OPTIMISING RESOURCE UTILISATION IN ARTISANAL STONE QUARRYING:
THE DEVELOPMENT AND DISSEMINATION OF APPROPRIATE AND SUSTAINABLE EXTRACTION AND PROCESSING TECHNOLOGIES

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Table of Contents

Introduction

Section One: Factors Determining Quarrying Techniques

1.1 Stone Type

1.2 Institutional Structures

1.2.1 Kenya

1.2.2 Goa, India

1.3 Environmental Regulations

1.3.1 Kenya

1.3.2 Goa, India

1.4 Health and Safety Regulations

1.5 Access to Capital

1.6 Labour Skills

1.7 Market Requirements

Section Two: Current Quarrying Techniques in Kenya

2.1 Overburden Removal

2.2 Extraction

2.2.1 Drilling

2.2.2 Blasting

2.2.3 Removal from the face

2.3 Breaking/Cutting

2.4 Stacking, Loading and Dispatch

2.5 Summary of Tool and Technical Deficiencies

2.5.1 Tools

2.5.2 Techniques

Section Three: Options for Improved Quarrying Tools and Techniques

3.1 Tools

3.2 Mechanisation

3.2.1 Overburden removal

3.2.2 Drilling and blasting

3.2.3 Face excavation and rock removal

3.2.4 Cutting and breaking

3.2.5 Stacking, loading and dispatch

3.3. Recommendations for Improving Production in the Kenyan Small-Scale Stone Quarries

Section Four: Obstacles to the Uptake of Improved Tools and Techniques

4.1 Social

4.2 Institutional
This paper is one in a series of papers that have been produced following a DFID funded ITDG project that examined the case of small-scale artisanal quarrying in the Nairobi region of Kenya. This research has shown that small-scale artisanal quarrying in Kenya suffers from low productivity resulting in a vulnerable lifestyle for quarry owners and workers alike. Productivity levels appear to have remained constant or even deteriorated since a 1945 study of the industry. Running concurrently is the increasing concern over the damage that small-scale quarrying is having on the environment. This paper concentrates on one aspect of small-scale artisanal stone production; that of the tools and techniques employed to extract the stone. These tools and techniques contribute significantly to current levels of productivity and to the present level of environmental degradation currently perpetrated by these quarries. The link between quarrying techniques and the environment is especially significant as processes that recover only small percentages of the available stone are currently wasting national stone reserves. The paper analyses how, by changing tools and techniques, levels of productivity may be increased and the amount of environmental degradation reduced.

The main study of this paper is the small-scale artisanal quarrying sector near Nairobi, Kenya. The paper, where appropriate, analyses another study of a similar mining area in Goa, India. It teases out the parallels and highlights the variations with situation there. The analysis also draws on some innovative technology used in a stone quarry in Rajasthan, India. As its introduction, the paper begins by examining the various factors that influence the tools and techniques used in small-scale stone quarrying. It then describes the tools and techniques currently used in the Kenyan and Indian quarrying process. The principle shortcomings of these are then addressed. The paper then proposes a number of technical changes that could improve productivity within the quarrying process. These are evaluated for their impact on productivity, jobs, the environment and for their initial cost outlay. The next section evaluates these proposed tools and techniques for their likely uptake. In particular, the social, economic and technical constraints to their uptake are examined. The final section of the paper draws out the most promising changes and considers how these proposals may be implemented.

SECTION ONE: FACTORS DETERMINING QUARRYING TECHNIQUES

1.1 Stone Type

The stone type of the deposit can determine the tools and methods used for its extraction and subsequent splitting and sizing. For example, the widely distributed rock surrounding Nairobi is consistent with a conchoidal fracture and the tendency to develop columnar joints. These conchoidal fractures and columnar joints facilitate the easy extraction of the rock by the informal sector (Jua Kali) as blocks are formed by fracture and the joints are easy to extract. The thickness of Nairobi building stone strata varies from place to place ranging from just a few metres up to 40 metres. Where the stone is hard, explosives are required to remove the rock, however, where the stone is softer, blasting is not required.

1.2 Institutional Structures

Institutional structures determine the size of quarries, the length of leases, the royalty payment structure, the level of skill within the labour force and the whole way in which quarrying is undertaken.
1.2.1 KENYA

In Kenya, leases are given for quarries of 100ft by 50ft, which then tend to be operated most efficiently, given current technology, by approximately 10 to 15, normally, men per site. The size of the lease limits the capitalisation of the quarry, as many of the capital items are indivisible and, hence, uneconomical on a small operation. The length of the quarrying lease is normally for one year, which again limits the use of machinery as large capital equipment may have to moved annually. Leases for quarries on Government of Kenya forestry land state that the owners must pay royalties on the stone they quarry at a fixed rate per metre of stone produced. Rates are variable according to the stone size. By-products also attract royalties on a cubic metre or per tonne produced basis. Quarry operators on private land often also have similar leases and royalty payment structures, although the leases are sometimes given on a monthly basis. Wells (1998) argues that the length of lease and this royalty structure compel quarry owners to operate on very short time horizons. This exacerbates environmental damage by encouraging quarry owners to maximise throughput of stone with little regard for the ratio of stone to waste produced. This in turn increases the amount of blasting that takes place, as blasting is the most rapid way of extracting stone from the rock deposit. Likewise, remuneration for much of the employment within quarry is based on stone output, thus promoting the use of tools and equipment that maximise stone output regardless of the amount of waste produced.

1.2.2 GOA, INDIA

In Goa, government policy designates certain land to be used for agricultural purposes despite high quarrying potential. This has led to the operation of many illegal quarries. For example, 14 out of the 16 randomly chosen mines visited in the study were operating illegally. Of these 16 quarries, 6 were manually operated and 10 had limited mechanization. All illegal quarries were operating on government land. The legality of the quarry then determines the quarrying approach. Illegal quarries have lower opportunities to obtain credit and are, therefore, more likely to operate manually as opposed to operating with partial mechanisation. This then determines the number of workers in the quarry. For example, the number of employees in the mechanical quarries ranged from 10 – 13, while in the manually operated quarries employee numbers ranged from 10 – 50. Quarrying leases, for those operating legal quarries on private land, are granted for a period of 5 – 10 years, thus inducing longer term decision making than is the case in the Kenyan quarries. In 1997, the average size of a lease granted for quarrying purposes ranged from 0.5 – 1 ha. In this study manually operated quarries averaged about 0.5 ha in size, while the machine operated ones were smaller, with a surface area of 0.15 ha. They tended to expand in a vertical direction achieving depths of 7.25 metres while the manual quarries expand laterally and, in general, do not go beyond 5 metres in depth (Noronha, 1998).

1.3 ENVIRONMENTAL REGULATIONS

Environmental regulations can constrain quarry owners in the tools and techniques that employ for the quarrying process. For example, if blasting is banned as a method of extracting rock due to adverse noise pollution, this necessitates the use of other technologies to extract the stone.

1.3.1 KENYA

There are no environmental regulations governing quarrying on private land in Kenya. On Government of Kenya Forestry land, environmental regulations stipulate that the quarry should back-filled with the waste and topsoil, if present, when abandoned. Forest Department trees should also be planted. Despite the fact that, in 1994, several licenses were revoked by the Forestry
Department due to complaints about excessive disturbance from blasting, environmental regulations have very little overall effect on quarrying techniques.

1.3.2 GOA, INDIA
Environmental regulations do pertain to stone quarrying in Goa but environmental regulatory enforcement is poor and as many artisanal quarries operate illegally, environmental regulations currently have little impact on quarrying techniques.

It is widely assumed that the influence of environmental regulation on the tools and techniques used in stone quarrying is likely to increase as environmental consideration become paramount in developing country decision making.

1.4 HEALTH AND SAFETY REGULATIONS
Health and safety regulations, if existent, are not widely enforced in either Kenya or Goa, India. These factors, therefore, appear to have little effect on quarrying techniques. As with the environmental regulations, this is unlikely to remain the case.

1.5 ACCESS TO CAPITAL
Poor access to capital can restrict a quarry owner’s use of capital intensive equipment. An undeveloped financial market is likely to result in the use of labour intensive technologies for stone production. Access to financial services for quarry owners is extremely limited in Kenya and, consequently, quarrying techniques have a low capital intensity. However, it is interesting to note that where larger operators have come into the market with sufficient capital backing, they too have tended to employ the same labour intensive techniques. Indeed, the mechanised quarries in the Nairobi area were not found particularly successful. By comparison, Indian quarry owners do have access to capital markets and, hence, have been able to invest in low-tech machinery.

1.6 LABOUR SKILLS
Labour skill levels determine the ability of owners and employees to take on new techniques and improve their productivity. In the Kenyan and Indian small-scale artisanal quarrying sectors, the skill levels of both employees and operators is low. Quarry owners lack the technical management skills for effective quarrying and quarry workers have a limited capability to perform skilled tasks, such as stone dressing. Quarry owners and their employees are likewise limited in their ability to take on new techniques and employ new technology.

1.7 MARKET REQUIREMENTS
There is little knowledge among quarry owners of the market for their product. Consequently, quarry owners who employ traditional techniques and are unaware of market opportunities that may be open to them if they changed their techniques to produce a slightly altered product or by-product, such as chippings.

SECTION TWO: CURRENT QUARRYING TECHNIQUES IN KENYA

Small-scale artisanal quarries in the Ngong and Njiru districts around Nairobi employ remarkably similar techniques for mining building stone. The quarries are approximately 100 feet by 50 feet and employ 10 to 15 men using hand held tools. These tools are shovels, wheelbarrows, hand-rotated
Section Two: Current Quarrying Techniques in Kenya

drills, hammers and chisels. The quarry faces being worked as one bench are typically 20 to 30 feet high and when fully developed, 50 foot in length. A second bench level of quarrying is generally not undertaken. The reasons for this are unclear, however, one site at Njiriu suggested that the water table was just beneath the quarry floor and this restricted quarrying depth. Consequently, the prevailing impression of Kenyan artisanal quarrying is consequently one of ‘a series independent cells being worked adjacent to each other sometimes with boundaries left intact, sometimes with intervening walls removed’ (Savery, 1997:10). The typical quarrying process can be divided into a number of component parts.

2.1 Overburden Removal

The first stage in preparing a new quarry is to clear the overburden. This normally consists of unusable rock and soil. This enables the quarry to be worked with minimal risk of falling rock and debris. The equipment used for this process depends on the nature of the overburden. Dependent on availability of equipment and labour, this may include bulldozers; shovel-dozers; ripper; high-pressure water hoses and power hoses. Alternatively, and most commonly in Kenya, it can be removed manually with hand tools. Explosives are also used but their use may damage the stone deposit.

In the Nairobi region of Kenya, overburden depths in current quarries range from 1 to 4 metres. Its removal is typically carried out by two men, using shovels and, where available, a wheelbarrow. The overburden then tends to be dumped at the nearest point behind the quarry face, often necessitating double handling. It is a slow and laborious task that often does not keep pace with the other quarrying activities.

2.2 Extraction

There is a variety of choices for extracting stone from a modern quarry. The extraction process employed depends on the stone, its physical and chemical properties, tectonic factors, colour, and mechanical properties. Likewise, the type of deposit will influence the extraction process, whether consolidated, for example, massive deposit, near vertical deposit, bedded deposit, cliff, or unconsolidated, for example, a boulder deposit. The objective is to extract the stone blocks without destroying other useful material, while simultaneously developing the quarry.

The nature of the rock around Nairobi, Kenya is of a relatively soft volcanic tuff variety that allows a manual extraction process. Typically, explosive charges are used to loosen the rock before manual extraction is undertaken using a variety of hand tools. The following section characterises the process of drilling, blasting and removal from the face as found in these quarries. However, it should be noted that in the softer stone quarries, the stone is extracted manually without the use of explosives.

2.2.1 Drilling

Savery (1997) states that there is a consistent drilling technique, whereby two drillers hand operate a 25-30 foot bamboo or metal pole (chirange) with a steel chisel fixed at the bottom. The drilling action consists of the two drillers standing facing each other, rotating the chirange clockwise and anti-clockwise in continuous motion. At intervals, the drill rod is withdrawn and a bamboo pole inserted in the hole. Water is then added and the pole withdrawn, thus, removing the fine stone dust that has accumulated from the drilling process. Typical work rates are 5 feet drilled per hour although the total depth of holes drilled is not noted.
2.2.2 BLASTING

The process of blasting the rock with explosives is undertaken by a blasting operator who may be responsible for blasting at up to about six mines. Holes are usually fired in pairs and are charged as follows:

- **Bottom of hole** - Gelignite
- **Main explosive** - Ammonium nitrate
- **Stemming** - Stone dust
- **Initiation** - Electronic detonator

Public warning of an impending blast is given by a whistle blow or the waving of a red flag. Variations in the sizes of rock piles after blasting would suggest that there is little or no adaptation of explosives for varying rock strata or joints.

The blasting process is regulated, each operator is licensed by the Mines and Geology Department of the Ministry of Environment and Natural Resources and explosives can only be obtained from Mines and Geology Department licensed suppliers. However, in practice, explosives are smuggled to the quarries and illegal blasting with unlicensed operators occurs.

2.2.3 REMOVAL FROM THE FACE

After the blast, shattered rock lies on the quarry floor, while other fractured rock remains in the quarry face. Typically, two labourers then remove the shattered rock from the quarry face to a position for breaking and cutting. Sometimes the breakers (Fundi) move it for themselves. Fractured rock is broken and cut at the face, from where labours move it to a stack for loading and dispatch. Tools used to extract the rock include levers, jacks, picks, hammers, chisels and a wheelbarrow.

2.3 BREAKING/ CUTTING

A manual process of extraction, especially when combined with blasting, leaves the stone in a variety of shapes. Therefore, before the stone can be sold it has to be cut and shaped. This is a skilled task and in a Kenyan quarry is generally carried out by two 'Fundi'. They normally work away from the face cutting the rock into blocks. As mentioned above, they sometimes the cut the rock at the quarry face. The selected rock is shaped into three standardised products: blocks 9 inches by 9 inches; 9 inches by 6 inches; or 9 inches by 4 inches. Production per Fundi runs at approximately 200 feet of dressed blocks per day. The tools used, three chisels and a hammer, are crude and poorly maintained. They are made from mild steel that is soft due to a low carbon content and they require regular sharpening. This lowers production rates and hence incomes. Other tools used include drills, saws and grinding stones. There are wide variations of waste estimates in Kenyan quarries but standardised stone blocks may account for only 15 to 20 percent of the rock removed from the face. The residue, with a poor or non-existent market outlet, is then often dumped in the excavated area. Sometimes it is sold cheaply for hard-core or for site-fill.

2.4 STACKING LOADING AND DISPATCH

After the stone has been shaped into blocks, casual labourers then either stack the blocks close to the working face area or move them away to flatter land where there is lorry access. Loading the stone
onto lorries for delivery is, likewise, a manual operation.

**2.5 Summary of Tool and Technical Deficiencies**

**2.5.1 Tools**

Tools used for drilling, extraction and breaking and cutting are generally supplied by informal sector (Jua Kali) blacksmiths who source their steel from scrap metal. The steel is usually mild and, consequently, cutting tools require regular sharpening. Other tools such as sledgehammers, wedges, lever rods, chisels and picks must be repaired or replaced approximately every three months due to their poor quality. Only tools made from hardened steel last longer. Consequently, quarrying tools are expensive to maintain. This is especially applicable to the drilling bars (choronge), which have to be sharpened nearly every day. Consequently, drilling bars contribute up to 80 percent of the cost of the repair and maintenance of tools.\(^1\) As a general statement, the poor quality of these tools contributes negatively to productivity.

**2.5.2 Techniques**

The process of overburden removal is, as mentioned, a laborious task that is consequently undertaken in a poor manner. In some cases, the inappropriate dumping of overburden necessitates its second handling. Likewise simple separation of topsoil from other burden would aid restoration of the site immensely, it is not common practice. With better carrying provision for the overburden it could be used as a visual screen to the quarry.

Blasting, while effective at removing rock from the face, results in much waste stone as the resultant stone has no uniform size. This is where productivity really fails as the large quantities of stone that can not be shaped into standard building blocks are put aside as waste. There appears little effort to size waste for subsequent use as aggregate stone or chippings.

The manual process of removing the rock after blasting and then stacking and loading cut stone is, like overburden removal, an unskilled yet harsh job. Reducing the tedium and back-breaking nature of this work by partial mechanisation would aid productivity and the health of employees even if it results in some job losses.

**3.1 Tools**

The simplest strategy to improve productivity in the Kenyan small-scale artisanal quarry sector is to improve the quality the tools that are used. Summaries of the various improvements that may be made are contained in Table 1. These improvements would largely result from improved practices among the blacksmiths and some new designs. These changes would result in productivity improvements for quarry workers and the higher tool costs could be justified by reduced maintenance costs. Jua Kali blacksmiths would need to be trained to carry out the necessary improvements and ensure that repairs are of equal high quality and efficiently and timely executed. Their reward would be the ability to charge higher prices for a better product. However, with improved steel some tool maintenance work would be lost.

Table One. Improved tools for small-scale artisanal stone quarrying
### SECTION THREE: OPTIONS FOR IMPROVED QUARRYING TOOLS AND TECHNIQUES

#### Tool / Technology | Areas for improvement | Proposed Intervention
--- | --- | ---
Drilling rod | Tip cutting edge | • Harden to reduce regularity of sharpening |
| Handle | • Round bar for ease of handling |
Chisel | Material | • Use higher quality steel |
| Tip | • Increase hardness of tip to reduce regularity of sharpening |
| Head | • Re-shape to suit quarry activities |
Mattock | Head | • Harden the head to reduce wear |
| | | • Re-shape to suit quarrying activities |
Hammer | Head | • Re-shape & harden to provide a better cutting edge |
Wheel burrow | Wheel Carriage | • Change wheel to be of metal & increase wheel diameter |
| | | • Strengthen stands |
| | | • Reinforce carriage |
| | | • Provide more supports |
Pick | Head | • Re-shape the head and sharpen |
| | | • Harden tip to decrease regularity of re-sharpening |

Source: Artisanal Quarrying Stakeholders' Workshop, 1997

### 3.2 MECHANISATION

In his study of small-scale artisanal quarrying in Kenya, Savery (1997) identifies five main activities within the quarrying process that could benefit from improved techniques. They are:

- Overburden removal
- Drilling and blasting
- Face excavation and rock removal
- Cutting and dressing
- Loading and dispatch

Each of these is examined in turn and evaluated in terms of impact on productivity, the environment, employment and its likely cost. A summary of the technologies and their impact is found in table two.
3.2.1 OVERBURDEN REMOVAL

*Motorised dump vehicles*

For the purposes of overburden removal, small motorised dump vehicles could be introduced to replace wheelbarrows. This would increase the stripping rate and enable overburden to be transported and tipped away from the top of the quarry to a location where double-handling would not be necessary. Overburden could then be used as a landscaping or bund feature until quarry closure when it would be used for restoration purposes. If topsoil and other overburden were stored separately then the restoration process could be improved. Savery (1997) suggests that this proposal would involve a capital outlay that would increase productivity without reducing employment levels.

*Bulldozer*

A bulldozer could be employed to clear overburden. It would only be effective if extensive areas of land were involved and a large face was to be developed. The cost of such an investment would be significant and it is likely that jobs would be lost. It should be noted that a bulldozer is often used in mechanised Goan quarries where it can be hired hourly from the Ministry of Agriculture.

3.2.2 DRILLING AND BLASTING

*Drill bits*

Experimental trials could be conducted to adapt modern drill bit technology to use some configuration of multi-blade or augur tool.

*Explosives*

An explosive manufacturer, such as ICI, could study current blasting techniques and advise on state of the art technology.

*Air operated drill rig*

To increase productivity on a long quarry face, the use of a compressed air operated drill rig could be justified but it would result in the loss of many jobs.

Table Two. Mechanisation options for small-scale artisanal stone quarrying

<table>
<thead>
<tr>
<th>Activity</th>
<th>Technique</th>
<th>Contribution of technique to:</th>
<th>Productivity</th>
<th>Employment</th>
<th>Environment</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overburden</td>
<td>Motorised dump vehicles</td>
<td>Positive</td>
<td></td>
<td>-</td>
<td>Positive</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
3.2.3 FACE EXCAVATION AND ROCK REMOVAL

*Hydraulic excavators*

Productivity in the excavation of the quarry face could be improved with the use of a hydraulic excavator to dig at the quarry face. Likewise, another smaller machine (a back-actor) could remove the shattered rock from the quarry face. Both of these tools are likely reduce the number of employment opportunities in the quarry and would also require a significant initial capital outlay.

3.2.4 CUTTING AND BREAKING

*Hydraulic cropping machines & hand held pneumatic drills*

Funds currently undertake the cutting and breaking the stone by hammer and chisel. An alternative approach would be to use a) hydraulic cropping machines that require no power source, or b) hand held pneumatic drills that require a compressor. Trials could determine whether a combination of both tools or the sole use of one tool would optimise production. Savery (1997) suggests that the use of these tools could boost production without reducing jobs.

3.2.5 STACKING, LOADING AND DISPATCH

The process of stacking, loading and dispatching of the stone blocks could be mechanised. It is envisaged that the stone could be stacked on wooden pallets ready for lorry dispatch. The loading of the pallets could then be undertaken either by forklift truck or by a lorry-mounted hoist. On arrival at
the delivery point, a hoist on the lorry could then unload the pallet off the lorry.

3.3. RECOMMENDATIONS FOR IMPROVING PRODUCTION IN THE KENYAN SMALL-SCALE STONE QUARRIES

Based on his findings, Savery (1997) recommended the following three-phased plan for selected mechanisation of the small-scale quarrying process in Kenya.

**Phase One:** To introduce small-motorised dump vehicles to move overburden.

**Phase Two:** To improve the hand drilling technology by introducing a cross-bit design. This uses four chisel-shaped lengths of tungsten carbide. It is suggested that ITDG liaise with UK drill-bit manufacturers to develop the most suitable configuration to improve rates of penetration.

**Phase Three:** To conduct trials of hydraulic cropping machines and hand-held pneumatic drills to test their suitability for breaking and cutting stone. If proven effective, these tools will increase productivity without reducing the number of jobs available at the quarry.

Savery (ibid.) suggests that further moves towards mechanisation should not proceed, as they would destroy the concept of artisanal quarrying. However, co-operation of artisanal quarry owners on the exploitation of one long quarrying face could allow mechanised equipment to be better utilised and shared more effectively between operators than at small, localised sites. One further recommendation regarding improved technology is that trials should be initiated with a major explosive manufacturer, e.g. I.C.I., for an examination of blasting practice. This should address the positioning of the drilled holes to take account of burden and spacing, variations in rock strata/characteristics and the need to reduce fragmentation.

**SECTION FOUR: OBSTACLES TO THE UPTAKE OF IMPROVED TOOLS AND TECHNIQUES**

Impediments to the implementation of new technology and techniques associated with artisanal quarrying are many. They are social, institutional, economic and technical.

4.1 SOCIAL

Changing techniques, particularly moves to mechanisation will be resisted by quarry workers who fear that they may lose their jobs. Those that have most to fear are the unskilled and lowest paid, and those who do have access to training necessary to upgrade their skill level. Resistance will also arise from quarry owners and workers who are unfamiliar and untrusting of new technology and techniques. Likewise, those livelihood depends on quarrying associated activities may be anxious of changes that may affect their position.

4.2 INSTITUTIONAL

The practice whereby quarries are not worked by the owner of the land but by holders of concessions creates an unfavourable climate for positive changes in quarrying techniques and technology. Concessions are now commonly let on short term leases, normally for one year but sometimes for as little as one month, especially where the illegal practice of sub-letting occurs. Smaller monthly fees and royalty payments on the quantity of stone produced are also replacing flat monthly fees. Typical rates equate to 20 percent of the price of the stone. Waste stone is not therefore charged, except in hard stone quarries where its ownership sometimes reverts to the quarry owner. However, it is not merely the operators who have the incentive to maximise production, regardless of waste; those working in the quarry are also often paid on work done. For example,
overburden removers are paid on area cleared so they have no incentive to separate topsoil from other overburden or to transport it to a position where it serves as a screen to the quarry operation. Likewise, stone dressers are paid on amount running stone produced with no penalty for wasted stone. Time horizons in the business are therefore necessarily short. However, the capital investments that are being proposed need a longer time frame to make them viable. For example, the fact that quarries have relatively short life span requires that the equipment must be portable. Such institutional factors will hamper the proposed changes to the effect that production rates remain static.

Further institutional impediments are:

- The lack of financial markets and access to credit for quarry owners
- The poor availability of skilled quarry workers due to the absence of any formal training institution within the country.
- The absence of any formal small-scale quarrying forum or trade association that could otherwise be a conduit for the dissipation of ideas and techniques

4.3 Economic

Quarry owners and their workers face a precarious lifestyle where earning a wage ensures that there is food to eat for the next day. Economic survival is, therefore, the main priority for artisanal quarry operators and workers alike. Suggested improvements to operating practices that improve the environmental impact will not be implemented unless they are economically viable. Changes to operating practice through regulation should however not be ruled out. As an example, if a law is enforced that prescribes certain environmental practice, this law will be adhered to if the probability of being caught, combined with the subsequent fine or imprisonment is greater than the gains to be made by flouting it. Likewise, changes in technology or quarrying approach will be implemented if they are shown to improve productivity and profitability. However, a critical factor for enacting many of these improvements is access to capital. Currently, the capital required to enact the changes necessitates the use of credit. However, beyond credit access, one must again consider is the time horizon. Although certain investments may known to produce a significant return on capital employed, if the initial change is a negative cashflow, then it is likely that many small-scale quarry owners will continue with their old practices. Survival for them and their families today is critical and more important than the gains that they may realise at some time in the future.

4.4 Technical

Some of the technical solutions would appear to require assistance from a partner in, for example, the UK. The feasibility of providing the necessary mechanised equipment is not addressed within the project documentation. However, if equipment, such as small, motorised dump vehicles, needs to be imported then the provision of appropriate back up and servicing needs to be addressed. A market opportunity may exist for mechanical repair or servicing firms to provide this support but this is an area that would need exploration. Other tools and techniques require training in, for example, the actual practice, the operation of machinery, and for repairs. However, with appropriate assistance, the technical limitations to improved tool and technique usage are not as serious as those described above in the social, economic and institutional domains.
An alternative approach, not yet adopted in the Nairobi region, is to alter the way in which stone is extracted. At present, as described the preceding section, most rock, particularly hard rock, is removed from the quarry face, in part, by blasting. Extraction of the rock, therefore, precedes the process of sizing. In an alternative approach, first found successful in Rajasthan (see the Kotah stone experiment, Box 1), the rock is extracted via a process known as benching. In this process the stone is sized using nails and string. It is then cut and split accordingly along the prescribed lines. The Goan quarries that operate this practice supplement their hand tools with motorised hand ploughs. A wheel with tungsten carbide bits is attached to each hand plough to cut the rock. These diesel powered ploughs are a minor adaptation of a farm plough and come in two sizes: a small plough costs Rs.80,000 and a bigger one costs Rs.100,000. This process of sizing before splitting the stone has been shown to greatly reduce the amount of waste generated. Thus facilitating the extraction of more stone from a given area of the quarry face. It should also considerably reduce the wastage that occurs from shattering the rock at blasting. As an example, it is estimated that stone waste in a manual Goan quarry ranges from 20 - 25 percent (50-55 stones produced per cubic metre of laterite) whereas in quarries of limited mechanisation, where benching is practised, wastage is reduced to 10 - 15 percent (58 - 60 stones produced per cubic metre).

Box One. The Kotah Stone Experiment
Kotah stone is a naturally riven limestone used for Indian flooring. The manual process of quarrying this stone began over 70 years ago in Rajasthan, India. For over 65 years the same quarrying techniques were employed. Firstly, the overburden was removed and then the exposed stone layers were quarried using crowbars, chisels and hammers. The non-dimensional pieces of stone were then separated, sized and spliced along natural splits. This practice was one of low productivity and poor stone recovery rates (24 percent). There were also high costs for waste handling, a local scarcity of water due to the quarrying process, and a rapid depletion of land and mineral reserves.

In 1992, with a quest to find a more environmentally friendly way of quarrying, Associated Stone Industries (Kotah) Ltd launched a 30,000 square foot pilot project using innovative technology. The experiment involved the reversal of the process of splitting the stone then sizing it, to sizing it then splitting it. The layers were sized in situ on the quarry floor using 600mm and 900 mm diamond wheel to give 150 and 300 mm deep cuts respectively. The cutting of layers was done on a chessboard pattern with a 2m long strike and 0.6 m long dip. Each block was then separated form its natural setting using crow bars. It was then split along natural cleavage planes to give a slab ready to use in the shape and dimension required by the market. This reduced the breakage and waste. As a consequence, the stone recovery rate increased remarkably (24 percent to 80 percent). Overall, productivity of the quarry increased by 150 percent, and the life of the stone reserve increased by 250 percent.

The gains were not limited to quarry productivity; Argwals (1995) argues that all associated with project gained from the changes. For workers, their average earnings rose due to higher productivity, physical fatigue reduced due to the use of machines, and likelihood of injury reduced due to better practices and the elimination of the use of explosives. However, employment within the mine reduced by 50 percent so not all quarry workers shared these gains. The quarry owner reaped the largest gains with a reduced labour force resulting in lower labour costs, better industrial relations with the remaining contented staff, on balance lower production costs, and a better, more marketable product. The surrounding community gained from reduced de-watering, less blasting noise, greater skilled employment opportunities, less air pollution and a reduced take of agricultural land. Finally, for the nation, due to a lower rate of resource degradation, the environment benefited, and, with increased profitability, the quarry was able to undertake environmental measures to reduce its long-term environmental impact. (Source: Agarwal, 1995).
SECTION SIX: ANALYSIS

In consideration, the idea of promoting the technique of benching seems appropriate. Evidence suggests that, through lower production costs and an improved product price, it increases returns to the quarry owners. This allows owners to pass on the gains to the workers in improved wages. Likewise, due to a greater degree of mechanisation, which reduces the amount of manual work, and a reduced incidence of blasting, employees are able to work in a healthier environment. Meanwhile the process itself, by reducing stone waste levels, contributes to a reduction in environmental degradation and, through improved quarry incomes, owners can take greater care of the environment. The first question that arises is, can the process be transferred from India to Kenya? The Kotah stone project was conducted on a quarry of 30,000 square foot quarry, whereas, the average Kenyan quarry at 100 feet by 50 feet is just 5,000 square feet. However, benching has occurred in quarries in Goa of 0.15 ha which is approximately the same size as the average Kenyan quarry. Scale would therefore not appear to be a significant obstacle to implementation.

The second question relates to the number of employees. Can the process operate with similar numbers of employees and achieve the same productivity gains? This may be unrealistic. If job creation and maintenance is critical, then on this basis, it could be argued that the implementation of benching is inappropriate. Should therefore Savery’s recommendations be implemented alone? They appear to offer the prospect of improved productivity without job losses. However, is this realistic? Evidence from Noronha’s (1998) Goan case study suggests that where limited mechanisation occurred average quarry employment was 10 to 13 men/ women, whereas for manual quarries average employment was 10 to 50 men/women per quarry. In addition, manual quarries tended to be smaller in surface area but were deeper to compensate. Productivity is certainly increased with mechanisation. Noronha found that production per quarry, despite a lower workforce, was between 55 and 75 percent greater in partially mechanised quarries. The productivity per worker per day shows even greater disparities, in a manual quarry it is on an average about 12.5 (hard) - 15 (soft) stones, while that in a mechanical quarry is about 35 – 40 stones.

SECTION SEVEN: CONCLUSIONS AND RECOMMENDATIONS

The recurring theme of these case studies is that for small-scale artisanal quarries to improve their productivity and reduce their environmental impact, some reduction in employment at individual quarries is inevitable. Limited mechanisation, whether of the type described by Savery (1997) or that adopted in India, will reduce employment within stone quarries. This will occur whether the interventions are subsidised by international agencies, paid for by credit or financed by co-operative arrangements between quarry owners. Therefore, the most critical question is which of the technologies or quarrying techniques best suits the Kenyan climate?

Based on the preceding commentary the following recommendations can be made.

1. To implement those recommendations as prescribed by Savery (1997) and outlined in section 3.3.

2. To conduct a Kenyan trial of the benching technique to:
   - evaluate the impact on jobs
SECTION SEVEN: CONCLUSIONS AND RECOMMENDATIONS

- evaluate the impact on the livelihoods and health of those retaining employment
- evaluate productivity rates
- evaluate the impact on the environment
- assess feasibility

3. For an external organisation to facilitate:
   - the formation of a trade association to aid information dissemination
   - formal training structures to improve the ability of quarry owners and workers to use the new tools and technology
   - credit access for quarry owners so that capital investment by quarry owners can be made possible
   - the formation of either co-operative arrangements for machinery sharing or machinery hiring firms

4. To lobby the Government of Kenya for
   - changes to the average length of quarrying leases
   - changes to current royalty structures

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1 The term quarry owners describes the owners of quarrying leases. Those with quarrying leases may or may not also be the landowner.

2 A conchoidal fracture is a fracture that has smooth shell-shaped convex and concave surfaces.


4 The Artisanal Quarrying Stakeholders’ Workshop (1997) also recommended that:
   - Holes for explosives should be a minimum of 8 feet from the quarry face to reduce the amount of wasted rock.
   - Benching rather than blasting should be used where possible to reduce wastage.
   - Topsoil should be stored separately from the other overburden and waste so that it may be used for site restoration.
   - The total depth of stone reserves should be exploited to reduce double handling of stored stone and hardcore.
   - The quarry face should be at different heights with various benches
   - The quarry face should be a minimum of 20 feet wide.

5 Noronha (1998) from her Goan case study argues that before any form of mechanisation is introduced the following issues should be examined:
What are the opportunities presented by limited mechanisation to bring about a beneficial change in the quality of life for workers apart from increased incomes?

What are the opportunities presented by limited mechanisation to bring about a beneficial change specifically for women? This can be studied perhaps in terms of a reduction in the harshness of work tasks that they perform in a manual quarry.

Is the expected change in activity profiles post the adoption of limited mechanisation conducive to a beneficial change for both males and females?

How will the intervention affect the access and control of resources and benefits?

What are the possible adverse effects on women? Is there a mechanism to identify/assess the effects on women?

How can one improve the living conditions of migrant workers?

Do the workers have necessary skills to use the new tools?

Is the organisational set up conducive to women’s participation?

Is there a way of building capacity and providing new skills?

Is the funding for the intervention sustainable?

REFERENCES


