

# Strategies for sustainable gold processing in the artisanal and small-Scale mining sector in Zimbabwe

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The artisanal and small-scale gold mining (ASGM) sector is considered one of the most important sources of income for both rural and urban communities in Zimbabwe, particularly with diminished access to alternative opportunities. However, gold processing in the ASGM sector is characterised by a lack of capital and limited use of appropriate technology in the processing of gold ores. This paper examines gold processing in the ASGM sector in Zimbabwe and identifies processing gaps that negatively affect the sustainability of the small-scale mining sector in Zimbabwe. The focus was to identify improvement opportunities to make processing more efficient, less destructive to the environment and more meaningful to the operators. Preliminary analysis suggests that the deployment and use of appropriate technology for small-scale gold processing will significantly improve productivity and reduce impact of operations on the environment. This paper further proposes ways of deploying such integrated and pragmatic interventions to the ASGM sector.

Key words: ASM, gold processing, appropriate technology, environmental impact, productivity, sustainability.

## INTRODUCTION

Gold remains one of the key minerals in Zimbabwe's mining industry, accounting for some 47% of the mineral exports as of 2016 (See Figure 1) (Pact & The Institute for Sustainability Africa, 2017).

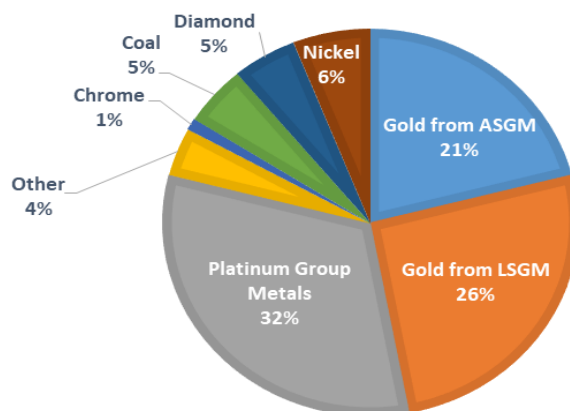


Figure 1. Mineral share in Zimbabwe's total minerals output value, 2016 (Pact & the Institute for Sustainability Africa, 2017).

The Zimbabwean mining sector employs in excess of 25% of those in formal employment and over 500 000 are believed to be involved in artisanal gold mining (AGM), (The Chamber of Mines of Zimbabwe, 2017)). Zimbabwe has a gold resource estimated at 84 million tonnes at an average grade of 4.9 gper tonne (Mlambo, 2015 ). Gold is one mineral among an estimated 60 other minerals, 40 of which have been exploited at some point. However, according to Pact and the Institute for Sustainability Africa (2017), only a handful of these minerals contribute significantly to the economy of Zimbabwe: gold, diamonds, platinum group metals, coal, and nickel (See *Figure 1*). From *Figure 1*, it is clear that the gold sector is certainly important to the country's economy. It is no surprise therefore, that the sector is considered key in poverty alleviation efforts. The structure of the gold sector as reflected by the distribution of contribution by artisanal, small-scale and large-scale gold miners (LSGMs), shows that ASGM has become an important sector that requires attention. In view of this, it is worthwhile taking some time to understand the different players in the sector.

There are two important sources of definitions for the players in the mining sector, the Ministry of Mines and Mining Development (MMMD) and the Environmental Management Agency (EMA). The Mines and Minerals Act Amendment Bill, 2015, defines a small-scale miner as: an indigenous person employing not more than 50 people including contractors, on a registered mining location of not more than 40 hectares in extent, who produces and or processes not more than 1200 tonnes of ore per year.

Zimbabwe's Environmental Management Regulations (2014) define an artisanal miner as: a miner who carries out mining activities using simple tools and employs up to 50 people; these include Government-registered groups or syndicates or co-operatives.

It is generally accepted in Zimbabwe that the distinction between ASGM and LSGM (and further, between artisanal gold miners and small-scale gold miners) is based on the scale of operation and degree of mechanization. On the other hand, artisanal miners are understood to be unregistered and hence possess no property rights. While the sector used to be dominated by LSGM, ASGM contribution has increased significantly in recent years as shown in *Figure 1*. Gold mining contributes a significant share of 47% of the entire mining sector. The 47% is divided broadly into 26% LSGM and 21% ASGM. ASGM therefore, makes significant contribution to the growth and development of the Zimbabwean economy (Pact, 2017).

The significant share of ASGM on the total gold output is attributed to an increase in the number of players over the past two decades. The economic instability over the past two decades left limited employment opportunities in the formal sector; consequently, informal, artisanal and small-scale mining becoming increasingly important as an income source (Spiegel, 2015). *Table 1* shows a comparison between the contributions of ASGM and LSGM to Zimbabwe's economy as of 2016.

*Table 1. A comparison of the contribution between ASGM and LSGM in Zimbabwe (Pact, 2017).*

	<b>Artisanal and Small-scale Gold Mining</b>	<b>Large-Scale gold mining</b>	<b>Total gold mining</b>
<b>Production</b>	311,000 troy ounces	428,000 troy ounces	739,000 troy ounces
<b>% of GDP</b>	1.2%	1.4%	2.6%
<b>Royalty (% of government revenue)</b>	US\$3.8 million (0.24% of government revenue)	US\$11.8 million (0.76% of Government revenue)	US\$15.6 million (1% of government revenue)
<b>Employment</b>	500,000 (7% of labour force)	11,000 (0.1% of labour force)	7.1% of labour force
<b>Direct and indirect beneficiaries</b>	1 million	81 000	1.1 million

In a study by Pact (2017), in 2016, the gold mining sector as a whole (both ASGM and LSGM) contributed 2.6% of GDP, 18% of exports, 28% of mining output, 1% of Government revenues (royalties only) and employed 7.1% of the labour force. The ASGM share of the total gross domestic product (GDP) in Zimbabwe was 1.2% against a share of 1.4% by LSGM; an indication of ASGM's profound contribution to the economy.

The sector does not only bring about economic benefits but numerous challenges for the environment, as well as the society as a whole. ASGM is associated with environmental degradation, social ills, and poor health and safety records (Pact & The Institute for Sustainability Africa, 2017). Environmental pollution through mercury and cyanide, land degradation, river siltation, mine accidents and high prevalence of occupational diseases are among the common negative impacts of ASGM. A number of these problems can be connected to the use of inappropriate/unsustainable processing methods/practices.

Generally, in Zimbabwe many ASGM operators use basic tools for mining, ore handling and mineral processing, leading to low levels of productivity. Hentschel, *et al.*, (2003) argued that most problems associated with ASGM are technical and require technical solutions implemented in an integral approach. Appropriate technological interventions on ASGM operators can enhance the economic sustainability of such operations without compromising on their environmental sustainability. Closing this technological gap is one way of transforming ASGM operations into vibrant mining entities. The technical solutions have to be commensurate with the economic potential of the target group and need to be accompanied by education and training and be affordably replicable.

## **METHODOLOGY**

The study was guided by the following research questions:

1. What are the typical gold processing techniques used by ASGM operators in Zimbabwe?
2. What are the inadequacies of these technologies?
3. Are there any sustainable processing alternatives suitable for the ASGM sector?
4. What strategies can be implemented to ensure sustainable gold processing for the ASGM sector?

Qualitative methods, inclusive of desktop research were used to establish sustainable processing methods for the ASGM sector. Data used in the research was obtained from secondary sources which includes reports published by Pact Zimbabwe, Ministry of Mines and Mining Development (MMMD), Zimbabwe Miners Federation (ZMF), relevant academic publications, reports, articles and government publications. A field survey of the existing gold processing techniques in Gwanda Mining district of Matebeleland South Province was conducted. Processing methods and attention policies to rendering the ASGM sector more sustainable were proposed.

## **FINDINGS**

### **An Overview of Common Gold Processing Methods in the ASGM Sector in Zimbabwe**

Most small-scale miners do not have ore processing facilities and rely on custom millers for their ore processing. Custom milling plant in Zimbabwe is defined in the Statutory Instrument 329 of 2002 as any plant for processing or extraction of gold or gold bullion that is not operated exclusively for the benefit of an operator who mines the gold. In this set up, artisanal and small scale miners bring ores for milling and recovery of free gold for a fee and leave gravity concentration tailings for the mill operator to leach. Most custom millers use stamp mills, three or five stamps, in the recent years there has been a noticeable increase of other milling and grinding machinery. *Figure 2* shows a typical stamp mill used in the ASGM sector.



*Figure 2. Stamp mill in a Custom Milling operation*

Ores from ASGM operators are typically a few wheel barrows, averaging seven tonnes, and after every milling cycle the milling machinery has to be washed off any residual ore. The change-overs' frequency and procedure favours machinery that is easy and fast to clean up, this made stamp mills preferred machinery for custom millers. Stamp mills are however operated with a mesh size 16 for faster throughput and retention of gold in gravity concentration tailing for the benefit of the miller on leaching stage. There has been an advent of new equipment for custom milling in the past three years, these include hammer mills, Chilean roller mills, and amalgam barrels (used for milling). These machinery not only offer the fast and easy cleaning change-overs but are less capital intensive on purchase. On average a stamp mill cost around US\$35000 to purchase while hammer mill is US\$2500, Chilean roller mill US\$8000 and amalgam barrel US\$2000. This equipment offer a finer product at a faster milling rate than stamp mill and artisanal miners are preferring them. The gravity concentration process is similar to those used on stamp mills. Figure 3 shows the setup of a typical diesel powered hammer mill connected to a gravity concentrator.



*Figure 3. Setup of a typical diesel-powered hammer mill connected to a gravity concentrator for ASGM operations.*

At custom milling plants artisanal miners recover free gold using either cloth lined sluices, centrifugal concentration bowls, or mercury smeared copper plates. For the later, the gold-mercury amalgam is removed by rubber plates from the copper plate. For sluices and centrifugal concentrator a gold concentrate, with a concentration ratio averaging 25 is obtained. The concentrate is hand mixed with mercury for amalgamation in small plastic dishes as shown in *Figure 4*. The amalgamation process normally takes 5 to 6 hours for every 7 tonnes of ore processed. These processes expose artisanal miners to skin contact with mercury which is a health risk to them directly. Disposal of the water used on amalgamation releases mercury to the environment.



*Figure 4. Hand mixing of gold concentrate with mercury for amalgamation.*

The produced amalgam is heated to evaporate the mercury. This process is done in open air, releasing the mercury vapour into the atmosphere. The obtained sponge gold is smelted and sold with purity estimated from its specific gravity. Statutory Instrument (S.I.) 329 of 2002 has set conditions for use of a retort to recycle mercury, however very few plants have the retorts. Generally, a great majority of miners in the region do not use retorts, as they claim that the process is time consuming as they use low-temperature bonfires.

Most of the gold is left in the primary tailings and the custom miller leaches these tailings from the gravity concentration to recover the remaining gold. Most custom millers use NaCN vat leach tanks, with a subsequent carbon adsorption circuit. However, miners receive no compensation for the extra gold extracted by cyanidation. *Figure 5* shows the set-up of a vat leach tank typical of ASGM operations.



*Figure 5. Vat leach tank for gold recovery from tailings in ASGM operations.*

The leaching cycles averages three days. The pregnant solution is drained and passed through activated carbons. The batch cycle is repeated until the activated carbon is fully loaded. The leaching tanks used are open posing a danger of possible poisoning of the fauna. It is very common to find dead frogs and birds in and around the cyanide return tanks. During the rainy season there is possible overflow into natural water channels of the cyanide solution in leach tanks. In 2015 the Zimbabwean Environmental Management Authority made it mandatory for millers to line tailings dumps to prevent seepage of heavy metals into the underground water. As such, tests are conducted regularly through boreholes to monitor possible contamination of underground water.

Activated carbon is used for the adsorption process because it has the following properties: highly developed internal pore structure; narrow mean size particle size distribution; high adsorptive capacity and adsorption rate; good mechanical strength; wear resistance; reactivation characteristics and low cost and readily available. *Figure 6* shows an adsorption circuit which consists of drums loaded with activated carbon and pregnant leach solution in ASGM operations.



*Figure 6. Adsorption circuit consisting of drums loaded with activated carbon and pregnant leach solution.*

After completion of adsorption process, the loaded carbon is then eluted at toll elution plants, which uses the Zadra process to recover gold from the activated carbon.

### **Key Issues Associated With Common Gold Processing Methods in the ASGM Sector**

ASGM makes noteworthy contributions to both economic growth and economic development, however, the gold processing techniques exhibit the following key issues:

- Poor recoveries: Lack of gold liberation is an evident problem when using stamp mills and this is the main reason why miners recover less than 30% of the total gold by gravity separation followed by amalgamation.
- Poor economic returns for miners: Due to low efficiencies, most of the gold is left in the primary tailings and the millers apply vat-cyanidation to extract the remaining gold. Miners receive no compensation for the extra gold extracted through cyanidation and this is a clear indication that miners are disadvantaged of their extra potential revenue.
- Environmental degradation: The use of inefficient technology and limited processing techniques in ASGM operations cause severe environmental impacts. For example, the disposal of water used for amalgamation releases mercury to the environment and happens to be problematic in ASGM processing operations.
- Occupational health and safety: The ASGM operators are exposed to skin contact with mercury which is a direct health risk.

Field data reflects that most of the issues associated with gold processing in ASGM sector can be attributed to lack of technical and environmental knowledge, education and training. For instance, in ASGM operations ore head grades are not known to ascertain recoveries. Further, some miners believe that adding more cyanide increases the gold dissolution kinetics. However, the chemistry of gold

extraction reveals that more cyanide is only effective when there is an excess oxidising agent that results in the formation of cyanate, which is not as efficient in leaching gold as cyanide (Santos, 2013).

### Proposed Processing Methods for ASGM in Zimbabwe

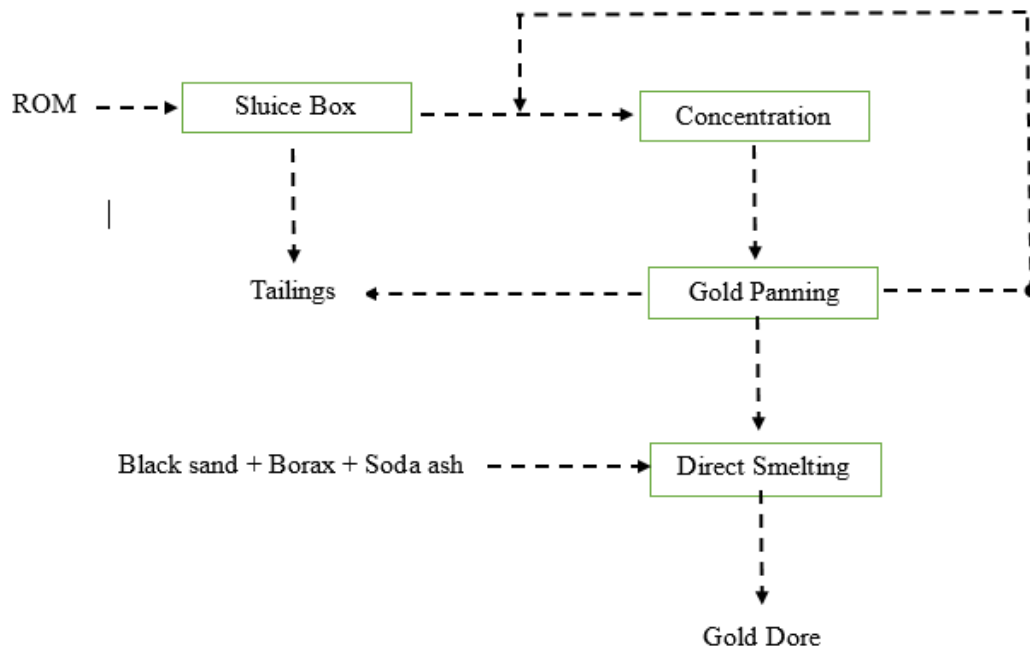
ASGM in Zimbabwe has great potential for growth and the technical solutions proffered to the sector are commensurate with the economic potential of the sector. In order to organize the rationale behind the decision on selection of processing methods, some criteria were followed:

- ✓ Must be easily accessible
- ✓ Must not be very complex
- ✓ Must be in-expensive and use locally available raw materials.

The proposed methods are methods which have been developed with a view to improving ore recovery in gold processing as well as to eliminate the environmental hazards associated with the use of mercury. A few processing methods meet that criteria, i.e., the direct smelting method and the Igoli processing technology and as such these were recommended for deployment.

#### *The Direct Smelting Method*

The direct smelting method is a safer process which was developed to eliminate the negative environmental/health-related effects of mercury which has been used extensively in small-scale mining communities to amalgamate gold particles facilitating their separation from sands. *Figure 7* and *Figure 8* show the processing flow sheets for the direct smelting method for free (alluvial) gold and hard rock deposits.



*Figure 7. Direct smelting process for alluvial gold deposits.*

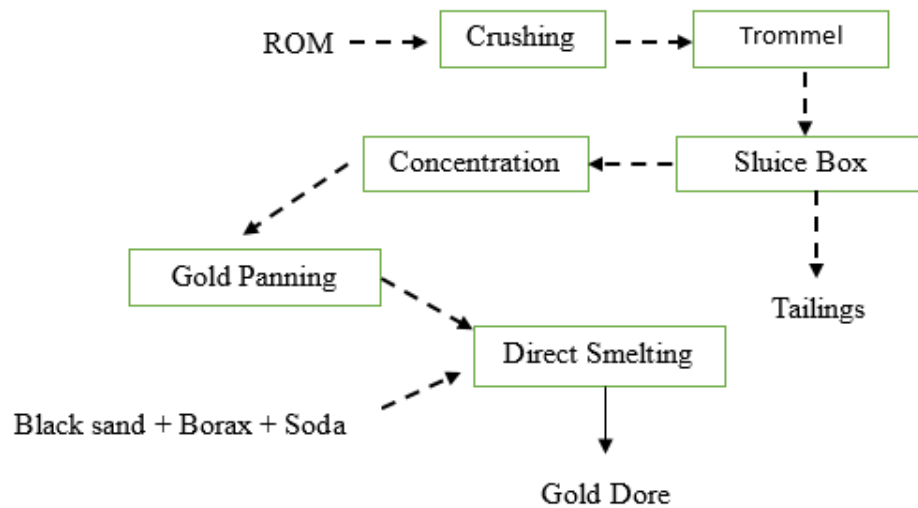


Figure 8. Direct smelting process for hard rock deposits.

In direct smelting method, a mixture of black sand containing gold, borax and soda ash, is melted by heating the mixture in a charcoal or gas fired smelter. Borax and soda serve the purposes of respectively lowering the melting point of the solution and helping the material to flow easily after heating (Salati, et al., 2016). A study by Amankwah, et al., (2010) on the application of direct smelting of gold concentrates as an alternative to mercury amalgamation showed that the direct smelting methods yields 99.8% recoveries against 97% recoveries for amalgamation.

#### The Igoli Processing Method

Figure 9 shows the process flowsheet of the proposed Igoli method, which was developed by Mintek South Africa.

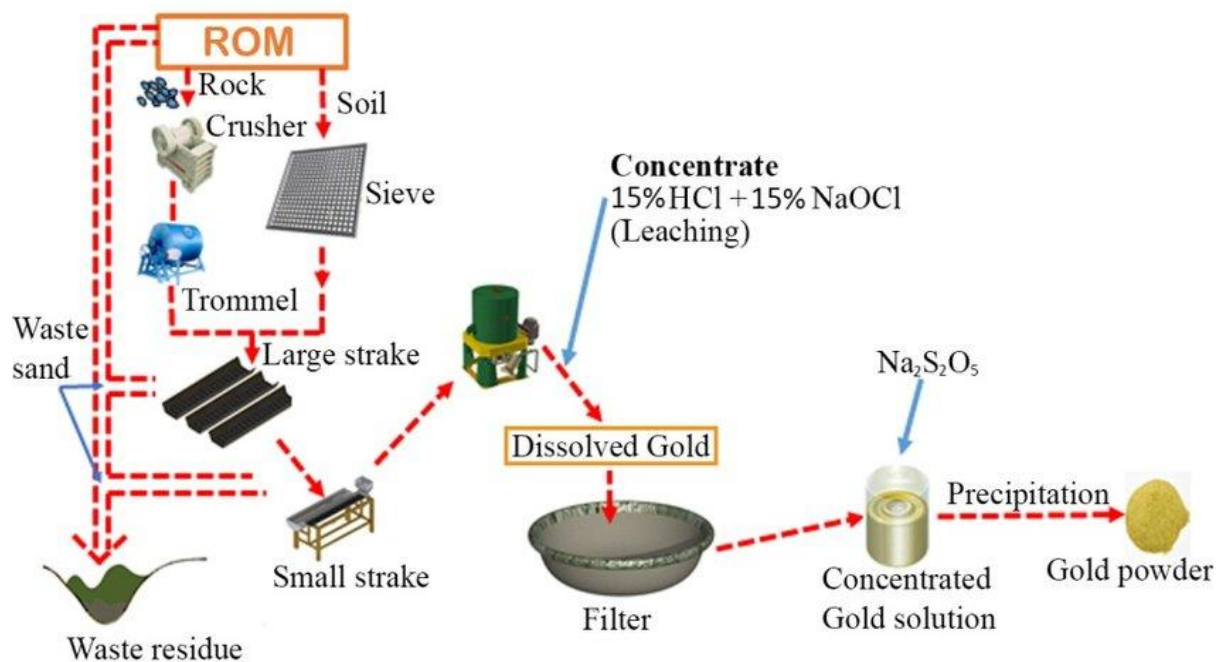


Figure 9. Processing Flowsheet of Igoli Technology (Salati, et al., 2016).

The Igoli process consist of leaching the gold concentrates with dilute hydrochloric acid and bleach (aka sodium hypochlorite ( $\text{NaOCl}$ )) to obtain a pregnant leach solution. The solution is filtered and sodium meta-bisulphite ( $\text{Na}_2\text{S}_2\text{O}_5$ ) added to the filtrate to precipitate gold as gold powder. The Igoli process has the following advantages:

- ✓ The process has high gold recoveries and produces very pure gold up to 99% which can be easily valued and sold;
- ✓ Most of the residue to be discarded contain a very high percentage of silica which is environmentally friendly;
- ✓ The liquid effluent is neutralised and gases released from the process can be minimised or controlled.

The Igoli process is highly suitable for groups of artisanal miners and is proposed for use in the ASGM sector in Zimbabwe.

Most operators in the ASGM sector in Zimbabwe operate under marginal economic conditions, providing no more than a daily living and as such, the proposed processing methods have better recoveries compared to the common processing techniques, thus offering better economic returns for the operators. They are also environmentally friendly as they eliminate various environmental hazards and health risks associated with the use of mercury. However, deployment of the processing methods remains a challenge in the ASGM sector and as such, ways of deploying such integrated and pragmatic interventions to the sector are proposed.

#### **Ways of Deploying The Proposed Methods: Strategies for sustainability**

The proposed methods are meant to ensure sustainable and environmentally friendly ASGM operations in Zimbabwe. Sustainable development has three overarching goals (Shields & Solar, 2005):

- Economic prosperity
- Environmental health
- Social equity for present and future generations

ASGM operations in Zimbabwe have relatively low recoveries and productivity per unit operation, low safety, environmental and health risks and as such the application of proposed processing methods requires efficient and effective instruments to ensure sustainability in the sector. Sustainable processing will go a long way in promoting income growth and poverty alleviation for the ASGM sector and the following strategies are recommended:

1. Education and training are key strategies to improve processing sustainability in the ASGM sector. Implementing technical change requires detailed knowledge of the proffered solutions/methods. Zimbabwe have quite a number of universities and institutions offering mining and processing programmes, with staff capable of finding practical solutions for the ASGM operations. These institutions should take a leading role in the education, training, co-ordination and research for appropriate technology in the processing and handling of environmental problems concerning ASGM operations.
2. Large Scale Gold Mining (LSGM) companies are highly encouraged to support ASGM operations in training and offer required services as part of their corporate social responsibility. Most ASGM operators are located closer to LSGM operations, and as such LSGM are encouraged to improve communication and assistance in educating and training ASGMs to foster good relationships in cohabitation. In ASGM operations, as with any other conventional ore processing, is subject to design problems, variability of ores and engineering problems. As a conventional processing plant relies on studies and characteristics of their ore, an ASGM operation would also benefit from these services.

3. ASGM operators face serious challenges in obtaining access to credit and formal banking, as they are considered to be too risky. As such, the ASGM operators lack capital to acquire improved tools and equipment for processing their ores. The government of Zimbabwe is encouraged to create a special fund to assist the operators in acquiring improved processing facilities. Non-governmental agencies (NGOs) supporting the sector should create funds available for prospective operators and are encouraged to dialogue and offer pragmatic solutions to ensure sustainable development in the ASGM sector of the Zimbabwean economy.

## CONCLUSIONS

The deployment and use of the proposed methods for the ASGM sector in Zimbabwe will significantly improve productivity and reduce impact of operations to the environment and enable operators to standardize their operations to levels in tandem with best global gold processing practices. ASGM operations in Zimbabwe have relatively low recoveries and productivity per unit operation, low safety, environmental and health risks and as such the application of proposed Direct smelting method and the Igoli processing method requires efficient and effective instruments to ensure sustainability in the sector. In view of this, technical solutions proffered are commensurate with the economic potential of the ASGM sector in Zimbabwe and need to be accompanied by education and training and be affordably replicable. ASGM operators are highly encouraged to partner LSGM and benefit from technology transfer as part of their capacity building. Fundamentally, the ASGM sector in Zimbabwe has the potential to alleviate poverty and be a tool for sustainable development and as such the strategies for sustainable processing will go a long way in promoting income growth and poverty alleviation for the sector.

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