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Technology, Managerial, and Policy Initiatives for Improving Environmental Performance in Small-Scale Gold Mining Industry

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ABSTRACT / This paper reviews a series of strategies for improving environmental performance in the small-scale gold mining industry. Although conditions vary regionally, few regulations and policies exist specifically for small-scale gold mining activity. Furthermore, because environmental awareness is low in most developing countries, sites typically feature rudimentary technologies and poor management practices. A combination of policy-, managerial- and technology-related initiatives is needed to facilitate environmental improvement in the industry. Following a broad overview of these initiatives, a recommended strategy is put forth for governments keen on improving the environmental conditions of resident small-scale gold mines.

Small-scale and artisanal gold mines have long been perceived as being environmentally destructive. Such operations, which are found throughout Africa, Asia, and Latin America (Figure 1), feature a number of rudimentary practices that pollute the air and contaminate resident waterbodies and soils. It is now a well-known fact that in a number of countries in South and Central America, Africa, and Asia intensive small-scale gold mining activity has caused extensive damages to a number of landscapes, forests, and rivers; it has also rendered a significant amount of land unsuitable for other industrial, commercial, or agricultural applications.

Governments are confronted with the monumental challenge of having to promote environmental improvement in the small-scale gold mining industry. Although a number of case studies have been presented in the literature that briefly examine the environmental problems and management at small-scale gold mines, the pressing question that still remains is what initiatives can realistically be undertaken to facilitate environmental improvements at small-scale gold mines. Although there is significant recent work on improving environmental performance in the gold mining industry, little of this has been directly applied to small-scale (gold) mining.

The purpose of this paper, therefore, is to outline a series of initiatives for improving environmental performance in the small-scale gold mining industry, to provide an evaluation of these in context, and to put forth a recommended strategy for Third World governments seeking to improve the conditions of resident operations. It will be argued that, to improve the efficiency and environmental management of operations, a series of technology-, management-, and policy-related measures can be undertaken. It is further postulated that, in order to put an environmental management plan of this scope into practice, governments must play an expanded role, since in most instances, they are the only organized body with the ability to direct activities along an efficient course (UN 1996). Several governments, however, have already made important strides and must now forge partnerships with international agencies and local educational units—groups with both networking and research capabilities—to perpetuate further the pattern of environmental improvement in the industry.

The paper is organized as follows. First, an overview of the small-scale gold mining industry is provided that briefly outlines the locations of operations and the socioeconomic importance of the industry, and details its environmental impacts. The sections that follow are devoted to examining more closely the individual technology-, managerial-, and policy-related initiatives capable of facilitating industrial environmental improvement. The paper concludes by recommending a strategy for governments keen on improving the environmental conditions of resident operations.

KEY WORDS: Small-scale mining; Gold; Technology; Policy; Environmental management

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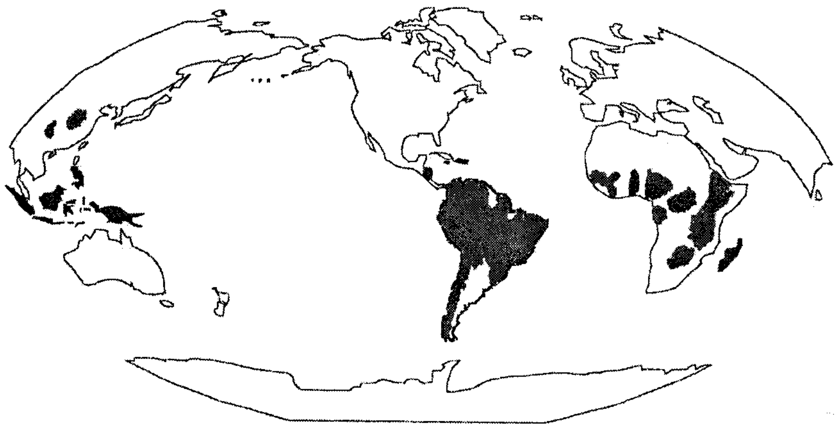

Figure 1. Global distribution of major small-scale gold mining regions. Central and South America: Bolivia, Ecuador, Suriname, Brazil, Venezuela, Chile, Colombia, Dominican Republic, Honduras, and Peru. Africa: Ghana, Kenya, Tanzania, Zambia, Zimbabwe, Ethiopia, Guinea, Liberia, Nigeria, Gabon, the Central African Republic, Burundi, and Madagascar. Asia: India, China, the Philippines, Papua New Guinea, Indonesia, and Malaysia. (Source: updated from Priester and Hentschel 1993).

Overview of Small-Scale Gold Mining and its Environmental Impacts

Gold is the mineral most commonly mined on a small-scale in the developing world because of its propensity to generate wealth quickly. Within the countries that support small-scale gold mining activities, this industry usually makes important contributions to national production output totals, foreign exchange earnings, and rural employment. In Brazil, for example, during heavy prospecting periods, an estimated one million people were involved in small-scale gold mining, accounting for as much as 90% of annual gold output (Buntenbach and others 1995). In another example, the Ghanaian government invested a modest US$1.4 million in the early 1990s to build regional buying stations that pay world prices to small-scale miners for their gold, and to set up district licensing centers. This investment has resulted in the collection of over US$140 million in revenues (Labonne 1996) and has contributed to well over US$70 million in foreign exchange earnings for the government (Davidson 1993). A number of other countries, including Tanzania, Indonesia, the Philippines, Mexico, Venezuela, and China, also have flourishing small-scale gold mining industries.

However, despite making important socioeconomic contributions, small-scale gold mining activities have also caused substantial impacts to the environment and human health. Rudimentary knowledge of exploitable reserves, improper training of workers, and an absence of appropriate technology have been responsible for these environmental impacts (McMahon and others 1999, Peiter and others 2000). Moreover, environmental regulations specific to small-scale mining are generally nonexistent or are improperly enforced by local governments, and most regional assistance schemes are ineffective. Small-scale miners—most of whom operate on a shoestring budget—often disregard health and safety practices, and fail to use the appropriate environmental technology when it is available (Preister and Hentschel 1992a, Preister and others 1993, Jennings 1994).

Environmental impacts are prevalent throughout all three phases of operation (Table 1). However, there are three main environmental problems associated with small-scale gold mining activity: (1) mercury pollution; (2) acid mine drainage (AMD) from tailings; and (3) land degradation. The first two of these three major environmental problems can be ameliorated through technological initiatives, but the third (land degradation) requires a much broader approach.

Arguably, it is the combination of gaseous mercury released from gold refining processes and toxic aqueous mercury discharged to streams and soils that represents the most serious environmental threat. During *amalgamation*, mercury is added to gold-aggregated sediments, which then wet and adhere to metallic gold, forming pasty amalgams. The amalgam is then panned, filtered, and burned to produce the final gold product. In the process, significant quantities of both gaseous and metallic (aqueous) mercury are dispensed into the surrounding environment. It is now a well-known fact that mercury is harmful to human health and potentially deleterious to a wide range of ecological entities. A change in mercury speciation from an inorganic state into stable toxic methlymercury (MeHg) by nonenzymic and microbial action is the principal cause of these ecological impacts. As Wolfe and others (1998) summarize, MeHg toxicity in mammals is primarily manifested as central nervous system damage. The compound is readily transferred across the placenta and concentrates selectively in the fetal brain, and acute exposure causes animals to initially become anorexic and lethargic, after which muscle ataxia, motor control deficits,

Table 1. Common environmental impacts resulting from small-scale gold mining

Environmental problem/issue	Potential impact
Exploration	
Deforestation	The geological deposits of gold are fixed, and intensive gold prospecting activity leads to massive clearance of forest and vegetation cover.
Erosion	After vegetation is cleared from exploration activity, soils are left exposed to erosional agents; land is typically not productive enough to support future industrial activity, namely agriculture.
Pitting	Pits are dug haphazardly throughout prospective gold mining communities; they often fill with water and attract malaria-infested mosquitoes.
Extraction and ore processing	
Mercury	Mercury emissions to both land and water are regarded as the most serious environmental problems in the small-scale gold mining industry. In sufficient quantities, the mercury is deleterious to a variety of organisms and plant life, and is hazardous to human health.
Acid Mine Drainage (AMD)	Improper tailings disposal causes AMD on a microscale, which, in turn, causes significant damages to resident water bodies and organisms.
Environmental Stress	The agglomeration of people at small-scale gold mines causes significant damage to the local environment. Examples include deforestation, and excessive pitting.
Closure	
Reclamation	Without proper reclaiming of mined lands, additional water pollution, heavy metals contamination and AMD can occur uncontrollably after abandonment.
Erosion and Landscape deformation	Landscapes are also scarred—often described as "moon-scaped"—with numerous holes and pits after abandonment of small-scale gold mining activity.

and visual impairments develop with convulsions preceding death. Similarly, for birds, acute MeHg poisoning can lead to weight loss, progressive weakness in the legs and wings, and kidney disease (Scheuhammer 1987). Moreover, MeHg has proven to be a chemical threat to humans, causing nausea, headaches, dizziness, weight loss, and sometimes, death (Ikingura and others 1997, Lacerda and Marins 1997, Appleton and others 1999). There have been numerous mercury-related projects (involving training, technology demonstration, and education) piloted in small-scale gold mining regions in Brazil, the Philippines, Papua New Guinea, Suriname, Tanzania, Zimbabwe, and Ghana. The combined research from these projects confirms that the mercury used in small-scale gold mining has had adverse impacts on both the environment and human health.

A second major environmental threat comes from waste tailings, the main problem being acid mine drainage (AMD), which results when rainwater flushes gangue or tailings. Gold, like most nonferrous metals, is usually accompanied by iron sulfides, which oxidize to become sulfuric acid and, in turn, solubilize residual metals when mixed with rainwater (Sanchez 1998). The ensuing AMD, which affects heavy metals concentrations and pH in waterways and soils, threatens a wide range of aquatic and terrestrial life. Although the environmental problems resulting from AMD are examined in great detail in the literature, its impact in small-scale gold mining regions has been largely ignored. This is most likely because of the difficulty of quantifying the contamination on a microscale, and the fact that mercury contamination largely overshadows most of the other environmental issues in the industry. Further AMD contamination can occur following gold mine closure. If abandoned without employing the proper mine closure techniques, additional contamination can result through seepage from the mine, tips, spoils, and contaminated land. The subsequent AMD and leaching of heavy metals, particularly cadmium, zinc, copper, lead, arsenic, and iron, can cause complications such as mine fires, precipitous slopes, subsidence, and groundwater contamination.

The third major impact resulting from small-scale gold mining activity is land degradation. During exploratory stages, vegetation is removed, and pits are dug haphazardly in areas believed to contain gold-aggregated ore bodies. The locations selected as exploration sites are largely based upon regional views. An absence of scientific and geological instruments for efficient prospecting often results in large tracts of land being unnecessarily left with potholes and exposed to erosional agents. In the Choco region of Colombia, for example, gold production increases 7.2% each year, affecting annually an additional 1000 hectares (Lacerda and Solomons, 1998), largely as a result of exploration activity. Heavy gold prospecting is also contributing to deforestation in Zimbabwe, where it is estimated that 100,000 ha of land are cleared each year in small-scale mining regions (Maponga and Anderson 1995). Furthermore, during operation, because sites are highly congested, sanitation is typically poor, there is deforestation from escalated demands for fuelwood, and productive soils are left contaminated. For example, as Traore (1994) explains, in the Liptako-Gourma region of West Africa—which includes Burkina Faso, Mali, and Niger—small-scale gold mining has intensified since 1984, and by the early 1990s, as many as 10,000 people were found on a single site. In fact, gold rushes occur in an anarchic manner, with little regard for ecological entities, and, as a result, excessive vegetation clearing has occurred and numerous pits have been trenched. In most cases, the damaged landscapes resulting from intense excavation activity are not reclaimed. Widespread precious metal extraction activity throughout the Brazilian Amazonian and southwest Colombia, for example, has left several "moon-surface" terrains devoid of vegetation (Lacerda and Salomons 1998). Similarly, in Ghana, the common practice with small-scale mining is not to rehabilitate mining land once it has been used. As Agyapong (1998) explains, as a migrating industry, it contributes to deforestation and degradation of large tracks of land as miners "hop on the ore deposits" wherever they are found. In the process, large pits are left uncovered, which renders the land unsuitable for any other purpose. They also fill with water and serve as breeding grounds for malaria-infected mosquitoes.

It is to the benefit of both national and local governments to improve environmental management at small-scale gold mines because intense activity is capable of causing damage to a wide range of economically and ecologically valuable resources—namely water, forests, crops, and soils. It is argued in this paper that with the assistance of international agencies, governments can facilitate environmental improvement in the small-scale gold mining industry by undertaking a series of important technological, managerial and policy-related initiatives. The next three sections of the paper provide an overview of these initiatives.

Technological Initiatives

A key to facilitating environmental improvement at small-scale gold mines is widespread implementation of efficient environmental technology (Hollaway 1993, UNIDO 2000). However, as Hentschel and others (2001, p. 41) note, "cheap and simple techniques, even if their efficiency is sub optimal, have a higher potential for dissemination than technically optimized but sophisticated processes." Against this background, technologies can be introduced that prevent emissions of

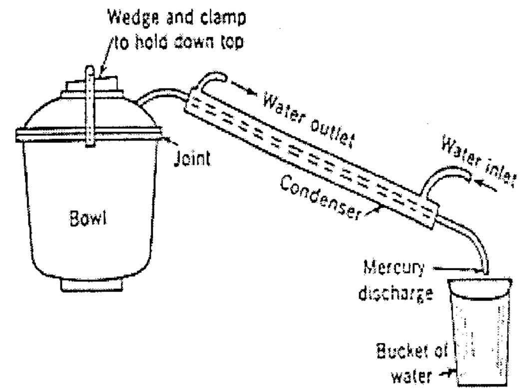

Figure 2. The mercury distillation retort. (Source: Priester and Hentschel 1992a).

mercury to both air and water; amalgamation techniques can be replaced with more controllable gold leaching strategies; and effective tailings disposal facilities can be constructed for storage purposes to prevent local tailings contamination. Moreover, improved environmental management practices can be introduced that could help prevent further complications.

As was established earlier, mercury pollution is one of the most pressing environmental problems in small-scale gold mining regions. Widespread implementation of improved mercury processing technologies—namely, mercury retorts, gravity traps, and hydraulic traps—would greatly reduce emissions. Each technology is relatively simple in design, inexpensive, efficient, and easy to operate. The distillation retort, as explained by Mutagwapa and others (1997), is simply a piece of equipment assembled with a closed crucible connected to a condenser, designed so that the mercury from the amalgam evaporates when heated, leaving the gold metal in the crucible (Figure 2). The crucible is then filled with amalgam and closed. The application of heat causes the constituents of the gold–mercury alloy to separate and the mercury to evaporate, after which it is precipitated in droplet form in a condenser pipe and runs off into a collector vessel. Various types of retorts have been developed, most of which have a mercury recovery rate in the range of 95%. Some models have even higher recapture rates, such as the design produced at the University of Dar-es-Salaam, Tanzania, which recovers up to 99.6% of mercury (Mutagwapa and others 1997). Furthermore, each unit is relatively inexpensive to purchase (between US$30 and $60, with some as little as US$10).

Traps—either hydraulic or gravitational models—can accompany implementation of retorts. Hydraulic traps, which are designed specifically for separating

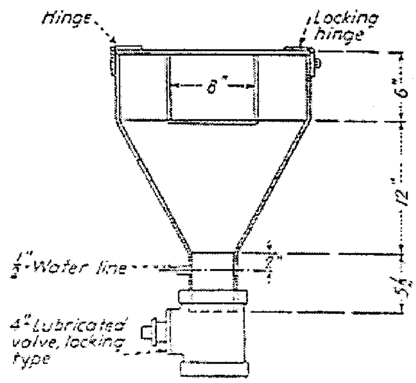

Figure 3. A basic hydraulic trap. (Source: Priester and Hentschel 1992a).

coarse gold particles, can be used for recovering amalgam and mercury downstream (Figure 3). As Priester and Hetschel (1992a) explain, in some models, the opening of a discharge valve enables recovery of sedimented concentrate. In other setups, pulp enters an inlet pipe and is forced to change direction multiple times before escaping, resulting in gold, mercury or amalgam settling to the bottom. Effective setups have a mercury recovery rate of 85%. Alternatively, gravity traps of even simpler designs can be used. These systems, many of which cost as little as US$20, also help to minimize emissions of liquid mercury and aid in the recovery of amalgam and gold particles from waste tailings (Buntenbach and others 1995). As Hentschel and Hruschka (1992) explain, simple models can be constructed from welded sheet metal, in which tailing sludge is forced to change direction of motion several times so that particles with higher specific densities, i.e., mercury, fall to the bottom. It has been indicated in the literature that recycled mercury—that which is recovered by retorts, hydraulic traps and gravity traps—loses its purity and is much less active (in amalgamation) than "fresh" mercury. However, a number of low-tech methods exist for cleaning and reactivation. These include the following (adopted from Priester and others 1993):

- Screening with a very fine-mesh screen
- Washing with wood ashes and water (whereby calcium carbonate contributes to the saponification of impurities)
- Washing the mercury with water containing tensides or with special plant-sap solutions, both of which are capable of saponifying grease and greasy substances and bringing them into solution
- Washing with reagents such as ammonia, ammonium chloride, cyanides, hydrochloric acid and nitric acid
- Admixing sodium amalgam, which, in turn, dissolves surface components of the mercury

Individually, or in combination, these strategies enhance the recyclability of "spent" mercury solution.

Although it is highly unlikely that the mercury amalgamation process will be replaced outright in the developing world, some promising substitute strategies have been developed and have even penetrated certain small-scale gold mining markets. Lins and others (1994) identify a number of alternatives to mercury amalgamation. These include the following: (1) The coal-oil agglomeration is a process in which high-grade gold-containing slurry is transposed by activated carbon into an oil suspension, after which the gold agglomerates onto oil-saturated carbon particles. Gold-activated carbon agglomerate can be mechanically separated following agitation of the slurry-reagents mixture (Priester and others 1993). (2) The gold-paraffin process is basically the selective adhesion of liberated gold particles to hydrophobic materials (a paraffin-wax) and their separation from a pulp of the ore (see Lins and others 1994). (3) The centrifugal concentration of gold is simply the recovery of gold through gravity separation.

The technique showing the most promise as a substitute for amalgamation is cyanidation. In fact, as Hollaway (1993) explains, as a long-term policy, cyanide extraction would be a more viable option than amalgamation for many small-scale gold miners because it is rapidly decomposed in solution (hence, fewer environmental concerns), particularly in sunlight, and is not a cumulative poison like mercury. Furthermore, pads and detoxification agents can be adopted to help prevent accidental chemical release. However, as Veiga and Meech (1999) explain, despite high gold recoveries, cyanidation techniques require much more skill and investment than simple amalgamation, which is why the technique is not yet widespread in the small-scale gold mining industry. Certain Andean countries and some operators in Brazil have begun using cyanide and, as Stewart (1997) explains, in the Baguio region of the Philippines, some operators have even constructed crude cyanide heap leaching operations.

The cycle of pollution prevention can be further perpetuated with improved tailings containment. As already noted, the issue of AMD and accompanying heavy metals pollution, although largely overlooked on a small scale, can cause local environmental damage. The chemical content of gold-aggregated ore—more specifically, its propensity to contain sulfide-bearing material and sulfide minerals—induces these problems. Moreover, gangue contains chemical residue, namely mercury, that requires proper detoxification prior to reentry into the natural environment. It is highly practical, given the limited amounts of funds that can realistically be allocated toward both preventing AMD and ensuring safe containment of waste tailings, that both problems be addressed simultaneously.

Educational and Managerial Initiatives

Improved environmental management and education can accompany implementation of improved technology. Ensuring that miners are informed about the environmental implications of their operations and the associated health risks of using toxic chemicals such as mercury is a necessary first step. This can be achieved by constructing regional educational centers, which would provide key informational sources for miners, stocking clean technologies, and coordinate training programs. In Zimbabwe, for example, the government constructed the Shamva Mining Centre, which provides some 200 miners access to central processing. As Peak and others (1998) explain, motivation for the center stemmed from the proliferation of small-scale miners in the region, none of whom were in a financial or technical position to operate their own gold recovery plant. Individuals formerly used rudimentary methods to crush ore and mercury to recover gold, which caused significant regional environmental pollution. The center, however, introduced much needed technical knowledge and organization to the region. In Pasto, Colombia, smaller service centers have been constructed, which provide concussion tables for the improvement of gravitational processing, an amalgamation press, a hydraulic trap, and a mercury retort to prevent the release of mercury, a system that allows for the recovery of 90% of mercury (Priester and Hentschel 1992b). The most specialized small-scale mining educational unit constructed to date has been the Venezuelan UNECA (unit of gold extraction and controlled amalgamation) type of processing center, which, as Veiga and Meech (1999) explain, is a stationary complex suitable for installation in most mining villages or any central location. Each serves to provide miners, through meetings and the issuance of brochures, with key information about the environmental and health implications of operations. Moreover, each features more efficient gold recovery techniques (hence, gold recovery is improved), does not expose miners to toxic mercury fumes, and provides less costly processing services to miners. The UNECA centers are far more flexible than the Shamva Centre simply because miners can continue their mining and processing activities on their own without interference, and the fact that each can be commissioned quickly with full support of environment agencies and mining departments. The United Nations International Development Organization (UNIDO) and the Venezuelan mining company, PARELA, jointly developed and designed the first UNECA centers.

Implementation of a series of environmental management measures would further improve the efficacy of operations and also help miners identify additional opportunities for waste minimization (Hilson 2000). A number of large scale-mining companies have already implemented a series of state-of-the-art environmental management tools and practices, including:

- Environmental audits
- Environmental reviews
- Environmental management systems (EMSs)
- Environmental monitoring systems
- Life-cycle assessments
- Environmental impact assessments (EIAs)

As Freer (1993) explains, improved environmental management at mines—achieved through implementation of environmental management tools—provides for cost-effective project development, improves cradle-to-grave management, and helps further preserve environment entities. Each environmental management tool serves a specific purpose, helping to improve the efficiency of a given area of operation (Hilson and Murck 2000). Take, for example, EMS, which has been adopted by many leading mining companies. Industry-wide, EMS is now viewed as a necessity in preventive environmental management and reportedly has resulted in a more systematic and cost-effective approach to environmental issues than ad hoc actions (Hilson and Nayee 2002). Similarly, mining environmental audits and reviews have proven invaluable in assessing a wide range of risks, including health, ecological and ecotoxicological impacts (Bunch and Garr 1990). Although the potentiality of these and other important intricate environmental management tools and processes in small-scale (gold) mining have been largely ignored, integration of more basic versions would facilitate additional environmental improvements. For example, in the case of EMS, which is a complex set of organizational procedures, responsibilities, and processes, basic prototypes can be adopted. More specifically, rather than viewing each operation individually and attempting to integrate an EMS into every working operation, implementation of a regional EMS, i.e., one which works to identify environmental problems and continuously monitor improvement in a designated area, might prove most practical. As Hagen and Priester (1998) explain, the regional EMS could prevent environmental impacts from small-scale mines because it has two complementary objectives: (1) to redefine responsibilities for workplace safety and environmental protection; and (2) to introduce a collective operations planning system.

In fact, regional environmental management would require the allocation of fewer resources and finances from (developing world) governments, a great number of which are already heavily indebted and understaffed. By using baseline scientific data, governments could conduct environmental audits, EIAs, and environmental reviews in small-scale gold mining regions. The regional concept, too, fits into the cooperative approach that a number of the steps discussed emphasize. For example, as has been explained, educational programs could be based in close proximity to small-scale gold mining regions and could involve wide-scale participation of local miners; likewise, the construction of a local retorting facility would require miners to share equipment. These steps involve interaction between miners and help to facilitate cohabitation and cooperation. Similarly, the underlying premise of a regional approach to environmental management is that it stimulates interaction between miners and gets them working towards achieving similar environmental targets. This can accomplish much in the way of further cooperation and harmony.

Policy Initiatives

Environmental improvements at small-scale mines cannot be achieved through improved technology and management alone. A sound regulatory regime must be in place to ensure that pollution is controlled and monitored and that violators are penalized. Therefore, once important operational changes have been made, it is imperative that environmental regulations are promulgated and that plans and procedures are drafted that address the important environmental issues in the sector.

A major problem in a number of developing countries is that small- and large-scale mines are not regulated with equivalent stringency. Part of the reason stems from small-scale mining not being clearly defined in national agendas, the other factor being that small-scale mining is rarely distinguished from large-scale mining in national mineral legislation. This, in turn, poses significant challenges from the standpoint of environmental management because each sector faces markedly different challenges (e.g., technological implementation, training, etc.). Furthermore, a number of the environmental management tools and techniques—namely environmental impact assessments (EIAs), audits, and reviews—adopted by Third World governments in recent years for use in the industry require significant resources to put into practice, which often renders them unsuitable for small-scale industrial applications.

Quite simply, if small-scale mining is not recognized as an industry nationally, how can sector-specific environmental problems realistically be resolved? Sector-specific legislation must first be implemented that regulates the titles, rights, and obligations of the miner, as well as administrative and judicial procedures (Kambani 2000) and must be identified and addressed in national mineral policies. Although many of the more recent regulatory schemes (e.g., in Zimbabwe, Zambia, and Brazil) appear to do this, most lack definition, place minimal demands on the small-scale miner, and fail to regulate operations with the same stringent conditions as large-scale mines. Therefore, in amending mineral policies, governments must use criteria such as size, employment, ore tonnage, or income to define a "small-scale mining operation" in a national context.

As Barry (1997) explains, the Harare Guidelines provide important guidance for governments and development agencies in "tackling the different issues in a complete and coordinated way". The guidelines, which are a product of the proceedings of a United Nations international seminar on Guidelines for the Development of Small- and Medium-scale Mining, held in Harare, Zimbabwe, in February 1993, provide a "framework for encouraging development of small- and medium-scale mining as a legal, sustainable activity" for the purpose of "optimizing its contribution to social and economic development" (Labonne 1994, p. 13). Specifically, the guidelines stipulate the initiatives governments and their agencies can undertake in the legal, financial, commercial, technical, social and environmental areas to develop plausible small-scale mining regulatory frameworks.

The virtual absence of sound small-scale mining regulatory frameworks and their reinforcement has resulted in widespread illegal gold mining activity, which has been responsible for a disproportionately large share of environment damage in the sector. Kambani (1995) argues that the high unit value and low barriers to entry (in terms of capital requirements, infrastructure, minimum resources and implementation time) are causing a number of gold miners to operate illegally. Black markets, in this case, for gold, develop once the difference between the government and the world market price exceeds a margin of 5% (Notestaller, 1994). Because most illegal mining occurs well out of the reach of regulatory bodies, many environmental damages go unnoticed and undetected. Furthermore, because of the constant need for illegal miners to elude government authorities and pursue further developments, operations are the most temporary of small-scale setups, featuring practices and equipment most likely to cause environmental problems. The resulting pollution and environmental degradation are therefore most severe as miners fully exploit the fact that their operations, for the most part, go undetected.

Once the small-scale mining sector has been formalized nationally, specific environmental regulations can be promulgated. This is not an easy task, however, given that a disproportionately large percentage of the environmental legislation already in place in developing countries lacks comprehensiveness. The specific problems include the following (de Nava 1996):

- A lack of clear, continuous policies to support waste minimization and environmental management
- Incomplete regulatory frameworks and uneven enforcement (as noted earlier)
- Ignorance of the characteristics of industrial production processes
- No clear understanding of the difference between compliance investments and cleaner (low waste) technologies
- Inefficient coordination among different governmental agencies at different levels

This imprecision and inaccuracy, in turn, "brings confusion in the classification and procedure for managing small-scale mining concessions" (Traore 1994, p. 208). Compounding this problem is the fact that in most developing countries, mines are regulated under general environmental legislative schemes. For example, as Hollaway (2000) explains, in Zimbabwe, the Ministry of Mines, Environment and Tourism, in 1994, adopted a policy mandating that all proposals for new (industrial) activities consult with members of government to determine if they require an EIA. The list of "prescribed activities" includes "mineral prospecting, mineral mining, ore processing and concentrating and quarrying." In Mexico, the General Law for Ecological Balance and Protection of the Environment, which was passed in 1988, serves as the "comprehensive piece of legislation which deals with all aspects of environmental stewardship and the conservation of natural resources" (Hernandez 1997). In short, both countries lack environmental regulations specific to mining, and to improve the efficiency of regulation, their governments must draft general environmental legislation for mining, and then craft regulations exclusively for the small-scale mining sector.

As funds are limited, governments must prioritize environmental research in the industry. At present, there is an acute shortage of work targeting the prevention of the industry's environmental problems, and most of the environmental research undertaken to date is largely effects-based, with little, if any, focus on cause. For example, how can cleaner production (CP) be promoted in the industry? What technologies are best suited for minimizing environmental problems, and how can they be integrated successfully into the industry? Can improved environmental management have an impact? Rather than funding projects that further identify the environmental problems resulting from small-scale gold mining activity, governments could sponsor research that targets preventing them in the first place. One excellent example is with mercury-related projects. Too much analysis in recent years has been devoted to analyzing and overanalyzing mercury contamination levels in soils and waterbodies surrounding small-scale gold mining regions. More specifically, funding has been provided for projects that employ conventional sampling techniques to ascertain mercury contamination levels. It has long been well recognized that mercury is a persistent contaminant that requires careful handling. It is therefore highly likely that the soils and water surrounding mines that feature the most rudimentary of techniques and that are operating with minimal environmental safeguards in place contain high concentrations of mercury. Replication of such mercury studies only further verifies the findings from numerous studies undertaken in countries such as Brazil, Venezuela, Tanzania, and Mexico: that mercury is found in elevated levels around small-scale gold mining regions. The next step is to research the feasibility of wide-scale implementation of retorts and traps and to develop mercury education programs for miners—projects that concentrate on pollution prevention, rather than environmental analysis. Often, the resources are available to engage in such projects, but they require funding to be properly channeled and managed.

Finally, to prevent unnecessary damages to land, partnerships can be encouraged between the management of large-scale mines and small-scale miners. Disputes have been known to occur between small-scale miners and the management of large-scale mines over land, since both parties are often engaged in the extraction of minerals from the same ore body. The critical question that needs to be answered and made clear is who *should* be mining the land? In the end, the large-scale mine quintessentially receives the preferred treatment from governments because of its noticeable and measurable economic contribution. Both domestic and foreign-owned large-scale mines rank among the most important of industries in the developing world. To stimulate further development of the sector, a great number of governments are encouraging foreign investment and are decreasing state control of domestic mine sites. Small-scale mining, in spite of its socioeconomic importance, has, in the process, become the forgotten segment of mining. Even in instances where it is formalized and recognized nationally as an industrial sector, the rights of large-scale mines still seem to take precedence when it comes to land-use issues.

To summarize, a series of initiatives have been suggested that, if undertaken, could lead to improved environmental management at small-scale gold mines. Few authors, however, have critically evaluated the effectiveness of these initiatives on a global scale, and of the recommendations that have been made, few feature a combination of technological, managerial and policy elements. Using evidence from the literature, the next section of the paper provides a recommended strategy for Third World governments seeking to improve environmental conditions at small-scale gold mines.

Recommended Strategy for Environmental Improvement

Although a number of individual initiatives have been outlined in the literature, it is recommended that governments aiming to improve environmental conditions in small-scale gold mining adopt a strategy that emphasizes: (1) improved (small-scale gold mining) regulation through licensing and environmental regulation; (2) the dissemination of improved mercury and tailings storage technology; and (3) land-use policy.

It is recommended that governments first adopt a licensing procedure for small-scale gold miners. Such schemes help to ensure that activity is "prosperous and safe," and helps to transform the industry from an "unorganized and unsupervised" state into a "modernized, monitored and supported" condition (Barry 1997, p. 108). As Stewart (1997, p. 181) explains, it is imperative that governments "aim to be in a position where they have reasonably accurate information on the activities of small-scale miners" so they can "take appropriate steps to maximize the benefit to the country from such activities" and "reduce the undesirable effects." Legalization, intervention, and control are keys to eliminating unacceptable work practices and the illicit marketing of minerals, and they are necessary prerequisites for removing operational constraints limiting productivity and competitiveness (Noetstaller 1994, Hilson 2002).

Table 2. Examples of small-scale mining regulations and licensing systems in selected developing countries[a]

Country	Small-scale licensing system
Brazil	General mining code has provisions for small-scale mines
Ethiopia	Mining Proclamation Number 52/1993 includes provisions for small-scale mining and artisanal mining
Ghana	The Minerals and Mining Law (1986) has provisions for small-scale mining, and the Small-scale Gold Mining Law (1989) provides some important sector-specific legislation
Indonesia	Basic Mining Law Number 11/1967 has provisions for "peoples mining," which refers to small-scale mining
Philippines	General Mining Law (RA 7942) has provisions for small-scale mining; specific legislation also exists (RA 7076 and PD 1899)
Zimbabwe	Mines and Minerals Act (Chapter 165) provides simple mechanisms of pegging and registration of claims; the Public Streams Regulation (1991) was passed specifically for small-scale gold mining

[a]Source Bugnosen (1998)

A number of countries have already taken this much-needed step and/or have included provisions for small-scale mining operations in general mineral legislation (Table 2). For example, in Zimbabwe the government passed the Mining (Alluvial Gold) Public Stream Regulations (1991), which require that relevant local authorities issue gold panning permits to "approved persons," cooperatives, and partnerships (Hollaway 2000). Similarly, in Papua New Guinea, under the Mining Act 1992, land tenure is now granted to registered artisanal miners in the form of an alluvial mining lease (Land 1994). It is recommended that when devising classificatory licensing systems, one or more of the following criteria be used (adopted from Bugnosen and others 1999):

- By mineral type: have separate licensing for gold, diamonds, gemstones, etc.
- Strata: provide licensing to mine only to certain depths
- Staggered or single: having one license that covers all stages from exploration, through development, through extraction, through processing to marketing or having one license for all stages
- Duration: assigning time lengths for small-scale mining

- Area: assigning specific plots of land for small-scale mining

The criteria selected for licensing purposes, however, are not of major importance; the major accomplishment here is that through licensing, governments acquire much-needed knowledge concerning the whereabouts of small-scale mining operations, which is necessary for facilitating effective regulation. Improved regulation through licensing enables governmental bodies, many of which are largely understaffed, to better locate and enforce environmental legislation and better prevent the damages small-scale mining activity causes to environmentally and economically valuable resources such as forests, crops, and water. Moreover, increased registration is key to preventing lost mineral resources, which, in turn, contributes positively to national exports and foreign exchange earnings. To further encourage the registering of small miners, policies can be implemented that explicitly state that illegal operations will be cut off from all types of assistance and support schemes.

Once it has been formalized through licensing, specific measures can be taken to regulate the sector environmentally. Some progress has already been made in certain developing countries. In the Philippines, for example, an environmental tax (Special Fund of the Philippines) is levied on small-scale mining output and is used to rehabilitate areas affected by operations (Bugnosen and others 1999). Other countries such as Guinea and Zambia require the posting of surety bonds to ensure compliance with environmental protection and pollution control plans (Bugnosen 1998). However, these efforts, overall, fall well short of what is needed environmentally. In the case of gold, laws are needed that address a number of specific issues, including: (1) ambient levels of mercury emissions to both air and water, (2) land regrading and reclamation practices, (3) exploration and prospecting techniques, and (4) tailings containment and disposal. It is important that within each piece of legislation, the government identifies suitable technologies, designs techniques, recommends strategies for environmental management, and provides the requisite assistance.

Davidson (1993) raises an interesting point concerning the potential social impact resulting from increased formalization and regulation of the small-scale mining industry. He suggests, inter alia, that the "constructive" reconfiguration of artisanal mining could mean enfranchisement of mining rights. Under current regulatory regimes, legislatively speaking, illegal miners do not have mining rights. However, formalizing the industry and providing the necessary support infrastructure and accompanying concessions would provide small miners more of an incentive to perform in accordance with set or newly established regulations, and to comply environmentally. More specifically, formalization of the small-scale gold mining sector would mean increased access to finances, equipment, and markets, which, in effect, would give small miners an expanded role and provide increased leverage in the industry and ultimately, the mineral rights they so desperately desire. These facts are confirmed in a study of 18 countries undertaken by Bugnosen (1998), the results of which indicate that the main justification behind the governmental enactment of small-scale mining legislation is the desire to curb illegal mining and smuggling and to improve environmental protection.

After formalization of the small-scale gold mining sector has occurred and relevant environmental legislation has been implemented, emphasis can then be placed on remedying the existing environmental problems at sites. First, the volume of waste tailings can be reduced through recycling gangue as backfill, something that, despite being well documented, continues to be largely unexploited in the industry. For example, typical small- and medium-sized mining operations in Peru use only between 9 and 20% of their tailings as refill—largely because environmental considerations are not taken into account during planning—when realistically, 50% of tailings can be reused, and as much as 70% with implementation of appropriate tailings containment systems (McMahon and others 1999). Most significantly, however, effective containment facilities must be constructed. The location that ensures minimal environmental risk is downstream, in a relatively open area, and far from riverbanks. Containment systems should be lined to prevent soil and groundwater seepage, something that can be accomplished through making use of local, naturally low hydraulic conductivity soil or rock. Second, and perhaps more importantly, improved mercury technologies—namely, retorts and traps—must be introduced to miners. The relative inexpensiveness of each, as noted earlier, makes this a feasible option for Third World governments. It is recommended, however, that representatives from the relevant governmental bodies, such as geological surveys, mining departments, and minerals commissions, play a leading role in disseminating these and related technologies to miners, since the construction of an educational and training center could initially be economically burdensome for governments (see, e.g., Veiga and Beinhoff 1997). Improvements attributable to increased usage of retorts and traps have already been reported in a number of countries including Ecuador, Colombia, Bolivia, and Papua New

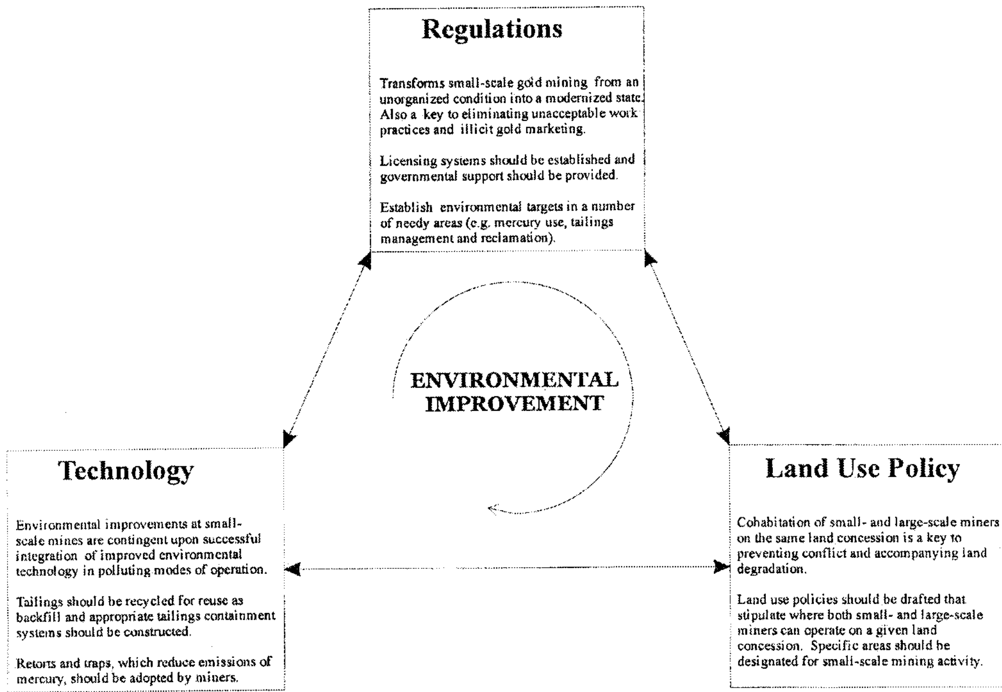

Figure 4. Recommended framework for facilitating environmental improvement in small-scale gold mining operations.

Guinea (see, e.g., Preister and others 1993, Mutagwaba and others 1997).

A final recommended initiative is that land-use policies be drafted that stipulate the rights of both large- and small-scale miners. In certain instances where unfavorable action has occurred, namely, when the management of large-scale mines has elected to neglect the needs of small miners, significant community disruption has resulted. For example, in the case of Ghanaian-based Ashanti Goldfields Ltd., an estimated US$1.05 million in damages occurred at its Obuasi site when violent clashes erupted over land rights. Although small-scale miners were registered and legally entitled to prospect the land, it included much of the already-excavated site, which precipitated the clash between the small miners and regional security agencies (Agyapong 1998). Similar disputes over land rights have occurred in Papua New Guinea's Mount Kare region, where claims have been made to preferential rights over alluvial gold by virtue of customary land title (Land 1994). Partnerships and working relationships must therefore be forged between large- and small-scale miners. Initially, cohabitation must be established, which, as Jennings (1994) explains, is simply a voluntary agreement by which mining companies accept artisanal mining but specify conditions under which it can continue within their concessions. Recently, a number of large-scale mines have concerned themselves with the small-scale mining sector (UN 1996). For instance, in the Baguio Region of the Philippines, small miners commonly work within the lease boundaries of large mines and have full support of their management, who note that they "are doing a useful job" of proving portions of the ore body (Stewart 1997). Once an agreement has been forged, management of large-scale mines can then stipulate the specifications of the agreement. This involves setting aside specific areas for small miners to operate. It is typically a win–win scenario for both parties because the areas in which it is less favourable to mine on a large-scale, more specifically, where it is unsuitable to use equipment, it is more viable to engage in small-scale mining. A primary example is the reprocessing of tailings and waste dumps, which is usually only economically viable on a small scale. Additionally, management can establish an internal program for training, or involve small miners in existing training activities, where they can be educated about the potential environmental impacts of their current practices.

In summary, these three elements form the basis of a basic, yet effective program for improving environmental management at small-scale gold mines (Figure 4). It is important to clarify, however, that, successfully implementing a framework of this scope depends largely upon the contributions of external parties, namely, governments. The fact still remains

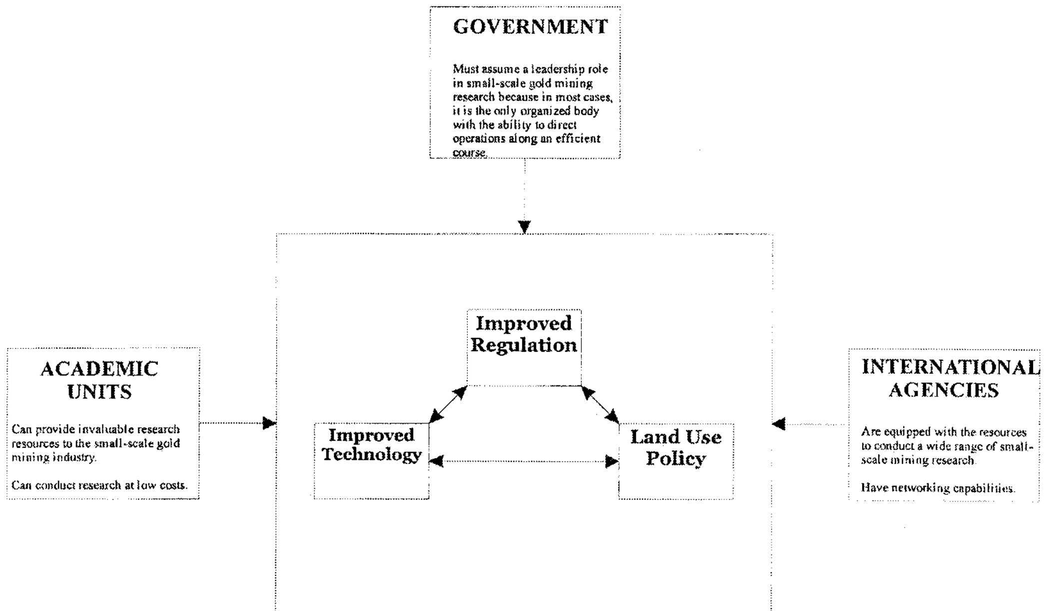

Figure 5. Potential small-scale mining research contributions of selected bodies.

that the level of environmental awareness in most small-scale gold mining regions is relatively low and that miners still engage in practices that can potentially cause significant environmental degradation. Miners, therefore, cannot realistically undertake a series of environmental management activities on their own if they do not understand fully the environmental implications of their operations in the first place. In the context of small-scale (gold) mining, the government's role takes on a great significance, because in many instances, it is the only organized body with the ability to direct activities along an efficient course (UN 1996). More specifically, through the establishment of a sound institutional and legislative regime, governments, a number of which have already intervened in small-scale mining operations to improve revenue flows, would provide a stable framework within which small-scale (gold) mining could further develop (Borla 1996). Governments must also forge partnerships with international agencies and educational and research institutes, organizations that have the resources to help bridge critical technological and informational gaps. A number of international agencies, including the UN, UNEP, World Bank, and WHO, have networking capabilities, the resources to initiate and support environmental research in a wide range of small-scale gold mining areas, and the staff and flexibility to conduct environmental and technological demonstration projects. Local universities and research units could further contribute to resolving these environmental problems since they have the facilities and manpower to investigate and develop practical environmental management measures and technologies at low costs (Figure 5).

Conclusion

The paper has identified a series of technological, managerial, and policy measures for improving environmental performance at small-scale gold mines. Given the budgetary limitations and shortages of scientific expertise prevalent in most developing countries, it was recommended that a strategy emphasizing improved regulation of small-scale gold mining, increased implementation of efficient mercury technologies, and the establishment of land-use policies be adopted. Putting a framework of this scope into practice requires increased input from governments, which, in many cases, are the only bodies capable of ensuring that small-scale gold mines operate efficiently. Partnerships must then be forged with local universities and regional branches of influential agencies such as the UN and the World Bank—in short, organizations with research and networking capabilities. As small-scale gold mining activity is intensifying in Africa, South and Central America, and Asia, it is imperative that environmental problems are tackled with improved strategies.

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