

Siltation load contribution of nickel laterite mining on the coastal water quality of Hinadkaban Bay, Surigao Provinces, Philippines

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Abstract. Satellite images of Hinadkaban Bay, in Surigao Provinces, Philippines have indicated quite extensive siltation. Apparently, hilltop mining operations and other anthropogenic activities have resulted to deposition of suspended solids into the stretch of Hinadkaban Bay. In this regard, a multidisciplinary team was dispensed to undertake study in line with determining the environmental conditions along Hinadkaban Bay. Coastal marine water samples and surface water samples were obtained in two separate occasions (March and October 2012) via grab sampling. It was found that soil erosion in the study area was exacerbated by mining operations, road constructions and other anthropogenic activities, with heavy siltation often observed in areas near causeways, stockyards or siltation ponds of mine companies. Mean total suspended solids data of 5.87 mg/L was obtained for samples collected during the dry season while as high as 1000 mg/L TSS was recorded during heavy runoff. Meanwhile, average concentration of total nickel in water samples ranged from 0.050 µg/mL during dry season to 0.25 µg/mL during wet season. On the other hand mean total chromium concentration ranged from 0.060 µg/mL (dry season) to 0.30 µg/mL (wet season). Results of this study shall contribute to the effort of protecting surface water resources and of optimizing their beneficial uses.

1. Introduction

Fluvial transport is one of the modes by which terrestrial components are introduced to oceans. Sediments and detrital organic matter from river bodies are dispersed in oceans together with other materials from various sources such as erosion and atmospheric dust. The overall water quality of coastal areas is directly influenced by the presence of these suspended solids as they bring nutrients that could alter many important processes in these systems especially during high run-off [1,2]. For instance, metal components of those suspended particles, if present, may partition between the water column and the solids. Pathways for toxicity can be anticipated in at least two convenient media, that is, in water (via exposure, ingestion, etc.) or in solids (via adsorption). Other environmental issues associated with siltation are loss of natural vegetation filters and eutrophication.

Surigao provinces in the Philippines are rich with mineral heritage, primarily, ferro-alloy metallic



commodities namely nickel, iron and chromium. These deposits are found in the provinces of Surigao del Norte and northern Surigao del Sur, majority of which are within the Surigao Mineral Reservation (SMR). Several large-scale mining companies are operating in this area and because of extensive side cut mining operations on hilltops, as well as transport to port areas and consequent loading of nickel laterite to barges, induce soil erosions. These activities in the area are thought to heavily contribute to the build-up of nickel laterite particles along Hinadkaban Bay.

Cognizant to the need of developing an integrated coastal management program [3] to achieving sustainability in these mine impacted areas, however, there is a need to describe the prevailing coastal water quality as well as an assessment of existing mitigating and/or remediation measures and programs by mining companies involved. A study was conducted pursuant to the Mines and Geosciences Bureau (MGB) Special Order No. 2012-19 dated March 2, 2012. MGB is a government agency in the Philippines mandated to regulate mining operations in the Philippines. The study was aimed at determining the current environmental conditions along Hinadkaban Bay, with focus on the assessment of the extent of siltation in the coastal areas of Surigao del Norte and Surigao del Sur provinces in the Philippines and to determine possible causes of siltation and its impact on the coastal marine environment of Hinadkaban Bay. Specifically, this study aimed to provide some trends in water quality characteristics (physical and chemical) and determined the effects of natural and anthropogenic factors on the observed water quality. Further, the study aimed to: 1) investigate and identify the current contributions of total suspended solids (TSS) to the Hinadkaban Bay; 2) establish spatial and temporal trends in the river loads of suspended solids, of nutrients such as nitrate and other chemical properties such as pH, salinity, temperature as well as the heavy metal load (Cr and Ni) as a function of varying seasons and 3) estimate suspended solids contribution using relationship between river flow rates and TSS concentration to determine the TSS input to Hinadkaban Bay [4].



Figure 1. A digital image of the sampling area Hinadkaban Bay. This image reflects the catchment or basin covering the scope of this assessment.

This study shall contribute to the body of knowledge as to the contribution of nickel laterite mining operations to siltation load contribution along Hinadkaban Bay in Surigao, Philippines. Specifically, the individual load contributions of four identified drainage basins located in the study area namely, Hinadkaban Drainage Basin, Hayanggabon Drainage Basin, Taganito Drainage Basin and Capandan Drainage Basin, shown in figure 1, were estimated from results of water quality analysis of samples obtained specifically in sampling areas located upstream and downstream of those mine sites operating in the area [5]. Moreover, the findings of the study shall also be utilized to initiate effort leading to the development of guidelines relevant to coastal water quality criteria such as turbidity and to the design

of appropriate coastal water quality monitoring program in mine-impacted areas.

2. Materials and methods

The study area was situated in Claver, Surigao del Norte and Carrascal, Surigao del Sur with approximate coordinates between 125° deg. 46" – 125 deg. 58" E and 9 deg. 26" – 9 deg. 34" N. Claver is approximately 50 kilometers from Surigao City while Carrascal, Surigao del Sur is about 70 kilometers. Access to the study area is from Butuan City through a four-hour land trip via Surigao City along the National Highway.



Figure 2. Site map of the Hinadkaban Bay in Surigao where coastal and river water samples were collected in March and October, 2012.

Field survey and sampling were carried out on two occasions: March 6-10 (dry season) and from October 22-26, 2012 (wet season) by the multiagency assessment team. The Philippines' climate is characterized by two seasons only: dry (summer) and wet (rainy). Generally, the months of January to June cover the dry season while during the months of July to December, Philippines is frequently visited by storms and typhoons. It is known that TSS is related to quality and transparency of coastal water [4] and is subject to variations with varying seasons. Therefore, it was designed that the assessment shall include sampling covering both dry and wet seasons [7]. Sampling areas along the Hinadkaban Bay are shown in figure 2. Trace metals were analyzed from the acidified samples while the un-acidified samples were subjected to cation and anion analysis including alkalinity, TDS and TSS analyses in accordance to standard methods for water analysis. The Environment Management Bureau-CARAGA Region (EMB-CARAGA) collected samples for TSS analysis only. It was also the EMB group who performed the in-situ analysis using their Horiba Water Quality U-15 unit. The probe is capable of providing seven (7) in situ data on: pH, conductivity (mS/cm), turbidity (NTU), dissolved oxygen (mg/L), temperature (deg C), salinity (ppt NaCl) and TDS (mg/L). MGB protocol on water quality analysis was adopted to ensure reliability of measurements performed. For each measurement, duplicate readings were recorded. Calculations of mean, standard deviation and other statistical parameters were performed using MS Excel®.

During the field survey, documents were reassessed on-site using the aforesaid assessment. Interviews/discussions were also conducted with mine company personnel and other representatives.

The sample collection was limited to two sampling periods only, commencing on March 6-10, 2012 and this was followed up on October 22-26, 2012. Further, there was no coastal marine water samples collected in October, 2012 due to high tidal waves at that time along the Hinadkaban Bay. In addition, some areas within the mine facilities cannot be accessed because of slippery slopes and

terrain hence, there were limited number of surface water and/or river water samples collected last October 2012. Field data presented herein are for the purpose of establishing prevailing patterns and any measurement deviations noted can also be partly attributed to uncertainties in measurements especially during high runoff which was noted during the October sampling period. Also, it is worth-mentioning that at the time sampling was conducted in March 2012, there was on-going dredging in Hayanggabon River commissioned by a nickel processing plant in compliance with another (separate) order from EMB-CARAGA. Said dredging was completed in October, 2012.

3. Results and discussion

The goal of this scientific undertaking was to collect data and to communicate information about water quality in Hinadkaban Bay that could be relevant and useful to support managers' and/or government regulators' decisions. This paper describes an overview of the role of the water quality team in this multidisciplinary undertaking and how water quality assessment was conducted. Although, a monthly multipartite monitoring is already in place, the water quality group shall provide scientific information to concerned stakeholders to initiate better understanding of the environmental conditions in Hinadkaban Bay [8] and to ensure that the water quality in the Bay adheres to both national and local standards [9]. Further, results were also compared to baseline data indicated in the Environmental Impact Statement (EIS) submitted by each mining company prior to commencing the mining operations.

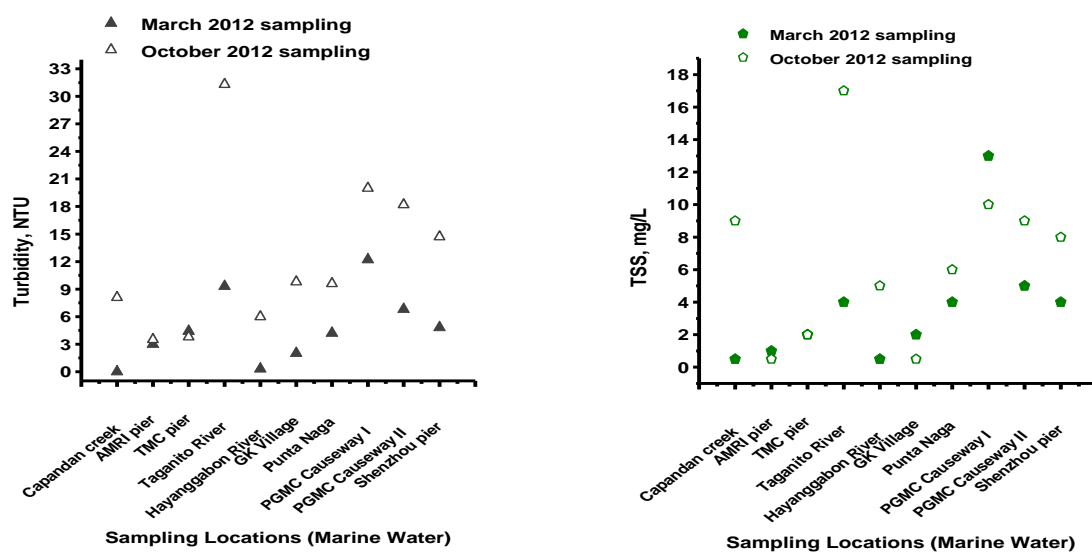


Figure 3. Turbidity and TSS levels measured in samples collected along Hinadkaban Bay.

It was found that along the study area, there were sites that were considered in poor condition (manifested by visible red-orange water discharges), generally impacted by point source discharges, and were often located near the causeways, stockyards or siltation ponds of each mine company. TSS and turbidity measured in marine water samples collected in March and in October 2012 were plotted against sample location to provide a glimpse of the existing spatio-temporal trends. It can be gleaned from figure 3 that TSS and turbidity of water samples collected in October were relatively higher than that of measured in samples obtained in March 2012. Results show that the turbidity and TSS readings have considerably increased during the month of October. The same observation was noted in the case of the Capandan creek. As previously pointed out, October is the time when the Philippines is frequented with typhoons. It should be noted also that in contrast to the previous results, TSS and turbidity levels were found to decrease in the Hayanggabon area with the completion of the dredging of the Hayanggabon River in October 2012.

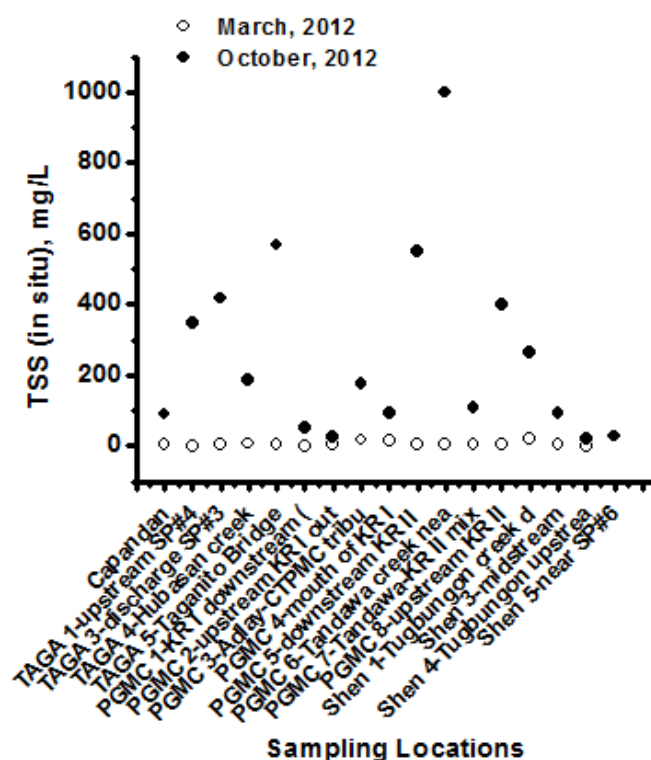


Figure 4. TSS levels in river and discharge outlets of siltation ponds within the mine facilities.

Such increase in the turbidity and TSS levels measured along the Hinadkaban Bay could possibly be attributed to the load contribution of the river bodies and discharges from siltation ponds of each mine facility. River delta (Capandan, Taganito, Hayanggabon, Kinalablaban and Tandawa) were found to be heavily silted due to wash off from river beds and creeks found within the mine facilities. Suspended solids from Capandan creek; Taganito River; Hayanggabon River; Tandawa creek; Kinalablaban River and Tugbungan creek directly flow into the Hinadkaban Bay. As such, it was presumed that suspended solids that have been transported to the above mentioned river systems came from stockpiles of nickel laterite near the Bay, as well as during loading of nickel laterite to barges. It was noted that it seems to be a usual practice for mining companies to have several valleys of nickel laterite ore stockpiled near the Bay prior to loading. Those activities were aggravated by heavy rainfall when runoff is high due to the fact that Surigao area is frequented by typhoons. As shown in figure 4, no clear trend as to the TSS data obtained from water samples collected in March 2012. TSS mean data (5.87 mg/L) is below the Department Administrative Order (DAO) of the Philippines' Department of Environment and Natural Resources (DENR) DENR DAO-2016-08 (Water Quality Guidelines [WQG]) and General Effluent Standards (GES) for Class SC and SD water, 100 and 150 mg/L, respectively. However, TSS levels measured reached as high as 1000 mg/L in samples obtained in October 2012 (wet season). The measured TSS levels were found to be non-compliant with the DENR-DAO 2016-08-WQG and GES for class SC and SD coastal marine waters. Further, it was found that the values did not also conform to the water quality guidelines in surface waters of Canada, the European Union member states and Australia and New Zealand [2].

An understanding of the changes in the sediment flux to the Hinadkaban Bay would be important to be able to provide for effective mitigating measures for the prevention of the further degradation of the coastal water environment. This is because the geochemical components such as heavy metals, some nutrients, etc., present in suspended solids may be released into the water body and may cause modification in its physical, chemical and biological properties leading to the eventual degradation of

the coastal area notwithstanding the potential toxicity of this suspended matter to aquatic life in the Hinadkaban Bay.

Thus, the load contributions of each river system as well as siltation pond discharges to the Hinadkaban Bay were determined [10]. It is assumed that the characteristic flow at each basin directly affects the amount of sediments that will go into the Hinadkaban Bay. As far as availability of data on the sediment load contribution of each river system is concerned, this study was the first to attempt to quantify the sediment load contribution coming from tributaries within mine facilities going to Hinadkaban Bay. However, the data particularly presented herein to quantify sediment contribution of each basin to the Hinadkaban Bay using equations (1) to (5), may be treated only as preliminary and needs to be subjected to further validation. The model/equations chosen were not specifically designed by the researchers based from prevailing environmental conditions in each basin in the study area. For the purpose of illustrating the contributions of these mining operations on the water quality of river systems situated in the study area that equations (1) to (5) were adopted from those cited references. For example, to get the best fit with reference to equations (1) to (5), river water flow needs to be monitored on a daily basis every year, necessary corrections have to be performed such that the equations shall reflect any variations relevant to prevailing climatological conditions [11]. It can be anticipated that discharges of sediments into the river will be low during the dry season. On the other hand, sediment load contribution of the river basin may shoot up during the rainy season.

To get through the target sediment load contribution per basin, the following information was utilized. A mean discharge rate of 3.3 m³/s was recorded from 18 sampling sites. Highest volumetric discharge, i.e. 25.3 m³/s, was recorded at the upstream of the Taganito River, near the siltation pond #4 of one mining company. The discharge rate at each gauging station was calculated based on the respective cross sectional area of each river system and on the recorded flow (in rounds per minute or rpm), measured during the actual sampling [12]. The gauging stations were located within and/or in proximity to the mine facilities. Meanwhile, the sediment load contribution was estimated from the river/pond discharge and TSS concentration data. Specifically, the TSS concentration data from each sampling station were correlated with the calculated discharge rate through equation (1):

$$\text{TSS} = aQ^b \quad [13] \quad (1)$$

where Q represents the river/pond water discharge, m³/s and TSS in mg/L. a and b are constants. A modified equation by Campbell and Bander (1940) may be used to establish the influence of fluvial flow (Q, m³/sec) on TSS load (L, gram/sec),

$$L = aQ^b \quad [14] \quad (2)$$

Results of the estimation analysis suggest that TSS concentration varies non-linearly with discharge. That is, elevated TSS concentrations were measured at each station where there was moderate flow rate. Also, it was observed that turbidity was found to be low in areas in which there was no heavy run-off. This observation supports the normal pattern in river transport [13]. The observed variability in the sediment load contribution may be attributed to the presence of point sources only and to some extent to factors relating to flow regulations within the river channels. For example, as previously emphasized that in the absence of point sources such as where there were no stockpiles near the river or absence of any rampant transport and loading activities, TSS levels were found to be at the minimum value.

Given the TSS concentrations and the calculated discharge rate, the mean TSS flux from each river system to the Hinadkaban Bay may be calculated using an equation which was derived and modified from Dolan *et al* [15] and then integrating the method adopted by Prego *et al* [16]. Average flow in all stations was also calculated. Using the modified equation (3), the mean TSS flux for each river was obtained,

$$F = Q \left[\frac{f_m}{q_m} \right] \quad (3)$$

where F is the average river load of TSS, gram/sec; Q is the mean daily flow, m³/sec; f_m is the mean

load for the day in which TSS was determined, gram/sec and q_m is the mean river discharge for the day in which TSS was determined, m^3/sec . In addition, this study has utilized and adopted the equation by Dolan *et al* 1981, as shown in equations (4) and (5):

$$F = Q \frac{f_m}{q_m} \left[\frac{1 + \frac{1}{n} \frac{S_{xy}}{q_m f_m}}{1 + \frac{1}{n} \frac{S_x^2}{q_m q_m}} \right] \quad (4)$$

$$S_{xy} = \frac{1}{n-1} (\sum q_i f_i - \sum n q_m f_m)$$

$$S_x^2 = \frac{1}{n-1} \left(\sum q_i^2 \right) - n q_i^2 \quad (5)$$

where F (g/s) – the annual average river load of TSS, Q (m^3/s) – the mean daily flow for the year, f_m (g/s) – the mean load for the day of the month on which TSS was determined, q_m (m^3/s) – the mean river discharge for the days on which TSS were determined, n – the number of days with TSS measurements, q_i – the individual measured flows (g/s) determined at each sampling and f_i – the individual measured load (g/s) determined at each sampling.

Table 1. Drainage Basin Area and calculated TSS load per basin per day (basis: *in situ* TSS measurements performed during the October 2012 sampling).

River	Basin, km^2	TSS flux, grams/sec- km^2
apandan creek	4	29.6
Taganito River	26.4	4.5
Hayanggabon River	11.5	10.3
Kinalablaban River	32.1	3.7
Tugbungon creek	Not available	n/a
Tandawa creek	4.4	26.9

Based on the data generated in the course of this study, a mean TSS load of 157.3 mg/L and a mean river discharge of 3.3 m^3/sec were obtained across the 18 stations sampled. The mean daily flow was assumed to be 2.5 m^3/sec based on the average linear flow multiplied by the average cross sectional area of the river system. Calculations yield a mean TSS load of 118.4 gram/sec. This means that under typical condition, the river systems take on, an average of 118.4 grams of solids per second. Using this mean mass of solids being discharged to river system, the TSS contribution per basin can be calculated and estimated. Table 1 gives the drainage basin area and the calculated estimated TSS load per basin.

Calculated values imply the TSS flux was observed at Capandan creek at 29.6 grams of solids/seconds per square kilometers and followed by Tandawa creek with calculated flux of 26.9 grams/sec- km^2 . Sediment load contribution was found to be relatively higher in those two river systems compared with the other river systems. Kinalablaban River contributed the least in terms of TSS flux into the Hinadkaban Bay.

It was clearly seen from the water quality data that under various extreme conditions such as heavy runoff, the chemistry associated with each process also tends to change and at this circumstance that a stringent action must be undertaken to averse the foreseen risk posed by siltation along the Hinadkaban bay. In anticipation of the potential release of other contaminants such as heavy metals present in suspended solids into the water column, total Ni and total Cr in water samples were also measured in those samples collected [17]. Average concentration of total Ni in the water samples was 0.050 $\mu g/mL$ during dry season while the mean total Cr concentration was 0.060 $\mu g/mL$. It was

observed that both the amounts of Cr and Ni increased during the wet season, that is, amount of Cr and Ni measured were 0.30 and 0.25 $\mu\text{g/mL}$, respectively. The DENR-DAO-2016-08-WGC and GES standard for total Ni and Cr in SC and SD water body classifications are 0.3 and 1.5 $\mu\text{g/mL}$. Results suggest that dilution is not apparent which means that at high runoff, which translates to ravaging, quite high volume of water coming into these river systems, the amount of Cr and Ni were found to be much higher during rainy season. Correlating the elevated concentration of TSS in the river system, it may therefore be concluded that the presence of suspended particulate matter could have directly influenced the total metal (Ni and Cr) concentrations in the overlying water. It is rationalized that long exposure of the suspended solids in the water column may cause Cr and Ni to partition into the water column, paving a convenient route for transport of Cr and Ni into the river system.

4. Conclusions and recommendations

This study has provided information as to the chemical concentrations in coastal marine water and surface and river water samples in Surigao provinces. Measured values of TDS, salinity and conductivity in coastal marine water samples were generally constant except in some areas where the site is situated 100-200 m from the Hinadkaban Bay where saltwater intrusion is possible and/or could be effluent waters flowing out of the siltation ponds (mouths of Taganito River, Hayanggabon River and Kinalablaban River). Mean values for TDS, salinity and conductivity for water samples collected in March 2012 were 169.5 mg/L, 0.1 ppt NaCl and 0.27 mS/cm, respectively. Study designs directed toward status and trends monitoring area are encouraged to be undertaken by a multipartite group, members of which will come from various stakeholders. As concerned stakeholders' management decisions will have to consider whether these chemical concentrations would decrease or increase upon implementation of proposed mitigating measures or remediation program. Based on the outcome of the chemical analysis conducted, the following study designs are suggested: 1) Mining companies must include in their environmental program methods [6] to quantify sediment loads (advective and dispersive) and modeling of runoff from mine sites on a quarterly basis every year to enable monitoring of the sediment flux from the mine site to the coastal area. 2) Chromium and nickel metal speciation of suspended particulate matter must be undertaken in order determine the extent of partitioning of chromium and nickel in the overlying water. 3) Ecotoxicological studies should be performed to determine the biological and chemical impact of the suspended particulate matter on aquatic organisms; and 4) Conduct characterization of the suspended particulate matter in terms of particle size distribution and chemical composition to further understand the potential risk posed to aquatic organisms.

Further, this study was able to establish the possible sources, pathways, and loadings of sediments and other solids in Hinadkaban bay. It was found that the occurrence of lateritic soil/sediments erosion due to sparse vegetation cover and rock weathering, gulley erosion, and the prevalence of landslides and landslide scars resulted in the transport of silt materials into the Hinadkaban Bay thus contributing to the siltation in the coastal waters of the study area. This siltation was evident in the watersheds of Taganito, Hayanggabon, Hinadladan and in the Capaguihan and Dahican area. These drainage basins contribute to the TSS flux along Hinadkaban Bay. Notwithstanding, the ongoing road construction in the vicinity of Hinadkaban Bay. Moreover, results of the study found that Capandan creek (29.6 grams sediment/sec per km^2) contributed the most in terms of TSS flux into the Hinadkaban Bay, followed by Tandawa Creek (26.9 grams sediment/sec per km^2). Further, inefficient mining activities such as absence of regular program to desilt those siltation ponds, increased sediment output that exacerbated the problem of turbidity and siltation due to river discharge.

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Declaration of no competing interests

We declare we have no competing interests and/or no non-financial competing interests, or other interests that might be perceived to influence the interpretation of this article. Also, the technical views presented herein do not necessarily reflect those of the views, opinions or decisions of the MGB or DENR management.

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