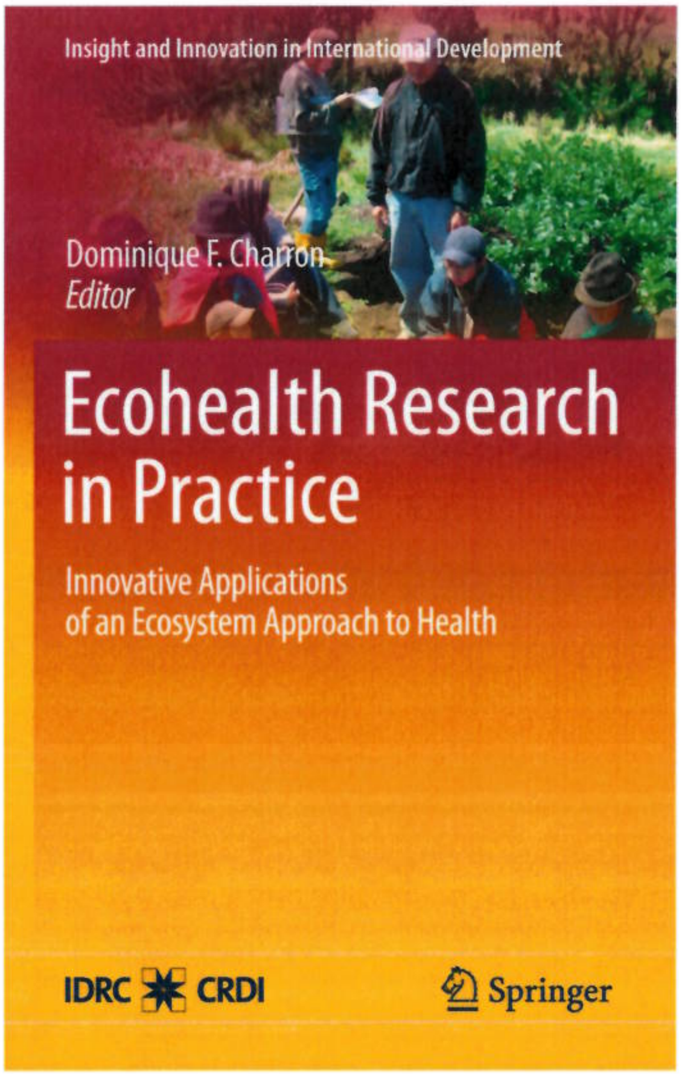
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Chapter 11
Impacts on Environmental Health of Small-Scale Gold Mining in Ecuador

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With the discovery of mining and metal-working techniques in ancient times, metals, metals pollution, and human health were linked (Nriagu 1996). Adverse health effects associated with exposure to metals have been at the root of occupational health since Ramazzini's work in the seventeenth and eighteenth centuries (Franco 1999). Everywhere, but particularly in the developing world in the context of small-scale mining, whole communities are deeply affected by mining not just because their livelihoods depend on mining, but because of the proximity of their dwellings to the mine operations (PRODEMINCA 1998).

The mining regions of Portovelo and Zaruma are located in the Puyango River basin in the southwestern part of Ecuador, bordering Peru. The Puyango crosses into Peru, where it becomes the Tumbes River, and drains into the Pacific Ocean at Tumbes, Peru. The extraction of gold and silver has taken place here for more than 500 years (since the time of the Incas), and this is reflected in the name of the province, El Oro. Throughout most of the twentieth century, large mining companies (foreign and domestic) dominated this region. In the economic crisis that ravaged the country in the 1980s, the remaining large mining companies closed, creating unemployment and worsening poverty. This same crisis pushed many people to invade abandoned mines, and led to the emergence of widespread and informal small-scale mining activities. Approximately 60,000 Ecuadorians (mostly men) were employed in small-scale gold mining in 2000 (Sandoval 2002).

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Ecuadorian small-scale mining operations are run with minimal organization, have limited technological development, and existing legislation targeting the sector is rarely enforced (Sandoval 2002). As a consequence, mineral exploitation is inefficient, the environment is often negatively impacted, and miners work in hazardous conditions and are poorly paid (OIT 1999). Because settlements are often close to or downstream from the mining sites, whole communities are impacted by mine-related environmental pollution.

The main health concerns from small-scale mining relate to pollution from metals and chemicals used to extract precious metals from the raw ore. But mercury, lead, arsenic, manganese, and other substances known to be toxic are also naturally found in the rocks and soils. They may be released into rivers with mining wastes and tailings, or because of soil disturbance from agriculture or erosion (Appleton et al. 2001; Betancourt et al. 2005). In this region, mercury and cyanide are commonly used in mining. Mercury's properties make it a solvent for most metals, which allows the miners to separate small amounts of precious metals from sediments, finely ground rock, and other sources. Sodium cyanide (NaCN) solution is also used to dissolve precious metals from their source materials. Lead nitrate is sometimes added to increase efficiency of the extraction. The precious metals are then precipitated from solution by adding zinc or other amalgamating agents.

Small- and medium-size gold-processing plants that use mercury amalgamation or cyanidation are situated along the tributaries of the Puyango River, mainly in the upper part of the basin. Ecuadorian informal gold extraction is estimated to produce between 5 and 6 tonnes of gold per year (Sandoval 2002; Velasquez-Lopez et al. 2010). Mercury released to the river can be converted by bacteria to methylmercury, which is much more toxic than inorganic mercury and is strongly biomagnified in food chains. Cyanide is toxic to humans and wildlife. It may increase the biological availability of mercury by dissolving metallic mercury, but it may also reduce methylmercury formation because it has a toxic effect on methylating bacteria.

The study area was in the Portovelo and Zaruma mining region situated in the upper part of the Puyango basin (Fig. 11.1). Typical of mining in Ecuador, there are many small-scale extraction operations for gold and silver in this region, but the total production has been declining over the years. The study focused on a stretch of river beginning 25 km upstream of the mining area to 115 km downstream on the semi-arid coastal plain. Portovelo and Zaruma are the main towns in the mining area, and the small communities of Gramadal and Las Vegas (approximately 30 households each) are situated 115 km downstream. The larger town of Puyango Viejo is in-between, about 80 km downstream. Human population density is unevenly distributed. Along the upper basin, Zaruma and Portovelo counties have a population of about 42,000 inhabitants; whereas, along the middle and lower basin, human settlements are small and scarce. In the lower basin communities are more dependent on the river resources. Agriculture, livestock, and mining are the major economic activities along the study area (Betancourt et al. 2005).

In the past 20 years, people living along the river have expressed concerns about possible health problems associated with upstream mining activities. Their main concerns related to pollution of the river, which is the main source of drinking water

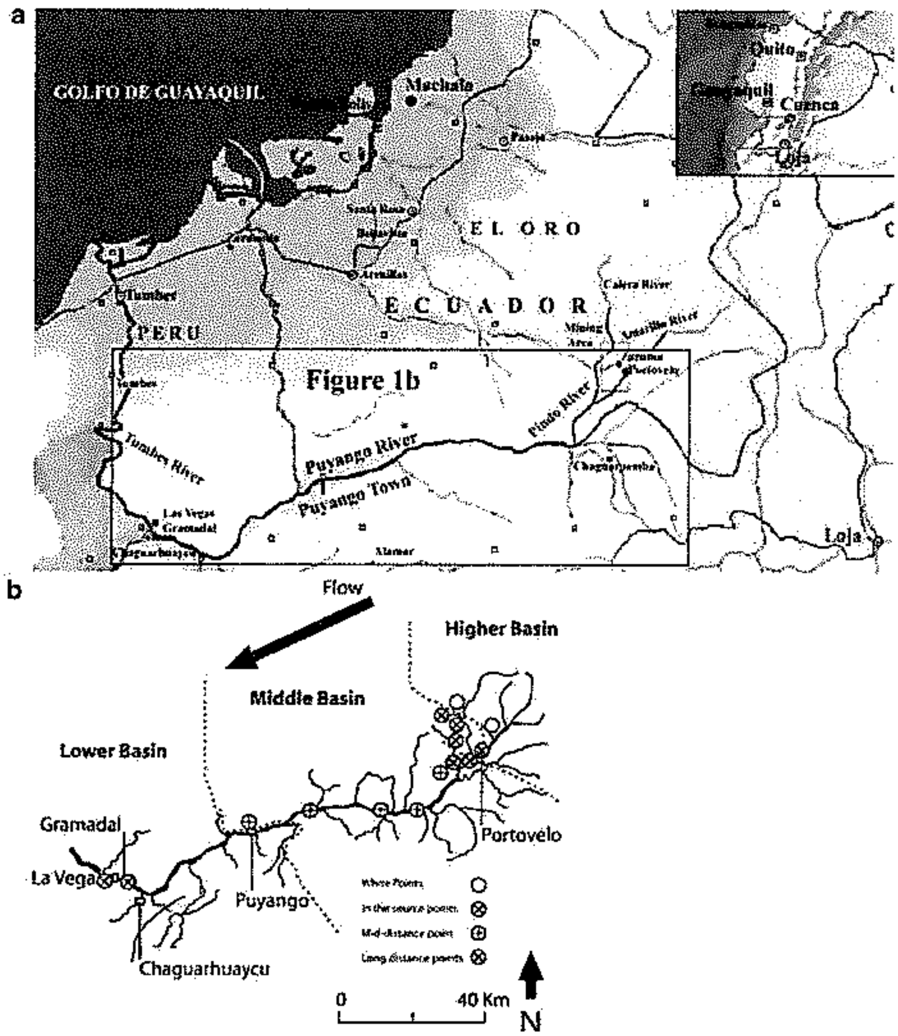

Fig. 11.1 (a) Southern Ecuador. (b) Puyango River basin: geographical zones and locations of villages included in the study and monitoring points. White points refer to control sites upstream from mining (reprinted from Betancourt et al. 2005 with kind permission from Springer Science+Business Media B.V.)

for the downstream communities of Gramadal and Las Vegas. Despite these concerns, water pollution has not been seriously addressed, partly due to deficiencies in the institutional control of mining pollution and weak environmental and health-management plans.

Half a ton of mercury is released annually with tailings, and NaCN (1.5–5 kg per tonne of tailings) is used for cyanidation, which produces cyanide-laden wastes with 200–300 mg/L of residual free cyanide that are released directly to the river (Velasquez-Lopez et al. 2010).

The research project was initiated in 1999. Initial consultations with the community helped identify the main objective: assess mining-related environmental pollution and associated health impacts and increase awareness among key actors of these effects. It quickly became clear that the communities were not very aware of the potential environmental and health hazards they were facing. Bolstered by exciting work coming out of Brazil (Malm 1998) on similar small-scale gold mining, the team was eager to experiment with ecosystem approaches to health (Lebel 2003).

The project's initial phase sought to explore the impact of mining on the ecosystem and on indicators of human health. The trandisciplinarity, multistakeholder participation, social equity, and gender-analysis aspects of ecohealth were emphasized. The project unfolded in two phases. This case study focuses on the results of the second phase, but key aspects and results of the first phase are presented.

The Social Dimensions of the Problem

From its inception, the project built on multistakeholder consultation and participation. The objective of the participatory process was to encourage members of the community to not only take part in the investigative process, but also to use the information to analyze the situation and identify, execute, and evaluate potential solutions. The project was implemented as a collective learning experience that involved academics, stakeholders, and community representatives (Torres 2001; Lebel 2003).

The roles and responsibilities of stakeholders were determined through the collection of qualitative data (2004) and workshops that discussed project issues and results (2006). Focus groups, workshops, and key-informant interviews were organized with miners, their families (men and women), government representatives, nongovernmental organizations, and community members to discuss project activities and findings, and to map potential strategies to reduce exposure to toxic substances. Figure 11.2 describes the roles of stakeholders involved in the project.

Leaders of the communities in Gramadal and Las Vegas (the downstream communities) expressed their concerns about the health implications of pollution from upstream mining. This community pressure influenced the later implementation of pollution-reduction initiatives by community organizations and local authorities in 2005 and 2006. The project invested time and effort to achieve a common understanding about a joint approach to community engagement and empowerment for action. This was a change for communities whose relationship with service providers was traditionally based on paternalism.

Key informants where interviewed to determine their knowledge about mining and its impacts on the environment and health. Initially, few people in Zaruma and Portovelo (the mining area) seemed concerned with environmental management

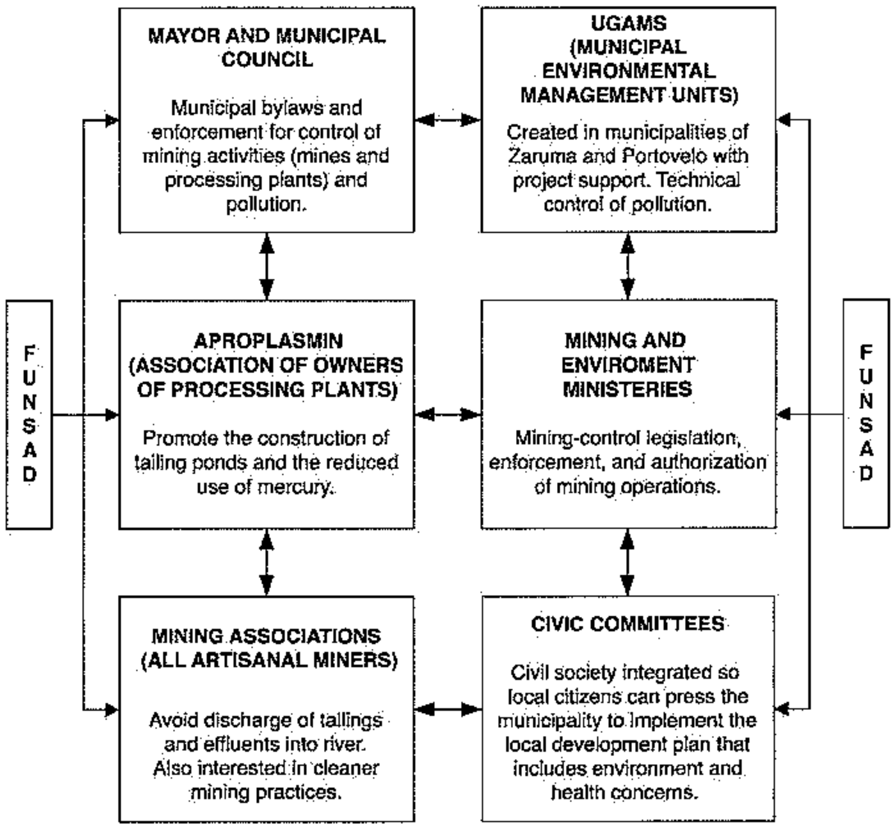

Fig. 11.2 Roles and responsibilities of project stakeholders (FUNSAD: Health, Environment, and Development Foundation)

and health (although level of concern increased with educational level). In the lower basin (Gramadal and Las Vegas) concern was higher from the outset. Awareness and concern increased over the life of the project. For example, by 2006, municipal authorities in Zaruma and Portovelo had started to appreciate the need for pollution-control mechanisms, and this facilitated the creation and enforcement of bylaws (see below).

Gender issues were identified in Portovelo and Zaruma. Men work directly in mining and carry a larger burden of exposure to metals. However, women tend to have traditional domestic roles and have little income. Interviews confirmed that men's work was considered more important because it earned income, which gave them greater decision-making power at the household level. Women encountered domestic violence and other hardships, and felt they had no power to change the situation.

Assessing the Environmental and Health Impacts of Gold Mining (1999–2002)

The project focused first on assessing environmental distribution of metals – mercury, manganese, and lead – to assess the extent of the pollution problem. Metals were measured in samples of river water, sediments, and suspended particulate matter (SPM), in both dry and rainy seasons, in the Puyango River basin. Particulate matter was used as a surrogate for mining-related environmental disturbance. Mining wastes are released directly into the river and increase SPM. Human population exposure pathways were also studied using household surveys and measurement of biomarkers (hair, blood, and urine) for mercury and lead (Betancourt et al. 2005).

Mercury and lead, at toxic levels, inhibit the functioning of the nervous system. Neurobehavioural tests are used to assess motor, sensory, and cognitive functions. Poor performance on these tests has been linked to metal toxicity (van Wendel de Joode et al. 2000; Cattell and Cattell 2001; Raven 2003). In 229 adult men working in, or living near, the mining areas, elevated blood mercury and lead seemed to be associated with poor performance on neurobehavioural tests. There were differences between the communities in fish consumption and drinking water source. Of the population in the gold-mining area, 10% consumed local fish compared with 98% of the population in the lower basin. In mining areas, people did not consume the river water, but in downstream communities, the river water was the sole source of water for drinking and cooking.

Lead concentrations in blood were found to be relatively high (mean 22 μg/dL, S.D. 22) among 40% of 225 adults investigated in the study area (all five communities: Portovelo, Zaruma, Puyango Viejo, Gramadal, and Las Vegas). People from Puyango Viejo (mid-way downstream from the mining areas) ($n=70$) had the highest concentrations of blood lead (mean of 34 μg/dL, S.D. 24). This level exceeded by a large margin the safe reference value of 20 μg/dL (WHO 1995).

Total mercury concentration in blood was observed to vary by occupation and geographical location, which indicated different exposure pathways. Among 32 miners (who did not generally consume fish), blood-mercury concentration was elevated (mean of 11 μg/L, S.D. 6.7 μg/L); whereas, among 128 people living far downstream in Gramadal and Las Vegas, who regularly consumed fish from the river, mercury concentration in blood was elevated, but lower than in the miners (mean 3.9 μg/L, S.D. 3.6 μg/L).

The detailed results of this first phase are described by Betancourt et al. (2005). After this first phase of work, the research team was left with questions that required further research. Although there was evidence of metal contamination in the watershed and evidence of human exposure, the pathways of exposure and their public health significance were not clear. Some findings, like the high exposure to lead, could not be fully explained by environmental exposure.

Defining the Sources of Exposure to Metals (2003–2009)

The second phase of research set out to better define the source of human exposure to potentially toxic metals – whether from mining or a combination of mining with other effects – that was found in the initial studies of the Puyango River populations. It also sought to explain the absence of mercury from the same downstream populations. Using participatory methods, the researchers developed interventions to better manage the pollution and reduce human exposure in downstream communities. The findings summarized here were also presented in FUNSAD (2007).

It was important to assess in depth the pollution problem in the second phase. The SPM measured at the baseline points was very low (3 mg/L during the March rainy season and 1.6 mg/L in the May dry season). Near the processing plants, elevated SPM were detected (132 mg/L in the rainy season and 328 mg/L in the dry season). In river-bottom sediments, mercury concentrations never exceeded 0.061 µg/g upstream of mining activities, but reached a maximum of 0.730 µg/g near the mining areas.

Fish-density indicators were higher upstream from the mining sites, including the headwaters of the Puyango River and a few of its tributaries, and also downstream (115 km from the mining sites) (Barriga 1991). Concentrations of mercury, manganese, and lead were measured in all fish species captured, using the methods of the Environmental Quality Laboratory (Chincheros 2007). Some fish were contaminated and exceeded WHO-recommended safe exposure levels. Although most fish (70% of the 195 samples) were not heavily contaminated by mercury (less than 0.50 µg/g, the WHO 1990 safe-exposure level), high levels of mercury contamination (2.25 µg/g) were found in dorado fish (*Brycon americus peruanus*), an omnivorous species caught in the middle and lower basin. However, this species is known to be eaten infrequently by people in the Puyango Basin. Manganese concentrations in fish were also generally safe, with a mean concentration of 0.40 µg/g in 112 samples. The recommended maximum concentration of manganese in fish is 2.5 µg/g (ATSDR 2000). The highest concentrations (3.18 µg/g) were measured in shad fish or sábalo (*B. atrocaudatus*), a fish that is eaten by local people. Lead concentrations in fish were on average 0.8 µg/g, substantially higher than the WHO-recommended maximum of 0.1 µg/g (WHO 1995).

In this phase, the project focused on the exposure of children to metals, in both mining and nonmining communities. Measurements were made of metal concentrations in hair, and of neurobehavioural performance. Household surveys showed that 12% of 72 children from Portovelo and Zaruma were working in mining activities at the time of the research (August 2006), mainly helping their parents in the processing plants.

Only 6% of 94 children had mercury concentrations in their hair that exceeded 2 µg/g, within permissible levels (WHO 1990). Arsenic concentrations in hair were also negligible in these children (not exceeding 0.1 µg/g).

In 2006, 83 children (8–12 years old) were assessed using the same neurobehavioural tests used to assess adults in the earlier part of the research. The study included 72 children from the mining areas of Zaruma and Portovelo, and 11 from the downstream areas of Gramadal and Las Vegas. Increased concentrations of manganese in the hair of girls (2.9–7.4 μg/g) were associated with decreased scores on the cognitive Raven test ($p=0.009$) and the digits test ($p=0.03$). In children, increased concentrations of mercury in hair (0.1–4.3 μg/g) was associated with decreased performance on Santa Ana dexterity ($p=0.005$), digits ($p=0.01$), and finger tapping ($p=0.04$) tests. These low levels of exposure have not previously been reported to be associated with neurobehavioural impairment. Children were found to have been exposed to lead, but the levels detected in their hair remained within permissible WHO levels. Although indicative, there is a need to further validate these tests in children. Further investigation should address other potentially relevant causes of poor performance on neurobehavioural tests, including education, nutrition, household environment, and culture.

The previously detected high level of lead in adults was puzzling because lead levels in fish were moderate, and thus dietary exposure from fish consumption was assumed to be low. Further investigation of potential household sources of lead exposure found that 84% of 40 families in the lower and middle basins used metal kitchenware thought to contain high concentrations of lead. This was confirmed by measuring the lead concentration in two pots (both from local suppliers, and similar to those used throughout the region) from different households. Pots were found to contain lead concentration of 230 and 1,135 μg/g, hypothetically enough to contaminate food cooked in these pots.

Why Was There No Methylmercury in the Puyango?

Although the environmental distribution of metals was associated with mining activities (Betancourt et al. 2005), the concentration of methylmercury (MeHg) in river-bottom sediments from the main channel of the Puyango River was negligible (0–0.1 ng/g) in seven samples. Mercury contamination was occurring, but it was not leading to formation of toxic methylmercury or its accumulation in the food chain or in people downstream. The project sought to explain why this was occurring. Methylmercury enrichment is usually found downstream from mining areas that release mercury and leads to health risks, notably through fish consumption (Boischio and Henshel 2000; Guimarães et al. 2000; Roulet et al. 2000; Gray et al. 2004). The natural methylation process depends on the presence of bacteria that transform the mercury into methylmercury.

The study set out to measure bacterial activity along the river. The hypothesis was that a toxic substance, perhaps cyanide from the gold processing, was impairing bacterial activity. Sampling points for cyanide and bacterial activity in water and potential mercury methylation in sediments were identified. Data were collected upstream and downstream of mining activities according to methods similar to Guimarães et al. 1995 and Miranda et al. 2007.

Cyanide levels were undetectable (<1 μg/L) upstream of mining activities, peaked at 280 μg/L immediately downstream from mining activities, and eventually returned to <1 μg/L 115 km downstream. Bacterial activity (in sediments), and thus potential for mercury methylation to occur, was high upstream of mining activities, but nearly absent near mining sites, and again high further downstream at Gramadal and Las Vegas. It is hypothesized that high levels of cyanide in the water immediately downstream from the mining areas could be so toxic to bacteria that they prevent mercury methylation in the river. Paradoxically, cyanide has also been shown to help in the mercury methylation process, by increasing the dissolution of mercury. For this hypothesized toxicity to be important, the cyanide toxicity to bacteria would need to override the mercury dissolving effect of cyanide. This result is in contrast with what has been suggested by other studies in the Puyango River basin (Velasquez-Lopez et al. 2010).

Community Empowerment to Protect Human Health (The Interventions)

To reduce exposure to environmental contaminants, project interventions were developed and implemented among the communities of Gramadal, Las Vegas, and Puyango Viejo (downstream from the mining areas). These interventions included the installation of water filters for homes and schools, the provision of an alternative source of potable water, electrification, and road improvement. Eventually, public drinking-water systems were established at Gramadal, Las Vegas, and Puyango Viejo to eliminate the direct intake of river water. Efforts were also made to eliminate other sources of heavy-metal contamination, such as the use of lead-containing kitchenware.

In Zaruma and Portovelo (the mining district), the project acted to protect people from exposure and to reduce contamination of the river. Project discussions with stakeholders led to the creation, implementation, and enforcement of new municipal bylaws to control the installation and operation of processing plants. These bylaws included requirements that processing plants not be built near rivers and that tailings and effluents not be dumped in rivers. The project promoted and supported the creation of Municipal Environmental Management Units led by environmental engineering or mining professionals. Workshops and other meetings also influenced mining organizations to implement additional pollution-control measures. Changes in environmental and health management at different levels were observed in a diverse number of stakeholders (Fig. 11.2). In Zaruma and Portovelo, the project assisted with the organization and operation of the canton civic committee, which successfully lobbied to include environmental and health-management plans in the cantonal development plan. The community lobbying efforts enhanced by the project also exerted some influence on national environmental authorities, notably in the

Ministry of the Environment and Mining. Reductions in the discharge of mining and urban wastes directly into the river resulted from a range of pollution-control measures, implemented mainly by the Ministry of Environment and Mining. Dumping of municipal solid waste directly into the Puyango River was formally prohibited in 2009.

New techniques have been adopted by miners to reduce contamination (e.g., settling ponds for tailings, and the use of enclosed apparatus for amalgam burning). Ecological clubs were created in schools and colleges in Zaruma and Portovelo to stimulate knowledge about health care and build awareness of environmental pollution among youth. There is strong ongoing interest in health and environment among communities in the lower river basin as well, a remarkable commitment considering their particularly challenging living and livelihood conditions. Local organizations were strengthened for environmental and health management that led to the use of filters to sanitize river water. A public drinking water system was established in some downstream communities.

Conclusion

The project found that mining wastes released into the river cause metal and cyanide pollution. This pollution impairs water quality in the lower basin. Observed pollution negatively affects the health of miners. Pollution also affects the health of communities downstream by contaminating fish that form an important part of their diet, and to a lesser extent by contaminating drinking water. Mercury exposure was a problem only in the downstream part of the basin, where methylation resumes, perhaps due to the lower cyanide levels. Children were showing evidence of chronic exposure and toxicity to manganese and lead. All communities may be experiencing substantial added lead exposure from cooking in metal pots that contain lead. The project contributed to the development of pollution-reducing municipal regulations and to processes for greater community engagement in decision making. The sharing and discussion of project results increased awareness among both miners and decision makers in all parts of the Puyango River basin.

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