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An estimation of the artisanal small-scale production of gold in the world

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HIGHLIGHTS

- Artisanal Au Mining releases ~727 t/y of Hg to the environment.
- From 2003 to 2011 Au price increased 417% and ASM population doubled.
- 380 to 450 t of gold are produced annually by ~16 million artisanal miners.
- Au recovery: South America > Asia and Central America > Africa
- Hg:Au: South America < Asia = Central America < Africa

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ABSTRACT

The increase in gold price of over 400% between 2002 and 2012, due to a shift towards safe investments in a period of crisis in the global economy, created a rapid increase in gold production. A response to this shift in production was observed for artisanal and small-scale mining (ASM) units in remote locations of the world, but this phenomenon has not been quantified yet. The work presented here was done to provide a quantitative tool for estimation of the gold (Au) produced by ASM and the population of workers involved in the production process, and assessment of mercury (Hg) consumed. The following hypotheses were addressed: i) It is possible to estimate, on first approximation, the amount of Au production in the world by artisanal mining; ii) Au production by artisanal mining varies by country and continent and iii) Hg consumption due to ASM can be correlated with the methods applied in the different countries and continents for the production of Au. To do this we estimated the number of miners, calculated the change in Au price and production and then applied an adjustment factor to calculate Hg production by country and continent. The amount of Au produced depends on technology of the miners by continents (highest in South America, medium in Asia and Central America, and lowest in Africa), and the geologic setting (not investigated here). The results of the estimation show that, as of 2011, over 16 million Artisanal Miners, in the world, were involved in gold extraction (mining or treatment), producing between 380 and 450 t of gold per year, with clear global behavior between the continents in terms of recovery efficiency, confirmed by data on Hg release that is higher in countries with lower technology.

1. Introduction

Artisanal and small-scale mining (ASM) of gold (Au) has been studied worldwide due to the use and release of mercury (Hg) to the environment (Veiga, 1997; Veiga et al., 2006, 2009; Shandro et al., 2009; Spiegel and Veiga, 2010; Velasquez-Lopez et al., 2010). The Global Mercury Assessment (UNEP, 2013) estimated that ASM of gold released ~727 t (metric tonnes) of Hg to the environment per year. This is 37% of the global 1960 t of Hg released annually by anthropogenic sources to the environment (UNEP, 2013). Such numbers are corroborated by various studies specifically on ASM of Au (Cordy et al., 2011; Bose-O'Reilly et al., 2010; Paruchuri et al., 2010; Castilhos et al., 2006). It was estimated that as many as 15 million individuals in developing countries are involved in extracting gold using rudimentary techniques ~10 years ago (Veiga and Baker, 2004). In 2004, the Au production by ASM was estimated at 20 to 30% (500–800 tonnes) of total global production (Swain et al, 2007). Telmer and Veiga (2008) suggested, based on investigation of the Hg consumption in ASM, that the Au production by these individuals might be around 350 t/a. In fact it is very difficult to obtain accurate estimates of the Au production from ASM since governments do not have reliable data on gold production and miners do not freely disclose recoveries. The most reliable information can be obtained from field surveys with miners and Artisanal Mining Associations, and from Au shops that buy Au directly from miners.

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This work was focused on fulfilling a lack of information regarding Au production and Hg release by investigating the following hypotheses. Through knowledge regarding changes in the price of Au and mining technology, and the relationship of number of artisanal miners with changes in prices in Au it is possible to: i) estimate, on first approximation, the amount of Au production in the world by artisanal mining; ii) quantify Au production through artisanal mining globally; and iii) determine Hg consumption.

1.1. Definitions

The definition of "artisanal and small-scale" mining is not uniform in many jurisdictions. The term "artisanal" refers to the rudimentary type of the operation, independently whether the mine is small or large, while small scale mining refers only to the size of the operation, and these can operate in a conventional or in a rudimentary fashion (Veiga, 1997). Very often the legislations of developing countries refer to "artisanal and small-scale mining" as "individuals, groups, families or cooperatives mining with minimal or no mechanization, often in the informal (illegal) sector of the market" (Hentschel et al., 2002). Nonetheless, a more precise definition is needed when dealing with the technical aspect of the problem. In 1972, the United Nations (UN) attempted a first definition of small-scale mining: "Any single mining operation having an annual production of unprocessed materials of 50,000 metric tons or less as measured at the entrance of the mine". In Brazil, the National Mineral Research Department (DNPM) defines small-scale mining as an operation producing between 10,000 t/a (t per year) and 100,000 t/a of ore (CPRM, 2002). A similar definition is given in Ecuador where a small-scale mine is one producing less than 300 t/d ROM (t per day in the Run-of-Mine production) of metallic ore or 800 t/d ROM of non-metallic ore (Vergara, 2009). In a mining process, the Run-of-Mine (ROM), also called "tout-venant", is defined as the ore mined-out and still unprocessed. The ROM is an operational parameter that characterizes both the mine and processing plant: it can be seen either as the volume or mass extracted at the mining site, or as the volume or mass feeding the plant. These data are summarized in Table 1.

Hilson (2002) described that an artisanal mining operation is that one with "intense labor activity located in remote and isolated sites using rudimentary techniques and low technological knowledge, low degree of mechanization, and low levels of environmental, health and safety awareness". Many definitions of artisanal miners mix up the term with "micro-miners" i.e. those who pan the river banks to produce 0.1 to 0.5 g of Au per day (Veiga, 2013). These individuals are usually spread over a large area, they are seasonal and/or they mine to complement their low income from agricultural activities. It must be highlighted here that micro-miners belong to the category of "artisanal miners", nonetheless they are not the major polluters. The large dredges, the processing centers, and those operations producing 0.3 to 3 kg of Au per day are responsible for a much larger environmental contamination (Veiga, 2013).

Considering the above definitions we propose the following general definition:

> *Small-Scale Mining (SSM) is a mining activity producing less than 100,000 t/a ROM for profit. Artisanal Mining is a subset of the previous, where operation does not follow the conventional ecological and engineering principles of mining and uses rudimentary or basic simple techniques to extract minerals.*

In this article, the term ASM (artisanal and small-scale mining) is broadly used to refer to those small or large operations that use rudimentary techniques to extract Au operating in a legal or illegal fashion that are not on the radar of many mining companies, governments, and international environmental agencies.

2. Materials and methods

2.1. Estimation of the ASM population in the world

Data show that a close relationship exists between the price of Au and the population of ASM operators in the world. Quiroga (2002) estimated a population of 13 million ASM operators at the time of publication. The same number is estimated by Hentschel et al. (2003) and Hinton et al. (2003). Eight years later Hruschka and Echavarría (2011) estimate an ASM population of 25 million. The World Bank (2012) estimated a population of 20 million. In the same years AU price increased 417%: from an average of 310 US$/oz (dollars per ounce) in 2002 to an average of 1600 US$/oz in 2012, with a peak of 1700 US$/oz in 2011 (GoldPrice, 2014). The data cited here are rough estimates, but a common trend is clear between Au price and ASM population. Based on this observation, it is possible to calculate the shift in ASM population during a given time, considering it directly proportional to the shift in Au price in the same period. This is shown in Eqs. (1) and (2).

References are available for general numbers of artisanal and small-scale miners (ASM) by country, regardless of mineral production. ASM of Au is a percentage that can vary from almost 100% to none, depending on the country. The proportion of Au miners versus population influences the Au productivity per miner. This is taken into account when dealing with the adjustment factors described in Section 2.3.

The calculation of the ASM population can be based on a relationship developed using the number of ASM population per country using data obtained from reliable available sources, such as the *Report on Mining, Minerals and Sustainable Development* (MMSD, 2002) and the *Communities and Small-scale Mining* (CASM, 2012) online database. The complete list of sources is reported in the caption of Table 3. The variation (percentage) in the price of Au can be calculated between the year of the reference (per each country) and the 2011 average Au price, updated to January 2012, as in Eq. (1):

$$\Delta_{\text{Au price}}[\%] = \frac{\text{Price}^{\text{Au}}_{2011} - \text{Price}^{\text{Au}}_{\text{year of reference}}}{\text{Price}^{\text{Au}}_{\text{year of reference}}} \cdot 100. \quad (1)$$

The same percentage shift, per country, can subsequently be applied to the ASM population, obtained the updated current value, as in Eq. (2):

$$n^{COUNTRY\ x}_{2011} = n_{year\ of\ reference} \times \Delta_{\text{Au price}} \quad (2)$$

where n is the number of artisanal miners operating in country x.

The analysis has been conducted using two different scenarios. *Scenario* 1: the "low-number scenario": when two references with the same credibility were available per country, the lower number has been chosen to feed Scenario 1. *Scenario* 2: the "high-number scenario" when two references with the same credibility were available per country, the higher number has been chosen to feed Scenario 2.

Table 1
Summary of production and investment features that define small scale mining. ROM = Run of mine and CAPEX = Capital Expenditure.

Source	ROM [t/y]	Daily ROM [t/d]	CAPEX [$]	Revenues [$/y]	Human resources
ONU	$<50 \times 10^3$	<200	$<1 \times 10^6$	$<1.5 \times 10^6$	40
DNPM (Brazil)	$10 \times 10^3 <$ ROM $< 100 \times 10^3$	–	–	–	–
Ley de Mineria (Ecuador)		<300 (metallic ore) <800 (nonmetallic ore)			

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