A Geoeconomic Planning and Evaluation Model for Artisanal Small-Scale Gold Mining in Ghana*

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Abstract

Following calls for comprehensive National Action Plans (NAPs) that outline training programmes for the handling of mercury and strategies for reducing emissions from artisanal and small-scale gold mining (ASGM) under the Minamata Convention, other follow-up calls intensified the need for the formalisation or regulation of ASGM in the sector. Aside from the precarious emission of mercury and hazards to the environment, the ASGM sector resorts to unsafe methods for exploiting minerals due to inadequate funding. It is not surprising that anti-mining groups constantly advocate against mining in general as a result of the harm unprofessional ASGM operators expose man and the environment to. In this light, several studies have been conducted to propose safe techniques of exploiting minerals by ASGM operators and the need for governments to regulate the sector through legal instruments. Unfortunately, the problems of ASGM seem to linger on. Notwithstanding, much attention has not been given to the formulation of procedures for accurate resource estimation and subsequent feasibility studies of ASGM, which could probably be a major cause of ASGM challenges. This study proposes Inverse Distance Weighting (IDW) technique for estimating the concentration of alluvium gold. The IDW method was successfully applied to the alluvial deposit of the Mpeasem Gold Project, and practical results were obtained for economic evaluations. The total volume of alluvial gold deposits was 3.4 Mm^3 at an average grade of 0.46 g/m^3. Economic evaluation yielded a net present value (NPV) and internal rate of return (IRR) of USD 2.8 M and 48%, respectively. The results indicate that reasonable data from outcrop sampling, pitting and trenching, and detailed cost estimates can present a more compelling case for funding. This way, the funding inadequacies which contribute to the use of shortcuts and unsafe tools, materials, and methods can be minimised.

Keywords: Artisanal Small-Scale Mining, Reserve, Exploration, Mine Economic Evaluation, Cashflow

1 Introduction

It is a fact that artisanal and small-scale mining (ASGM) is second to agriculture in terms of job creation potential in Ghana (Eshun and Okyere, 2017). Unfortunately, the impact of ASGM is limited by illegality, environmental damage and revenue leakages. After several recommendations were made following the Minamata Convention, all aimed at providing alternative processing reagents and minimising the impact of ASGM (Evers *et al*. 2016), the problem seems to persist across most African countries and, for that matter, Ghana. Nonetheless, ASGM continues to make substantial contributions to the total gold production in the mining industry and livelihood, especially in Ghana. According to Eshun and Okyere (2017), in 1989, ASGM accounted for only 2.2% of Ghana's gold production. By 2016, that figure had risen to 31%. After a year in 2016, Ghana's economy improved significantly, mainly driven by a strong performance of the extractive industries. During the first half of 2018, all minerals except bauxite witnessed a significant increase in production compared to 2017. Gold production rose from 2 157 148.54 ounces in the first half of 2017 to 2 452 011.67 ounces in 2018, representing a 13.67% increase. This contribution appears to be significant but could have been more if ASGM owners were to conduct a feasibility study that could have quantified the mineable gold reserve and therefore assisted in planning increased production. Unfortunately, most ASGM owners do not carry out feasibility studies or economic analyses which could have determined the quantities of mineable gold reserves and the viability of intended projects. Such feasibility studies could also be a solid base for securing funding from credible financial institutions.

The assertion that political clemency and law enforcement corruption has resulted in an uncontrolled small-scale gold system under poor government control with concomitant environmental and safety concerns (Teschner, 2012) also finds its roots in inadequate or no reserve estimation, evaluation and planning. Even though the Minerals and Mining (Licensing) Regulations, 2002 (L. I. 2176) section 258 (1) (b) provides for the delineation of ASGM areas in the country by the Minerals Commission where the Commission has done some exploration work, this exploration work is not sufficient without the estimation of the resource available in terms of quantity and quality in a resource model. To perform professionally and profitably, ASGM operators must be adequately funded based on sufficient feasibility studies, planning and design, processing flow sheets, environmental impact assessment, reIsource estimation and economic evaluation reports. n this paper, the Inverse Distance Weighting (IDW) is explored to conduct feasibility studies of ASGM projects in alluvial deposits while addressing their specific features as a strategy to test economic

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viability to attract funding. The IDW interpolation approach assigns weights to sample points, such that the influence of one point on another reduces with.

distance from the new point being estimated. It is simple but efficient and easy to understand.

1.1 Relevant Information about Study Area

1.1.1 Location and Mineralisation of the Mpeasem Gold Project

The Mpeasem gold concession of Seafor Mining Company (Gh) Limited (SMCL) measures approximately 52.63 km^2. It is bounded by latitudes 6°20'N and 6°15'N and longitudes 2°05'W and 2°00'W. The concession lies within the Upper Denkyira District in the Central Region and the Amansie West District in the Ashanti Region of Ghana (Fig. 1). A small portion of the concession is at Nkronua in the Bibiani District in the Western Region of Ghana

The measured alluvium gold reserves of the concession constitute about 3 403 750 m^3 at an average grade of 0.46 g/m^{3,} which is translatable to 1 330 866g gold content.

2 Resources and Methods Used

2.1 Materials

In this paper, the mineral reserves of the Mpeasem Gold Project have been investigated using the IDW approach and the economic potential evaluated. Secondary data from MGP used by Mireku-Gyimah (1996) comprising the mineral reserves, annual production estimates, capital and operating costs of the Mpeasem Gold Project were used. The mining regulations governing the mineral investment sector in Ghana were applied to investigate the economic viability of the Mpeasem Gold Project.

2.2 Methods

2.2.1 Mineral Resource Estimation

A mineral resource could be defined as a concentration or occurrence of natural, solid, inorganic, or fossilised organic material in or on the earth's crust in such form and quantity and of such a grade or quality that it has reasonable prospects for economic extraction. The steps involved in estimating the resource of a sample include:

(i) Defining the mineralisation constraints or geological domains;
(ii) Statistical analysis of the sample data; and
(iii) Application of a suitable grade interpolation technique.

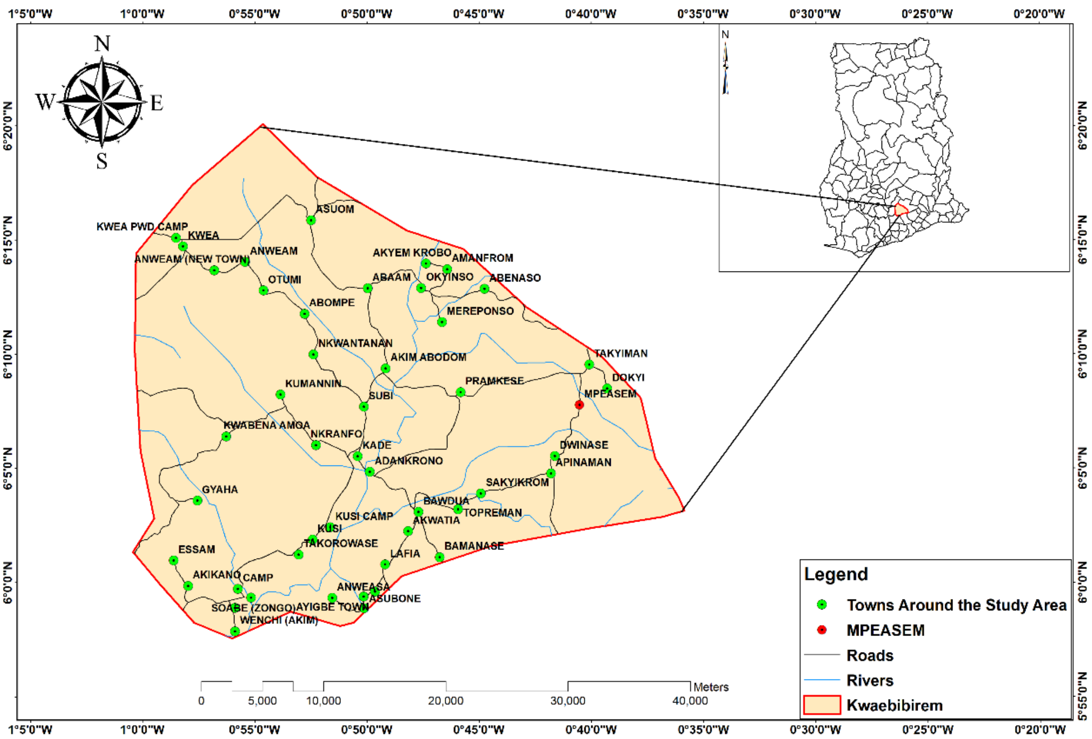

Fig. 1 Map of Ghana showing Location of Concession

Geological Domains

A domain represents an area or volume within which the mineralisation characteristics are more similar than outside the domain. In weathered gold deposits, geological units are mostly the same as the mineralisation domains. This makes the grade model truly reflect the geology as it is entirely constrained by geological modelling. There could also be structurally controlled mineralisation like shear hosted gold deposits.

Statistical Analysis of Sample Data

Statistical analysis helps to understand the behaviour of grades at the domain boundaries. Statistical analysis reveals trends, correlations, and outliers where several variables of interest exist. The numerical characteristic of the mineralisation helps with the choice of grade interpolation and informs about the need or not for special treatments like grade cutting. For the purposes of data analysis, samples should be of equal volume, which is done by composting samples into equal lengths (Glacken and Snowden, 2001).

Interpolation Techniques

Grade interpolation techniques are deployed to estimate grade in between channel information with the assumption that there is some degree of continuity of the mineralisation from one channel to another. There are the conventional or classical methods and the geostatistical methods (used in large scale mining). Also affecting interpolation techniques is the empirical reasoning or generalisation method adopted based on experience and opinion. A typical example is adopting a definite weight factor for reserve computations from other similar mineral deposits. Projecting continuity of a mineral body beyond the outlying workings along the strike or at depth and fixing cut-off boundaries for computations are examples of the generalisation method.

The nature of the deposit can drive the interpolation technique, whether stock type or bedded; the exploration type, whether by grid random or cross-section lines; the required degree of accuracy and the geology (Popoff, 1966). The reasoning used to interpret variables between any two adjacent observations in a mineral body determines the block construction and the accuracy of computations. The reasoning is hinged on rules of nearest points and gradual changes.

The concept of the nearest points is that all factors determined for a certain point of a mineral body extend half the distance to adjoining and surrounding points, thus forming an area of influence. An example is the polygon method of interpolation. It is simple, quick, and inexpensive in checking the unbiasedness of a sophisticated resource model. It, however, requires a higher degree of selective mining, which may not be practical and therefore lends itself to overestimation (Al-Hassan, 2016).

The concept of the rule of gradual changes is that all elements of a mineral body that can be expressed numerically change gradually and continuously along a straight line connecting two adjoining points. An example is the Inverse Square Distance of interpolation. In all methods of reserve computations, the principle of weighting is applied to individual blocks of different sizes to determine the average thickness and grade of the entire deposit. Allocations of weights are made in length, area, volume, and tonnage units. The cross-sectional area can generally be likened to an established polygon; the volume is calculated as a cross-sectional area multiplied by the height.

The geologic and economic factors that influence the interpolation technique are the presence of geological faults, the stripping ratios, the water level, the mining and extraction methods, and the cost of extraction.

Inverse Distance Methods

The method is based on the distance of the samples from the centroid of the block. The common ones include Inverse Distance, Inverse Square Distance and Inverse Cube Distance (Idrus, 2016). Equation (1) is the general formula of the Inverse Square Distance Weighting method.

$$g_{av} = \frac{\sum_i^n g_i d_i^{-r}}{\sum_i^n d_i^{-r}} \quad (1)$$

where*:*

d is the distance from point i to the centroid;
g is the grade of point i of weight;
g_{av} is the average grade of the block; and
r is the power to which the inverse of the distance is raised.

Sampling

The basis in all geological evaluation work is the sample. Within the acceptable limit of error, the sampling concept determines certain properties of an entire population by measuring only a small portion of that population (Gentry and O'Neil, 1984). Therefore, sample collection is crucial, ensuring that errors or contamination are avoided as much as possible. Outcrop sampling, trenching, pit sampling, and various drilling techniques are deployed to obtain samples that are evaluated to determine the representativeness of the entire deposit. Outcrop sampling, trenching and pitting are usually considered for ASGM operations as against drilling because of the capital intensiveness and the degree of sophistication involved in the latter. Essentially, near-surface mineralisation is also the target compared to deep-seated ones.

Initial reconnaissance work through geophysical and geochemical studies, notably airborne geophysics and lake sediment geochemistry, are leading indicators for further exploratory work. Geobotany and geobiochemistry are also used to predict the presence of minerals. The presence, absence or condition of a particular plant or species can indicate the presence of mineralisation or a particular rock type; this is referred to as geobotany. Geobiochemistry is the measurement and study of the elemental content of a plant. The enrichment of carbon dioxide and depletion of oxygen caused by weathering of sulphide deposits are examples (Moon *et al.*, 2006).

Pitting

This involves manually digging to a depth of 3 - 4 m or using mechanical excavators for sampling. The method is convenient for alluvial deposits. It is safer in lateritic soils, but dugouts beyond 1 m could pose a danger in soft ground. Two (2) labourers digging at a rate of 2 m per day can advance 1 m to 2 m conveniently using local tools. The same dimensions can be worked with an excavator within an hour. Fig. 2A and B are exploration pits dug mechanically and manually, respectively.

Fig. 2 Exploration Pits

Trenching

Digging at right angles to the general strike to test and sample over long lengths across a mineralised zone characterises trenching. Trenching up to 4 m depth of 1 m^2 size can be completed manually or mechanically with excavators. Usually, a dozer is preferred along a slope for convenience and safety. Fig. 3 is an exploration trench.

Fig. 3 Exploration Trench

2.2.2 Exploring Alluvial Deposits

Mining Methods

Whilst the style of mineralisation and competence of the rock mass are key influences in deciding surface and underground operations respectively (Carter, 2011), ASGM operations could be grouped depending on the type of deposit (Table 1). Among other considerations for all operations are the available finances and the equipment type to be used.

Table 1 Deposit Type and Mining Method

Type of Deposit	Mining Method
Alluvial	Strip mining
Weathered Gold (laterites and oxides)	Terrace mining
Hard Rock (Auriferous lodes and quartz veins), depth less or equal to 15 m	Shallow open pit
Hard Rock (Auriferous lodes and quartz veins), in hilly terrains or flat plains, depth greater or equal to 15 m but less than 50 m	Underground (adit or vertical shaft opening)

The alluvial mining method involves the extraction of loose and unconsolidated mineral deposits. Alluvial mineral deposits are generally minerals contained in alluvium resulting from the action of water and found on riverbeds, river banks and old river beds. Minerals here include beach sands, nodules of manganese, gold.

Strip Mining

This is used for alluvial deposits located on flat, dry areas and is popularly called “dig and wash”. Strip mining is a responsible mining method that deploys six mining sequences and therefore necessitates the demarcation of the area being mined into six blocks. The method allows for concurrent rehabilitation of flora and fauna of the area mined. The sequences are illustrated in Fig. 4.

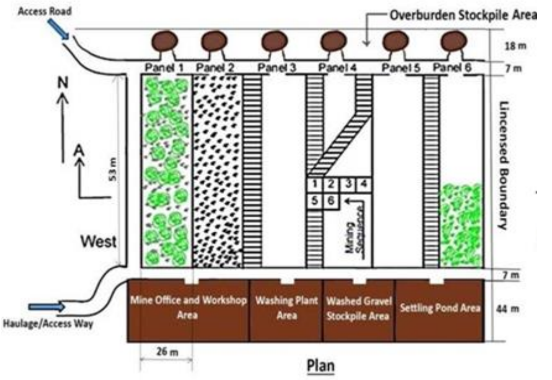

Fig. 4 Strip Mining Method (Source: Mireku-Gyimah and Tsidzi, 1996)

The method involves an initial heavy mineral panning of stream sediments, after which a series of hand-dug pits would have to be sunk through the overburden and gravel layers to the top of the weathered bedrock. The steps include the following:

(i) Survey and cut a baseline parallel to the stream with predetermined equal interval crosslines along the base. Place pegs at smaller equal intervals within the crosslines;
(ii) Survey and dig square-meter pits to the bedrock at the pegged positions using local tools and fetch any water inflows with buckets or a paddy pump. The pits must be identified by unique numbers;
(iii) At 0.5 m depth intervals, scoop out gravels using a shovel and a bucket tied to a rope;
(iv) Once the bedrock has been reached, another sample is taken at 30 cm into bedrock to check for gold that may have migrated downwards;
(v) Pile up individual 0.5 m samples separately on tarpaulins around the perimeter of the pit collar;
(vi) Wash each 0.5 m^3 sample with wooden sluice boxes lined with Astroturf matting or jute sacks;
(vii) Remove the lining material to recover the concentrates in every 0.5 m^3 and pan in a washing bowl to recover free gold; and
(viii) The free gold is then weighed and expressed in terms of the volume of the material.

Mine Economic Analysis

The economic analysis involves evaluating the relative merits of investment options using costs, revenue and profits. Revenue is computed as a product of tonnes of ore mined, grade, mill recovery and gold price expressed as a percentage of ore loss and dilution. Costs in open pit mines are generally categorised into capital costs, operating costs and general and administrative costs. Capital cost is the money required to bring a mining property into production. The costs are recovered annually over a period by deductions from revenue before a taxable income is reached. The fixed portion of capital costs is required for primary equipment and infrastructure/facilities. The Working Capital portion is required to begin the operation and meet subsequent obligations during startup. The operating cost is the cost required for the day-to-day running of the mining operations. It is generally divided into direct or indirect, variable or fixed and general or overhead costs. The direct costs are generally linked to the production rate, while indirect costs do not vary directly with product throughput.

General and administration costs comprise management, supervision and labour; office items and stationery; general consultancy and miscellaneous costs. Allocations are made for annual operating fees, ground rent and corporate social responsibility costs. Here, provision is also made for Health Safety and Environment (HSE) officers, cleaners, security men and an accounts officer.

There are several approaches to estimating these cost items. These include proration of historical estimated or actual cost (O'Hara, 1980), factored estimates based on the (sometimes installed) equipment cost, unit cost method, the turnover ratio method, cost ratio method, component cost ratio method, conference method, module method, cost indices, similar project method and detailed cost estimates.

Detailed Cost Estimates

This is the most accurate cost estimation method, and it is proposed to estimate ASGM operations. Usually, exact specifications including layouts, engineering drawings, flow sheets of equipment and other infrastructure are developed to the stage that suppliers can give either budget or actual quotations. Labour hours are based on previous experience, and costs are usually at unit (all-in) rates. This estimate is, however, laborious and, therefore, time-consuming.

Revenue Estimation

It is essential to estimate the revenues to help establish the profitability of the project. The challenge in estimating revenues is uncertainty in the future prices of the gold and whether it will indeed be produced in the predicted quantities and times. Allen (1986) suggested that a mineral project should at least be able to break even at the lowest

predicted price regime. Even though it is possible to have arrangements for guaranteed future prices, eventually, it would come to the reality of demand and supply influences on price.
The annual mine revenue (R) may be estimated as:

$$R=T\left[1+\left(\frac{D-L}{100}\right)\right]G\times r\times P \qquad (2)$$

where:
T = tonnage of ore produced per year t/yr)
G = mill head grade (g/t)
r = mill recovery (in decimal) P = unit price of processed ore ($/g)
L = Ore loss (%)
D = Ore dilution (%)

The annual tonnage is determined by dividing the mineral reserve in tonnes by mine life.

Mill Recovery

This depends on the efficiency of the plant and the chemical composition of the product. To arrive at this percentage, significant test work would have been done with ore samples obtained during the exploration stage. In general, ASGM operations can recover between 60% and 80% of the alluvial gold compared to more efficient mills of large-scale operations with 80% to 95%.

Dilution and Ore Losses

The mining practice would always introduce some amount of waste into ore during blasting and mucking, which must be accounted for. Moreover, not all the ore could be mined and transported to the processing plant due to spillages in material handling, blasting, losses due to wall failures.

Metal Price

Information on gold prices in Ghana can be obtained from the Precious Mineral Marketing Company (PMMC) and shops in mining communities that have been licensed to trade in gold. It is always good to use a more conservative price as a precautionary measure in the planning and economic evaluation.

3 Results and Discussion

Geology Database

The data include Test Pit Number (Identity), Collar Information (Eastings, Northings and Elevation), Area of Test Pit, Depth of Test Pit, Remarks (soil description) and the Assay (Au value).

Results of Inverse Distance Weighting

The inverse distance weighting (IDW) method was used to estimate the alluvial ore deposit. A boundary string was digitised around the data points in graphics and used as the extents to create an empty block model. A string file was created from the original data to include String Number, XYZ of the data points, Grade and Soil Description.

The grade data distribution was analysed to determine the presence of outliers that would warrant top-cutting (placing an upper cut-off on the grade) not to skew the estimation. Au (grade) and Soil Type attributes were added to the empty model. A solid was formed using the hole collars as the top surface, and the bottom surface was obtained by projecting the top to the depth of the pits.

The IDW tool in the Geovia software allows for the string file of the sample points to be imported into the empty model filtering off the Au and Soil Type and constraining the entire data in the solid created. Search parameters were set on sample radius and vertical distance for the estimation process, as shown in Fig. 5.

The minimum and a maximum number of samples were arbitrary, and the consideration was only to avoid excessive computer memory work. It is assumed that the estimation would not be significantly influenced by the number of samples chosen with such homogeneous data.

Using the Geovia Surpac software, the resource of the alluvial deposit was reported after being constrained in the estimation solid. The reserve was obtained after the application of mining dilution and ore loss. Table 2 is the alluvial deposit reserve estimate calculated, using a cut-off of 0.2 g/m^3.

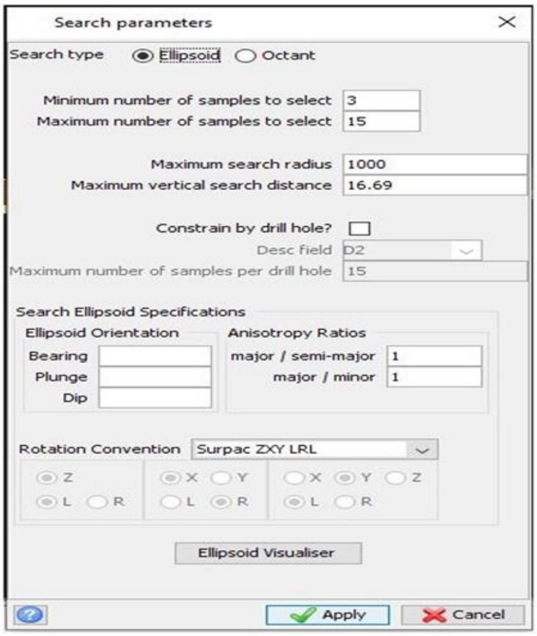

Fig. 5 Search Parameters

Proposed Mining and Processing Methods

The mining method employed is strip mining, as the mining area is a low-lying area. The mining area is divided into panels and the sequence from one panel to another include vegetation removal, stripping of topsoil, mining out, backfilling the mined-out area and vegetating the backfilled area.

Table 2 Alluvial Reserve Estimate

Volume (m^3)	Grade (g/m^3)	Grammes
3,403,750	0.46	1 330 866

The material is processed by feeding into a vibratory feeder through a hopper, allowing the undersize material of less than 120 mm to be transferred into a sizing trommel from where the undersize enters a centrifugal concentrator. Further sizing is achieved using a sluice box and a shaking table, and finally, concentrate is smelted directly using borax as flux. Fig. 6 is the proposed processing flowsheet

Rehabilitation

The mining method deployed has the advantage of concurrent rehabilitation as part of the mining sequence. Topsoil is stripped and stockpiled at a height not exceeding 2 m during the land preparation. The mined-out area is backfilled with tails produced from the washing plant and sand from the settlement pond with the tails at the bottom and the sand on top.

A 10 cm layer of topsoil is spread on the fill material, after which grass or native plants are planted to facilitate revegetation. The primary mining equipment that can be used is a Shantui SE 240 excavator or a CAT 325 equivalent operating Sinotruck highway dump trucks. Two (2) shifts a day was planned for 10 hours per shift for load and haul operations while the process plant was fed continuously. The project was estimated to have a life of 62 months; the last year is mainly for processing stockpile material as mining would have completed. Mining produced 871 416 m^3 of material per annum while the processing plant treated 620 953 m^3 per annum. Table 3 is a summary of the assumptions of the mining capacity used.

Summary of Operating and Capital Cost

This has been grouped into mining, processing and general and administrative costs. Table 4 summarises the estimated operating cost for the alluvial deposit.

The open pit costs were driven by equipment hiring costs for load and haul. The additional costs included rehabilitation and running costs for the light vehicles for supervision. Mining cost also captures grade control, survey, pumping, and ancillary services. Table 5 is a summary of the equipment hiring costs. The capital cost is captured preproduction, mining and processing capital and general site infrastructure Tables 6a and 6b summarises estimated capital cost.

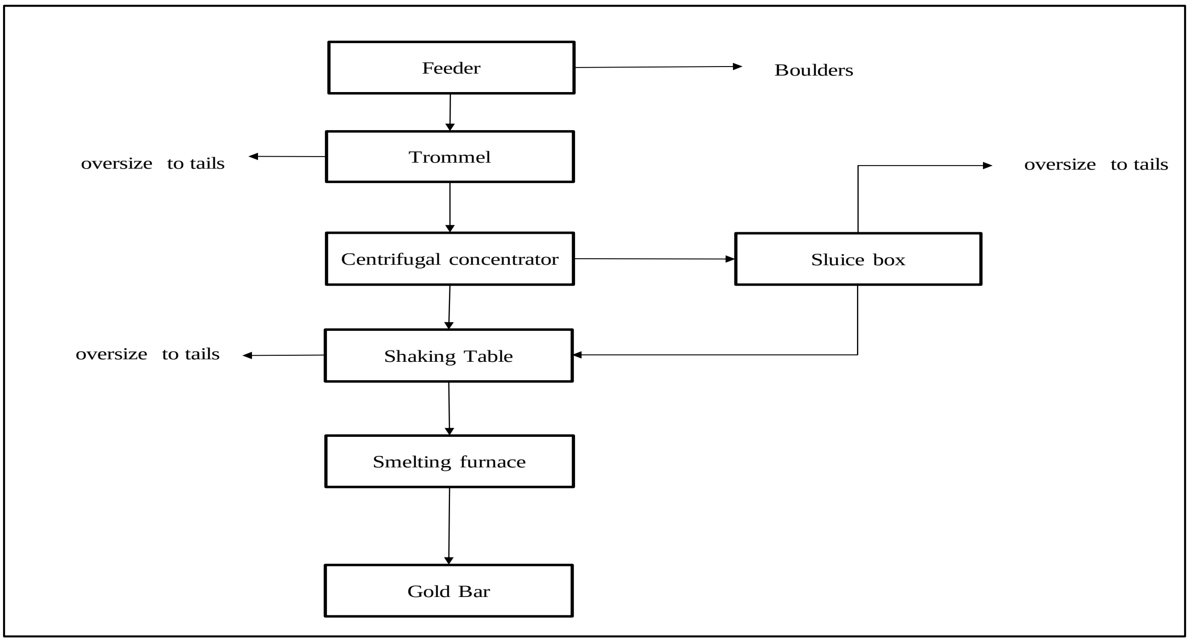

Fig. 6 Alluvial Deposit Proposed Flow Sheet

Table 3 Mining Capacity and Assumptions Alluvial Deposit

Equipment	Value	Unit	Comments
Excavator Bucket Capacity	1.20	m^3	Shantui SE 240
Bucket Cycle Time	0.35	min	
Truck Capacity	19.60	m^3	Sinotruck CNHTC SWZ10
Excavator Bucket Pass	16.33	-	
Excavator Loading Time	5.72	min	
Truck Cycle Time	15.00	min	Assumed
No. of Trucks per Excavator	2.62	-	
Scheduled Hours/Shift	10.00	-	Assumed 2hrs shift change - Equipment refuelling, etc
Number of Shifts/Day	2.00	-	Day and Night Operations
Equipments Availability	0.90	-	
Use of Availability	0.95	-	
Number of Loads/Hour	10.00	-	
Production/Hour	196.00	m^3	
Effective Working Time/Day	17.10	hour	
Production/Day	3351.60	m^3	
Production/Week	16758.00	m^3	Mining shut down and maintenance on Saturdays and Sundays - Outsource maintenance
Production/Year	871 416.00	m^3	Assumed 52 weeks flat in a year
Process Treatment/Year	620 953.04	m^3	02 x 52.2 m^3/h trommel, continuous operations. 1 day shut dowm maintenance per month. (120 t/h capacity considered)

Table 4 Summary of Estimated Operating Cost

Cost Centre (OCA)	**Units**	**Cost/Unit (USD)**	**Amount (USD)**	**Remarks**
OCA1 MINING COSTS				
Equipment	1		4,902,290	All inclusive hiring cost
Contractor's Fixed Fees	1		125,000	Survey/pumping service, etc.
Owners Vehicles (km)	37,440	0.80	29,952	Running Cost at USD 0.8 per Km
Subtotal			**5,057,242**	
OCA2 TREATMENT COSTS				
Maintenance			394,259	15 % of purchase value
Fuel (l)	637,942	1	650,700	75 l/h for genset
Flux (Borax) (g)	8,352	0.22	1,840	$ 100 per 454 g
Rehabilitation (ha)	64	1,003	64,472	
Subtotal			**1,109,432**	
OCA3 G and A				
Management, Supervision and Labour	16	32,899	526,380	
Office Items and Stationery	1	3,000	3,000	
Consultancy	1	10,000	10,000	
Annual Operating Fees	92	175	18,514	Units in cadastral units (0.85 ha)
Ground Rent	92	6	507	Units in cadastral units (0.85 ha)
Corporate Social Responsibility	1	50,000	50,000	
Subtotal			**608,401**	
Contingency (15%)	1	-	1,016,261	
GRAND TOTAL			**7,791,336**	

Table 5 Mining Equipment Hiring Cost Detail

Number	Specification	Generic Name	Units	hr	Av	UofA	Effective hours	Unit Cost ($/hr)	Cost ($)	Comments
1	CAT D8	Dozer	1	7 196	0.9	0.95	6152.58	150	922,887	
2	Shantui SE 240	Excavator	1	7 196	0.9	0.95	6152.58	140	861,361	
3	Sinotruck CNHTC SWZ10	Tipper Truck	3	7 196	0.9	0.95	6152.58	40	738,310	
4	CAT 14 H	Grader	1	7 196	0.9	0.95	6152.58	40	246,103	
5	CAT 966	Wheel loader	1	7 196	0.9	0.95	6152.58	120	738,310	
7	MLLED200K-9AC-K	Lighting Plant	2	7 196	0.9	0.95	3031.83	56	339,565	Single shift use
8	18 l, 4 wheel drive	Water Cart	1	7 196	0.9	0.95	6152.58	40	246,103	
9	Toyota Hilux	LV	3	7 196	0.9	0.95	0		-	In fixed costs
10	18 l, 4 wheel drive	Fuel Bowser	1	7 196	0.9	0.95	1783.53	40	71,341	6hrs of use per day
11	VAR 4-250 FZD51 G11	Dewatereing Pump	3	7 196	0.9	0.95	6152.58	40	738,310	
								Total	**4,902,290**	

Table 6a Estimated Capital Cost for Alluvial Deposit

Cost Centre (CCA)	Units	Cost/Unit ($)	Amount ($)	Remarks
CCA1 PREPRODUCTION				
Land Acquisition (Mining, Processing and offices) - ha	78	5,000	390,000	
Land Acquisition TSF - ha	179	5,000	895,000	
Development-ha	78	2,500	194,138	Site Preparation
Pitting and Resource Estimation	1	35,385	35,385	Resource modelling and Planning
Permitting and Licensing	1	5,000	5,000	
Subtotal			**1,519,523**	
CCA2 MINING	**Units**	**Cost/Unit ($)**	**Amount ($)**	Contract Mining (CM)
CAT D8 Dozer	1		-	CM
Shantui SE 240	1		-	CM
Sinotruck CNHTC SWZ10	3		-	CM
CAT 14 H Grader	1		-	CM
CAT 966 Wheel Loader	1		-	CM
MILLED 200K-9AC-K Lighting Plant	2		-	CM
18 l, 4 wheel drive Water Cart	1		-	CM
19 l, 4 wheel drive Fuel Bowser	1		-	CM
VAR 4-250 FZD51 G11 Pump	3		0.00	CM
Contractor's yard	1	5 000.00	5 000.00	
Contractor Labour mobilisation	1	10 500.00	10 500.00	25% of equipment mobilisation
Contractor Equipment Mobilisation	1	42 000.00	42 000.00	Assumed at USD 3,000 per equipment
Toyota Hilux	3	40 000.00	120 000.00	
Subtotal		**97 500.00**	**177 500.00**	

Table 6b Estimated Capital Cost for Alluvial Deposit Cont'd

CCA3 PROCESSING	**Units**	**Cost/Unit ($)**	**Amount ($)**	**Remarks**
Hopper and Grizzly	2	13 797.00	27 594.00	11Kw, 80-120 t/h, 120 mm grizzly
Shaking Table	1	1 500.00	1 500.00	4.5 x 1.85 x 1.55 m, 1.1 kW
Sluice Box	4	1 200.00	4 800.00	50 tph, 1 x 6 m, with carpet
Sizing Trommel	2	26 470.00	5 2940.00	150 t/h, 1.8 x 3.5 m, one layer Mn steel screen
Centrifugal Concentrator	2	12 800.00	25 600.00	10-20 tph, 15 kW, conc. wt. 35-40 kg, cone speed 400 rpm, fluidisation 17-25 t/h
Power Plant - diesel	1	32 000.00	32 000.00	300 kW Capicity Genset
Water Pump	1	20 000.00	20 000.00	
Tailings pump	1	20 000.00	20 000.00	
Smelter	1	950.00	950.00	Model :1 -2 kg, power: kW, weight: 15kg, melting weight:1 - 2 kg, process time: < 5 mins.
Amalgamator	1	1 600.00	1 600.00	50 kg capacity, model: 400 mm x 400 mm
Retort	1	250.00	250.00	Capacity: 10-15 kg/time, drum size: 150 mm, length: 200mm
Electric Control Cabinet	1	3 075.00	3 075.00	
Wire and Cables	1	3 230.00	3 230.00	
Installation and Commisioning Cost	1	15 000.00	15 000.00	
Subtotal		**151 872.00**	**208 539.00**	
CCA4 INFRASTRUCTURAL	**Units**	**Cost/Unit ($)**	**Amount ($)**	**Remarks**
Office/ablution/Chop House/1st Aid Room	1	30 000.00	30 000.00	
Boreholes	2	50 000.00	100 000.00	
Fuel Tank/Bay	1	50 000.00	50 000.00	
Workshop (incuding tooling/Store - fixed plant	1	50 000.00	50 000.00	
Mine Closure Works	1	150 000.00	150 000.00	
Subtotal			380 000.00	
Contingency			342 834.28	
GRAND TOTAL			**2 628 396.18**	

Table 7 Cash Flow Analysis - Alluvial Deposit

Item / Year	0	1	2	3	4	5
Gross Revenue (Sr)	0.00	5,040,838.52	10,469,175.02	10,469,175.02	10,469,175.02	10,469,175.02
Less:						
Royalty , Rt = ro*Sr	0.00	252,041.93	523,458.75	523,458.75	523,458.75	523,458.75
Operating Cost (Opcost)	0.00	3,751,476.64	7,791,335.78	7,791,335.78	7,791,335.78	2,764,046.22
Net Revenue (Rn)	0.00	1,037,319.96	2,154,380.49	2,154,380.49	2,154,380.49	7,181,670.05
Less:						
Investment Allowance		131,419.81	0.00	0.00	0.00	0.00
Capital Allowance		525,679.24	525,679.24	525,679.24	525,679.24	525,679.24
Interest	0.00	189,244.53	151,395.62	113,546.72	75,697.81	37,848.91
Loss Carry Forward	0.00	0.00	0.00	0.00	0.00	0.00
Taxable Income (Ti)	0.00	190,976.38	1,477,305.64	1,515,154.54	1,553,003.45	6,618,141.91
Less:						
Tax, T = (35% of Ti)	0.00	66,841.73	517,056.97	530,304.09	543,551.21	2,316,349.67
Net Income	0.00	124,134.65	960,248.66	984,850.45	1,009,452.24	4,301,792.24
Add:						
Investment Allowance	0.00	131,419.81	0.00	0.00	0.00	0.00
Capital Allowance	0.00	525,679.24	525,679.24	525,679.24	525,679.24	525,679.24
Loss Carry Forward	0.00	0.00	0.00	0.00	0.00	0.00
Working Capital (Last year only)	0.00	0.00	0.00	0.00	0.00	1,558,267.16
Less:						
Loan Principal Repayment	00.00	315,407.54	315,407.54	315,407.54	315,407.54	315,407.54
Equity Capital	1,051,358.47	00.00	00.00	00.00	00.00	00.00
Working Capital (first year only)	0.00	1,558,267.16	0.00	0.00	0.00	0.00
Windfall Tax (WT)	0.00	65,507	132,192	130,867	129,542	454,991
CASH FLOW (CF)	-1,051,358.47	(1,157,948)	1,038,329	1,064,255	1,090,182	5,615,340
NPV @ 15% =	**$ 2 841 752**					
IRR =	**47.67%**					

Results of Economic Evaluation

Using the reserve estimate in Table 2 and mining capacity assumptions from Table 3, the yearly revenue from Equation 2 can be estimated based on the following assumptions:

r = 0.80 (in decimal)
P = 48.23 ($/g) (Au price of 1500 $/Oz)
L = 15 (%)
D = 10 (%), and
G = 0.46 (g/m^3) - undiluted
V = 620 953 m^3 (average volume per year)
R=620 953 ×[1+(0.10-0.15)/100]×0.46×0.80×48.23
R = 10 649 175 $/yr

Outcomes of Cash Flow Analysis

A cash flow was run using a discount rate of 15% for a capital mix of 60/40 percent loan and equity, respectively. The loan interest rate was taken to be 12%.

Table 7 illustrates the results of the cash flow analysis for the project. Revenue, operating, and capital costs were varied in increments of 20% to investigate their effect on the base internal rate of return (IRR) and net present value (NPV). One parameter was changed at a time while all the others remained constant.

From Table 7, the base case NPV was USD 2.84 M. A revenue decrease by more than 15% or an operating cost increase by more than 24% makes the NPV negative (Fig. 7). However, the NPV of the project is relatively less sensitive to capital cost increases.

The base IRR is 48%. The sensitivity analysis results show that a decrease in revenue by more than 15% and an increase in operating cost by more than 24% culminate in IRR dropping below the minimum rate of return of 15% (Fig. 8), making the project unprofitable. The IRR of the project is relatively less sensitive to increases in capital cost

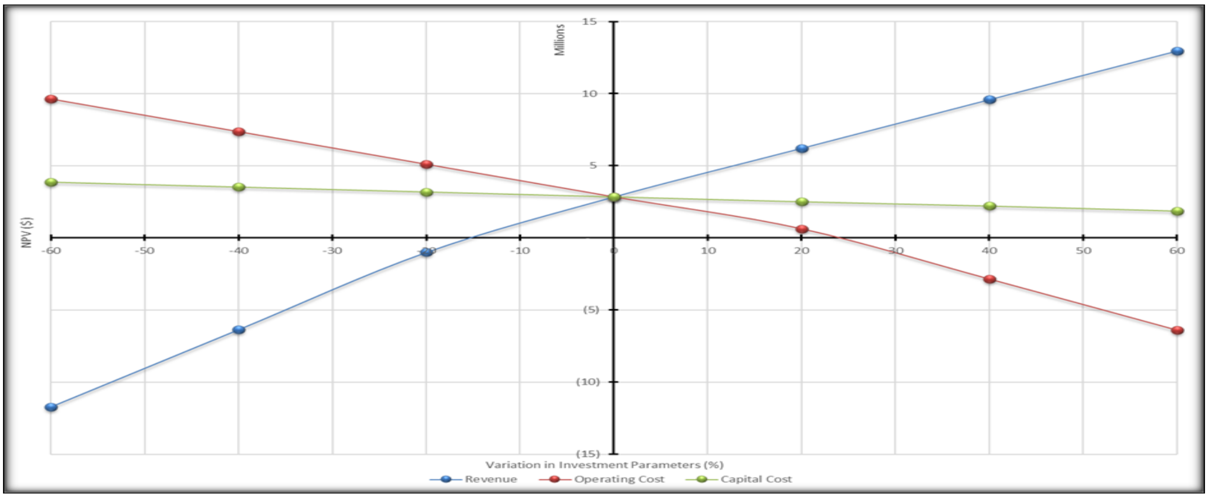

Fig. 7 Sensitivity on NPV

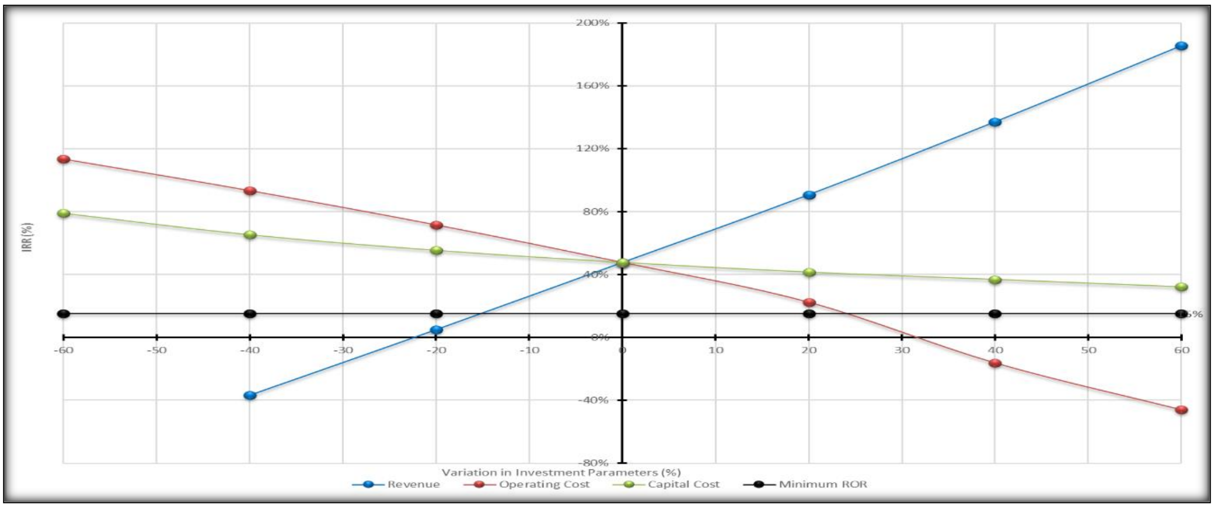

Fig. 8 Sensitivity on IRR – Alluvial Deposit

4 Conclusions and Recommendation

4.1 Conclusions

In this work, the IDW approach has been useful for estimating ASGM projects' reserves due to its simplicity and minimum cost requirements. At least the method provides the potential ASGM operator with some requisite data measurable enough to deduce the geological risk associated with the uncertainty in grade prediction. The reason is that the lesser the risk/uncertainties of the project, the lower the discount rate required for economic evaluations. Thus, if the geological risk in terms of grade is known, a more reliable discount rate can be established for improved economic analysis. Additionally, financing accurately estimated deposits comes at a lower cost of capital. The sustainable operability of ASGM projects depends on adequate funding to prevent the ASGM operators from taking shortcuts and using unsafe tools, methods, and reagents for processing to sustain economic livelihood.

The alluvial gold deposit was 3.4 Mm^3 at an average grade of 0.46 g/m^3 in reserves and yielded an NPV and IRR of USD 2.8 M and 48% respectively, for the base case. Keeping all other variables constant, results of the sensitivity analysis show that the project would continue to be viable if measures could be put in place to avoid increasing operating costs by more than 24% and decreasing revenue cost by more than 15%. The alluvial project viability was relatively less sensitive to increased capital cost.

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