

Manganese Mining Impacts on Water Quality in the Caucasus Mountains, Republic of Georgia

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ABSTRACT

One of the world's richest manganese (Mn) deposits and largest Mn mining areas lies in the foothills of the Caucasus Mountains, near the city of Chiatura in the Republic of Georgia. This study was an initial evaluation of the effects of Mn mining on water quality in the Chiatura region. Seven river and stream locations (three on the Kvirila River and four on tributaries), five untreated drinking water supplies (four springs and one groundwater well), and one untreated industrial wastewater discharge (Mn processing) were sampled and analyzed for field indicator parameters, anions, cations, and metals. Five river bed sediment sites (co-located with river water sites) were also sampled and analyzed for metals. Three of the public water supplies were contaminated by coliform bacteria, and concentrations of dissolved Mn, Fe, and Ni exceeded Georgian drinking water criteria in the groundwater supply well. The Kvirila River had very high concentrations of total Mn and Fe relative to an upstream location, especially downstream of the industrial discharges. Several tributaries also had elevated concentrations due to nonpoint source pollution from mine waste near the streams. Mn and Fe loads in the Kvirila River and tributaries were primarily in the particulate form. The river bed sediments at all five sampled river sites contained elevated metal concentrations. Mn and Ni, in particular, were very high in the Kvirila River near the discharges compared to background soil levels. Although Mn and Fe oxide solids in sediment can increase adsorption and attenuation of other metals from the water column, the contaminated sediments can also serve as a long-term residual source of metal contamination of river water, with potentially significant adverse ecological and human health effects.

Keywords: Georgia, manganese, metals, mining, water quality

INTRODUCTION

Numerous former Soviet Union (FSU) nations have diverse mining industries that account for a relatively large percentage of their economic output. The Republic of Georgia's output of ferrous and nonferrous metals, ferroalloys, industrial minerals, and fuels is second only to agriculture in terms of gross national product (Levine and Wallace 2004). The country has more than 300 explored mineral deposits, only about half of which (copper, iron ore, barite, lead, zinc, arsenic, clay, sand, gravel, and a range of secondary metals, including gold and silver) have been brought into production. Georgia has been a major producer of high-grade manganese (Mn) for about a century. It has one of the world's richest Mn deposits and largest Mn mining areas in the foothills of the Caucasus Mountains, centered around the city of Chiatura, in the Imereti region of western Georgia.

The Mn ore deposits near Chiatura, first discovered in 1849, have been exploited since 1879. The ores include pyrolusite and psilomelane (oxide ores) and rhodochrosite (carbonate ore). The country's largest producer, Chiaturmarganets, mines Mn ores from open cast and underground operations in Chiatura, which are supplied to the nearby Zestafoni ferroalloys plant. The Chiatura deposit was estimated to be 215 metric tons of Mn ore, of which about half has been depleted since mining began. Following the dissolution of the Soviet Union, mineral production in Georgia declined sharply. However, Mn has become a critical component in metallurgy, where it has a twofold application: it scavenges impurities such as oxygen, sulfur, and other elements during the steel-making process, and imparts toughness, hardness and abrasion resistance as an additive to steel. Approximately 90% of the Mn consumed in the world is used in Mn ferroalloys. The rest is used to produce nonferrous products, such as aluminum alloys, fertilizers, bricks, and paint, and for water purification.

Although the mining and processing industries in FSU nations have provided many economic and societal benefits, they also have caused significant environmental impacts, including acid mine drainage (AMD) in some areas and contamination of groundwater, surface water, and soils. The degree and significance of AMD and metal contamination of water and soils are affected by complex biochemical reactions in the disturbed ore bodies and associated mine waste materials (tailings and waste rock; Caruso and Bishop 2009; Church et al. 2007; Nimick et al. 2004). Microbes in soils and water help to oxidize the sulfide minerals and catalyze acid- and dissolved metal-generating reactions. However, in Mn deposits, AMD generation is often not the major problem.

Mn is a redox sensitive metal that can exist in water as the manganous ion (Mn^{2+}), or in the oxidized state (Mn^{4+}). Most Mn salts are very soluble in water, but Mn oxides are not and can easily form solid oxy-hydroxide precipitates that can coat streambeds where concentrations are high. Mn speciation is governed by pH and redox conditions, with Mn^{2+} dominating at lower pH and redox potential, and an increasing proportion of colloidal Mn oxy-hydroxides above pH 5.5 (Scott et al. 2002). Dissolved concentrations undergo diel variations in streams (Brick and Moore 1996; Filipek et al. 1987). Toxic metals and nutrients can co-precipitate with or sorb to Mn oxides ($MnOx$) on the streambed. Surface catalyzed oxidation and photoreduction can be important processes with regard to fate and transport, particularly in mountain streams (Scott et al. 2002). Light promotes oxidation, precipitation of $MnOx$, and removal from streams through photosynthetically enhanced oxidation processes (Scott et al. 2002).

Mn in water can be significantly bioconcentrated by aquatic biota at lower trophic levels. Uptake by aquatic invertebrates and fish greatly increases with temperature and decreases with pH, but is not significantly affected by dissolved oxygen (DO). Dissolved Mn concentrations of about 1 mg/L can cause toxic effects in aquatic organisms, and many countries have adopted 0.2 mg/L for protection of 95% of species with 50% confidence (Howe et al. 2004). Mn can be toxic to humans through exposure routes that include ingestion, dermal exposure, and inhalation of particulate forms in air. Inhalation of particulates, especially by workers at Mn mines and processing plants as well as nearby residents, is one of the primary exposure mechanisms and human health risks in the Chiatūra mining region. Ingestion of contaminated water or soils/waste material and dermal exposure of residents are also major risks. These risks can be particularly high given the lack of regulations and pollution control, and the high density of poor communities interspersed with the mines, processing facilities, and waste piles, as well as downstream. Mn compounds are well known neurotoxic substances that may cause manganism in humans, a severe neurological disorder characterized by disturbances of movement, as well as Parkinson's disease (Howe et al. 2004; Olanow 2004).

The primary objective of this study was to evaluate the extent and significance of metal contamination, in particular Mn, in waters in the Chiatūra region and potential risks to human health from operational and abandoned mines and mine facilities. The study was conducted in collaboration with the Science and Technology Center of the Ukraine, Georgia National Center for Disease Control and Public Health, and the Technical University of Ukraine through the US State Department and US Environmental Protection Agency's Biochemical Weapons Redirect Program. The goal of this program is to aid FSU states in redirecting their biochemical research institutes and scientists to peaceful objectives.

METHODOLOGY

Study Area

Chiatūra is located in the Imereti region of western Georgia in a canyon of the Racha Mountains, in the southern foothills of the Greater Caucasus Mountains, 180 km west of Tbilisi, the capital and largest city (Fig. 1). The mines, main factory, and other industrial facilities are situated over an area of 50 km². The city lies in a mountain valley along the Kvirila River (named because of its yellow color); the main Chiatūra Mine is also located in the valley adjacent to the city (Fig. 2). The city and its ore-enriching plants cluster in the narrow valley, with mines in the surrounding hills linked by cable railways and aerial carriers. The smelter receiving Mn concentrate from mines in Chiatūra is located in the city of Zestafoni, 30 km to the southwest. The primary Mn factory (owned and operated by the Chiatūra Manganese Company) is located adjacent to the left bank of the river in the village of Perofi in the Darkveti area. There is a railway connection between Chiatūra and Zestafoni.

The Chiatūra Mn deposits are situated in the north periphery of the Dzirula crystalline massif, in the middle reach of the Kvirila River. The area represents an almost horizontal plateau, divided by the Kvirila River and its tributaries. The ancient rocks are Palaeogene formations overlain by Jurassic rocks. These are overlain by Cretaceous sediments. Oligocene rocks are in upper layers with Mn beds, topped with middle-upper Miocene and ancient– modern Quaternary alluvial formations. The deposits are confined by major faults to the southwest. Within the boundaries of the deposit, Quaternary, Tertiary, Upper Cretaceous, Jurassic, and Palaeozoic hydrogeological

complexes can be delineated. Alluvial water-bearing horizons generally have high concentrations of Mn. Waters of the Sarmatian water-bearing horizons are used for water supply by the settlements on the left bank of the Kvirila River. The average hydraulic conductivity of these formations is approximately 0.8–0.9 m/day; the depth to water is 6–8 m and the water is dominantly calcium bicarbonate, with 0.6–0.8 g/L of total dissolved solids and 9.8 mg-eq of hardness.

The climate in Chiatura is humid; the winters are moderately cold and the summers are hot and dry. Due to its location in the foothills of the Greater Caucasus Mountains, the Chiatura region receives a significant amount of precipitation, including a high snowpack with peak seasonal snowmelt in spring. The average annual precipitation is 1,100–1,200 mm, with greater depths at higher elevations and a maximum in autumn and winter. This water can drive the mobilization and transport of pollutants, including metals, from source areas such as tailings and waste rock piles to ground and surface waters in the form of nonpoint source pollution. Drinking water in the area is supplied primarily by four springs with headworks and one communal groundwater well; no water treatment or chlorination occurs.

There are approximately 20 Mn mines in the Imereti District and Chiatura region. Eleven mines are open pit and nine are underground mines. Sixteen of the 20 mines are located in tributary watersheds north of the Kvirila River and four are located south of the river. It is not known how many of these mines are currently operating because this type of information is not readily available from Georgian authorities or from the mining company. The Kvirila River flows through the center of the main Chiatura Mn deposit and is a tributary of the Rioni River, which flows west to the Black Sea. Numerous small mountain rivers and streams discharge to the Kvirila River, and several villages are located in the canyons of these tributaries. Mn mines are also located near some of these villages. Tailings and slag waste is present in large quantities above ground throughout the area. The waste contains primarily Zn, Pb, Ni, Co, Mn, and other potentially toxic substances based on preliminary information from the mining company. Industrial wastewater is also directly discharged untreated from the Chiatura Mn factories (including the peroxide enrichment factory (PEROF) and the “central keeping facility” (CKF), which is the main ore processing facility) to the Kvirila River. The environmental conditions, the proximity of the mines, tailings, and discharges to the river and human settlements, and the lack of adequate management or regulation of operations cause significant environmental and human health risks not only to the Chiatura region, but to all territories that the river flows through on its way to the Black Sea.



Figure 1

Figure 1 Location map of the Republic of Georgia, Caucasus Mountains, and Chiatura

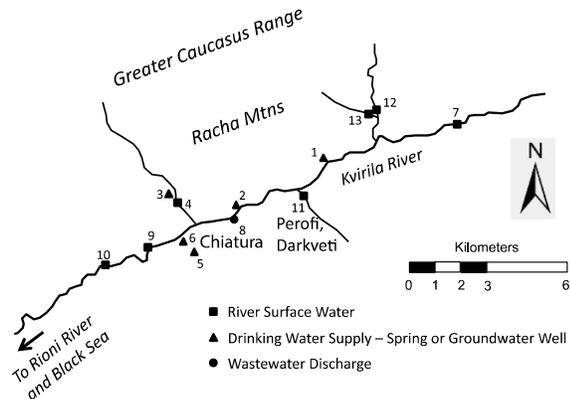


Figure 2

Figure 2 Sampling location map for Chiatura. Sites numbers refer to locations in Table 2

Sampling and Analysis

Water quality samples were collected at seven river and stream locations and five drinking water supply locations (four springs and one groundwater well) throughout the Chiatura study area (Fig. 2; Table 1). One sample was also collected directly from the industrial wastewater discharge from the main Mn factory (Perophi peroxide enrichment factory). Samples were collected as part of three synoptic sampling events during spring (April high flow) and late summer/autumn (September low flow) 2009, and early summer (June high flow) 2010.

Field indicator parameters included temperature, pH, DO, and specific conductivity (SC). Laboratory analytes included alkalinity, chloride (Cl), sulfate (SO₄), nitrate (NO₃), 5-day biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), E. coli, metals (Na, K, Ca, Mg, Al, Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn), and As. All water quality-sampling tasks followed USEPA Region 8 standard operating procedures (SOP) for field sampling protocols (USEPA 2002). Field meters were calibrated according to the USEPA Region 8 SOP for the HydroLab multiprobe (USEPA 2003). Precision and accuracy for field indicator parameters were based on the USEPA field sampling protocols (USEPA 2002), or the manufacturer's specifications. Total carbonate hardness was estimated from Inductively Coupled Plasma Mass Spectrometry measurements of dissolved calcium and magnesium as CaCO₃. Samples for hardness, alkalinity, SO₄, NO₃, and Cl were collected in 250 mL HDPE containers and chilled to 4°C for preservation. A minimum of 125 mL of sample was collected for both dissolved and total metals analysis. Dissolved metals samples were filtered within 15 min of collection using a 0.45 μm filter (USEPA 2002). Total and dissolved metals were only sampled and analyzed during the first sampling round in April 2009. Only dissolved metals were sampled and analyzed during the other two sampling events. All metals samples were collected into HDPE or LDPE containers and preserved with 0.5 mL nitric acid in the field. Samples were analyzed by either a privately contracted laboratory (GAMMA), the Georgia Ministry of Environment Protection and Natural Resources, or the Technical University of Ukraine. Chain-of-custody procedures followed the USEPA field sampling protocols (USEPA 2002).

Table 1 Summary of Chiatura area water quality sampling locations

Table 1. Summary of Chiatura area water quality sampling locations

Site	Location	Description	Type
1	Grudo water supply	Near village of Grudo	Drinking water supply/Spring
2	Monasteri water supply	Water collecting reservoir near Fasknara	Drinking water supply/Spring
3	LeJubani water supply	Near village of LeJubani	Drinking water supply/Spring
4	Rgani stream	Right bank tributary	Tributary
5	Gagarin groundwater well water supply	On Gagarin Street	Drinking water supply/Well
6	Sakurdglia water supply	Near village of Sakurdglia	Drinking water supply/Spring
7	Kvirila River upstream	Near village of Sareki upstream of most mines	Main stem river
8	PEROF	Peroxide enrichment factory	Industrial wastewater discharge
9	Kvirila River upstream of CKF	Near administration building and village of Tiri	Main stem river
10	Kvirila River downstream of CKF	Downstream of most mines	Main stem river
11	Shuqruti Stream	Left bank tributary	Tributary
12	Jruchula River	Right bank tributary	Tributary
13	Darkveti Stream	Right bank tributary	Tributary

Dissolved As, Pb, and Zn were not sampled or analyzed after the first sample round in April 2009 because neither the total or dissolved forms of these metals were detected at any locations during that round. This was also partly the result of our limited budget for analysis, a typical issue in FSU countries. It is believed that these metals are only present at very low concentrations in the ore and the Chiatura environment, but the reason for their low levels is not known. Ca and Mg, alkalinity, sulfate, Cl, NO₃, BOD₅, and COD were also not sampled or analyzed during the last sampling round (June 2010) due to funding limitations. E. coli was only sampled and analyzed once during the first sampling round at the drinking water supply locations.

River bed sediment samples were collected at five locations during the three water quality sampling events. These were co-located with five of the surface water sampling sites: the Kvirila River upstream of Chiatura, the Kvirila River upstream and downstream of the CKF, Shuqruti stream, and the Jruchula River.

Field and analytical results were evaluated over time/between high and low flow sampling events and across locations and water types (river surface waters, spring or groundwater drinking water supply, and wastewater discharge). Results were also compared to applicable water quality standards and criteria. Georgian Ministry of Labour, Health and Social Affairs (2007a) maximum allowable concentrations (MACs) for drinking water were used for most analytes. Georgian regulations do not include MACs for toxic substances (including metals) in river bed sediments. Therefore, representative reference or ‘background’ values for Georgian soils (Ministry of Justice of Georgia 2003a, b) were used for comparison.

RESULTS AND DISCUSSION

The focus of the results here is on dissolved and total metals. With regard to indicator and other analytes, however, pH ranged from 6.5 to 8.8 across the 13 locations and three sampling events, reflecting circumneutral or slightly alkaline conditions. SC values were greatest in the Darkveti Stream samples (up to 1,869 µS/cm). Alkalinity was low and within the guidelines, with a range of 1.9–5.4 mg/L. Sulfate was above 100 mg/L in several stream samples, although all values were below the criterion of 250 mg/L, and concentrations at other sites were low. Alkalinity and sulfate values indicate that AMD is not a problem in this area. In April 2009, E. coli values exceeded the criterion (1 cfu/100 mL) at three locations (up to at 12 cfu/100 mL at the Grudo water supply).

With the exception of Mn and Fe, few samples had dissolved or total metal/semi-metal concentrations that exceeded drinking water MACs, and even the frequency of detection was rather low. In surface waters, the only dissolved or total metals that exceeded drinking water MACs were Mn and Fe at numerous locations and Ni in Darkveti Stream. Darkveti Stream generally had the highest concentrations of most metals, but values in the Kvirila River upstream and downstream from the CKF, and in Jruchula, Shuqruti, and Rgani streams, also sometimes exceeded criteria. As expected, the PEROF industrial (peroxide enrichment factory) discharge from the enrichment factory, which is untreated, had the highest levels of total Mn and Fe, but relatively low levels of dissolved Mn and Fe. Concentrations of dissolved and total Al, As, Cd, Pb, and Zn were all below detection limits.

For total metals sampled and analyzed in April 2009, Mn and Fe concentrations exceeded the MACs in most surface water samples. Total Mn concentrations were also very high upstream of the CKF, and in the Darkveti and Shuqruti stream samples. In the PEROF discharge, total Mn concentrations ranged from 0.85 to 7.62 mg/L. Total Fe concentrations increased to 18.4 and 22 mg/L in September 2009 and June 2010. These increases were likely due to increased mining and processing operations during this time period.

With regard to dissolved metals, Mn concentrations were very high in the Darkveti September 2009 (2.4 mg/L) and June 2010 (6.65 mg/L) stream samples relative to the MAC (Fig. 3). Only two other locations exceeded the MAC: the Shuqruti April 2009 stream sample and the Gagarin water supply well in both April and September 2009. Dissolved Mn concentrations in the PEROF discharge ranged from <0.2 to 0.34 mg/L. Mn loads in most surface waters are dominated by suspended Mn.

Dissolved Fe was only detected above the MAC in the PEROF discharge during the second sampling round in September 2009, and in the Rgani stream and Gagarin water supply samples in June 2010 (Fig. 4b). Similar to Mn, dissolved and total Fe data also indicate that Fe loads in the Kvirila River are dominated by particulate Fe.

All drinking water supply samples met the criteria for metals, except for the Gagarin groundwater supply well, where dissolved Mn, Fe, and Ni exceeded the MACs on at least one occasion. The June 2010 Mn and Fe concentrations were higher than in the previous sampling events in the Gagarin groundwater supply. Dissolved Co and Cu were only occasionally detected below the MACs. Total and dissolved metal concentrations were very similar between the other four public drinking water supplies.

Evaluation of temporal changes showed that concentrations of dissolved Mn increased in Darkveti Stream from April 2009 to June 2010. Increases of Na, K, Ni, and Co were also observed in 2010. These increases are generally attributed to greater inputs from metal sources and concentrations over time, rather than correlation with season or river flows. Both Mn and Fe concentrations were greater in the PEROF discharge in 2010 compared to previous years. Total Mn increased to 34 mg/L in the PEROF discharge in 2010, which was much higher than previous values.

Mn oxides do not readily dissolve and can easily form solid oxy-hydroxide precipitates that can coat streambeds where high concentrations occur, or can be transported as suspended particles under adequate hydraulic conditions (Scott et al. 2002). Other metals and nutrients can coprecipitate with or sorb to Mn oxides (MnOx) on the streambed (Butler and Caruso 2009; Gadde and Laitinen 1974). This adsorption can increase significantly with an increase in pH (Gadde and Laitinen 1974). Therefore, hydrous Mn oxides can play an important role in the fate and transport of other metals in rivers, such as Cd, Cu, and Zn, and should be considered in modeling and remediation (Butler and Caruso 2009). Adsorption of metals to bed sediment is also a function of

the percent of fine particles and clay, as well as organic matter/carbon (Caruso and Bishop 2009). The physical and chemical characteristics of the bed sediment and form of solid Mn and Fe on the river bed in the study area should be analyzed further.

The oxides and hydrous oxides of both Mn and Fe dissolve under reducing conditions that can occur with burial or mixing below surface layers of sediments beneath oxygenated waters (Van Cappellen and Wang 1996). Fe²⁺ and Mn²⁺ in pore water generated in the anaerobic zone can adsorb onto sediment, co-precipitate as a number of mineral phases, or move (by pore water diffusion and dispersion) back to the sediment-water interface. Redox of Fe and Mn is complex and can occur through a number of pathways, including benthic microbial and macroinvertebrate activity (Van Cappellen and Wang 1996). Biotic oxidation is an important process for removal of Mn²⁺ onto Mn oxides in the hyporheic zone and is directly proportional to Mn²⁺ concentration and pH (Fuller and Harvey 2000; Harvey and Fuller 1998; Marble 1998). Surface catalyzed oxidation and photoreduction can also be important with regard to fate and transport, especially in mountain streams (Scott et al. 2002).

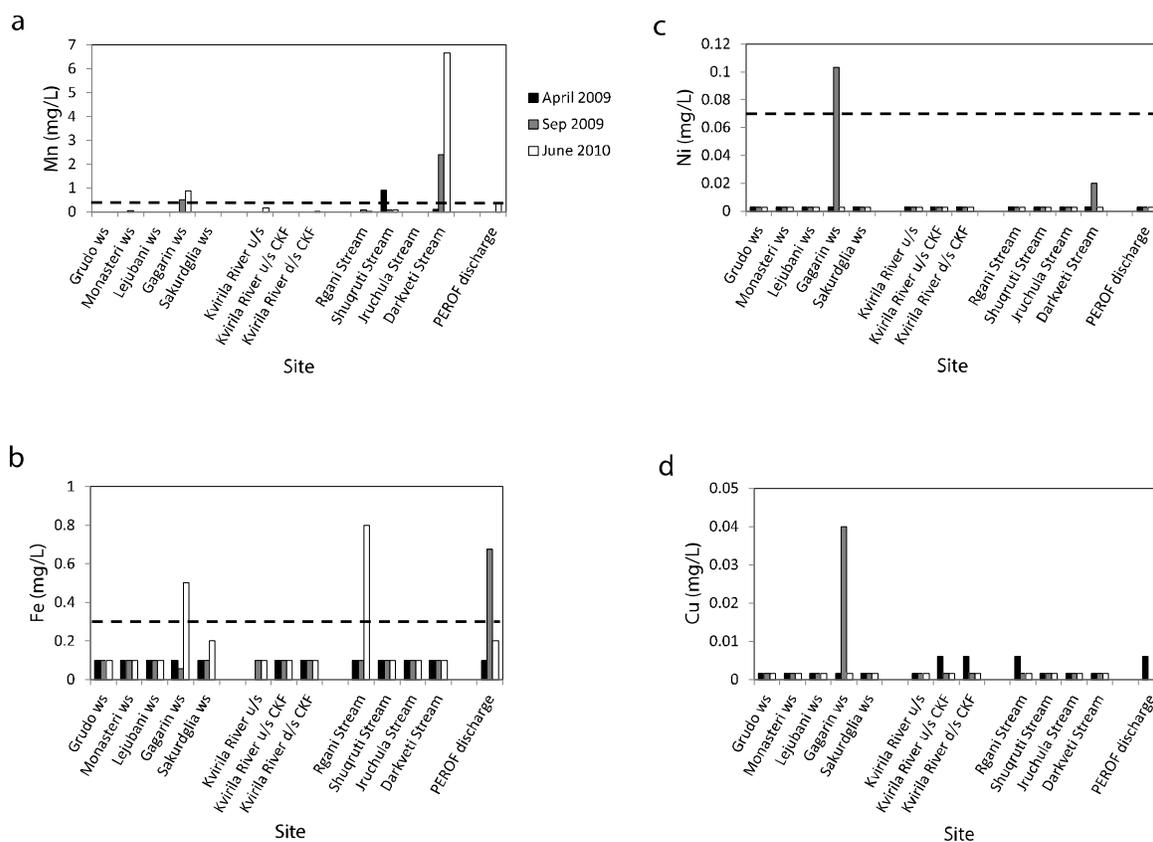


Figure 3 Chiatura dissolved metals results in water for a Mn, b Fe, c Ni, and d Cu. Dashed line is Georgian maximum allowable concentration (MAC). All MACs are for drinking water; MAC for Cu is 2.0 mg/L (not shown); ws water supply; u/s upstream; d/s downstream

River bed sediment metals concentrations were elevated at all five surface water sites. Background concentrations from Georgian estimates for soils were not available for Al and Fe, but Al values

ranged from 3.9% in the Kvirila River upstream of the CKF to 6.7% in the Jruchula Stream. Cd concentrations exceeded the background value of 0.5 mg/kg at all five locations, and were highest in the Kvirila River upstream and downstream of the CKF (3.2–4.5 mg/kg). Cu values followed a similar pattern, exceeding the background concentration of 3 mg/kg and having the greatest values at those two locations (44–70 mg/kg). Mn concentrations in the Kvirila River upstream and downstream of the CKF were very high and exceeded the background value for soils of 1,500 mg/kg (in the range of 80,000–95,000 mg/kg or 8–9.5%). Mn values also exceeded the background value at the other sites. Fe concentrations ranged from 1.5% in the Kvirila River upstream of the CKF to 3.9% for the furthest upstream Kvirila River sample). Fe concentrations were also elevated in the Kvirila River upstream and downstream of the CKF during some sampling rounds (2.4–3.6%).

The Kvirila River bed sediment metal concentrations generally were higher in 2010 than in 2009 with the exception of two locations (upstream and downstream of the CKF) where Mn concentrations in 2010 decreased (5.35 and 4.8%) compared to 2009 (9.5–8.0 and 8.5–8.0%, respectively). Cu values also decreased somewhat at these two locations. The reason for these decreases is not known, but transport and flushing of sediment from high flows could be a factor, as could dissolution of metal oxides or adsorbed metals to the water column. No other temporal trends were apparent in sediment concentrations at other locations. Although MACs for metals in river bed sediments have not been established by the Georgian government, comparison of Mn and Fe concentrations in sediment samples from the Kvirila River upstream and downstream of the CKF with Georgian background values for soils indicates that the sediments meet the criteria for “highly-polluted soils”; sediment samples from the Jruchula and Shuqruti streams meet the criteria for “low-polluted soils” (Georgia Ministry of Labour, Health and Social Affairs 2007b).

CONCLUSION

Drinking water samples taken from three of the public water supplies (Grudo, Monasteri, and LeJubani) in the Chiatura mining area were contaminated by coliform bacteria. *E. coli* concentrations exceeded the criterion of 4 cfu/100 mL in samples from the Grudo and Monasteri supplies. Concentrations of dissolved Mn, Fe, and Ni exceeded the drinking water MAC in the Gagarin groundwater supply well.

Simple water treatment systems should be installed for the Grudo, Monasteri and LeJubani water supplies. The water should not be used for drinking without disinfection due to the risk of water-borne infectious and viral diseases. Drinking water in the catchment reservoirs of the Grudo, Monasteri, and LeJubani water supply systems should also be routinely disinfected. Drinking water quality in Chiatura’s central water supply lines should be monitored based on Georgian government requirements and standard international practice to protect public health.

The communal Gagarin Street groundwater supply well should be cleaned and disinfected in accordance with Georgian government regulations and standard practices. Long-term consumption of this water may damage the digestive tract. The well should be re-sampled and analyzed for Mn, Fe, and Ni on a routine basis. If these metals continue to occur at levels above the MACs, the use of well water for drinking should be discontinued.

The Kvirila River is contaminated with Mn and Fe relative to the upstream location. Total Mn levels were almost 15 times the MAC downstream of the discharge from the CKF. Concentrations of total Mn were 2–12 times the MAC in Darkveti, Shuqruti, and Rgani streams, and total Fe values were 8–

55 times the MAC in these tributaries. Mn and Fe loads in the Kvirila River and most tributaries are primarily in the particulate form. Concentrations of dissolved metals in samples from the seven surface water locations were below the MAC except for dissolved Mn in Darkveti Stream and the Kvirila River upstream and downstream of the CKF. The primary sources of Mn and Fe in the Kvirila River are the untreated industrial wastewater discharged from the CKF, tailings and waste rock associated with the Mn ore disposed of on the Kvirila River floodplain, and the main tributaries (primarily Darkveti and Shuqruti streams).

Concentrations of all metals, including Mn and Fe, in river bed sediments were elevated at all seven river sites. Mn and Ni, in particular, were very high compared to background soil levels in the Kvirila River upstream and downstream of the CKF. Although Mn and Fe oxide solids in sediment can increase adsorption and attenuation of other metals from the water column, contaminated sediments can also serve as a long-term residual source of metal contamination of river water with significant adverse ecological and potential human health effects.

Use of the Kvirila River before and after the CKF, as well as Darkveti Stream, for drinking, economic, cultural, and household purposes should be prohibited. Based on Mn concentrations, these areas are extremely highly polluted water, according to Georgian regulations. Use of these rivers may result in increased exposure to Mn and associated diseases and symptoms. Water in Shuqruti and Rgani streams meets the criterion for moderately polluted water. Water from these rivers may be used as a drinking and economic water supply source only if the pollution level is reduced through end-of-the-pipe treatment.

Solid mine waste (tailings and waste rock) have been disposed of on the floodplain surface along the Kvirila River and some tributaries. This waste material is a significant source of metals that will continue to impact the water quality and ecological health of the Kvirila River and some tributaries. Industrial mine waste from the enrichment and processing plants should be managed in a way that isolates the material from the rivers and groundwater. The specific pollution sources in the Kvirila River should be identified and evaluated, and routine sampling of the river should be conducted at key locations. Discharge of untreated wastewater from the peroxide enrichment factory into surface waters should be discontinued as soon as possible and treatment facilities should be installed at the plant.

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