.000
Obs8	<b>0.671</b>	0.273	0.030	0.026	0.000

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*Values in bold correspond for each observation to the factor for which the squared cosine is the largest*

## Summary of data and data sources

Summary of data obtained from OGC sustainability reports from year 2009-2018							
Year	Surface water consumed (cu.m)	Groundwater consumed (cu.m)	Disturbed area (sqm)	Rehabilitated area (sqm)	Gold Produced (oz)	Copper Produced (t)	Population
2009	800,000	1,500,000	0	0	0	0	2,243
2010	750,000	195,000	0	0	0	0	2,344
2011	600,000	7,400,000	0	0	0	0	2,407
2012	720,000	980,000	0	0	0	0	2,608
2013	945,909	1,321,227	0	0	66,277	23,059	2,708
2014	3,023,654	1,096,141	2,895,115	0	106,256	25,010	2,847
2015	688,671	1,138,072	3,103,456	127,500	127,086	23,109	2,984
2016	899,244	1,442,040	3,265,525	197,683	147,150	21,123	3,123
2017	1,128,495	5,008,111	3,331,526	213,122	176,790	18,351	3,273
2018	900,676	17,108,873	3,935,193	228,837	115,000	15,000	3,424

Summary of data obtained from NAC sustainability reports from year 2010-2017							
Year	Total volume of water consumed (cu.m)*	Disturbed area (ha)	Rehabilitated area (ha)	Nickel ore sold (WMT)	Silt Collected (WMT)	Total Spending for EPEP (PHP)	Population
2010	65,689	1,032	69	1,200,000	181,000	29,177,743	16,577
2011	125,178	1,061	80	1,700,000	220,000	84,215,524	17,123
2012	165,477	1,118	83	2,381,513	567,200	249,660,682	18,274
2013	284,989	1,157	99	3,893,100	510,761	260,100,247	19,272
2014	193,446	1,368	117	7,087,700	593,547	345,100,000	20,518
2015	156,425	1,559	123	7,740,700	631,760	255,750,300	21,330
2016	149,594	1,798	154	7,997,000	307,669	144,722,152	22,938
2017	74,194	2,079	204	7,645,000	574,714	192,817,041	24,331

\*water used by TMC disclosed as lump sum volume only, but mentions Taganito River as primary source of water in the mine.