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Environmental Pollution by Hexavalent Chromium, etc. Caused by Nickel Mining and Smelting Operations in Rio Tuba, Palawan Island

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1. Introduction

Global demand for nickel is in a growing trend; in 2020, nickel ore production was 2,438,000 tons, placing Indonesia in first place with 694,000 tons, followed by the Philippines with 345,000 tons, Russia, and New Caledonia.1) Although currently the largest use is as a raw material for the manufacture of alloys, including the conventional stainless steel, demand from battery manufacturing has shown remarkable growth in recent years. According to data from the Japan Organization for Metals and Energy Security (JOGMEC), stainless steel accounted for 68% of the 2.31 million tons of global demand for nickel in 2018, while batteries accounted for only 5%, but the 2040 forecast shows that stainless steel will fall back to 48% of the 4.03 million tons demand and batteries will account for 30%.2) This is presumably due to the surge in demand for batteries for EV automobiles and as backup for renewable energy in the trend toward decarbonization.

Figure 1: The Sulu Sea and Rio Tuba

Looking at Japan's partners for nickel ore imports, Indonesia was the top importer until 2013, accounting for more than half of all imports, but due to a ban on Indonesian ore exports in 2014, the imports drastically declined, and since then the Philippines and New Caledonia have taken over the top two positions in each year's imports. On the other hand, in terms of imports of nickel matte to Japan, the main raw material for nickel metal, Indonesia is by far the largest importer, accounting for 87% on average from 2012 to 2021.3)

Nickel is a key metal in the decarbonization trend, but what is happening at its mining sites? In the Rio Tuba area (Figure 1), located near the southern tip of Palawan Island in the Philippines, the Rio Tuba mine and a nickel smelter using the high pressure acid leach (HPAL) process from low-grade ore (Coral Bay Nickel Corporation (CBNC), a joint venture owned 84.375% by Sumitomo Metal Mining Co. (SMM)), are operating. A preliminary survey was conducted by FoE Japan, mainly through questionnaires and interviews, in response to reports on environmental pollution and health problems from the Palaw'an, the local indigenous people. Based on the results, it was found that an additional physico-chemical study was necessary, and the author decided to participate in the study. The physico-chemical environmental survey began in 2009. This paper focuses on the actual situation of water pollution by heavy metals such as hexavalent chromium and nickel that were revealed in the survey.

2. Local Situation

The first smelter, which started operation in 2005, has an annual production of approximately 10,000 tons of nickel and 700 tons of cobalt. The second smelter, which started operation in 2009, is of the same size, with total annual nickel production of about 20,000 tons and 1,500 tons of cobalt, equivalent to about 1% of global demand for nickel in 2018. While high-grade ore is exported to China, the smelter plants process low-grade ore piled up locally for on-site metallurgy, cutting transportation costs, and coal-fired power plants are installed alongside to operate them. There was also a limestone mine, which was necessary for the smelting process, and 190,000 tons of limestone was mined annually, which was a source of dust.

An overview of the Rio Tuba area is shown in Figure 2. Mt. Bulanjao, which slightly exceeds 1,000 meters above sea level, is a sacred mountain for indigenous peoples, and part of the area is a “core zone” as defined in Section 9.1 of Republic Act No. 7611 in the Philippines (the Strategic Environmental Plan for Palawan Act: The SEP Law, 1992), or “an area of maximum protection,” which requires full and strict protection. The Rio Tuba Mine is located at the southeast foot of this mountain, and the smelter plants and the tailings dam are situated in the lower part of the mountain. The Rio Tuba estuary, which opens into the Sulu Sea in the lower part of the figure, is channeled by the Sumbiling, Gamayon, Togpon, and Kinurong Rivers, in that order from west to east. The mangrove belt illustrated in green-gray on both banks of the estuary is presumably what used to support the rich ecosystem of Rio Tuba estuary and the fishing activities of the indigenous peoples.

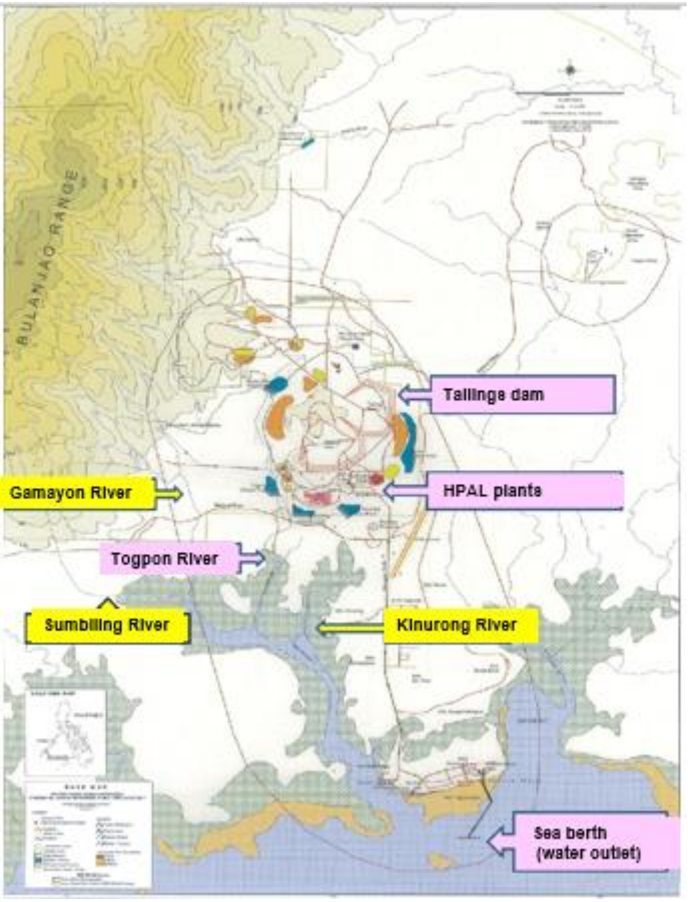


Figure 2: Overview Map of Rio Tuba Area (Processed by the author from the material provided by SMM at the meeting held on December 9, 2009)

With the establishment and operation of CBNC, a sea berth was constructed 1 km offshore by destroying coral reefs, and wastewater from the plants is carried by pipes and discharged into the sea at a depth of a few meters in the sea berth. Concentrated sulfuric acid transported from Japan is also unloaded here. According to interviews with indigenous people and others, they have reported that they have been unable to catch fish in the adjacent sea waters since the start of operation.

To briefly explain the HPAL process, low-grade nickel ore excavated from the Rio Tuba mine is dissolved with high-temperature sulfuric acid, hydrogen sulfide is blown in while adjusting the pH of the dissolved solution, nickel sulfide (including cobalt sulfide) and zinc sulfide are precipitated and separated, and lime is added to the remaining solution to make gypsum which is discharged into a huge settlement pond (tailings dam). Due to the large amount of gypsum (calcium sulfate) deposited as waste, the No. 1 tailings dam was already full, and the No. 2 tailings dam is now in operation.

3. Survey Method

It is not possible to enter the plants and mines to conduct surveys. As already mentioned, sampling is not possible because the plant effluent is transported by pipeline to the sea berth and discharged into the sea at a depth of several meters. For this reason, the first comprehensive survey (2010) was conducted regarding the water quality of on the river water of the Togpon River, which has the Rio Tuba Mine and CBNC plants area as its catchment area, the water from the wells of the indigenous communities, the drinking water that CBNC provided to the indigenous communities, and several rivers including the Sumbiling River, which is considered uncontaminated, as comparison subjects.

At the sampling sites, simple pH measurements using pH test papers and hexavalent chromium measurements using a simple pack test (KYORITSU CHEMICAL-CHECK Lab.,Corp.) were conducted. Samples were transported to the laboratory in Japan in polyethylene bottles that were co-washed with sample water and tightly sealed to prevent air from entering. Samples transported to the laboratory were heated to just before boiling in a microwave with concentrated nitric acid added to reach 1%, then cooled, filtered, and analyzed for metals by ICP/MS (Inductively Coupled Plasma Mass Spectrometry). Water from wells was also analyzed for anions by ion chromatography.

For the Rio Tuba estuary, where the Togpon River and other rivers flow into, bottom sediments were collected from the top of a chartered fishing boat using an Ekman-Birge Bottom Sediment Sampler. Samples were brought back to the laboratory, decomposed by aqua regia, and analyzed for metals by ICP/MS method.

Continuous monitoring surveys have been conducted twice a year (dry season and rainy season), mainly in the middle and downstream (at three tidal areas from the upper end to the inflow point of Rio Tuba estuary) of the Togpon River, up to the present day (2024). The surveys were suspended from 2020 to the dry season of 2022 due to COVID-19 Disaster.

4. Survey Results and Discussion

1） Findings of Hexavalent Chromium Pollution

In a preliminary survey conducted in 2009, we brought several types of simple pack tests to the field and attempted to measure at a survey point (a crossing point of a public road) set in the midstream of the Togpon River; as a result, we found that hexavalent chromium exceeded the then Japanese Environmental Standard and the then Japanese Water Supply Act standard (0.05 mg/L). When the sample was brought back to Japan and re-measured, it still exceeded the standards. When this sample was analyzed by ICP/MS, total chromium was detected at a concentration almost equivalent to the hexavalent chromium. Among the simple pack tests, the test kit for hexavalent chromium is relatively accurate, since it uses almost the same principle as the analysis method of the Industrial Standardization Act (JIS Act) 4), with the only exception that the accuracy is slightly reduced in the comparison with the concentration class color printed chart when determining the concentration. The linear relationship between hexavalent chromium and total chromium for the samples collected in the midstream of the Togpon River is shown in Figure 3.

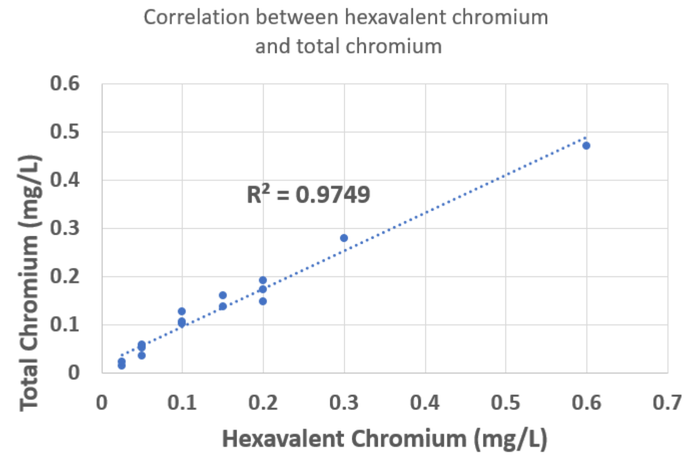


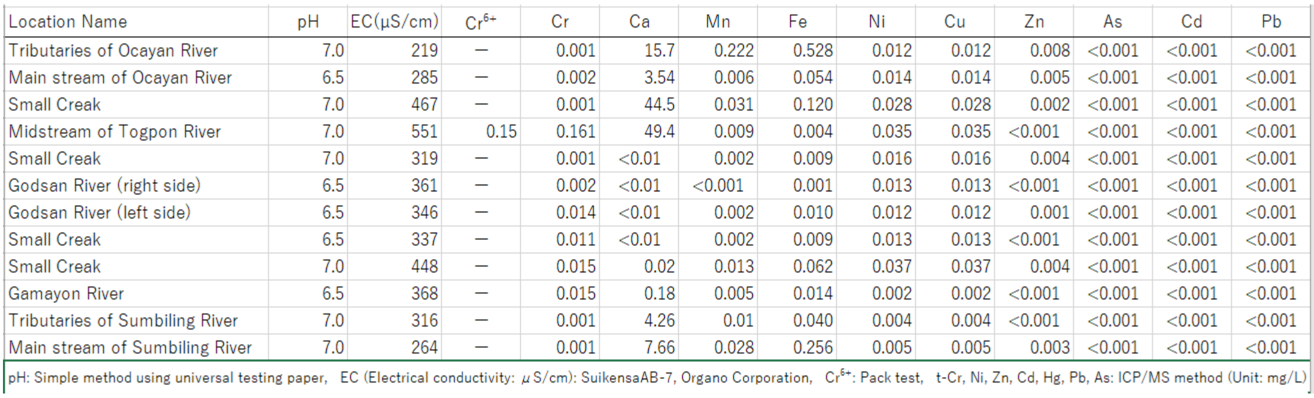
Figure 3: Correlation between hexavalent chromium by simple pack test and total chromium by ICP/MS

In environmental water quality surveys in Japan, rapid measurement is necessary because highly reactive hexavalent chromium is easily reduced to trivalent chromium by reacting with organic matter in the water. However, it was found that the reduction reaction is unlikely to occur in tropical regions where organic matter is less abundant.

The water quality standard for hexavalent chromium has been revised since then, with both the Japanese Water Supply Act standards (March 2020) 5) and Japanese Environmental Standards (2024) 6) set at 0.02 mg/L. The WHO Guidelines for drinking water quality remains at 0.05 mg/L, but was upgraded from a provisional standard to an official standard in March 2020 7) , and moreover, it should be noted that the standard is for total chromium, instead of hexavalent chromium.

2） Results of the First Comprehensive Survey

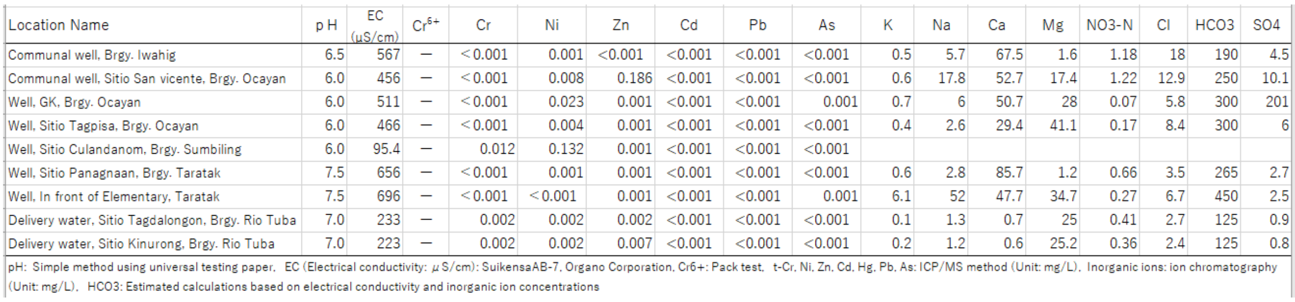
Table 1 shows the results of the survey conducted in 2010, including the Togpon River and other river waters. Of all the sites, hexavalent chromium was detected only in the midstream of the Togpon River. In addition, it was about three times higher than the Japanese Environmental Standard for Water Quality at that time, and seven to eight times higher than the current revised standard. Although there is no Japanese Environmental Standard for water quality with regard to nickel, there is the guideline value of 0.01 mg/L for items requiring monitoring under the Japanese Water Supply Act at that time. There were several locations where the nickel concentration exceeded the value. There was no other heavy metals found for concern. The four “small creek” locations are individual locations where the name of each river could not be identified.



Location Name	pH	EC(μS/cm)	Cr^{6+}	Cr	Ca	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb
Tributaries of Ocayan River	7.0	219	—	0.001	15.7	0.222	0.528	0.012	0.012	0.008	<0.001	<0.001	<0.001
Main stream of Ocayan River	6.5	285	—	0.002	3.54	0.006	0.054	0.014	0.014	0.005	<0.001	<0.001	<0.001
Small Creak	7.0	467	—	0.001	44.5	0.031	0.120	0.028	0.028	0.002	<0.001	<0.001	<0.001
Midstream of Togpon River	7.0	551	0.15	0.161	49.4	0.009	0.004	0.035	0.035	<0.001	<0.001	<0.001	<0.001
Small Creak	7.0	319	—	0.001	<0.01	0.002	0.009	0.016	0.016	0.004	<0.001	<0.001	<0.001
Godsan River (right side)	6.5	361	—	0.002	<0.01	<0.001	0.001	0.013	0.013	<0.001	<0.001	<0.001	<0.001
Godsan River (left side)	6.5	346	—	0.014	<0.01	0.002	0.010	0.012	0.012	0.001	<0.001	<0.001	<0.001
Small Creak	6.5	337	—	0.011	<0.01	0.002	0.009	0.013	0.013	<0.001	<0.001	<0.001	<0.001
Small Creak	7.0	448	—	0.015	0.02	0.013	0.062	0.037	0.037	0.004	<0.001	<0.001	<0.001
Gamayon River	6.5	368	—	0.015	0.18	0.005	0.014	0.002	0.002	<0.001	<0.001	<0.001	<0.001
Tributaries of Sumbiling River	7.0	316	—	0.001	4.26	0.01	0.040	0.004	0.004	<0.001	<0.001	<0.001	<0.001
Main stream of Sumbiling River	7.0	264	—	0.001	7.66	0.028	0.256	0.005	0.005	0.003	<0.001	<0.001	<0.001

pH: Simple method using universal testing paper, EC (Electrical conductivity: μS/cm): SuikensaAB-7, Organo Corporation, Cr^{6+}: Pack test, t-Cr, Ni, Zn, Cd, Hg, Pb, As: ICP/MS method (Unit: mg/L)

Table 1: Results of river water quality survey in the Rio Tuba area



Location Name	p H	EC (μS/cm)	Cr^{6+}	Cr	Ni	Zn	Cd	Pb	As	K	Na	Ca	Mg	NO3-N	Cl	HCO3	SO4
Communal well, Brgy. Iwahig	6.5	567	—	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.5	5.7	67.5	1.6	1.18	18	190	4.5
Communal well, Sitio San vicente, Brgy. Ocayan	6.0	456	—	<0.001	0.008	0.186	<0.001	<0.001	<0.001	0.6	17.8	52.7	17.4	1.22	12.9	250	10.1
Well, GK, Brgy. Ocayan	6.0	511	—	<0.001	0.023	0.001	<0.001	<0.001	0.001	0.7	6	50.7	28	0.07	5.8	300	201
Well, Sitio Tagpisa, Brgy. Ocayan	6.0	466	—	<0.001	0.004	0.001	<0.001	<0.001	<0.001	0.4	2.6	29.4	41.1	0.17	8.4	300	6
Well, Sitio Culandanom, Brgy. Sumbiling	6.0	95.4	—	0.012	0.132	0.001	<0.001	<0.001	<0.001								
Well, Sitio Panagnaan, Brgy. Taratak	7.5	656	—	<0.001	0.001	0.001	<0.001	<0.001	<0.001	0.6	2.8	85.7	1.2	0.66	3.5	265	2.7
Well, In front of Elementary, Taratak	7.5	696	—	<0.001	<0.001	0.001	<0.001	<0.001	0.001	6.1	52	47.7	34.7	0.27	6.7	450	2.5
Delivery water, Sitio Tagdalongon, Brgy. Rio Tuba	7.0	233	—	0.002	0.002	0.002	<0.001	<0.001	<0.001	0.1	1.3	0.7	25	0.41	2.7	125	0.9
Delivery water, Sitio Kinurong, Brgy. Rio Tuba	7.0	223	—	0.002	0.002	0.007	<0.001	<0.001	<0.001	0.2	1.2	0.6	25.2	0.36	2.4	125	0.8

pH: Simple method using universal testing paper, EC (Electrical conductivity: μS/cm): SuikensaAB-7, Organo Corporation, Cr6+: Pack test, t-Cr, Ni, Zn, Cd, Hg, Pb, As: ICP/MS method (Unit: mg/L), Inorganic ions: ion chromatography (Unit: mg/L), HCO3: Estimated calculations based on electrical conductivity and inorganic ion concentrations

Table 2: Results of water quality analysis of communal wells and delivery water in the Rio Tuba area

The results of groundwater measurements from the communal wells in each village are shown in Table 2. The detection of 0.132 mg/L of nickel at Sitio Culandanom, Sumbiling village may indicate that the groundwater is affected by the nickel laterite layer of Mt. Bulanjao. For nickel, 0.01 mg/L was indicated as the guideline value for items requiring monitoring under the Japanese Water Supply Act; however, according to a document from the 17th Meeting of the Living Environment Water Supply Subcommittee of the Health Science Council, dated February 17, 2016 under the Ministry of Health, Labor and Welfare (“Draft Policy for Future Revision of Water Quality Standards, etc. Based on the Latest Scientific Knowledge”), the previous provisional value was deleted and 0.02 mg/L was determined as an evaluation value.7) According to this document, the EU and Codex Alimentarius Commission set 0.02 mg/L respectively. The well water at Sitio Culandanom is approximately seven times higher than this standard, and we informed the residents about this because of concerns about health effects. In addition, the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) has published a toxicological profile for nickel in 2024 (October 2024, p. 415), which states that the U.S. Food and Drug Administration (FDA) drinking water standard is 0.1 mg/L.8)

To compare the ionic balance of the groundwater, hexadiagrams are shown in Figure 4. Location numbers 4 and 6 are Ca-HCO_3 type, location numbers 12 and 13 are CaMg-HCO_3 type, location numbers 1 and 5 are MgCa-HCO_3 type, location number 22 is MgNaCa-HCO_3 type, and location numbers 7 and 8 are Mg-HCO_3 type. The delivery water discussed below has a completely different ionic composition from the others, and is probably not groundwater but surface water from some river. It has a peculiar composition with low sodium and high magnesium. The sample 22 differs from the others by having a relatively high sodium concentration. It is also distinctive for its relatively high concentration of barium. The sample 12, 13, 1, and 5 may be groundwater accumulated in limestone layers of coral reef origin, while samples 4 and 6 are low in magnesium and high only in calcium cations, but may also be accumulated water in the limestone layers. Except for the sample 1 in Sumbiling village, no groundwater contamination by nickel or hexavalent chromium of nickel laterite origin was identified.

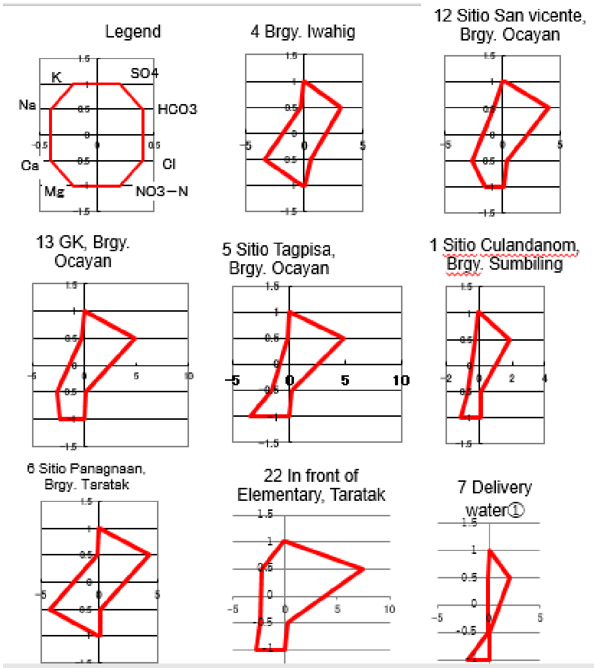


Figure 4: Comparison of groundwater by hexadiagrams

We also analyzed delivary water as drinking water at two locations where CBNC had installed stainless steel tanks in indigenous villages (Figure 5) and supplied the water by tank trucks on a regular basis. This was because hexavalent chromium had been detected in the delivary water collected during a preliminary survey in 2009, and the company had been notified about it. Fortunately, no hexavalent chromium was detected in this survey. CBNC reported to us that it had changed the source of the water supply after discovering that the tank truck driver had collected and supplied contaminated river water. This is an incident that should not be tolerated at all, even if it was a free service project to the indigenous community. In addition, without our survey, there is a possibility that the incident would have remained undetected and could have led to health problems.

Figure 5: Delivery water tank

3） Results of Continuous Monitoring Surveys

Figure 6 and Figure 7 show the results of the continuous monitoring surveys at a survey point in the midstream of the Togpon River. Surveys were conducted in March or April during the dry season and between August and October during the rainy season; the interruption from 2020 to 2022 was due to the COVID-19 disaster. It is again shown that hexavalent chromium and total chromium are well matched. It is also clear that hexavalent chromium and total chromium are lower during the dry season and higher during the rainy season. Significant exceedances of the Japanese Environmental standard and the Japanese Water Supply Act standard (both 0.05 mg/L, and 0.02 mg/L after the revision) are evident during the rainy season. In 2024, a highest concentration of 0.6 mg/L of hexavalent chromium and 0.471 mg/L of total chromium was observed during the rainy season, equivalent with 24 to 30 times higher than the standards and the highest concentration in 15 years, respectively. The slightly lower values in 2017 and 2018 as well as in 2022 and 2023 were likely due to less rainfall in the rainy seasons than in normal years. Furthermore, it should be noted that the Philippine Department of Environment and Natural Resources (DENR) Administrative Order No. 2016-08, “Water Quality Guidelines and Effluent Standards,” (2016. 5-year grace period) stipulates the standard for hexavalent chromium as 0.01 mg/L for freshwater (the effluent standard is 0.02 mg/L) and as 0.05 mg/L for marine water (the effluent standard is 0.1 mg/L), while the Philippine Department of Health (DOH) “National Drinking Water Standards” (2017) stipulates the standard for total chromium as 0.05 mg/L.

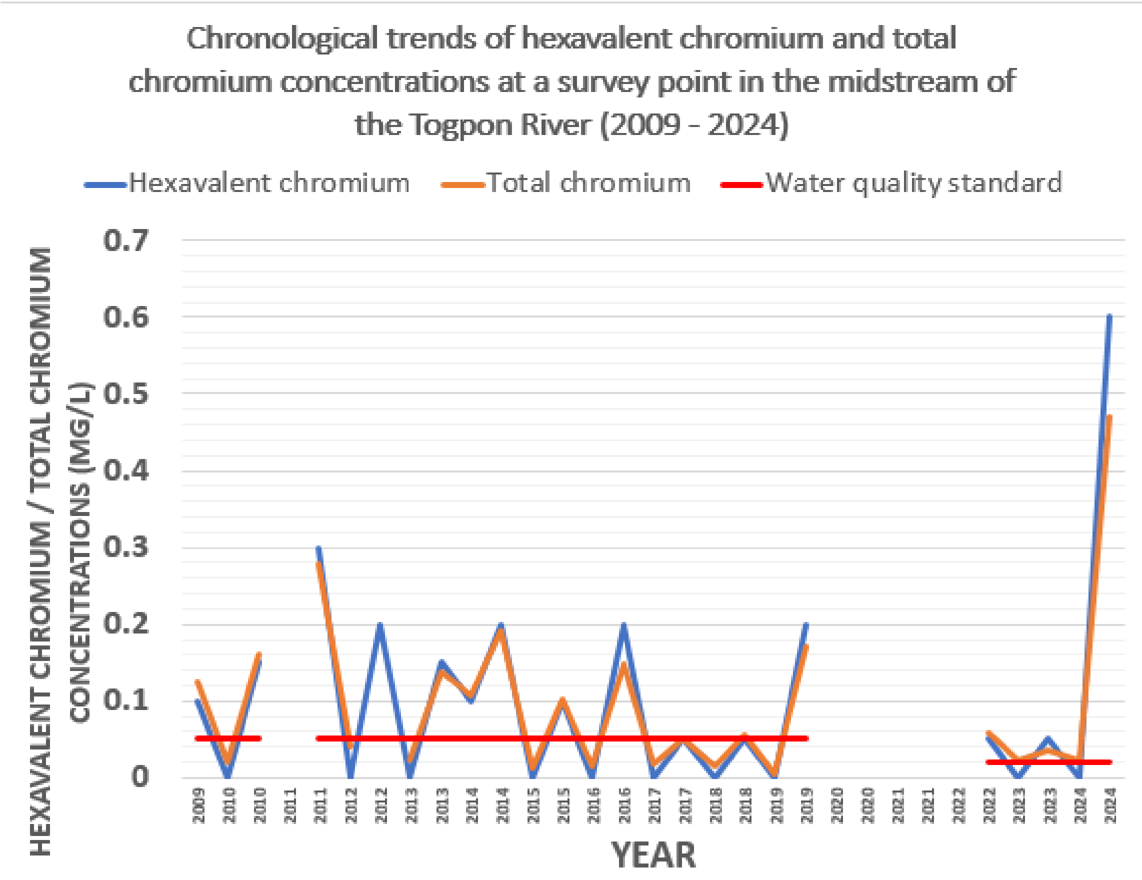


Figure 6: Chronological trends of hexavalent chromium and total chromium

For nickel, the correlation with the dry and rainy seasons is not clear, which may suggest that the mechanism is different from the elution of hexavalent chromium. Unlike hexavalent chromium, the water quality always exceeds the standard significantly compared to the 0.02 mg/L as evaluation value under the Japanese Water Supply Act, regardless of the dry or rainy season. In particular, the 1.66 mg/L in the rainy season of 2024 is approximately 80 times higher than the standard value. Although there is no Japanese Environmental standard for water quality, it is listed as an item requiring monitoring for the protection of human health.

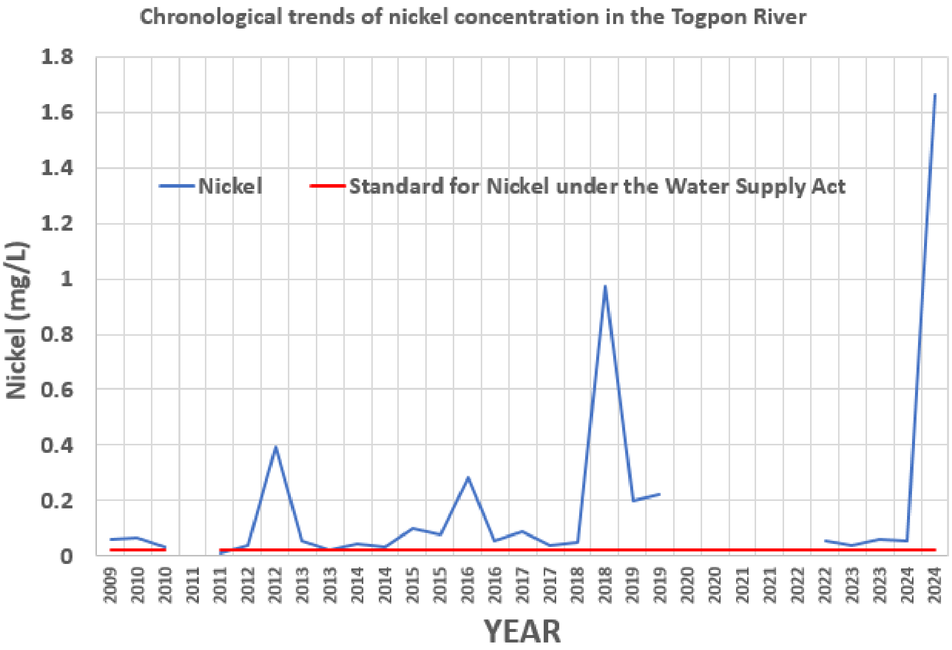


Figure 7: Chronological trends of nickel concentration at a survey point in the midstream

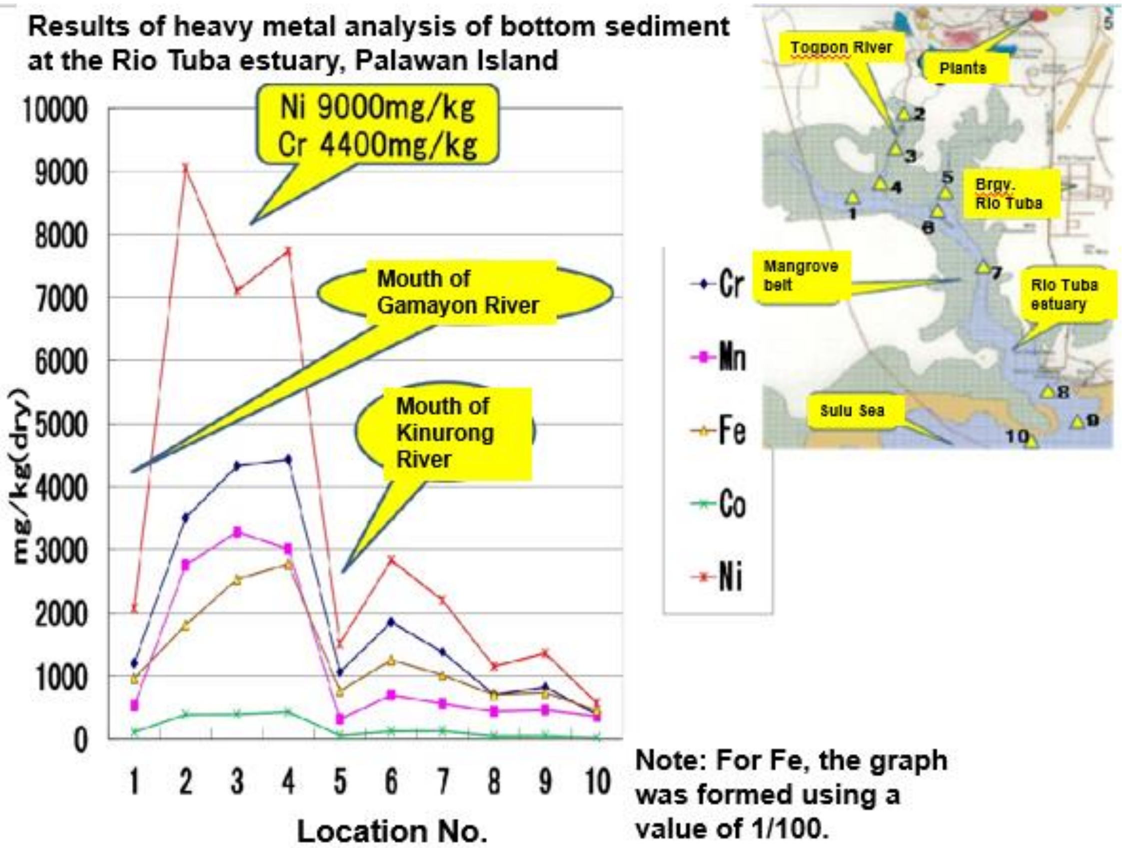
It is deeply concerning that the situation of contamination has not shown any sign of improvement in the 15 years since this survey was begun. We strongly urge SMM to take responsible measures to prevent pollution.

4） Survey of bottom sediment in the Rio Tuba estuary

Figure 8: Tidal area of the Togpon River

During the survey of the tidal area of the Togpon River, it was observed that a mound had formed near the confluence of the Togpon River with the Rio Tuba estuary, which was big enough to get a hold of the bottom of the chartered fishing boat. In addition to the large inflow of sediment from the Rio Tuba mine via the Togpon River, the dissolved metal ions were estimated to have mixed with seawater (pH 8.2~8.4), which is slightly alkaline, resulting in hydroxide precipitation. The reddish-brown turbidity of tidal river water during the rainy season (Figure 8) supports this presumption. The main components of the reddish-brown precipitation are iron and manganese, which are the main components of laterite soils, and it is assumed that toxic heavy metals are also precipitated by the same mechanism.

To reveal these facts, in 2011, we collected bottom sediments in the Rio Tuba estuary using an Ekman-Birge Bottom Sediment Sampler, and the results of heavy metal analysis are shown in Figure 9. Compared to location No. 1, which is under the influence of the Sumbiling and Gamayon Rivers while still being influenced by the Togpon River but not polluted, the upper end (No. 2), middle (No. 3), and river mouth (No. 4) of the Togpon River tidal area showed higher accumulation of nickel (7,000 to 9,000 mg/kg (per dry weight)), chromium (3,600 to 4400 mg/kg), Manganese (about 3,000 mg/kg), and iron (170,000-280,000 mg/kg). The concentration of heavy metals gradually decreases from location No. 6 to location No. 9 at the mouth of Rio Tuba estuary, but has not reached zero. The influence of reddish-brown sludge can be seen even from the external appearance at the open sea (location No. 10). This result indicates that the bottom sediments throughout the Rio Tuba estuary are strongly contaminated by heavy metals sourced from the Togpon River. Although the mangrove forests have not yet reached the point of dying out, the destruction of the ecosystem must be considered to be continuing, given that fisherfolks have reported that they could no longer catch fish, and it is expected that their path to restoration will be quite difficult.



Note: For Fe, the graph was formed using a value of 1/100.

Figure 9: Results of heavy metal analysis of bottom sediment at the Rio Tuba estuary, Palawan Island

5. Mechanism of Occurrence of Hexavalent Chromium

Although it is difficult to discuss the mechanism of occurrence because it is not able to conduct surveys in the area of the Rio Tuba mine and CBNC plants, it can be made inferences from the survey reports of previous studies on the Sorowako mine and the Pomalaa mine in Sulawesi Island, Indonesia, where the nickel laterite layers are being excavated.

Figure 10: Cross section of nickel laterite ore vein at USSU Mine, Sulawesi

After surveying some nickel laterite mines such as the Sorowako mine in Sulawesi, Indonesia, Dr. Akane Ito described the vertical layer structure of the ore veins as follows. 9) A well-developed nickel-laterite deposit consists of a slightly weathered layer, which retains the primary minerals and textures of the bedrock, called saprolite, on top of an unweathered bedrock; above the layer, there is a layer rich in iron and aluminum hydroxides, which have completely lost the reddish-brown bedrock texture, called laterite or limonite (Figure 10 shows an example). The nickel concentration in limonite ore is about 1 to 1.6%, whereas saprolite ore is composed of nickel-rich serpentine and other rocks with nickel concentrations up to 2 to 5%. Saprolite layers often contain nickel ores composed of various silicate mineral aggregates, such as garnierite, a bright green, nickel-rich (30-40%) ore. A similar description of the layer-by-layer vertical structure of nickel laterite deposits can be found in the study report by Mr. Hajime Ikeda on the Sorowako and Pomalaa mines in Sulawesi Island. 10)

Regarding the behavior of chromium in nickel laterite deposits, in the same paper 9), Ms. Akane Ito stated the following based on the measurement of chromium isotopic ratio δ_{53}Cr (‰). The chromium-bearing mineral in ultramafic rocks is chromite. It is generally an sparingly soluble mineral, but is dissolved and released as $Cr(OH)_2^+$ when exposed to severe weathering. During the weathering process, $Cr(OH)_2^+$ is somehow oxidized to hexavalent chromium chemical species such as CrO_4^{2-}, increasing its solubility and transporting it out of the soil, or it is reduced and reabsorbed into iron-aluminum hydroxides and clay minerals as trivalent chromium, where it is fixed.

A complicated reaction system has been described as follows: chromium that was trivalent in bedrock is leached by weathering, is oxidized to hexavalent chromium upon contact with highly oxidizing manganese and iron compounds, moves through the layer, is reduced to trivalent chromium by organic matter and highly reducible divalent iron, and is deposited. The mechanism of hexavalent chromium contamination encountered in this survey would be approximately similar to the above-mentioned. It is expected that a field survey in the Rio Tuba Mine will be realized.

The incident of hexavalent chromium contamination by ferrosilt that occurred in the Tokai region of Japan in the early 2000s can be used as a reference for consideration of the mechanism of hexavalent chromium formation in this case. Ishihara Sangyo Kaisha, Ltd, one of the companies responsible for the Yokkaichi pollution, refines titanium oxide from monazite. Monazite is dissolved in concentrated sulfuric acid, titanium is separated and refined from the dissolved solution, and lime (calcium carbonate $CaCO_3$) is added to the waste solution for neutralization and precipitation. The large amount of precipitates (mainly iron-containing gypsum $CaSO_4$) generated during this process is industrial waste, but after heat-drying treatment, it was sold as backfill material throughout the Tokai region with certification as a recycled product by Mie Prefecture. The environmental department of Gifu Prefecture investigated the ferrosilt and found that it contained hexavalent chromium exceeding the standard, which triggered the collection, removal, and compensation of the materials in each area. In a report by Mr. Kentaro Miyawaki 11) on this incident, it was shown that hexavalent chromium was formed when ferrosilt, a product that did not contain hexavalent chromium, was subjected to wetting and drying repeatedly. Ferrosilt collected at a backfilling site was brought to the laboratory of the author of this paper, and it was confirmed that the concentration of hexavalent chromium increased simply by leaving it at room temperature in the laboratory. The process of adding lime to sulfuric acid effluent and precipitating it is similar to the process of adding lime to the sulfuric acid effluent after nickel extraction in the HPAL process conducted by CBNC in the Rio Tuba area, in order to neutralize and precipitate it. This effluent is sent to the tailings dam for precipitation separation, but the material precipitated in the tailings dam is precipitated gypsum containing iron, manganese, and chromium that was contained in the nickel laterite ore. It is assumed that, depending on conditions, hexavalent chromium may be formed in this precipitate.

6. Recommendations to Sumitomo Metal Mining and the company's pollution control measures

Meetings are held once or twice each year with the head office of SMM. We have repeatedly proposed to the SMM a joint investigation of the Rio Tuba mine area, which is a strong potential source of hexavalent chromium, the area where low-grade ore is piled up in the open fields, the HPAL smelting plant area, and the tailings dam, but this has not been realized yet. The SMM side responded that as countermeasures against hexavalent chromium, there were ongoing efforts to cover the low-grade ore piled in the open fields, to expand and widen the siltation ponds, to develop a method to treat contaminated water through joint research with the University of the Philippines, and so on.

However, as we have already mentioned, there is no sign of improvement in the water contamination of the Togpon River. The method of reducing and precipitating water by adding reducible materials to water stored in siltation ponds, which was proposed as a measure to treat contaminated water, does not seem to have been attempted. Several years have passed without the results of joint research with the University of the Philippines being clarified. Although it was mentioned that attempts were being made to remove hexavalent chromium by activated carbon adsorption, no result has been obtained. Even the results of beaker tests have not been disclosed. In the first place, it is extremely insincere that the analysis results of the effluent water are only presented as relative values, and that the raw data is not made public. Although they are working on the issue as part of their responsibility to the supply chain, the fact that they keep responding that both the Rio Tuba Mine and CBNC are separate companies from SMM and therefore not subject to the will of SMM is nothing more than an excuse.

7. Geographical Universality of Hexavalent Chromium Contamination from Nickel Mining Mines

Nickel laterite layers, which are widely distributed in the tropics and subtropics, are formed when ultramafic rocks are subjected to chemical weathering under hot and rainy climates and nickel is concentrated in such weathering products. 12) The nickel mines in which SMM is involved are not limited to the Rio Tuba area in Palawan Island, the Philippines, as reported in this paper. There are also widespread mines; in the Taganito area in the province of Surigao Norte, Mindanao Island, the Philippines; the Pomalaa and Sorowaco areas in Sulawesi Island, Indonesia; and the Goro area in New Caledonia. Hexavalent chromium contamination has also been confirmed in the Taganito area, where a preliminary survey has begun. Similar large-scale contamination with hexavalent chromium has been confirmed in the Sorowaco area, where commercial operation of SMM-related mines has been conducted for long time, as well as in the Pomalaa area, where commercial operation of SMM-related mines has not yet been conducted but other companies have started mining. SMM is required to take immediate and sincere countermeasures to prevent contamination. Therefore, the pollution countermeasures taken by SMM could serve as a model for other foreign companies causing similar pollution, and it is an urgent issue that must be pursued and implemented as a global countermeasure against pollution.

8. Concerns about the Mining Expansion Plan in Mt. Bulanjao

The Rio Tuba Mine has been granted permission to expand its mining concession by a total of 4,538.44 hectares (including 990 hectares of existing mining area) over the middle part of Mt Bulanjao due to concerns about resource depletion in the existing area (990 hectares). As mentioned already, Mt. Bulanjao is sacred to the indigenous people and contains the “core zone” as defined in Section 9.1 of Republic Act No. 7611 in the Philippines (the Strategic Environmental Plan for Palawan Act: The SEP Law, 1992), and therefore, it is concerned that the expansion of mining activities in this area will have a destructive impact on the life of the indigenous peoples and farmers nearby. Given that the development of existing mining areas has caused severe hexavalent chromium and nickel contaminations in the Togpon River, as well as toxic sludge sediments within the Rio Tuba estuary ecosystem, it is easy to presume that the current situation, which has yet to be solved, will extend to the Sumbiling and Gamayon rivers, and other river systems that have catchment areas in Mt. Bulanjao. Since there are also rice cultivations in Sumbiling and Taratak villages, using water from the Sumbiling River system, pollution of the Sumbiling River is highly likely to cause serious agricultural damage. Moreover, mining development could further intensify groundwater contamination in Sumbiling village. Pollution of the Rio Tuba estuary would also become worse. SMM, Rio Tuba Mine, and CBNC must first restore the water quality and ecosystem of the Togpon watershed and the Rio Tuba estuary before expanding the mining area.

9. Appendix

Some of the results of these surveys have been presented at the annual meetings of the Japan Society on Water Environment (2012 and 2013). 13) 14)

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