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Post-mining landscapes within the City of Johannesburg Metropolitan Municipality:

Assessing the opportunity to create Stone paper from rock wastes (Builder's rubble, mine tailings and mine dumps).

Version 1.3

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Post-mining landscapes within the City of Johannesburg Metro:

Assessing the opportunity to create Stone paper from rock wastes- Builder's rubble, mine tailings and mine dumps.

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EXECUTIVE SUMMARY:

Both rock waste from mining and builders rubble can be converted into a valuable Stone paper product, and in doing so avoid the pollution burdens and land degradation from landfilling these wastes. Stone paper is a durable and water-resistant paper-like product that could be produced locally and can help to avoid the need for the import of packaging as well as the land and water footprint associated with paper made from trees.

There have been huge quantities of mining rock deposited on the land surface in mine dumps and mine tailings from over 100 years of mining- mostly gold in the Witwatersrand and there is 3203 Megatonnes of legacy mining wastes available as a stock accumulated from the mining over the last 100+ years.

The area occupied by mine wastes (mine residues areas MRAs) within the CoJ Municipality is **5764 ha** and ⅔ of these MRAs are gold mining. A large part of the mining waste within CoJ is present 15 large dump sites that totals at least 400 Megatonnes and occupies 1143 ha land.

In addition, current and future mining activities will produce another 722 Megatonnes rock waste over the estimated 33 years until depletion of the gold resource in 2044; with an average of 22 Megatonnes per annum mined and the degradation and loss of **another** 1500 ha from mine wastes. **The current and future mining wastes (as opposed to legacy wastes) are the most appropriate resource as this can tailor the stone paper production to current mining technology and infrastructure, while also ensuring improved rehabilitation of lands upon exiting the mining area that avoid future pollution and burdens on CoJ citizens.**

There is approx. 7 Megatonnes rubble that has accumulated in the existing CoJ landfills, but it is mixed with other wastes and not seen as readily available (costs of mining landfill for rubble prohibitive). Currently, there is also an annual flow of at least 197 515 tonnes per annum (0.2 Megatonnes) builders rubble produced that is destined for the four existing Municipal landfill sites that will amount to 6 Megatonnes in the next 30 years. However, over half is seen as valuable on-site cover for other wastes at the landfill and the rest takes up valuable landfill space. A large portion of rubble is currently illegally dumped and mixed with other wastes around CoJ- a practice CoJ are trying to discourage as it pollutes and degrades natural areas. Therefore, there is at least 44 813 tonnes per annum rubble is realistically available for stone paper.

The other essential component of Stone paper is 20% plastic HDPE (or PET)- a non-renewable resource derived from oil. It would be preferable to use recycled HDPE or PET and data indicates that this plastic forms 1-1.5 % of CoJ waste stream (1.6 million tonnes per annum total)- indicating that there is 15 000 HDPE and 25 000 tonnes per annum PET theoretically available. **Assuming at least 30% can be recycled and is available for Stone paper, then approx. 4500 tonnes is available. Since HDPE is used at 20% in Stone paper, this will support 22500 tonnes per annum Stone paper production facility.**

There are sufficient resources of waste rock to support a small (4000-40 000 tonnes per annum paper) stone paper production facility using builders rubble, and a medium to large (60 000-120 000 tonnes per annum or more) stone paper production facility using wastes from current and future gold mining. The rock waste resource from both past and near future mining is considerable, with the current and future mining in the next 33 years generating sufficient rock waste for large to very large stone paper production facilities (ie 10 to 20 million tonnes per annum).

However, based on local availability of mining rock wastes and recycled HDPE, it is recommended that a small to medium size Stone paper production facility be established (4000-20000 tonnes per annum). The exact location and costs will depend on the resource and site selection, as well as business model (phase 2 of this project).

The use of Builder's rubble and mining rock waste for stone paper also has notable environmental and social benefits to CoJ that should be considered in the cost accounting and business model. Removal of these wastes can avoid many burdens to the environment and human-health, including:

- **Land development potential and land degradation.** The mine residues and builders rubble has resulted in landfill with loss of land space, land degradation and the loss of biodiversity. The land area impacted by mining waste is **5764 ha from legacy mine waste** and **1500ha from future mining waste (until gold resources are depleted).** Similarly, the land area required specifically for builders' rubble waste in landfills amounts to 0.75 ha per year, implying that 22.5 ha of land is required for disposal of builders' rubble over a 30 year timeframe. As such, if the land area impacted by legacy mine rock waste is rehabilitated and developed, then values ranging from R27 billion to R77 billion can be unlocked, depending on the type of land use. Alternatively, if this land were rehabilitated and revegetated, then a minimum value of of R34.4 million per annum could be derived in terms of ecosystem service provision. In either case, however, the costs of rehabilitating the land for the required land use would also need to be taken into account. On the other hand, the value from avoiding future mining waste dumps (in terms of keeping 1500 ha of land available for other development options) ranges from R7 billion to R20 billion; or at least R9 million per year in terms of ecosystem services. Finally, if builder's rubble could be diverted from landfill sites, land with a value ranging between R60 million and R325 million could be preserved for other uses.

- **Biodiversity loss.** Over the history of mining, thousands of hectares of land has been transformed and degraded through mining with significant local biodiversity loss. Currently 89% of the Ecological Support Areas (ESA1 and ESA2) exposed to mining residues, 14 % of mine residues are adjacent to perennial rivers and 38% are adjacent to non-perennial rivers. This highlights the current and ongoing impacts of mining pollution and waste with the important loss of ecosystems and biodiversity and the impacts to water and other natural resources. It also calls for interventions to protect and enhance the biodiversity and ecological infrastructure that provides services, such as regulation and purification of water and air, vital to human well-being and livelihoods.

- **Water pollution and availability.** Stone paper has a water footprint considerably less than conventional tree paper- with a water-saving during production of on uses 41 cubes per tonne paper. In addition, since stone paper does not use wood, it avoids the water needed to grow trees for conventional paper production which saves a further 237 cubes water per tonne paper produced. The overall life-cycle water saving of stone paper instead of tree paper is 278 cubes water per tonne paper or 278L per kg paper. If this water was included in the value of the paper it would save R1002 per tonne paper or R1.00 per kg paper (assumes marginal value of water at R3.60 per cube water) and it also avoids the land area needed for this. Lastly, the use of mining waste for stone paper can reduce the water-pollution associated with mining; such as Acid Mine Drainage (AMD). **AMD forms when** water which interacts with the exposed sulphide bearing minerals in rocks to form acdic water rich in

- **Soil pollution and air pollution (dust).** The soils impacted by mining (compaction, loss organic matter, leachate and acid mine drainage containing low-PH water with several metals that can cause health impacts, including radioisotopic uranium. The mine dumps and tailings are subject to wind-erosion that carries dust for kilometres and can only effectively be mitigated by removal or vegetation

The **caveat for achieving these benefits and avoiding unintended impacts** is the use of these wastes in a safe and effective manner. This includes the above-mentioned preference for avoiding the disturbance of existing wastes that have been (partially) rehabilitated and focussing on current flows of mining wastes and builders rubble. This approach can avoid many unintended risks from re-mining dump sites, while helping to avoid current and future flows of mine wastes and builders rubble to going to landfill, and thereby create future land space needed for development (housing, industry, open space). A notable technology risk for the stone paper product is achieving negligible levels of contaminants in stone paper that can present a health hazard. The existing extraction processes are not 100 % effective and even after re-processing, the tailings will still contain about 10 % of the gold and 15% of the uranium present tailings prior to processing. Typical background levels of uranium are in the order of 3 ppm. Average uranium content of slimes (before processing) is around 100 g/t but can range from 50 g/t to over 300 g/t. Thus if 90% is removed you will still have about 10 ppm on average in the final tails-but it could also range from say 5 to 30ppm. There is therefore a significant risk negligible/background levels of uranium can be achieved without exorbitant cost. In the longer-term the rock wastes of the mining areas of the Witwatersrand are a significant and promising rock waste resource, but will require implementation at a much larger scale (millions of tonnes per annum) with prior research and development to ensure radioactive uranium is removed to negligible levels; since even small amounts in stone paper will cause health concerns.

The **recommendation for Stone paper production is therefore at the Municipal landfill sites where Builders rubble can be collected together with recycled plastic HDPE**; which will reduce illegal dumping and enhance recycling. Stone paper plants generate jobs in the production plants, as well as will also increase secondary jobs and skills in upstream recycling and the downstream production of various paper-products from Stone paper.

1. INTRODUCTION

Stone paper: Assessing the opportunity to create paper from waste rubble and mine tailings", is a CSIR project proposal within the post-mining landscapes initiative which aims to assess the opportunity for Stone paper in the City of Johannesburg Metropolitan Municipality.

In the move towards zero waste and more sustainable development pathway, the CoJ identified a number of initiatives. A meeting in November 2014 between the CoJ and Gunther Pauli discussed Blue economy initiatives and decided that the "Blue Economy team will continue to investigate the feasibility of some 29 potential projects and firm proposals for funding will be taken to the first Budget Lekgotla in 2015"[1]. This document, "*Stone paper: Assessing the opportunity to create paper from waste rubble and mine tailings*", is a CSIR project proposal to assess the stone paper opportunity; and it details the scope of work, tasks, deliverables, timeframes and budget.

Stone paper, also referred to as mineral paper in literature, is a paper-like product that uses waste rubble or mine tailings for its manufacture and thereby avoids the disposal costs of rubble sent to landfill or mine tailings treated. Compared to traditional paper, stone paper may also offer other benefits as it avoids the use of wood pulp from trees, has lower water and energy requirements for production, and is recyclable and photo-degradable. However, many of these claims are not fully verified and currently debated[2]. Stone paper is a manufactured from calcium carbonate or other rock material bonded with high-density polyethylene and is used for stationery, leaflets, posters, books, magazines, bags, packaging, wallpaper, adhesives, tags, in-mould labels, plates, trays, and containers. The process for creating stone paper was first developed by the Lung Meng Tech Co. of Taiwan[3] during the late 1990s, and has now been patented in over 40 countries, where it is marketed under a variety of trade names such as GPA UltraGreen, MIST Paper, Parax Paper, Terraskin, ViaStone, Kampier, EmanaGreen and Rockstock, Pixz Printing, KYStone Paper and Nu Stone. Stone paper claims a number of advantages over traditional paper- it has no grain and a smooth texture; it is water, grease and insect resistant; and tears with difficulty, and therefore favours applications where durability is important (Sustainable Business Network, 2015).

1.1 Need and problem statement

The causes of the climate-change, food and economic crises that have unfolded during the last decade vary, but they all share a common feature: the gross misallocation of capital. During the last two decades, much capital was poured into property, fossil fuels and structured financial assets with embedded derivatives. However, relatively little in comparison was invested in renewable energy, energy efficiency, public transportation, sustainable agriculture, ecosystem and biodiversity protection, and land and water conservation. In addition, decades of creating new wealth through this "**Brown economy"** model based on fossil fuels have not substantially addressed social marginalisation, environmental degradation and resource depletion. The "**Green economy"** was brought to international focus, because it offers a response to the climate-change, food and economic crises that the world has been facing in recent years. The Green economy aims to improve human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP 2013). A Green economy requires a move to more sustainable utilisation of natural resources; so that economic growth and development (or the creation of well-being) is decoupled from increasing resource use and environmental degradation. However, the Green Economy model has generally required additional investments to achieve the same economic output in order to account for the costs of environmental preservation. In contrast, a "**Blue Economy**" model aims to address the issues of sustainability beyond mere preservation. It considers that "no waste can be wasted" so that developments are structured towards a zero waste society, and innovation fosters a more inclusive and equitable society.

In line with these values for **zero-waste, sustainability and resilience;** the CoJ is seeking innovative Blue economy development opportunities. One such opportunity that has been identified[1] is the use of builder's rubble and mine tailings for the production of stone paper. The main resource for stone paper is calcium carbonate rich stones, but it is possible to use a wide variety of mineral sources provided that the input material meets the standard size of fine dust. The material is crushed and the stone dust is mixed with approx. 20% polyethylene and fed into the paper film production to produce stone paper; which can be used by secondary industries to produce various products like permanent signage and tags, notebooks, bags, etc.. While the financial cost of this process may not be competitive with wood-based paper, it will also reduce the costs of rehabilitating previously-mined and marginalised land and also deliver a suite of other benefits in terms of the downstream job generation, transform mining and construction wastes into a valuable market product, free up- and rehabilitate degraded and mining impacted land to make available for other development options (housing, business, agriculture), and reduce the national water demand when compared to using trees for paper production. The processing of tailings from mine dumps requires a cleansing process known as chelation to extract residual gold and uranium, and other metals. This technology is less established commercially, but will need to be implemented in concert with the stone paper production to ensure that waste metals are recovered and beneficiated.

1.2 Project aims and objectives

This project intends to employ a multidisciplinary team to assess the opportunity of Stone paper production to contribute to the Blue economy. A guiding principle is to maximise the efficient use of material and energy resources through an Industrial ecology approach that identifies and implements development strategies to more closely emulate harmonious, sustainable, ecological ecosystems.

The project objectives are to:

- Assess the opportunity for stone paper production in terms of resource availability, market readiness and technology maturity, and compare with brickmaking, landfill material, road construction material
- Highlight any social, economic and ecological risks from Stone paper production, in comparison to traditional paper production.
- Develop a business model based on the smallest stone paper factory operation to serve as a demonstration plant.
- Make recommendations for the CoJ Request for Proposal (RFP) that will be used to solicit private investment in a Stone paper project.

2. RESOURCE AVAILABILITY

This part of the assessment of the opportunity for stone paper production considers the resource availability. Two types of rock resources are considered for Stone paper: Mine waste and Builders rubble waste. Both these types of resources have existing stocks of dumps/landfill from wastes to date (legacy stocks) as well as current and future amounts (current flows) of these wastes.

2.1 Mining waste

2.1.1 Composition of mining wastes

The gold in the Witwatersrand Basin area was deposited in ancient river deltas, having been washed down from surrounding gold-rich greenstone belts to the north and west. Geologists believe that the gold came from unusual three billion year old mantle sourced intrusions known as komatiites present in the greenstone belts. The gold, as well as uranium deposits are found in quartz-pebble conglomerates.

A typical composition of gold-bearing conglomerate mined in the Witwatersrand Basin is given in Table 1.

Table 1: General mineralogy of Witwatersrand basin (Rosner, 2000)

Mineral	Abundance
Quartz (SiO2), primary and secondary	70 - 90%
Muscovite and other phyllosilicates	10 - 30%
Pyrite	3 - 4%
Other sulphides	1 - 2%
Grains of primary minerals	1 - 2%
Uraniferous Kerogen	1%
Gold	approx. 45 ppm in the Vaal Reef

Some 70 different ore minerals have been identified in the conglomerates, the most abundant of which, after pyrite, are uranite (UO_2), brannerite (UTi_2O_6), arsenopyrite (FeAsS), cobaltite (CoAsS), galena (PbS), pyrrhotite (FeS), gerdofite (NiAsS) and chromite ($FeCr_2O_4$).

The table indicates that the mineralogical and chemical composition of the tailings bear close similarities with the composition of the conventional materials used for commercial brickmaking, as well as with the waste materials that have been tested in the past (see Table I). The results indicate that the major oxides in the mine tailings sample are silica, magnesium oxide, alumina, sulphur trioxide, potassium oxide, calcium oxide, and haematite. The other constituents such as uranium oxide are found in trace quantities. **Mine tailings** are the wet waste from processing gold-ore. The **Mine dumps** are discard from mining of the ore.

Table 2: Composition Mine tailings (Malatse & Ndlovu, 2015)

Table III

Major constituents of the gold mine tailings

Number	Component	Result (%)
1	Na_20	0.613
2	MgO	1.79
3	Al_2O_3	10.2
4	SiO_2	77.7
5	P_2O_3	0.085
6	SO_3	0.905
7	K_2O	1.19
8	CaO	1.93
9	TiO_2	0.469
10	Cr_2O_3	0.45
11	MnO	0.0549
12	Fe_2O_3	4.51
13	Co_2O_3	0.0063
14	NiO	0.0177
15	CuO	0.007
16	ZnO	0.008
17	As_2O_3	0.01
18	Pb_2O	0.0041
19	SrO	0.0151
20	ZrO_2	0.0312
21	U_3O_8	0.0064

Table 3: Composition Mine tailings and residues (GDARD, 2009)

	Vryheid[1] n=21	East Rand [1] Footprint soil n-45	West Rand[2] Tailings n=33	West Rand[2] Soil below TDF/Footprint n=22	West Rand [2]Wetlands (WCA)[3] n=19	Return water dams [2] n=12
pH	4.9-7.6	3.06-7.7	2.8-4.9	2.5-7.8	3.4-6.0	2.6-4.8
EC (mS/m)	12-126	165-912	182-843		16-1709	269-2569
Lime requirement (t/ha)	NA	0-82[2]	0-185	0-91	NA	NA
Radiation (Specific activity Bq/g)	-	-	-	0.01-4.738 (n=34199)	-	-
Sc (mg/kg)	8-18	1-41	0.01-0.05	-	-	-
V	34-106	31-937	0.25-137	12-137	8-85	-
Cr	80-223	97-622	14-124	7-563	22-227	-
Co	10-21	3-295	1-2.3	0.3-182	3-22	-
Ni	26-61	37-312	0.8-72	540	0-50	-
Cu	21-46	26-170	0-49	0-252	1-45	-
Zn	41-230	22-282	2.8-6.8	2.8-336	3.8-107	-
As	14-31	3-200	3.4-321	2.4-1348	1.0-134	-
Rb	50-97	43-129	-	-	-	-
Sr	22-102	13-89	-	-	-	-
Y	21-31	6-115	-	-	-	-
Zr	443-793	186-612	-	-	-	-
Nb	17-24	10-41	-	-	-	-
Mo	17-39	0-43	-	-	-	-
Sn	0-7	0-9	-	-	-	-
Sb	0-16	0-85	-	-	-	-
Ba	85-341	109-1696	-	-	-	-
W	6-14	3-12	-	-	-	-
Pb	3-33	0-118	1.4-41	5.4-521	0.09-134	-
Th	8-18	0-50	0.3-6.0	-	-	-
U	0	0-1175	1.37-23	1.04-234	0.63-7.55	0.12 - 301

Reference: -
1: Rosner et al (2001)
2: Van Deventer (2009b) (Personel files)
3: Hattingh et al (2003)

Although uranium oxide is present only at 0.0064% its presence is worth noting as uranium is a very radioactive element and therefore can present safety implications. Of concern is high levels of uranium related radiation (more than 4 time background in mine wastes, as well as water sources and areas that have used mining waste as fill ie road construction) For examples see Figure 1.

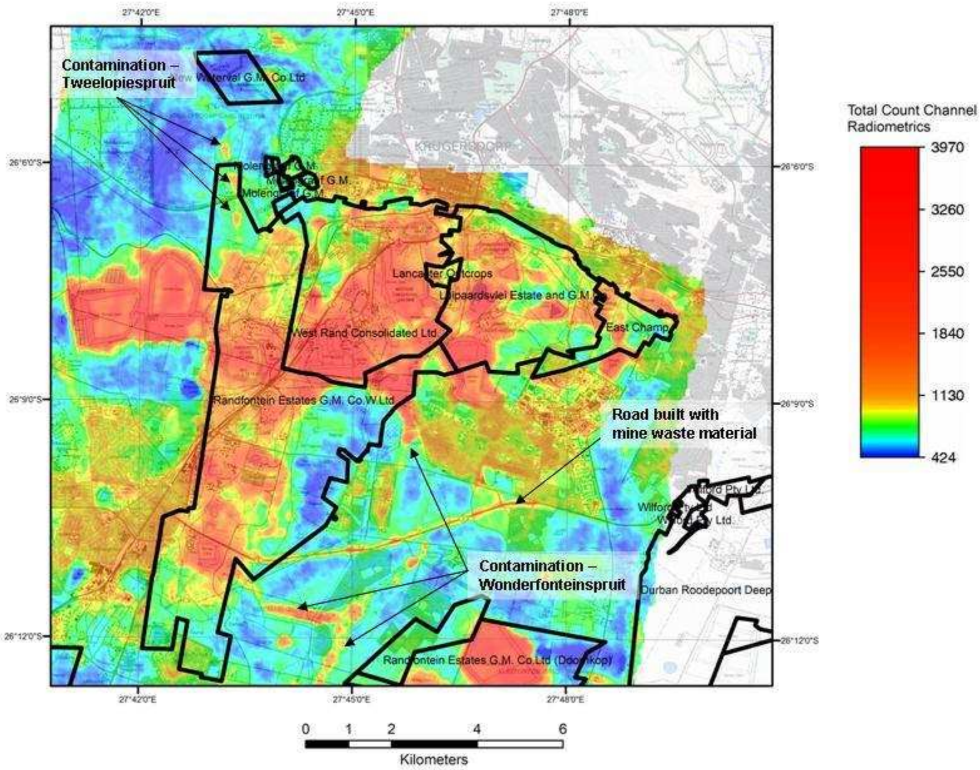


Figure 1 Uranium related radioactivity associated with the Wittwaterswand gold bearing ores (Stassen, 2015)**.**

The mineral extraction processes from past mining eras were not as efficient as those used today and often mineral prices have increased dramatically from the time the orebody was first mined. Therefore the tailings generated at these old mines often still contain payable values of mineral, especially the sand and slimes dumps at old Witwatersrand gold mines.'Dump reclamation' refers to the reprocessing of these dumps. Typically, the material in the old dump is monitored (sprayed with a very high-pressure jet of water which erodes the dump material away into a sluice). The sluice gravitates the dump material to a low point where it is collected and pumped, via a pipeline, to the treatment plant which could be located some distance away. Amalgamation was the principal gold recovery method used in South African gold mines at the start of mining in 1886. The gold-bearing ore was crushed to fine sand (typically about 10% minus 75 micron) in stamp mills, mixed with water to form a pulp, and passed over copper plates coated on their upper surface with mercury. Due to its high relative density, the gold sank through the pulp to contact with the mercury and was converted into amalgam. This amalgam (a solution of gold in mercury that took the form of a thick paste) was scraped off the plates, and retorted to yield a gold sponge. The tailings were transported to sand dumps near the processing plant. Tube mills were introduced in 1904 and this allowed the ore to be ground much finer (about 80% of material less than 75 micron) – thus forming slimes. In the period between 1904 and about 1946, both sand and slimes tailings were produced since different plants employed different processing routes. After 1946, all plants produced only slimes as tailings. As mining operations becoming deeper and the ore contained more pyrite, the mercury amalgamation method became less efficient since mercury reacts with sulphur, making it less selective towards gold. The cyanidation process was discovered in 1888 and introduced to the mines on the Witwatersrand in about 1890. This process involved treating the finely ground ore with a diluted solution (about 0.01 - 0.03%) of KCN or NaCN. Lime was added to the pulp to keep the pH above 10, the cyanide was added and the pulp was then allowed to oxidize by blowing air through the pulp whilst it was kept in large tanks. The gold in the pulp was dissolved by the cyanide. After about 16 hours, the pulp was filtered and the gold in the filtrate recovered by adding zinc powder to precipitate the gold. The gold-zinc powder was sent for smelting to recover the gold. The filter cake was re-pulped and pumped to tailings dams.

More modern gold recovery processes have since been introduced. The Carbon-in-Pulp (CIP) and Carbon-in-Leach (CIL) are currently widely employed in the gold industry. The CIP process was developed in South Africa by Mintek during the 1970s and is presently the most widely-used process due to its cost-effectiveness. The process uses activated carbon which is introduced into the gold-bearing pulp where the gold is absorbed into the carbon. The gold is recovered from the activated carbon using a hot aqueous caustic cyanide solution. Zinc cementation or electro-winning is finally employed to recover the gold from the from the leach solution. Uranium is present in the Witwatersrand quartz-pebble conglomerates in the form of uraninite (UO_2) or brannerite (UTi_2O_6) and is often associated with galena (PbS) in the ore. The first uranium extraction plant in South Africa was commissioned in 1952 and production of uranium increased rapidly until 1959 when there were 17 plants in operation. The market for uranium, however, declined and only recovered in the early 1970s when the oil crises made nuclear power generation an attractive option again. By 1980, South Africa produced more than 6000 tons of uranium annually. Uranium is extracted from the milled ore after gold recovery by sulfuric acid leaching under oxidising conditions. In the early uranium plants the leach liquor obtained after filtration was passed through ion-exchange resins to recover the uranium. The uranium was then eluted from the resin and precipitated with ammonia to yield ammonium diuranate (yellowcake). In later uranium plants, solvent extraction (Purlex process) replaced the ion exchange resins

2.1.2 Location and amounts of mining wastes

The Witwatersrand is by far the largest known repository of gold on earth, having yielded over 47 000 tonnes of gold between 1886 and 2002 (Figure 2.3), which represents between 33% and 40% of all gold ever produced, South Africa's peak annual gold production of close to 1 000 tonnes occurred in 1970. As illustrated in Figure 2-3, there has been an overall decline since then to a low of 394 tonne in 2002 and below 250 tonne in 2007. This decline is mainly the result of the increasing cost of extracting gold ores from deeper levels, the increasing cost of labour and the steady overall decline in the US$ price of gold. China has recently overtaken South Africa as the world's largest gold producer.

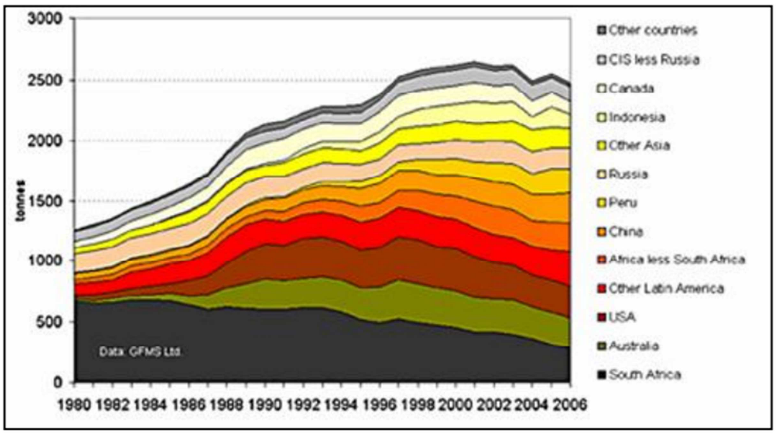
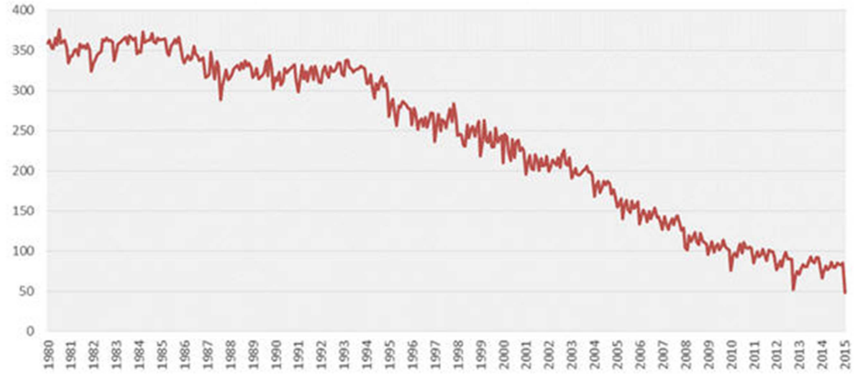


Figure 2-3: Estimated World gold production in tons (1990-2006)
(Source: Gold News, 2008)



Monthly gold production index, 1980-2015 (Base: 2010=100). Chart from Statistics South Africa.

Figure 2 Decline of gold mining (GDARD, 2008)
A Global gold production
B South Africa gold production

Mining waste is the largest waste stream in South Africa, by mass (Purnell, 2009 and DST, 2014). A large portion of mining waste is rock discard both from exploration activities (excavating access tunnels) and the processing metal rich ores and extraction of the metal. Therefore mining area and surrounding land impacted by mining is considerably larger than the above area that would be occupied by waste rock alone. These wastes and associated mining footprint are described as Mine Residue Areas (MRAs) and includes waste rock dumps, fine tailings disposal facilities (dams and dumps), waste spillage sites, water storage facilities (including return water dams), footprints, quarries, open cast mines and solid waste disposal sites GDARD (2012) (GDARD, 2009).

Between Randfontein and Nigel - the limits of the Witwatersrand - there are some 247 slimes dams and 95 sand/rock dumps.[13] Most of which falls either within, or directly adjacent to, CoJ boundaries. Of interest for the manufacture of Stone Paper are mine dumps and slimes dams (usually a combination thereof) that contain these waste rock and processed tailings. The settled dry density, and subsequently the specific volume, of ore deposits vary as a function of depth, but for general design purposes a material density of 1450 kg/m^3 is used[10]. Since the **Witwatersrand** gold rush in 1886 until 2007 a cumulative total of **50 877 tonnes (t) of gold has been extracted in the area[11], resulting in an estimated 6108 Megatonnes of ore milled between 1910 and 2007 (Appendix A).** The total volume of which amounts to 6108000000/1.45 = 4212413793m^3 (cubic meters). If that were equated to a single square dump with a flat height of 35 m and a slope angle of 37°, the length of each side would stretch for almost 11 km. The dump would cover a **total surface area of 119 km^2,** (11900ha) equivalent to more than 16 800 soccer fields and accounting for 0.7% of the total surface area of Gauteng.

However, mined waste rock from mining does not reside in a single consolidated dump and therefore occupies more land area. Also, mining waste has several fates:- dumps, slimes dams and backfill (returned to fill mine shaft and tunnels). A hazard assessment investigating different methods used to seal unused mine shafts, found that roughly 50% of shafts (that are closed) are closed by backfilling using milled waste rock, or more commonly de-slimed tailings[16]. However because of the increase in cost (9% of project capital expenditure) as a result of the significant amount of infrastructure required to backfill, many mines have opted for alternative methods of shaft closure. Of the mines that implemented this method, no more than 50% of the total mined material is used for backfilling[17]. It is therefore safe to assume that a maximum of 25% of extracted waste rock and tailings end up back underground.

Of the 6108 Megatonnes rock unearthed from mining the Witwatersrand during the mining history, ⅔ of this is within CoJ Municipality, and If 25% has been backfilled then then 3203 Megatonnes of mining wastes is available in CoJ as a stock sitting on the land surface from the mining over the last 100+ years.

In recent years large quantities of gold mine tailings has been reclaimed and re-processed to recover gold, uranium and pyrite from the tailings. The viability of re-processing tailings is based on the following factors:

- The price of gold and uranium
- The recovery efficiency of modern gold and uranium extraction processes
- The cost of reclamation and re-processing
- The value of the land which becomes available for development

It should be kept in mind that re-processing of slimes dams does not significantly reduce the tonnage of the tailings and that after re-processing, the final tailings has to be stored again. Usually this will be at a different site but the problem posed by the presence of tailings dams will not have been eliminated. There is furthermore the possibility that the ‘final’ tailings could be re-processed again at a future time should conditions make this a viable option. Re-processing of slimes dams have been practised in South Africa since 1977 when the first plant built specifically to re-process tailings was commissioned at the Blyvooruitzicht Gold Mine. The Chemwes, Merriespruit, ERGO and other similar operations followed.

At most of the operations re-processing tailings, material is recovered from slimes dams using high-pressure water hoses to re-pulp the slimes. The material is then pumped to the recovery plants where the gold, uranium and pyrite are recovered. The final waste material from the plants is thereafter pumped to new dump sites for storage. One advantage of recovering the pyrite, which is used in the manufacture of sulphuric acid, is that the acid mine drainage potential of the tailings is reduced. Hydraulic reclamation of a slimes dam is shown in Figure 3 and further details from Mintails in box.

Figure 3: Reclamation of a slimes dam for re-processing

...Mintails has about 100-million tonnes of tailings over a 25,000ha area, hard rock resources as well as two gold-processing plants and a water-treatment plant.
Old gold dumps, like the water that has been welling out of old mine workings since 2002 and spilling on the surface, are tainted with sulphuric acid, uranium and other heavy metals including

manganese, as well as iron.
The underground water and rain runoff from the dumps around Krugersdorp are leaking into rivers and streams, while the wind blows the fine sand off the dumps into surrounding settlements.
The government has put a partial solution in place on the West, East and Central Basins of the Witwatersrand, for the Trans Caledon Tunnel Authority (TCTA) to pump and neutralise some of the spillage, but a comprehensive treatment solution would cost billions of rand.
Mr Brune says Mintails is pursuing a "mine closure" strategy to clean up the land and treat acid mine water to a standard suitable for industrial or agricultural use.
It is extracting the gold from the tailings and flattening the land to make it fit for other uses. It is also extracting the gold from disused underground workings and shallow pits. After these operations, it will close off these areas so they are no longer accessible to illegal miners.
All this can be done only if there is an economic case for it, Mr Brune says. It also requires consultation: with communities and farmers, scientists, local district municipalities and government
The commercial incentive for extracting this gold from South Africa's mine dumps, many of which are more than 60-years old, may be the only way to mitigate job losses at deep-level mines where the cost of mining as deep as 3km below surface is fast becoming prohibitive. Companies like

Mintails currently has rights to mine about 120 million tons of surface tailings at its cluster of properties outside the West Rand town of Krugersdorp, as well as conduct opencast mining in an area roughly contiguous with the land on which its surface operations are situated. It also has a prospecting right over an additional 120 million tons of tailings in the Soweto area. Jacobs says this will allow the company to access sections of reef that were left un-mined in years gone by when exploiting higher-grade ore bodies was the more economically attractive option. Mintails also play an important role in reducing the likelihood that the cost of rehabilitating surface tailings could one day be shifted to the tax payer when traditional mining companies disappear…(depletion of the gold resource) (Mathews, 2014) (Mintails, 2012).

There are also **current and future flows of mining waste** that will continue until resource depletion. The United States Geological Survey conservatively estimates South-Africa's gold reserves at 6000 tonnes of **remaining recoverable resource** (RRR), although this is highly speculative as estimates range between 3000[11] and 10 000[14] t of RRR (gold) in South-Africa. Using 6000 tonnes RRR of gold, and an optimistic ore grade of 8.3 g/t, this would see the milling of at least another **722 megatonnes** (Mt), or 497 931 m^3 of ore. Following the current trend of mining, the estimated number of years to depletion for proven gold reserves in 2011 was 33 years- indicating depletion in 2044 with an average of 22 megatonnes per annum mined. This mining would see a projected loss of **another 15 km^2** (1500ha) of land that could have been developed (residential, agricultural or industrial) in the next thirty years. The actual figure will also be greatly dependant on mostly external factors such as the Rand-gold price, cost of labour and technological advances in deep robotic mining. Along with concerns about the cost and availability of already scarce resources like water and energy, the economic and environmental legacy costs of gold mining are escalating at an increased rate. The decline in gold production means that if the trend continues the ore tonnage milled is predicted will reach zero soon after 2020, about the same time that the average ore grade may be forecast to reach around 3 g/t[11]. According to Statistics SA gold production in South-Africa was down 5.9% between Dec 2014 and Feb 2015[15]. Depending on the gold price at that time, such a relatively low ore grade could mean that excavation and extraction is no longer profitable. From Figure 4 it is clear that the drop is not a blip but rather indicative of a larger (non-linear) trend spanning several decades..This trend proposes two contrasting outcomes: either technological advancements in deep robotic mining and ore cutting techniques will develop sufficiently fast to save the mining-industry in Witwatersrand, or the lack of economically recoverable gold will necessitate the re-mining of old dumps and especially dams. Each case providing a unique set of benefits and disadvantages to the proposed manufacture of Stone Paper. Depending on the gold price at the time and available technology it could then prove profitable for mines to re-work existing dumps and tailings dams, which typically contain around 0.3 g/t of residual gold. In this case the additional income from stone paper (along with cost saving from rehabilitation) to company revenue could mean the difference between economic viability and mine closure.

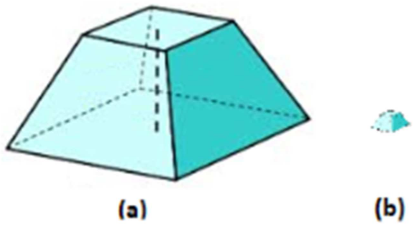


Figure 4: Theoretical estimates of amount of waste rock from mining the Witwatersrand. (a) Volume of gold ore mined to date and theoretical area occupied (single dump and without considering backfill, slimes dams and other uses of rock waste):- **6108 Megatonnes - occupying 119 km^2** (b) remaining gold ore to be mined until depletion:-**722 Megatonnes - further occupying 15 km^2**.

There are three sources or types of waste and tailings from gold mining operations namely waste rock, sand tailings and slimes tailings. Waste rock originates from shaft sinking operations as well as off-reef development. In addition, un-crushed or partly crushed rock arises from sorting operations in the processing plant. The rock is transported by conveyor belt to a rock stockpile, usually in close vicinity to the shaft. A typical rock dump is shown in Figure 5.

Figure 5: Rock dump at a gold mine

The rock dumps is generally considered not to contain gold and as such, some of the rock is crushed for use as aggregate in the civil engineering industry as well as for use as railway ballast or road fill. There are however, always exceptions to this and some rock dumps can contain gold as the result of errors in tramming or sorting. At one gold mine in the Carltonville area, gold is recovered from such a rock stockpile. The second type of tailings is sand heaps that were deposited in the earlier days when sand processing of the ground ore was practised. These heaps are typical of the ones seen around Johannesburg. Figure 6 shows the sand heap on which the Top-Star drive-in cinema used to be in the process of being reclaimed.

Figure 6: Sand heap gold mine tailings

The third, and probably most abundant, type of tailings is slimes dams. Slimes dams have been constructed to dispose the tailings from gold processing plants especially since the 1940's when the all-slimes type of gold ore processing came into use. The dams were constructed using a daywall-nightpan paddock method. This method enabled the complete dam structure to be built from tailings and is based on dividing the impoundment into two sections namely the embankment or daywall and the interior or nightpan. During the day, slurry is delivered into the daywall section where the coarser material settles out close to the wall whilst the more dilute material overflows into the nightpan. The settled material is then removed by shovel and placed onto the outer wall – thus raising the level of the wall. During the night, slurry is delivered into the nightpan. Supernatant water is drawn off using penstocks and returned to the processing plant. In later years, hydro-cyclones were employed to separate the slurry into a coarser and finer fraction with the coarser fraction being placed directly onto the daywall and the cyclone overflow being directed into the nightpan. Figure 7 shows a typical slimes dam and construction of a dam using cyclones is shown in Figure 8. The composition and size analysis of tailings from different areas will vary as a result of the differing geology and history of the tailings. Some tailings heaps and dams have also been used as disposal areas for municipal waste, abattoir effluents and sewage plant effluents in the past. In an effort to reduce dust pollution from tailings heaps and slimes dams some of these dams and heaps have been vegetated or covered with broken rock.

Figure 7: Slimes dam

Figure 8: Slimes dam construction using a hydro-cyclone

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Map showing below shows the locations of the Mine Residue Areas (MRA's) the City of Johannesburg Metro

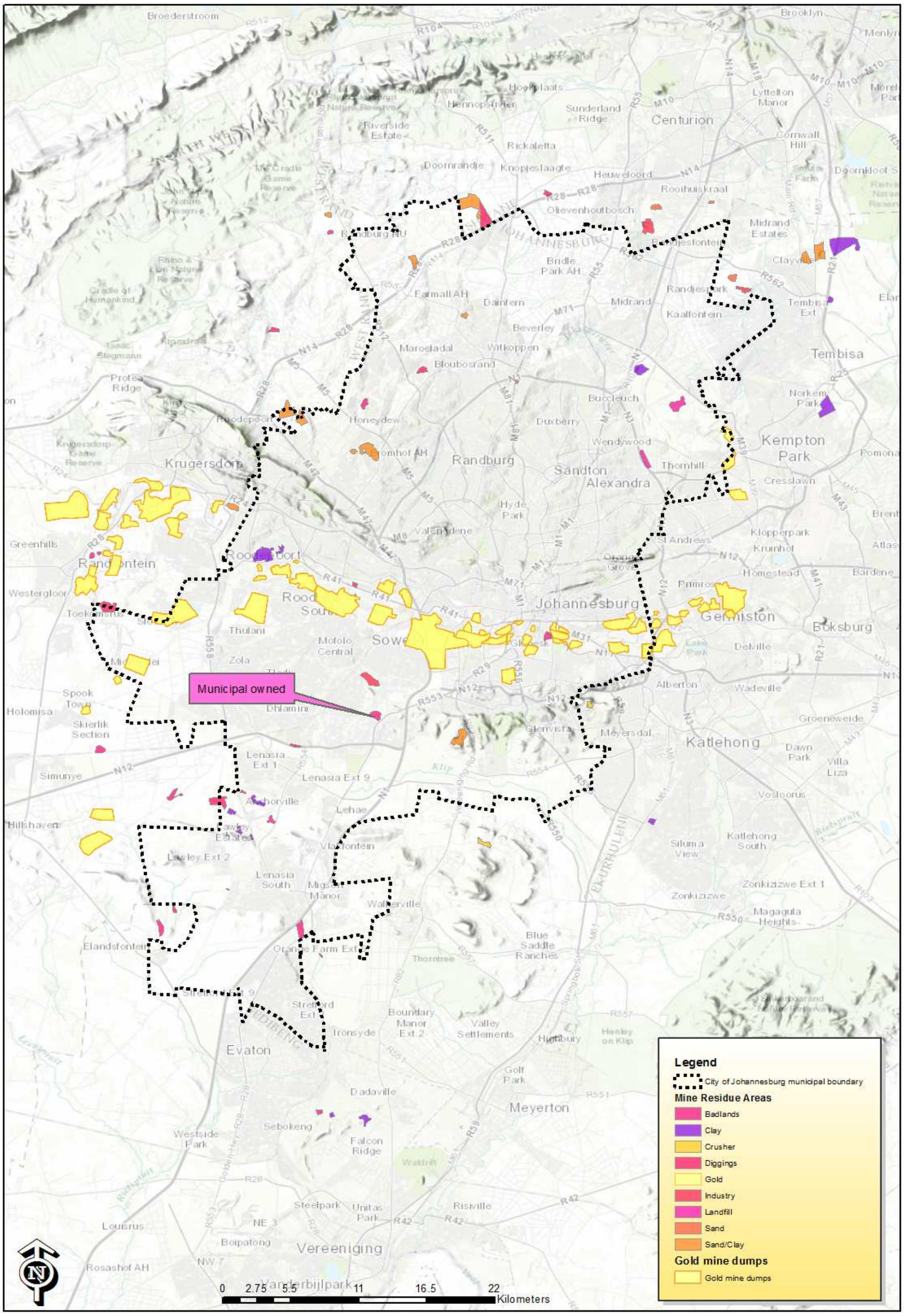


Figure 9: Map showing locations of the MRA's in City of Johannesburg Metro

The table below shows the type of MRA, the count of each type, the area (in square meters) and percentage of each of the MRA types that are located inside the City of Johannesburg Municipality. As shown in Table 4 7over 70% are gold mining

Table 4: MRAs in CoJ Metro

MRA Type	MRA Type Count	Area (sqm)	% of Total MRA
Badlands	8	2071753	3.6
Clay	9	2844864	4.9
Diggings	4	1928890	3.3
Gold	26	36157035	62.7
Gold (RM)	8	5683852	9.9
Gold(Indus)	2	1144902	2.0
Indus	2	779046	1.4
Landfill	2	1224167	2.1
Sand	1	45232	0.1
Sand/Clay	8	5758974	10.0
Total	**70**	**57638715**	**100**

The map in Figure 9 and table 4 below shows location, the area (in square meters) as well as the estimated average base and top height of some of the mine dumps that are predominant and visible on satellite imagery in the City of Johannesburg. The averages was calculated by moving the cursor around the base and top of the mine dumps and making an estimate of values that was observed in Google Earth. The total area works out to 57,638,715 square meters, or 5764 hectares.

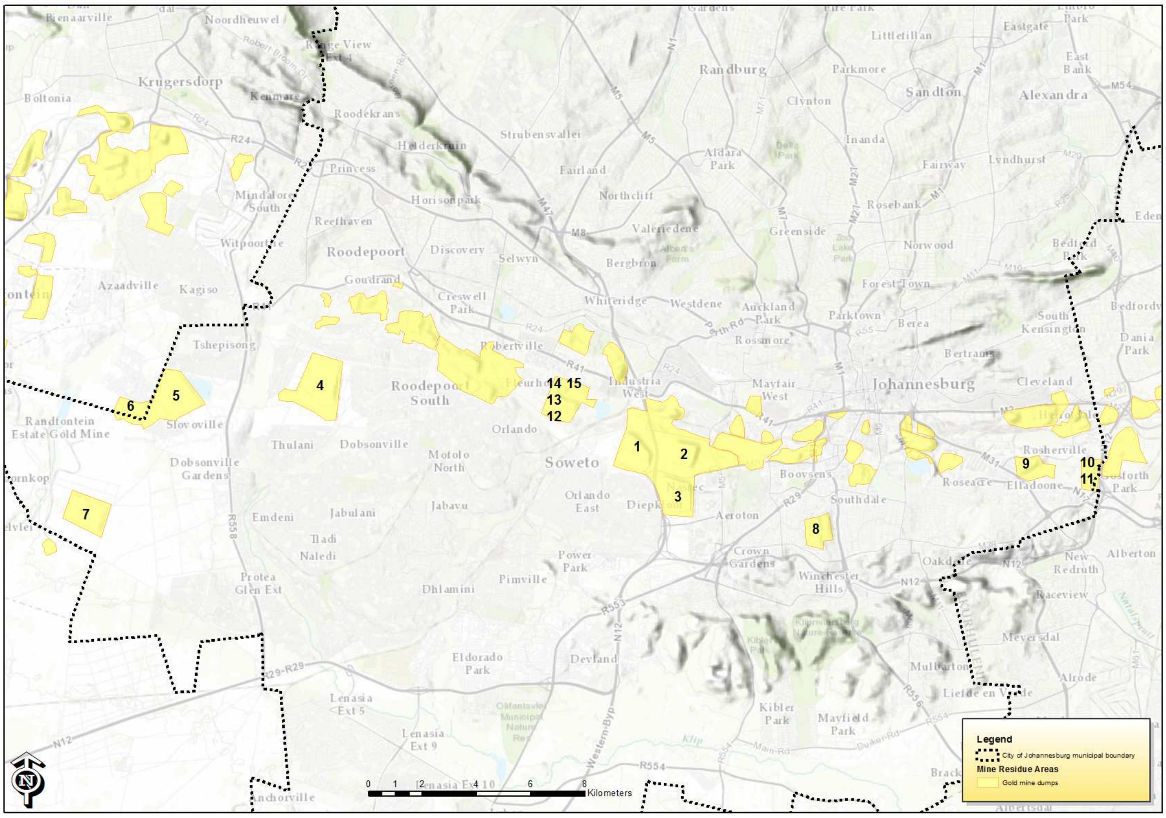


Figure 10 Main gold mining dumps in CoJ Metro

Table 4 Area occupied and amount of rock waste in Main gold mining dumps in CoJ Metro

No.	Area (sqm)	Mass of rock waste in mine dump* (tonnes)	Avg height of base	Avg height of top	Avg height of mine dump
1	1354941	47 500 000	1696	1730	34
2	441108	15 470 000	1686	1731	45
3	1317985	46 210 000	1698	1750	52
4	2235101	78 360 000	1684	1712	28
5	1697849	59 530 000	1670	1682	12
6	409125	14 340 000	1670	1684	14
7	1496264	52 460 000	1624	1649	25
8	944510	33 110 000	1749	1780	31
9	314550	11 030 000	1670	1694	24
10	202072	7 085 000	1648	1655	7
11	181088	6 349 000	1637	1643	6
12	187456	6 572 000	1666	1698	32
13	393920	13 810 000	1682	1701	19

14	151333	5 306 000	1680	1710	30
15	106750	3 743 000	1672	1696	24
Total Area	**11434052**	**400 875 000**			
TOTAL 11.4 km^2 or 1143ha land occupied by these MAJOR mine dry dumps in CoJ with 400 Megatonnes (calculated sing total area and average height and assume square with 1.45t/m^3 density).					

2.1 Builders rubble

2.2.1 Composition of builders rubble

Builders rubble presents a significant proportion of waste going to landfill in South Africa. Construction and demolition waste makes up 20% by mass of general waste (i.e. all waste other than hazardous and unclassified waste; excluding biomass from industrial sources) generated in South Africa. Of this, only 16% is recycled, with the rest (approximately 4 millions tonnes per annum across South Africa) going to landfill. In Gauteng specifically, builders rubble makes up 20% of municipal waste generated; and in Johannesburg, 13% (DEA, 2012).

With respect to builder's rubble, CoJ and Pikitup (the City's designated waste management service provider) have two strategic objectives, namely to reduce illegal dumping of builders' rubble (builders' rubble constitutes the bulk share of illegally dumped waste in COJ (REF: CoJ IWMP 2011), and to divert builders' rubble from landfill sites, i.e. to reduce the quantity of builders' rubble disposed at landfill sites (REF: Pikitup Business Plan 2015/16). While a certain amount of builders' rubble (provided it is sufficiently fine and uncontaminated) can be used as a daily cover material at the landfill sites, not all builders' rubble (e.g. materials that are contaminated or too bulky) is suitable for this purpose (REF: CoJ IWMP 2011). Builders' rubble disposed at landfill sites which is unsuitable or exceeds the quantities required as a cover material therefore takes up valuable landfill airspace and decreases the lifespan of existing landfills. At the same time, some components of builder's rubble contain materials that can be used as resources in other manufacturing processes (such as stone paper production), thereby potentially displacing virgin materials. Building and demolition waste includes the excess material produced during construction, renovation, and demolition of buildings and structures. Building and demolition waste is generated when new structures are built, existing structures are altered or demolished, when existing structures collapse due to natural causes such as ground movement or unnatural causes such as explosions (GDACE, 2009). Fittings such as partitions, frames, light fittings, ceilings, etc., are included in the classification of building and demolition waste, as is the soil aggregate displaced from building foundations and tunnelling activities.

Figure 11 Examples of Builders Rubble

Builders' rubble typically refers to the non-combustible portion of this waste stream including:

- bricks
- concrete
- rocks
- soils

Building and demolition waste streams may therefore include the following:

  - aluminum
  - asbestos
  - asphalt
  - bricks
  - concrete
  - corrugated cardboard
  - drywall (interior wall paneling),
  - glass
  - lumber (or timber)
  - insulation
  - masonry
  - plastics
  - rocks
  - roofing materials
  - soil
  - steel

2.2.2 Location and amounts of builders rubble

Builders' rubble is collected as part of the bulk container service offered by Pikitup and some private companies. Pikitup also provide skips at garden sites where the public can drop-off wheelbarrow loads of builders' rubble free of charge (Pikitup, 2007). Some builders' rubble, although relatively small quantities, still finds its way into the household waste stream. Illegal dumping of builders' rubble is a problem in certain parts the City. Cleared illegally dumped waste is also disposed of at landfill.

Clean, uncontaminated builders' rubble is accepted free of charge at the landfills, if it is suitable for use as cover material. Mixed builders' rubble is also accepted, but the normal disposal fee applies. Pikitup does not have accurate data on the tonnages of builders' rubble disposed of at their landfills due to weighbridges at all landfills not being fully operational. The Robinson Deep landfill, which is the busiest landfill in the City of Johannesburg, is a case in point where the weighbridge has not been functional since 2013 (City of Johannesburg, Pers. Com. 2016). In 2011 the total remaining volume of all four active landfill sites in CoJ was 13 606 750 m^3, expected to reach capacity by 2019. This incoming stream of waste consists of 13% builders rubble amounting to 1 769 000 m^3 of usable resource and at least 2 476 000 m^3 of additional airspace (using compaction ratio of 1.4). According to the (CoJ IWMP 2011), one hectare of land is needed for every 300 000 m^3 of waste. Effectively this means that 22.5 ha of the 171.8 ha of land used by 2019 will be required specifically for builder's rubble. Assuming a density similar to that of mine waste rock and 100% usability, this rubble could have been used to produce 9.714 Mt of stone paper while reducing landfill deposit in the process. At the current rate of landfill in CoJ, 221 110 m^3/year of builders rubble, repurposing it to manufacture stone paper could supply an estimated 320 000 tonnes of raw material, and reduce land required for landfill by 0.75 ha annually.

Illegal dumping refers to waste that is dumped indiscriminately by the public in areas that are not earmarked for drop-off or disposal of waste. Illegal dumping is cleared by Pikitup or its appointed contractors and taken to landfill for disposal. The composition of this waste stream is variable depending on the area from which the waste is cleared and the season. The general consensus when discussing illegal waste with Pikitup officials (Pers. Comm., Komane and Loggerenberg, 2014) seems to be that in the built up areas this consists mostly of garden waste, while in the peripheral areas, this consists mostly of builder's rubble. Samples of illegal dumping from the Johannesburg Central Business District (CBD) (served by Selby depot), Alexandra Township (served by Marlboro depot) and Bosmont (served by Waterval depot) were analysed during the waste characterisation study (CoJ, 2015). The waste composition of the illegally dumped waste were largely miscellaneous non-combustible waste i.e. rubble (28.25%), wood waste (11.27%), and textiles and footwear waste (8.95%)

Map in Figure 12 shows locations of of landfill sites accepting builders rubble to be dumped. Some garden waste drop-off sites (12 of the 48 garden sites operated by Pikitup), accept wheel barrow loads of builder's rubble dropped-off by the public (Pikitup, 2007). The waste disposal figures by landfill as reported in the *Feasibility study for builders' rubble crushing* (Pikitup, 2007) are provided in Table 5.

Table 5 Amounts of builders rubble as reported in the Integrated Waste Management plan for 2007 (CoJ, 2011) (A) and projected to 2022 (B)

A					
Summary (2006/7) (Tonnes/year)	Ennerdale	Goudkoppies	Marie Louise	Robinson Deep	Totals
Cover (no charge)	1 703	9 543	99 879	41 577	152 702
Builders' rubble (Depots)	13	3 601	-	3 260	6 874
Builders' rubble from illegal dumping*	22 306	14 166	-	1 468	37 939
Total	24 022	27 310	99 879	46 305	197 515

Total available for stone paper (excludes portion used for cover material)	**22 319**	**17 767**	**0**	**4 728**	**44 813**

B

WASTE CATEGORY	ANNUAL GROWTH RATE %	TOTAL MASS (ton/month)	TOTAL WASTE GENERATED (1 000 ton/year)					
			2006	2008	2010	2012	2017	2022
General	4.1	84665.1	1 016	1 101	1 193	1 293	1 581	1 932
Builders Rubble	4.1	16237.1	195	211	229	248	303	370
Garden waste	4.1	15077.3	181	1 196	212	230	281	344
Recycling material	4.1	301.5	3.6	3.9	4.2	4.6	5.6	6.8
TOTAL	4.1	116281.2	1 395	1 512	1 639	1 776	2 170	2 654

Source: Pikitup, 2007a

*Illegal dumping is waste cleared from illegal dumping areas contributing 16.5% of total CoJ waste. The 134 298 tonnes per annum of illegally dumped waste and the amount of builders rubble in the illegally dumped waste is estimated to be 28%.)

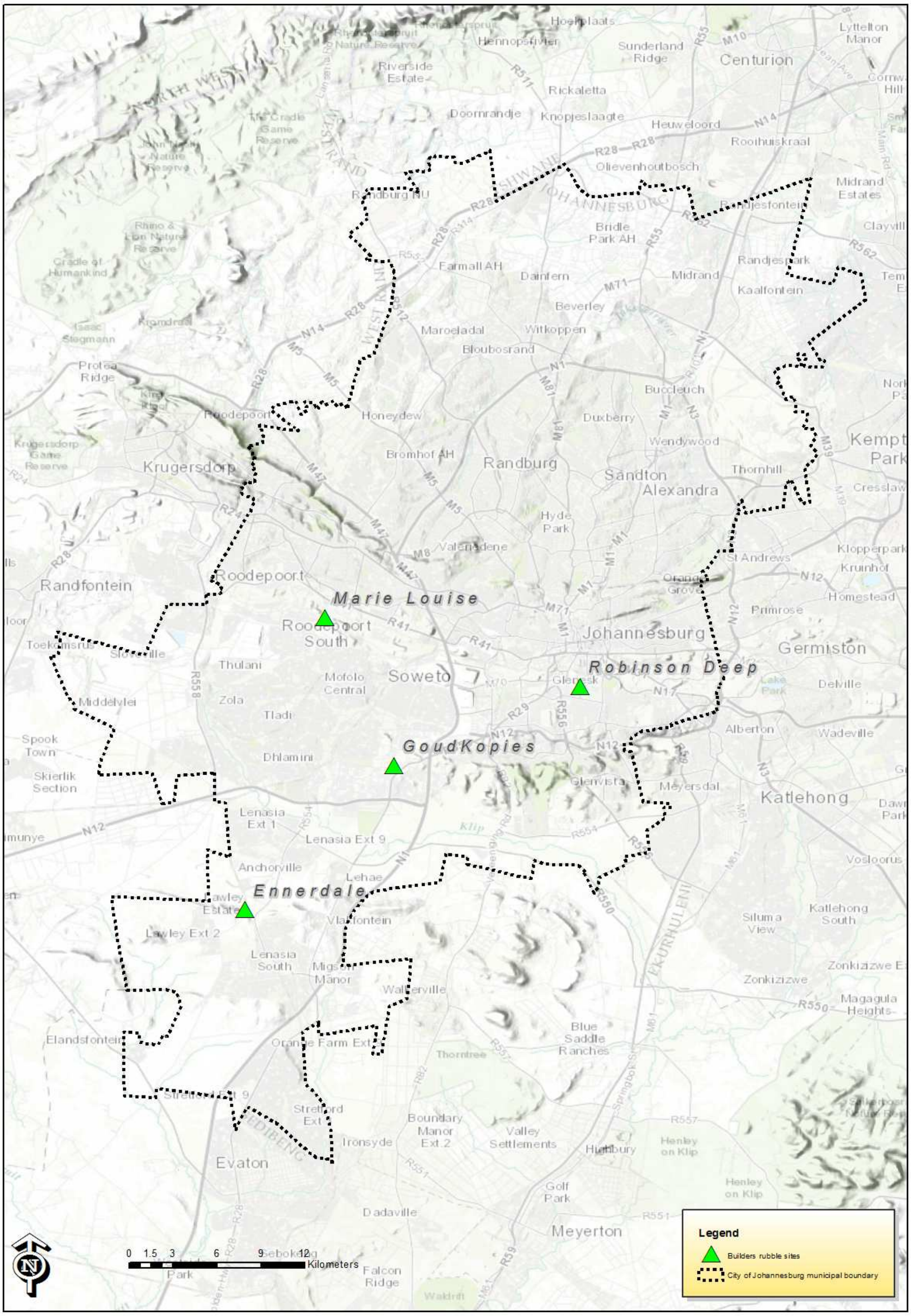


Figure 12 map of landfill sites where Builders Rubble is disposed of

Crushing of builders' rubble is common practice to enhance the usability of the material as aggregates in the building industry, road building and as cover material at landfills. There are reports of crushing of builders' in the City of Johannesburg which is discussed in more detail below According to the feasibility study report for the Pikitup Builders' rubble crushing plant (Pikitup, 2007), there are a number of builders' rubble crushing operations active in Johannesburg. These operations are all reported to make use of mobile crushing plants and the crushed material is sent to landfill (Pikitup, 2007). A list of the companies that were contacted during the feasibility study is provided in Table 4.

Table 6| Companies involved in builders' rubble crushing in Johannesburg (adapted from Pikitup, 2007)

Company	Waste (tonnes/annum)	Description
Blue Rainbow Consulting	Unknown	Sent to landfill
Bradis	Unknown	Sent to landfill
Concrete cutting and drilling	Unknown	Big concrete blocks
Jet Demolition	Unknown	Particle size 12x8; 36x24 and 46x32 inch
M&M Plant hire	Unknown	Sent to landfill
Murphy Demolition	100 000* (estimate)	G5 as base material in road works
Reharvest - a Subsidiary of Davies Civils	220 000***	As G5 material provided to Davies Civils for construction
Steirer Bruch	365 000*	G5 and fill material (generally used on demolition site for levelling and new construction, however excess G5 material may be sold as Road Works material).
Skip Waste	30 000**	As G5 base material in Road Works.
Waste Giant	120 000*	G5 (Road works) and fill material
Wreckers Group	Unknown	Fill material on own sites.

*Builders rubble feed density 1 tonne/m^3

** Builders rubble post-crushing density 1.6 tonnes/m^3

***Builders rubble post crushing density taken as 1.4 tonnes/m

According to the Gauteng Provincial Building and Demolition Waste Guidelines, crushed rubble can be used for the following purposes (GDACE, 2009) taht may compete with rubble for Stone paper

Bricks

- Landfill cover material
- Berms in landfills to give structural strength to cells
- Cell cover once a cell is filled
- To provide paved and firm tipping and loading zones, particularly during rainy conditions at landfills

Concrete

- Fill on construction sites
- Aggregate for new ready-mix
- Granular sub-base layers in road pavement construction
- Drainage
- Excavation fill applications (on or off-site)
- Waterway applications
- Used as riprap, i.e. large pieces of rock or other material used along the bank as foundation
- Geotechnical applications
- Permanent, erosion-resistant, ground cover of large, loose, angular stone with filter, facric or geotextile underlining.

3. STONE PAPER TECHNOLOGY

3.1 Existing Stone paper production

The primary ingredient in stone paper is Calcium Carbonate ($CaCO_3$), one of the most common elements on earth, and the principle component in many types of stone, including limestone and marble. Stone Paper products can be made from any crushed stone powder, combined with a non-toxic and recyclable binding agent HDPE (High Density Polyethylene). No tree fibre. Depending on the application, stone paper comprises up to 80% calcium carbonate. Stone Paper is made using a patented paper making technology that does not use water or create air pollution. No chlorine or acids are utilized in the production process, and the resulting stone paper is completely non-toxic, and is even food safe (Nivirana Canada).

The creation of water repellent paper that requires neither tree fibres nor water is a breakthrough. However, this redesign of paper is accompanied by an innovative and yet highly standardized production process that permits the manufacturing of 17 custom designed paper types coated to the client's specifications. This offers unique opportunities to create more value and take market share while generating jobs. The starting point is the supply of rocks. While calcium carbonate rich stones are the reference, it is possible to use a wide variety of mineral sources provided that the input material meets the standard size of fine dust (Pauli, 2014). The stone paper rolls or sheets are delivered to "converter" companies that produce notebooks, paper bags, golf score cards, children's books, packaging and wrapping paper even humidifiers and medicine boxes. While the factory in Benxi City (near Shenyang) starts with a production capacity of 120000 tonne/year, it is set to increase to one million ton, good for one thousand jobs. The downstream job generation in bags and notebooks is a multiple compared to production of the paper itself demonstrating the potential of transforming mining and construction waste into a product that saves the forest, frees up land for farming and liberates millions of tons of water for productive use while adding value to society (Pauli, 2014).

It can be recycled to make new Stone Paper or other plastic products such as lumber, furniture, or receptacle bins. FiberStone Paper can also be recycled in the building & construction industry, waste treatment, steel manufacturing, farming, and glass making. Stone paper can be used to substitute traditional papers used in the printing industry, such as Synthetic Paper & Film, Premium Coated Paper, Recycled Paper, and PVC Sheet. Being impervious to water it can also be very useful for outdoor applications. Stone paper is photodegradable after a period of about 14-18 months.

Table 7 Some notable Stone paper suppliers and equipment

Taiwan Lung Meng	http://www.taiwanlm.com/
Rockstock	http://www.stonepaper.co.nz/about-rockstock
Stone age packaging	http://www.stoneagepack.com/about-us/
Terraskin	http://www.terraskin.com/
Nustonepaper	http://www.nustonepaper.com/
Solizstonepaper	http://www.solizstonepaper.com/en.html
Paperontherocks	http://paperontherocks.com/
Yasutomo	http://www.yasutomo.com/index.php?option=com_content&view=article&id=167:mineral-paper&catid=49:product-reviews

The type of equipment:
**Stone crushers and mills
http://beckerce.org/products/mtm130x-series-strengthened-ultrafine-mill.html

**Paper production machine
http://suzhoucmt.en.made-in-china.com/product/LXTxeqcdXkWn/China-Stone-Paper-Production-Line-Project.html

US $3000000.0 / Piece
I. Outline
1.Usage condition 380V/3P/50Hz
2.Suitable material Pe+CaCO3
3.Finished sheet specification L=1400mm, T=0.15-0.4mm
4.Extrusion capacity 550Kg/h
5. Designed line speed 50m/min

II. Equipments:
1. High torque single screw extruder
2. Screen changer (hydraulic station included)
3. T-Die
4. three roll calander and temperature control system
5. preheating rollers group
6. set MDO longitudinal stretching system
7. cooling and back fire system
8. cooling system and edge cut
9. thickness gauge
10.set rotational winder with double position
11.electrical cabinet
12.other auxiliary machine
13.spare parts

III. technical details

1. 130/38 High torque single screw extruder	Specification
Material	38CrMoAIA
nitrided thickness	0.5-0.7mm
screw hardness	HV≥740
barrel hardness	HV≥940
screw diameter	130mm
L/D ratio	38:1
barrel heating method	ceramic heating
Screw structure	Suitable for olefin polymer
Heating zone	7 zones
heating power	around 60KW
cooling methods	fan cooling
fan power	0.55KW
barrel cover	stainless steel
temperature gauge	hermocouple
Driving system	
Motor type	DC motor
Motor power	220KW
gear type	helical gear
heat treatment	grinded gear
Connection type	direct connection(use elastic coupling)

Rotate speed	0-93rpm
venting system	
vacuum pump	water ring
Power	11KW
Vacuum tank	Double tank, interchangeable
Hopper	Stainless steel

2. Screen Changer

Screen changer brand

Motor	Hydraulic station equipped, max pressure16Mpa
Screen type	double column double position
Screen diameter	150mm
Acceptable melt pressure	≤40Mpa
Heating method	Stainless steel heating stick

:

**.Printing on stone paper

3.2 Potential scale of operations relative to the resource

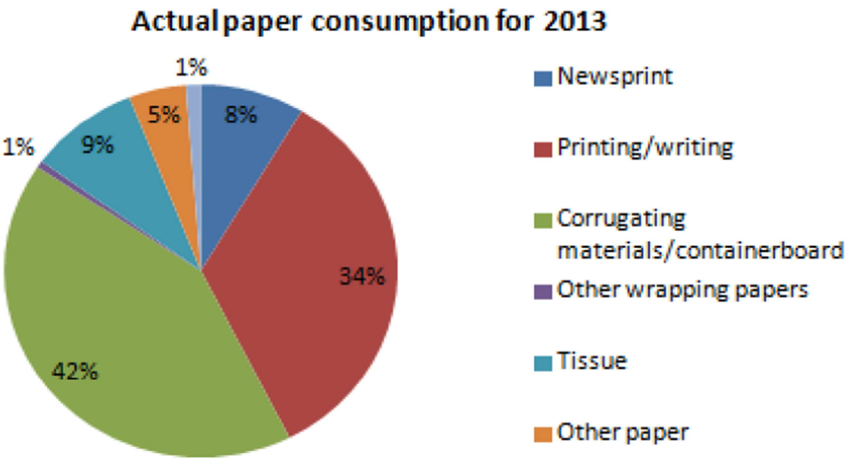
The investment cost of equipment is estimated at $150 million (about R2 Billion), 40% less than a traditional paper plant for equivalent volume (120000 tonne/year). The reason for this considerable reduction of capital requirements is due to the fact that neither water nor water treatment is needed. This subsequently reduces energy demand. In addition, the cost of pulp is replaced by a low cost crushed stone seldom costing more than $200/tonne (about R2, 4 million/tonne). However, it must be pointed out that virgin PE costs $1,500/tonne (about 3 million/tonne) which is double the fibre cost. Since the percentage of PE can range from 20-40%, the overall cost of raw materials by weight can be up to 40% lower than standard fibre-based paper (Pauli, 2014). The crushing installation valued at a capital investment of $10 million (about R160 million) provides a core material transported through a pipeline to avoid the generation of dust at the pellet production unit. The stone dust is mixed with 20% polyethylene (PE), today a virgin material to be replaced by a recycled PE, and ultimately by a bio-based PE generating more value for the local farmers and creating a higher impact in the region that now can reconnect farming and mining with industrial production (Pauli, 2014). All technologies and copyrights belong to Lung Meng Technologies. The Benxi plant with the stone dust supply pipe to 3 production units and converter to the left Raw materials: stones delivered from a mine 13km away Pellet production Stone paper production The pellets are fed to the paper film production. A battery of 17 different paper types with a weight varying from 80 to 800 microns in thickness, and a stone content of maximum 80% and as low as 60% is then processed through one of the 4 coating machines into dozens of final products. The coating adds maximum 2% material offering colour and printing specifications with combinations of one or double sided treatment ensuring compliance with nearly all clients' requirements at short notice. Thus a standard stone pellet can be converted into over 50 different paper types (Pauli, 2014).

While the factory in Benxi City (near Shenyang) has a production capacity of 120000 tonnes per annum, small Stone paper manufacturing plants could be as small as 4380 tonnes per annum (0.5 tonnes per hour), so can have modular units depending on waste rock/rubble resources (ZERI, 2014). The plastic HDPE or PET is also a required resource for Stone paper. Instead of using virgin PE, recycled PE and PET should be used. There is a total of 1.6 million tonnes/annum of household waste is generated in the CoJ. From limited data available, the HDPE and PET component of the household waste stream in CoJ varies across seasons with approx. 1-1.5 % each present ie 15 000 HDPE and 25 000 tonnes per annum PET. Assuming at least 30% can be recycled and is available for Stone paper, then 4500 tonnes is available. Since it is used at at 20% in Stone paper, this will support 22500 tonnes per annum Stone paper production facility

3.3 Market potential and appropriate market share

The SA demand and current consumption of paper is 2532254 tonnes per annum and nearly half is packaging paper (Figure 13). SA *imports* 13% of paper packaging material. If locally made stone paper displaces **these packaging paper imports, 141 335 tonnes per annum of Stone paper will be produced, while also increasing CoJ manufacturing skills and stimulating local economic development**.

Pie chart representation of consumption of 2,532,244 tons by category



Paper production and consumption

All values in metric tons	Paper Production	Paper Imports	Paper Exports	Paper Consumption
Newsprint	241 722	16 140	40 756	217 107
Printing/writing	498 571	585 510	223 049	861 032
Corrugating materials/containerboard	1 197 699	141 355	279 861	1 059 193
Other wrapping papers	15 411			15 411
Tissue	221 656	22 370	14 651	229 374
Other paper	111 995	59 254	52 251	118 998
Board	31 129			31 129
Total	**2 318 183**	**824 629**	**610 568**	**2 532 244**

Figure 13 Paper production and consumption in SA (PAMSA, 2013)

3.4 Indicative costs and investment needed for stone paper production

Ozdemir et al. (2013) have investigated the costs associate with traditional paper production (system 1) in comparison with stone paper production (system 2), in terms of initial system investment and total maintenance and operating costs. Their analysis is based on a production capacity of **23100 tonnes of paper per year (**see Table 8).

Table 8. Indicative costs of a small to medium size paper plant: System 1 Ordinary tree paper, System 2 Stone paper

	System 1	System 2
Initial investment, $		
Machine and equipment	11,500,000	1,500,000
Transportation and insurance cost	55,000	55,000
Assembly cost	80,000	-
Total	***11,635,000***	***1,555,000***
Annual Maintenance and operating cost, $ per year		
Raw material cost	6,000,000	10,500,000
Other material cost	2,300,000	
Water and electricity	8,675,000	2,800,000
Workforce cost	550,000	400,000
Maintenance cost	100,000	55,000
General expenses	180,000	140,000
Marketing and sales expenses	400,000	400,000
Packaging cost	300,000	300,000
Total	***18,505,000***	***14,595,000***
Life, years	30	30

Source: Ozdemir et al. (2013)

3.5 Environmental impacts of Stone paper production

Research has been undertaken on the life cycle comparison of stone and conventional pulp and paper production, although little is reported in available literature. The LCA study of Bjørn and Hauschild (2012) focussed on the graphic and packaging paper products of TerraSkin (www.terraskin.com), using the ISO 14040 and 14044 standards. These products were compared with two graphic cellulose-based paper products - Light Weight Coated (LWC) and Supercalendred (SC) - and two packaging cellulose-based paper products - bleached and un-bleached kraft paper. The functional unit, for the comparison, was 1 m^2 of paper with a thickness of 0.1 mm. The characteristics of the respective products are similar, although it is noted that different masses will be required to meet the functional unit; for example, 80g and 120g for LWC and stone paper respectively. The life cycle systems are illustrated in Figure x.

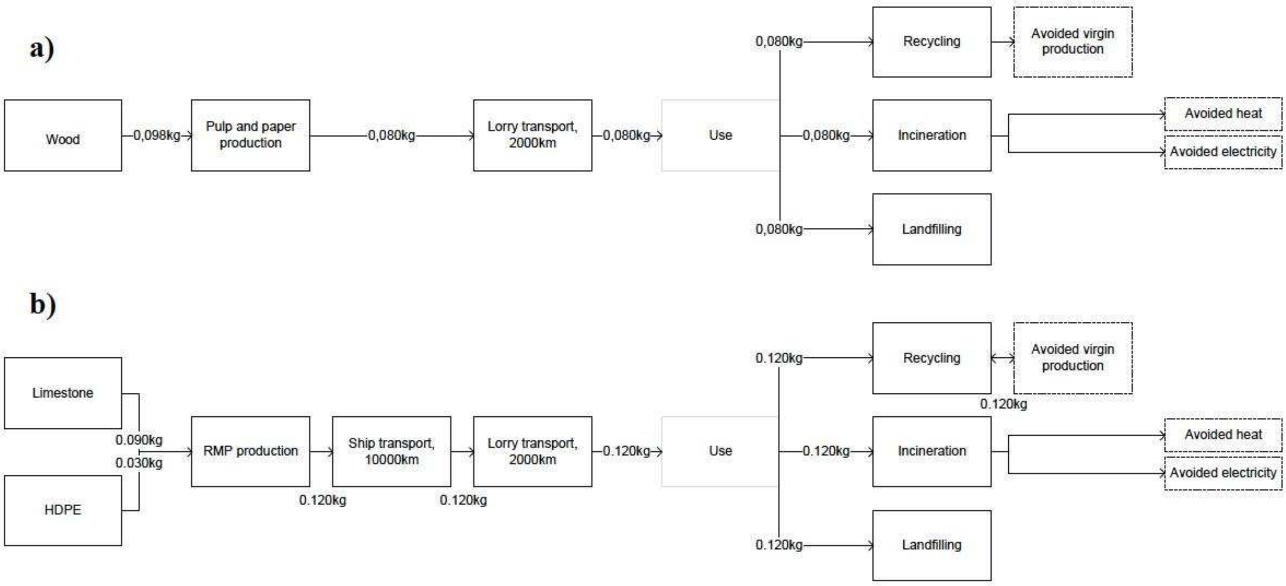


Figure 14. The two product systems: a) cellulose-based paper (LWC), b) comparable TerraSkin product Source: Bjørn and Hauschild (2012)

The use phase was not included in the analysis. In the South African context ship transportation will not be relevant, since the production of stone paper will be for local consumption. If it is assumed that the majority of the product will be consumed close to production, in other words in and around the Gauteng Province, then the impact of road transportation will also be less. With respect to the end-of-life, incineration is not an option, and therefore only landfill and recycling can be considered. In terms of the latter, and given the current infrastructure and relatively small and distributed market, recycling will, in all likelihood, not be an option in the near future. The producers of stone paper claim that their product is photodegradable. However, only slight degradation has been reported (Arutchelvi et al., 2008) and, thus, for the landfilling option, it is expected that the HDPE component of the stone paper will remain in tact. The environmental profiles of the energy consumption will also differ in the South African context. These, and other, differences need to be considered when interpreting the results, although the trends, when comparing stone and traditional paper products, should be similar; see Figure x.

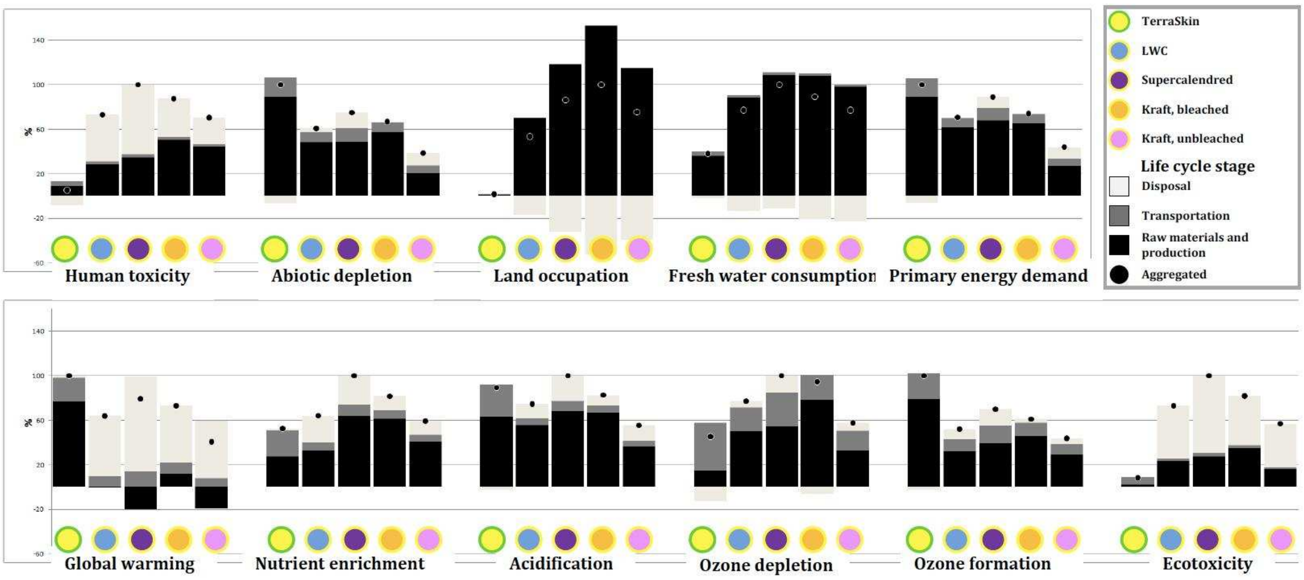


Figure 15. Relative characterized results of the comparisons Source: Bjørn and Hauschild (2012)

When comparing the stone paper products with the cellulose-based paper with lowest impact (in most cases unbleached kraft paper), it has the lowest impact in 4 out of 11 impact categories. However, when comparing stone paper with cellulose-based paper with the highest impact (supercalendred paper in most cases), it has the lowest impact in 6 out of 11 impact categories. Therefore, the sustainability of stone paper is somewhat dependent on what products it is compared with and the function it fulfills; for example, writing/printing medium, or packaging.

When considering the contribution from the different life cycle stages, it varies depending on the impact category. Generally the raw material and production stage is dominant, especially if only landfilling, and not other end-of-life options, is considered. The transportation stage is generally less significant. The impact categories where stone paper seems to be superior are most notably those related to toxicity, as well as land use (at least 70% less) and fresh water consumption (at least 50% less); across the entire life cycle - including energy production.. This fits well with the claims of stone paper produces; that it uses less water, wood and chemicals than cellulose-based paper. A major concern, however, is the primary energy consumption in the raw materials and production process. Per tonne of paper produced, Ozdemir et al. (2013) report that the energy consumption is approximately half that of conventional pulp and paper production, similar to the claims made by the stone paper producers. In contrast, per functional (use) unit, the stone product production consumes in the order of 30% more than LWC cellulose paper, and more than 60% when compared to un-bleached packaging material (Bjørn and Hauschild 2012). In terms of the latter, it must be noted that the waterproof coating of the kraft paper, to really have similar characteristics to stone paper, was not included in the life cycle assessment. Nevertheless, given the carbon emissions intensity of the South African energy system, the impact on global warming, of stone paper paper production, is expected to be significantly higher, since the raw materials and production process cannot claim the carbon sequestration benefits of pulp and paper production (see Figure 14). A summary is provided below:

Comparison of the water pollution impacts of production processes of stone and cellulose based paper

	Comparative performance (Bjorn and Hauschild, 2012)		**Comments on water quality impacts**	**Comments on water quantity impacts**
	Stone paper	Cellulose base paper (Kraft unbleached)		
Human toxicity	5%	70%		
Abiotic depletion	100%	40%		
Land occupation	0%	70%		
Fresh water consumption	40% (5%)	70% (100%)	Direct water quality impact of stone paper is unknown. Savings due to reduction in AMD could be significant.	This comparison only refers to the processing stage and therefore excludes the water been used to grow trees. The indicative figures in brackets represents the scenario for taking into account the whole value chain. See section 2 above.

Primary energy demand	100%	40%	Worrisome, especially given SA's dirty energy profile.
Global warming potential	100%	40%	
Nutrient enrichment	50%	60%	
Acidification	90%	55%	AMD?
Ozone depletion	50%	60%	
Ozone formation	100%	40%	
Eco-toxicity	10%	60%	

Given that packaging paper is the focus for this report, all comparisons will be made as such, i.e. in terms of packaging paper (which similar than the "Kraft unbleached" paper mentioned in Bjorn and Hauschild, 2012.The categories where stone paper was superior are most notably the two toxicity related ones (human and eco-toxicity) as well as land use occupation and fresh water consumption. However, given the dirty nature (i.e. carbon intensive) of South Africa's energy supply profile, the comparatively higher energy demand of stone paper is of concern.

Summary of the environmental comparison:

- The land usage for stone paper production is negligible when compared to pulp and paper production, due to the feedstock production (stone quarries or waste sites versus plantations).
- The fresh water consumption is at least 50% less for stone paper production when compared to pulp and paper production, including the related energy production. However, it must be noted that this takes into account the processing stages only. If the water consumption for biomass (feedstock) production is taken into account, then the water consumption of stone paper production will also be negligible in comparison, which is important in the South African context.
- The primary energy consumption, for a product with a similar function/characteristic, can be between 30% and 60% more for stone paper. However, the process is relatively new, and the literature assumes that electricity and heat demands will drop by a third in the near future, which will make stone paper comparable with, or better than, some pulp and paper products. Also, much of the energy demand lies in the pre-processing stages; to crush and ground the mineral feedstock to a powdery substance with granules of about 0.05 mm to 0.08 mm in diameter (US Patent 20150097310 A1). The characteristics of the mineral feedstock would then influence the energy demand of the production stage.
- The impact on global warming, of stone paper paper production, is expected to be significantly higher due to the carbon emissions intensity of the South African energy system, since the raw materials and production process cannot claim the carbon sequestration benefits of pulp and paper production. Stone paper, however, has the benefit of less carbon emissions in the landfilling stage, due to the decomposing nature of the products compared to pulp and paper products.

4. BENEFITS OF USING MINING WASTE/BUILDERS RUBBLE FOR STONE PAPER

There are complex and often unrecognised linkages between the social, political, technological, economic, ecological and governance aspects of mining and how they contribute to South Africa's development trajectory. Many of these linkages are contextual and dynamic (change over time), and interact in numerous ways to reveal new and emergent properties of the system. This complexity presents challenges in understanding and predicting the origin, spread and the numerous inter-related impacts from AMD. The figure below, (Figure 1), is an example of a highly simplified conceptual diagram showing some of the main inter-relationships of mining activities with other parts of the ecological, social and economic system. Natural capital is the stock of capital of natural resources, such as biological diversity and ecosystems, in addition to land and geological resources such as fossil fuels and mineral deposits. Natural capitals are needed as inputs for economic production and they also provide the ecosystem goods and services (clean air, water etc.) essential for human well-being and all life. Mining will compete with other uses in various sectors (domestic, agriculture and industry) for the natural capital to deliver benefits to society, in terms of economic development and job creation. However, mining activities will generate acid mine drainage (AMD) that will cause flooding, sinkholes and seismic activity, as well as the pollution of water, air and soils. These ecological impacts will negatively human well-being and thereby place additional demands on the provision of public services (housing, transportation, water and sanitation services) which will reduce the availability of these services to further reduce human well-being. Therefore, the impacts on human well-being and the depletion and degradation of natural capital will constrain mining activities and other economic developments. This feedbacks highlights the need for an integrative approach with adaptive management that can address complex and changing variables that will affect the economics of mining and how it will contribution to South Africa's sustainable development path.

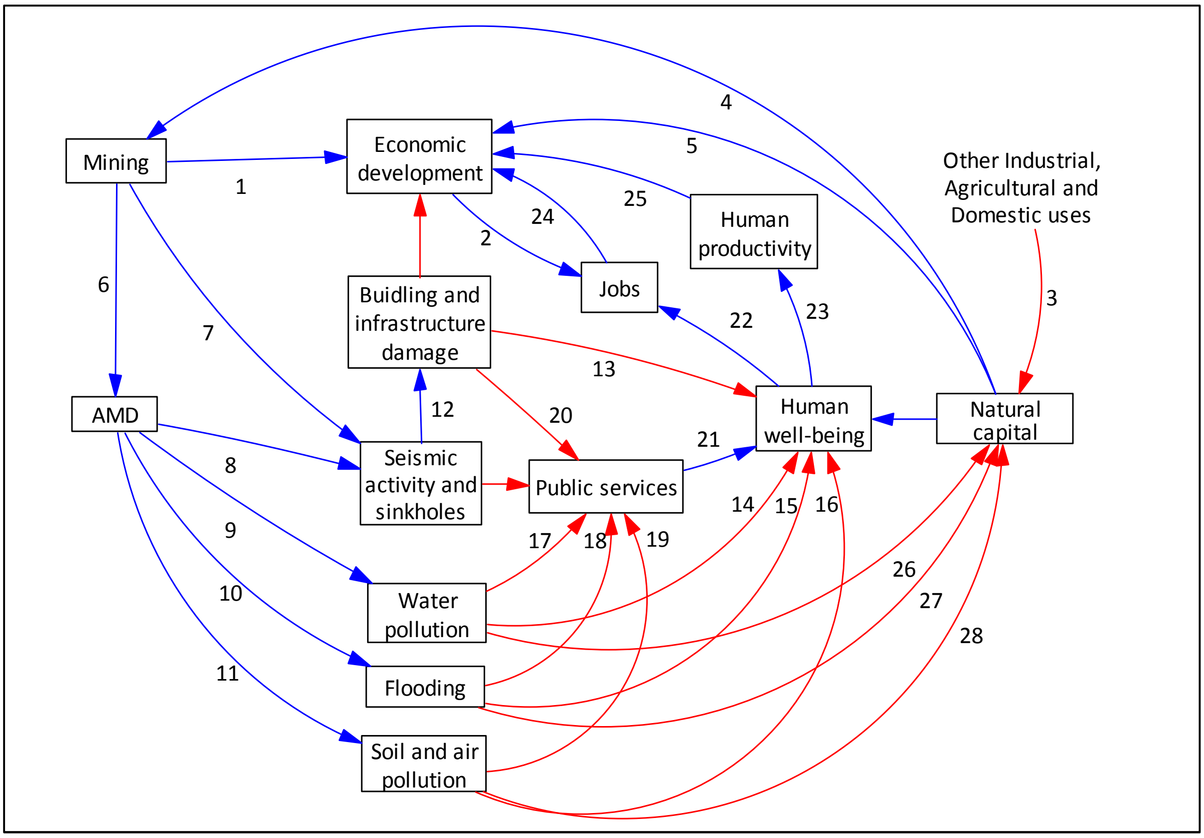


Figure 16. System diagram showing the complex inter-relationships between mining and the economic, ecological and social variables. The causal loop diagram shows the variables boxed

with arrows representing inter-relationships (blue for positive interactions and red for negative interactions) (Kim, 1992). Mining will deliver benefits to society in terms of economic development and job creation (1,2), but will compete with other users in various sectors (domestic, agriculture and industry) for the available natural capital (3,4,5). However, mining will generate acid mine drainage (AMD) (6) that will increase seismic activity and sinkholes (7,8), water pollution (9), flooding (10), and the pollution of air and soils (11). These various ecological impacts will cause damage to buildings and infrastructure (12) and negatively human well-being (13,14,15,16). This will place additional demands on public services (the provision of housing, transportation, water and sanitation services) that will further reduce human well-being (17,18,19,20,21). A reduction in human well-being will reduce human productivity and the potential for jobs (23,23) and thereby impact economic development (24,25). In addition, the ecological impacts of mining will deplete and degrade the natural capital (26, 27, 28) and thereby reduce or constrain the potential of further economic developments (3,4,5).

Three main issues relating to mining and builders rubble wastes MRAs in Gauteng have been identified (GDARD, 2012), namely:
1) air-quality, with particular reference to dust and fine particulate matter (PM) pollution
from MRAs (including radioactive pollutants);
2) water-flux and water-quality, with special note of AMD and the transport of radioactive materials associated with the exposed uranium ore; and
3) geotechnical concerns related to abandoned mine workings, unsealed mine Shafts, dangers of sinkholes, ground instability and collapse that also presents a danger to nearby settlements.

A total of about 52 kilotonnes of gold has been extracted over the course of the 125-year history of Witwatersrand mining, while a total of about 430 kilotonnes of low-grade uranium is estimated to be still present in the mine residue (Council for GeoScience (CGS) estimate, cited in Sutton and Weiersbye, 2007). Because uranium was not extracted as a by-product of gold-mining prior to the 1950s, nor at many Witwaterstrand gold mines outside the western region, the bulk of uranium from the mined reefs is now left as a residue on the surface. Although the concentrations of both gold and uranium vary widely within the ores, on average the Witwatersrand gold-bearing ores contain almost ten times the amount of uranium than gold. The typical background concentration of uranium in the earth's crust is typically 2-4 parts per million (grams per tonne; g/t), whereas the overall average uranium grade of 1952-1988 production from the Carbon Leader reef on the Far West Rand was 145 g/t, with grade averages for other individual ore reefs in the West and far West Rand ranging between 51 g/t and 383 g/t (Coetzee et al., 2006, Table 1, p. 5-6).

These radioactive tailings co-exist in these MRAs alongside the iron sulphide mineral pyrite, which reacts in the presence of oxygen and water to form a sulphuric acid solution – the major cause of acid mine drainage (AMD). Since this acid solution is capable of dissolving and mobilizing the naturally occurring radioactive elements. The considerable tonnage of low-grade uranium ore at surface constitutes one of the most serious pollution hazards in the region (Turton, 2008a). Furthermore, there are nonradioactive hazardous elements, which are also contained within the ore and are susceptible to mobilisation by AMD. An additional environmental threat is the salinity, dominated by the sulphate load. The increased slate concentrations in surface water resulting from AMD and MRA diffuse pollution threaten Vaal River system, which almost reached its assimilative capacity (National Assembly, 2011) The Gauteng region on both sides of the Limpopo-Orange divide is confronted with an emerging slow-onset disaster related to the overflow ('decant') of polluted groundwater from abandoned gold mines (Coetzee et al, 2006; Adler et al, 2007; Turton, 2008).

The reuse of the mining waste and builders rubble may offer an opportunity to address their ongoing environmental costs to CoJ society. The costs and benefits to CoJ if the Stone paper project is implemented are shown in the Table below:

Table 9. Costs and Benefits to CoJ from creating functioning and resilient landscapes by cleaning up mine tailings/ dumps: with respect to among others making Stone paper

Benefits for the city	Costs for the city
1. Avoid the loss of land area by reducing the current and future landfill/dumping of mining wastes and builders rubble 2. New land area available from removal of legacy mine dump (and reduced use of landfill space in the case of builders rubble?) that can be restored to green open space such as wetlands, grasslands and parklands. 3. Improve water resources by partially avoiding pollution of water resources (e.g. AMD) and reducing water footprint of paper production* 4. Avoided impacts to human health by partially reducing the exposure to hazards from mine wastes (soil, dust, particulates, radioactivity etc.)*** 5. Gains in jobs, skills, trade from turning a waste into a resource: stimulates local industry and local economic development 6. Attracting investment and growing the city's revenue through private sector investment in metal recovery, stone paper production etc. 7. Marketing and positioning the city in the Green/Blue economy (e.g. in terms of reducing water use in the paper industry)	1. Use of additional new resources** 2. Generation of new wastes and pollutants in stone paper production 3. Increase costs in Stone paper recyclability and increased landfill space over product lifetime 4. New biodiversity impacts from Stone paper production? 5. Cost of reclaiming and rehabilitating land (shared responsibility between Mines and government), especially if it is destined for human habitation****.

* Making paper from stone uses less water than making paper from trees
** (ie additional ingredients such as HDPE, limestone in Stone paper production
***Mining waste contaminates soils (and hence dust) with metals such as arsenic and uranium
****The costs of removing contaminated soil which is located underneath the mine dumps and is hazardous, will be high. Further, the costs will be very high to build a concrete barrier on top of contaminated land that can prevent hazardous radon gas emissions, and permit some form of industrial land use. Costs to rehabilitate for safe urban settlement would be extremely high, if possible. The lowest-cost and greatest benefit for many of the existing wastes is to rehabilitate them further, through revegetation and to utilize the area as urban green open space (wetlands, grasslands and parklands) that contributes to CoJs ecological infrastructure and helps to provide needed ecosystem services such as water purification, flood attenuation, dust suppression and heavy-metal removal.

The Stone paper opportunity needs to be financially feasible to attract the investor as it will not be CoJ doing the stone paper production. However, CoJ cost accounting is not purely from typical business case as they need to account for public goods and services and "the commons". CoJ Metro recognise that while the land has development potential, the waste is an obstacle and financial burden, so they are interested in a business model that includes this in the business case for CoJ. As a bare minimum they clearly value the land area occupied by mine waste/builders rubble and this is readily accounted for financially. Other burdens (to society or ecology) from mine waste/builders rubble are less readily accounted for by CoJ. This includes the land, soil, water pollution from these wastes that are largely externalities (although do incur costs needed for waste disposal and treatment.as well as to treat the impacts to human health)...and these should be considered in CoJ decisions and the business model and the extent of the public private partnership and who bears the costs, Figure 17.

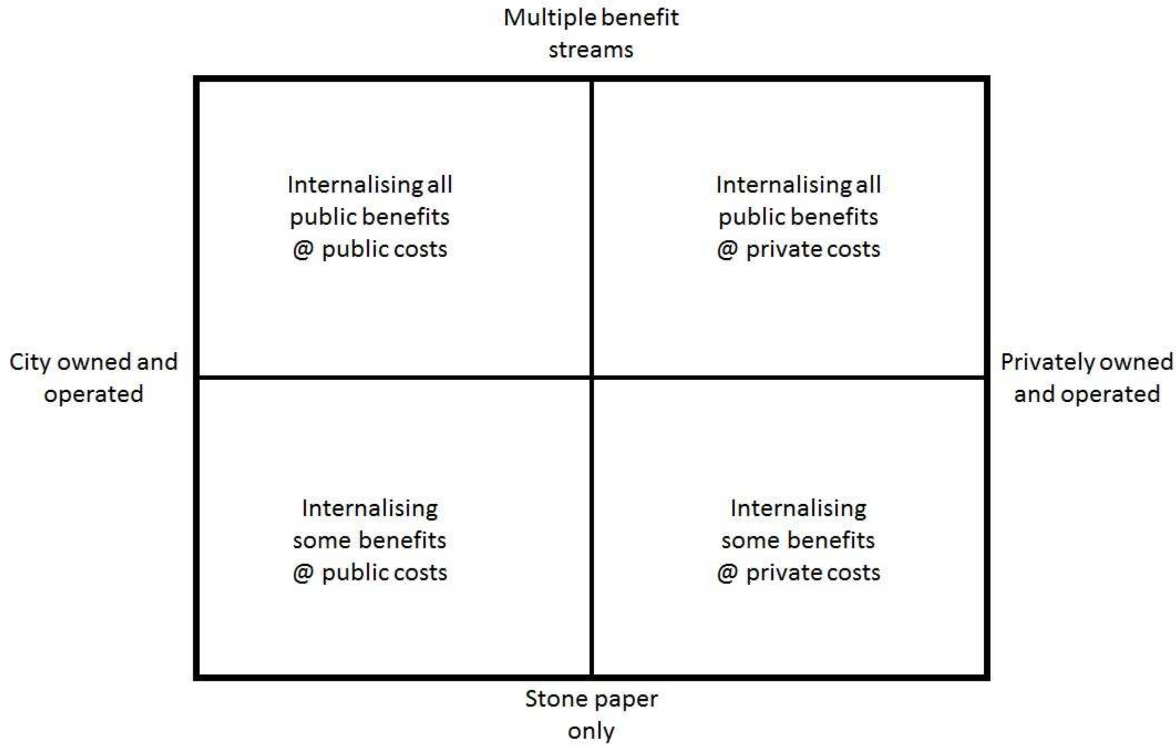


Figure 17. Costs and benefits streams: showing extend of benefits and degree of with Public-Private partnerships possible in the business model.

4.1 Benefits from opening up land for development

4.1.1 Mine dumps and tailings:

MRA's impose opportunity costs to the City in that they occupy valuable land area, which could otherwise be put to more productive use. There are therefore benefits associated with removal of mine tailings in terms of making land available for productive use (in the case of existing mine dumps from legacy mining); and with avoiding further accumulation of mining waste in terms of keeping land available for other uses (in the case of future mining). These benefits could be valued in terms of the value per hectare of land in different potential uses (agricultural, commercial, industrial, residential, etc.). In order to provide an indicative estimate of these values, we collected data on asking prices of different categories of properties (vacant land, farms, commercial and industrial) in Johannesburg, as listed on http://www.property24.com/. We restricted the search to properties within a 5 km radius of MRAs, using the distance calculator on Google Earth combined with visual inspection to identify MRAs.

Owing to a small sample size of farms for sale within a 5km radius of MRAs, these were combined with vacant land, in order to provide a lower-bound estimate of potential land values; while commercial and industrial properties were also combined, in order to provide an upper-bound estimate assuming the land were to be developed to for commercial or industrial use. Based on a sample of 11 vacant plots and farms (with a minimum size of 1ha), an average value of R4.68 million per ha was calculated. This can be seen as a lower bound estimate of potential land values in an undeveloped state or for agricultural use. On the other hand, based on a sample of 20 commercial and industrial properties (with a minimum size of 0.5ha), an average value of R13.36 million per ha was calculated. This can be seen as an upper bound estimate of potential land values.

In section 2.1.2 it was established that mine dumps currently occupy 5764 ha of land in CoJ (from legacy mining); and that a further 1500 ha could be added through future mining. As such, applying the above-mentioned land values per ha to these land areas, the total value of clearing existing mine dumps (5764 ha) ranges from R27 billion (low value based on vacants plots and farms) to R77 billion (high value based on industrial and commercial properties). The total value from avoiding future mining waste dumps (in terms of keeping the 1500 ha of land available for other uses) ranges from R7 billion to R20 billion. In fact, in the case of avoiding future mine dumps on new land, the values could be even higher (as such land could potentially be used for higher value uses, such as residential).

Table 10 Potential land values from clearing existing mine dumps and avoiding future mine dumps in the City of Johannesburg

	Area (ha)	Low (Rands)	High (Rands)
Value per ha		4 681 755	13 362 778
Existing mine waste (legacy mining)	5 764	26 985 636 239	77 023 050 902
Additional mining waste associated with future mining	1 500	7 022 632 609	20 044 166 612
Total	7 264	34 008 268 848	97 067 217 515
Notes: Assumes ‘high to medium’ value of residential land and ‘low to medium’ value for Industrial land. Legacy mining wasteland rehabiltated to ‘low to medium value’ Future mining avoids wasteland of ‘high to medium’			

At the same time, however, rehabilitation of this land would be required in order to make it suitable for these or other uses (different levels of rehabilitation may be required for different uses). The costs of rehabilitation would therefore also need to be taken into account in the analysis. Due to the presence of radon gas associated with these mining sites, a seamless concrete barrier is required to prevent any radon gas leakage from the underlying contaminated soils. Such barriers are expensive to construct. Furthermore, the threat of the radon would preclude any form of residential development. This implies that only high value noxious land uses may suitable users of these rehabilitated areas.

4.1.2 Builders Rubble

As mentioned in Section 2.2, while a certain amount of builders’ rubble can be used as a daily cover material at landfill sites, not all builders’ rubble is suitable for this purpose. Builders’ rubble disposed at landfill sites which is unsuitable or exceeds the quantities required as a cover material therefore takes up valuable landfill airspace and decreases the lifespan of existing landfills. At the same time, some components of builder’s rubble contain materials that can be used as resources in other manufacturing processes (such as stone paper production), thereby potentially displacing virgin materials.

Landfilling of excessive quantities of builders’ rubble is therefore problematic for a number of reasons, including:

- Direct CAPEX and OPEX costs associated with landfilling of waste and the construction of new landfill sites when existing sites reach capacity
- Landfills occupy land which could otherwise be put to more productive use
- Foregone value associated with resources that are disposed at landfill which could otherwise be reused or recycled in manufacturing processes, displacing the use of virgin raw materials

There are therefore three types of benefits associated with the use of builders rubble to produce stone paper, in terms of avoiding the above-mentioned problems. These benefits could be valued as follows:

Current information (provided by CoJ, pers. commun.) suggests that the 250 000 tonnes of building rubble generated annually costs CoJ R100 million per annum for disposal (i.e. R400 per tonne).
The benefit of diverting builders' rubble from landfill sites in terms of making land available for other productive uses was valued in much the same way as for mine tailings in Section X.1 However, it has been reported that builders' rubble may also contain significant quantities of radioactive material as mining waste is being used in the manufacture of building materials. This implies that builders rubble may also be problematic from a human safety perspective. Data collected on asking prices of different categories of properties listed on http://www.property24.com/; this time for properties within a 5 km radius of landfill sites within CoJ (including the four existing municipal landfills in the City (Robinson Deep, Ennerdale, Marie Louise and Goudkoppies), as well as two closed sites (Linbro and Kya Sands). Again, farms were combined with vacant land, and commercial properties with industrial properties. Based on a sample of 27 vacant plots and farms (with a minimum size of 1ha), an average value of R2.67 million per ha was calculated. This can be seen as a lower bound estimate of potential land values in an undeveloped state or for agricultural use. In the case of commercial and industrial properties (sample of 20 properties with minimum size of 0.5ha), an average value of R14.46 million per ha was calculated, as an upper bound estimate of the potential value from developing this land for commercial or industrial use (Table 10).

Diverting builders' rubble from landfill sites in the CoJ and using it for stone paper production could save 0.75 ha of land per year (Table 11). Applying the above-mentioned land values per ha to this land area, the value (per annum) of diverting builders' rubble from landfill (in terms of land saved) ranges from R2 million (low value based on vacants plots and farms) to R10.8 million (high value based on industrial and commercial properties) per year. Over a 30 year time horizon, values are in the range of R60 million to R325 million. Again, however, the values could be higher than those indicated in the table; as we do not include the value of residential land in our estimates, which is another potential land use.

Table 11 Potential land values from avoiding builders rubble going to landfill in the City of Johannesburg

	Area (ha)	Low (Rands)	High (Rands)
Value per ha		2 666 774	14 455 336
Per year	0.75	2 000 080	10 841 502
Over 30 years	22.50	60 002 404	325 245 054

A report for the DST (2014) estimates economic values of different waste streams that are currently being landfilled in South Africa that could otherwise be recovered as valuable resources. For construction and demolition waste, the study reports a saving of R87.50 per tonne for waste that is recovered and used to produce recycled aggregates for the construction industry (e.g. in the construction of roads and buildings); although this value is based on somewhat conservative assumptions. Applying this to the assumed 250,000 tonnes per annum of builders rubble generated in Johannesburg implies a potential benefit of R22 million per annum (conservative estimate) in terms of recovered resources.

However, for the sake of the current study, the benefits in terms of making builders rubble available as a resource by diverting it from landfill should rather be valued in terms of the value of this resource as an input to the production of stone paper (See Section X).

It is worth noting that the argument regarding resource value applies to the use of mining waste as well. While the DST study did not specifically look at the resource value of mine tailings, it did consider the potential value of recovered waste slag from mineral processing as an aggregate for the construction of roads and buildings. This waste stream consists of ferrous metal slag from steel, manganese, chrome, vanadium etc. processing, and non-ferrous metal slag from aluminium etc. processing. A value of R175 per tonne was estimated; although again, to the extent that benefits in terms of resource savings should be included in the analysis, this should be assessed specifically in terms of the use of the resource in stone paper production.

4.2 Benefits from restoring land through revegetation and rehabilitation

The utilisation of rehabilitated mine tailings for alternative land uses has risks. Hattingh's research (Hattingh, 2006) indicates that the soils below mine tailing are generally polluted by the chemicals found within the tailings, and may include metals. The implications of this is that radium-226 may remain in the site as it is relatively immobile and consequently may expose homes built on the site to radon, a radioactive gas that is generated by decaying radium. Raina Hattingh (pers comm) suggests that utilising waste from gold mines is problematic in terms of the paper production and the freed up land, as gold mine residues are hazardous. Producing paper which may have radioactive chemicals and other hazardous mine residues which could have serious public perception issues. Furthermore, pollutants may be present in significant quantities some 2 to 3 meters deep in the soil, and consequently this contaminated soil would need to be removed and dumped at an alternative site, generating significant further risks in regard to the disposal and transporting the hazardous material. This removal and disposal process would incur high costs. An additional problem associated with settlement of former waste dumps is acid mine drainage. The acid may generate serious corrosion problems for metal infrastructure within the soil, such as pipes (van Deventer, Hattingh, Botha, & du Plessis, 2009).
Consequently, it would be unwise to make any broad statement on the value of freed up lands, until one understands exactly what pollutants existed, what site specific rehabilitation measures are necessary to neutralise these threats, and to identify what land uses are appropriate for the residual pollutants. International experiences, in using hazardous dump suites for urban development, indicate that such sites can only be used if radon gas emissions can be prevented. Prevention requires a sophisticated concrete slab, which guarantees no cracks or joins and which ensures no radon gas leakage. Such systems are extremely costly and would not be feasible for large scale land development, but may be possible for selected high value land uses.

Rehabilitated land may however be developed as open space, an element of the urban landscape also important for human wellbeing. Importantly, the ecological processes associated with green spaces, have the ability to self-repair, and will constantly improve in functionality with time, and increasingly make the landscape safer for humans on rehabilitated sites and downstream, by stabilising soils with vegetation. The large volumes of hazardous chemicals bound up in the Klip, Rietspruit and Blesbokspuit wetlands in Gauteng attest to this high value service (Sullivan, C., Macfarlane, D., Dickens, C., Mander, M., Bonjean, M., Teixeira-Leite, A. and Pringle, C. 2008. Keeping the benefits flowing and growing. Quantifying the benefits from wetlands in the upper Orange/Senqu basin.) These open spaces, such as Highveld grasslands and wetlands, have the ability to generate a wide range of ecosystem services, that have value to society. See Table 12 which identifies the range of services supplied, and some indicative values of selected services in Gauteng.

Table 12 Ecosystem services generated by open space in urban landscapes

Ecosystem services	Annual Value per ha	Ref
Flood attenuation –		

A reduction in the peaks of flood events due to vegetation cover slowing the run-off of storm water, and by slowing water flow within wetlands. The reduction in flood peaks reduces damage to urban infrastructure, reduces repair costs and saves lives.		
Stream flow regulation The provision of dry season stream flows due to the ability of vegetation to promote rainfall infiltration into the soils and to slowly release the water into drainage lines many months after the rainfall event. Dry season water is very valuable, as it is the only surface water available in water scarce periods.		
Sediment trapping Vegetation traps sediment which could have been released into drainage lines and reduce the effectiveness of dams' water storage capabilities, and stormwater infrastructure such as road culverts. Sediment trapping increases the lifespan of dams, culverts and bridges.		
Phosphate trapping and nitrate removal Grasslands and wetlands trap phosphates and assimilate nitrates in the landscape and in water bodies. This reduces the pollutant levels in water, thereby reducing water treatment costs and reduces the algal blooms that may occur, which also elevate water treatment costs.	R1534 (2006)	(Sullivan, et al., 2008)
Toxicant removal Soils and wetlands have the ability to fix or stabilise toxic chemicals which prevents or reduces the levels of discharge into water bodies, which if present in water, could be hazardous for human consumption. This action reduces clean-up costs, and also reduces the risks to human health. Similarly, bacterial contamination is also reduced by vegetation in grasslands and wetlands, and reduces the numbers of e.coli entering water bodies, which reduces clean-up costs and reduces risks to human health.		
Erosion control Vegetation in the landscape reduces stormwater run-off in terms of volumes and speed, thereby reducing the capacity of water in the landscape to erode soils off the surface, and reduces damage to infrastructure such as roads, drains, culverts and buildings.		
Carbon storage The reestablishment of highveld grasslands and wetlands have the capacity to capture and store large volumes of carbon dioxide both within plants and within the associated soils. This action serves to reduce carbon in the atmosphere and its associated impacts on climate.	R1210	(Blignaut)
Meeting provincial biodiversity conservation goals The Gauteng provincial government has a mandate and obligation (through national legislation) conserve a representative percentage of naturally occurring ecological habitats in the province. Establishing grasslands and wetlands could assist in meeting such goals.		
Harvestable resources (such as reeds and thatch grass) Wetlands and grasslands produce large volumes of reeds and thatch grass which may be suitable for building purposes. These resources offer economic opportunities for local users.		
Food for livestock Grasslands and wetlands produce large volumes of grass with a high potential for livestock feed.	R1387 (2006)	(Sullivan, et al., 2008)
Mitigating the urban heat island effect		

Green spaces within the built environment have the ability to absorb heat and to reduce heat through evaporative cooling, thereby reducing the ambient temperature in a locality, thereby reducing the heat build-up in adjacent built environments, generating human wellbeing and reducing energy costs associated air-conditioning.		
Visual amenity Green urban spaces provide visual amenity for nearby residents or commuters. The value of this amenity can be gauged by the elevated property values associated with properties which have views of open space. An example from Kloof in Ethekwini, shows that properties with views of the open space had a 10% greater value, compared to properties without views.		(Mander)
Recreation space Green urban spaces offer recreational opportunities for urban residents, in the form of walking, running, mountain biking, football, etc.		
Education and knowledge creation Urban open spaces are a laboratory for schools and universities, wherein practical learning can take place. They are also sites of research, thereby generating new knowledge for society.		

The rehabilitation of mine tailings dumps for the purposes of providing open space and ecosystem services in the City of Johannesburg will provide a valuable asset for urban residents. An analysis of open space values in Cape Town and Durban, estimated that the annual value of open space was R4billion (De Wit et al) and R4.1billion (Markewicz et al) respectively. This highlights the magnitude of the value of open space in urban landscapes. In the case of Durban, the total municipal budget was some R25billion at the time of valuation, implying that the green spaces generated an additional 16% of the budget, for a mere R100million spend.

The conversion of old mine dumps to green open space, would make a significant positive impact on the wellbeing of Johannesburg residents. For those ecosystem services in Table 12 where we have information on values per ha, these can be applied to the land areas under mine dumps and landfill sites, in order to obtain a rough (albeit conservative) estimate of the value that could be derived from ecosystem services were these areas to be revegetated . 2006 values were updated to 2016 values using data on consumer price index (CPI) inflation from the South African Reserve Bank (SARB, 2016). Assuming that the values associated with different ecosystem services can be aggregated, i.e. that the services are not mutually exclusive, an annual value of R34.4 million per year could be derived from ecosystem services if existing mine dumps were to be rehabilitated and revegetated; while a further R9 million per year would be derived from avoiding the creation of new mine dumps through future mining and instead allowing continued provision of ecosystem services on currently vegetated land. Note however that the estimates in Table 13 are conservative, since they are based on only three ecosystem services, not the full range of services listed in Table 12, due to lack of data.

Table 13. Valuation of Ecosystem services from avoiding mine dumps and landfill sites

		Phosphate trapping and nitrate removal	Carbon storage	Food for livestock	Total
Annual value in Rands per ha	Value per ha (year)	R1534 (2006)	R 1 210	R1387 (2006)	
	Value per ha (2016 Rands)	2499	1210	2259	5968
Ha’s of		5 764	5 764	5 764	5 764

land	Mine dumps - legacy				
	Mine dumps - future mining	1 500	1 500	1 500	1 500
	Builders rubble - future waste generation	22.5	22.5	22.5	23
Value (Rand per annum)	Mine dumps - legacy	14 404 236	6 974 440	13 020 876	34 399 552
	Mine dumps - future mining	3 748 500	1 815 000	3 388 500	8 952 000
	Builders rubble - future waste generation	56 228	27 225	50 828	134 280

4.3 Benefits to Biodiversity

Spatial layers within a GIS were used to determine potential interactions between mining residues and important biodiversity features within Gauteng. A spatial layer containing the mining residues was buffered by 200m and then intersected with the Gauteng biodiversity plan. This provided information on biodiversity areas that were located within 200m of a mining residue. The data layer was assessed to determine which biodiversity areas (i.e. PA, CBA, ESA) were being impacted on. Table 14 shows that mining residues are in contact with 2 % of CPLAN areas equating to approximately 17600 ha within a 200m radius of a mining residue area. Ecological support areas contribute to the largest biodiversity class. These were followed by Important areas, Irreplaceable areas and Protected areas. In relation to the entire CPLAN network approximately 3% of ESA are adjacent to mining areas, 2% of important areas and 1.3% adjacent to irreplaceable areas- see Figure 18.

Protected Areas (PA): Protected Areas are areas which have legal protection under relevant legislation or which are managed with a primary conservation objective. Protected Areas include Provincial Nature Reserves, Municipal Nature Reserves, Other state owned protected areas (Meteorite Crater Reserve & natural portions of Botanical Gardens), Private Nature Reserves and Natural Heritage Sites with management plans that have biodiversity conservation as the primary objective.

Critical Biodiversity Areas (CBA): CBAs include natural or near-natural terrestrial and aquatic features that were selected based on an areas biodiversity characteristics, spatial configuration and requirement for meeting both biodiversity pattern and ecological process targets. These targets are applied to all habitat types at a national scale. CBAs include irreplaceable sites where no other options exist for meeting targets for biodiversity features, as well as best-design sites which represent an efficient configuration of sites to meet targets in an ecologically sustainable way that is least conflicting with other land uses and activities. Although the conservation planning process preferentially attempted to meet biodiversity targets in natural or near-natural landscapes, in some cases intensive agricultural landscapes may perform a key role in maintaining populations of threatened species (e.g. ploughed fields may be key foraging areas for threatened bird species such as Blue Crane or Secretary Birds).

Ecological Support Areas (ESA): Ecological Support Areas are areas required to prevent the degradation of Critical Biodiversity Areas and Protected Areas by supporting the ecological processes that act across larger scales. These may include any natural, near-natural, degraded or heavily modified areas required to be maintained in an ecologically functional state to support Critical Biodiversity Areas and/or Protected Areas. “

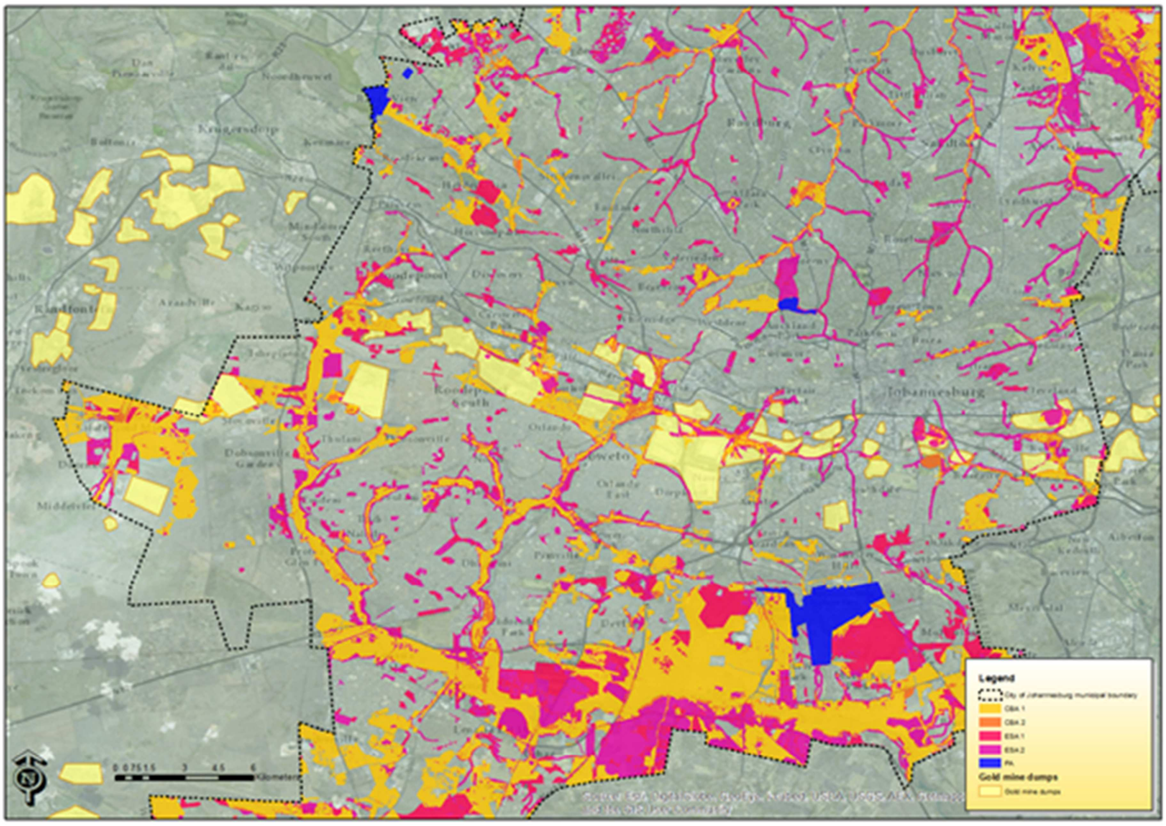


Figure 18 Map of CoJ with C-Plan biodiversity areas (SANBI, 2011)

The intersected data layer (Mining residues within 200m of important biodiversity areas) was assessed to determine the potential impact riverine systems. This information is located in mining residue data layer and indicates whether a river system adjacent or near by the residues dump.

Table 14 show that 14 % of mine residues are adjacent to perennial rivers and 38% are adjacent to non-perennial rivers. Further analysis indicates that 55% of biodiversity areas (ESA1) are exposed to mining residues and 88% ESA1 and ESA2- Table 14 and 15

Table 14: Mine residue areas and proximity to water bodies and biodiversity areas.

	Intersected biodiversity and mining layer			
Row Labels	**Area in ha that overlap with biodiversity areas**	**% of biodiversity areas that are affected by mine dumps**		**The total % of biodiversity areas in adjacent to mining residues**
Ecological Support AreaESA1	9776.5	55.55		2.93
Important AreaESA2	5927.5	33.68		1.98
Irreplaceable AreaCBA1	1723.4	9.79		1.34
Protected AreaCBA2	171.4	0.973		0.39
Grand Total	17598.8	100		2.19

River type	%
NON PEREN	37
PERENNIAL	14

(blank)	49
Grand Total	100

Table 15: Areas of vegetation type lost due to mining (MRAs)

	Total area	**Area (ha) of vegetation type in Gauteng**	**Areas lost due to mining (ha) in Gauteng**
Andesite Mountain Bushveld	95982.1	72903.2	513.4
Carletonville Dolomite Grassland	895671.5	264726.4	4277
Central Free State Grassland	1598160	8282.7	46.7
Central Sandy Bushveld	1071406	182767.2	1403.4
Eastern Highveld Grassland	1266904	35197.9	92.6
Eastern Temperate Freshwater Wetlands	14625.7	14513.2	398.7
Egoli Granite Grassland	109318.9	109318.9	1085
Frankfort Highveld Grassland	987613.9	3174.8	0
Gauteng Shale Mountain Bushveld	94747	85582.1	3175.3
Gold Reef Mountain Bushveld	156779	51505.5	665
Loskop Mountain Bushveld	173428.8	35225.6	104.9
Marikana Thornveld	252870.2	101747.2	1845.5
Moot Plains Bushveld	152979.7	40267.5	73.1
Norite Koppies Bushveld	5070.5	4134.6	149.6
Northern Afrotemperate Forest	95.1	0.1	0
Rand Highveld Grassland	865403.1	246648.7	2044.6
Soweto Highveld Grassland	1450090	424965.7	14641
Springbokvlakte Thornveld	876116.3	28750.9	0
Subtropical Freshwater Wetlands	424.8	298.6	0
Subtropical Salt Pans	8.8	8.8	0
Tsakane Clay Grassland	110706.9	107382.2	3660.8
Waterberg-Magaliesberg Summit Sourveld	2015	428.7	0
	10180417	1817831	34176.5

4.4 Benefits to Water resources

Using mine wastes for stone paper can partially improve water resources by avoiding pollution of water resources from acid mine drainage, and also by reducing the water footprint of paper production.

Quality management refers to the maintenance of the inherent quality (and thus usefulness) of the resource. Water pollution results when wastewater discharges exceed the natural assimilative capacity of drainage systems, consequently rendering the water resource less useful for downstream users. Water pollution thus directly affects the ‘fitness for use’ of water and decreases its opportunity cost (polluted water has fewer uses compared to clean water). Water pollution occurs because natural resources (and the services derived from them, such as waste-disposal services) are typically under-priced in free-market economies. Within a free-market economy, private (company and individual) production and consumption decisions are dominated by costs and benefits that directly affect the private decision-maker and not those incurred to and received by society. Generally, water pollution does not affect the polluter directly, so they do not consider the impact of such pollution in their decision-making. The resulting decisions and choices made by the polluter are, therefore, not always beneficial to society because the trade-offs exclude the costs on society.

Acid Mine Drainage (AMD) is generated in mine spoil heaps, tailings and slimes dams. AMD also forms in underground workings of deep mines, although this is generally a relatively minor importance when the mine is an active production and water tables are kept artificially low by pumping. It is estimated that in the 1920s approximately 50% of the world’s gold production came from the Witwatersrand and in the 1980s South Africa was still the largest gold producer in the world. However, mining has declined since the 1990s and many mines have closed. While the mines were operating, they pumped water to the surface to dewater the mine workings; but since mining stopped, the underground voids steadily fill with water, which interacts with the exposed sulphide bearing minerals in rocks to form Acid Mine Drainage (AMD). Once the process of acid generation has begun, it is very difficult to contain or stop, and can continue for tens or thousands of years until the available sulphide minerals are exhausted (Blodau, 2006). As a result of many variable factors over these long-time periods, there is considerable uncertainty in assessing the AMD origins, extent, loads and impacts. AMD is characterised by a water with a low pH and an excessive concentration of dissolved metals and sulphate salts which has numerous downstream social and ecological impacts. However, the true extent of AMD and the impacts are largely unknown because the AMD impacts are complex, long-lived and difficult to predict, determine and value. There are both uncertainties of the range of impacts that are likely to occur as well as uncertainties of the value of these impacts (since not all social and ecological impacts can easily be reduced to monetary terms). The impacts of AMD in the Witwatersrand include the contamination of groundwater used for human and agriculture use; serious negative ecological impacts; regional impacts on major river systems; flooding in low-lying areas; and increased seismic activity. The removal of mine dumps and slimes dams for stone paper production has the potential to partially avoid the production of AMD and the impacts. This is highly relevant, given the scarcity of water resources.

There are also water savings from the paper production process. The question could be asked how much water will be saved and what is the indicative monetary worth of such a saving if cellulose based paper is substituted with stone paper. A quick estimate for the CoJ based on the following information and assumptions:

- assuming the size of the stone paper industry is directly related to the current use of paper products in the CoJ, i.e no paper is exported to other provinces or countries
- stone paper is a perfect substitute for cellulose based paper
- people in CoJ use 50 kg paper and paper products per year
- the CoJ population is 4300000 people
- cellulose based paper requires 55 liters of water per kilogram to process (Avsar and Demirer, 2008)

- to produce one cube of pulpwood requires between 131 (Gush, 2016) and 343 (van Oel and Hoekstra, 2010) cubes of water (237 cubes on average)
- stone paper requires 14 liters of water per kilogram to process (ref **)
- we ignore the water use for producing building rubble (water been used to produce cement etc) and mine tailings (i.e. water utilised for mining), since both these are considered as waste streams
- a 1:1 input – output ratio is assumed for woodpulp to cellulose based paper
- one cube of pulpwood weighs one tonne
- marginal value of water for pulp and paper is R3.60 per cube (Nahman and De Lange, 2013)

Above mentioned assumptions lead to the following: It is estimated that CoJ population consumes 215000 tonnes of paper and paper products per year. The water footprint for this amount of cellulose based paper consists of the water been used to manufacture paper and paper products as well as the amount of water required by trees to grow the wood from which paper pulp is processed. The water footprint for the equivalent amount of stone paper relates mainly to the processing side, since it is assumed that both sources of feedstock (builders rubble and mine tailings) are considered waste streams (i.e. sunken water). Above-mentioned 215000 tonnes of paper and paper products represents approximately 11.8 million cubes of water for cellulose based paper and 2.9 million cubes of water for stone paper (per year) on processing side. To put these figures in perspective one need to compare to the water use profile of the CoJ. CoJ administers approximately 574 million cubes of water per year, which implies that, on processing side, the water saving of stone paper over cellulose based paper is estimated on 1.5% (or 8.8 million cubes) of the total annual water use. Although this figure is insignificant (especially when compared to the average unaccounted for water in South Africa of 20%) it only accounts for the processing side of both products.

One the production side one needs to account for the 51 million cubes (215000 tonnes * 237 cubes per tonne) of water used to produce the pulpwood for cellulose based paper. Adding the 8.8 million saving on processing side, yields an estimate saving of 59 million cubes, which is 10% of total water use. This translates to an estimated life-cycle water saving of at least 278 (237 + 55 - 13.75) cubes water per tonne of stone paper when cellulose paper is substituted with stone paper.

Above-mentioned figure of 59 million cubes is significant in monetary terms if the volume is multiplied with the marginal value of water for the paper and pulp industry of R3.6 per cube water (Nahman and De Lange, 2013) which equals to R215 million per year for COJs 215000 tonnes of paper and paper consumption products per year (equivalent to R1002 per tonne paper or R1.00 per kg paper). However, water savings are only one aspect in arguing the socio-economic merit of stone paper. Other variables such as employment impacts (if cellulose is substituted by stone paper) needs to be accounted for (i.e. jobs been lost in the forestry sector vs jobs been aimed in the stone paper industry), human health impacts due to higher energy requirements of stone paper, etc.

4.5 Benefits to Human health and reduced risk liability

Using mine wastes for stone paper can partially improve human health and livelihoods by avoiding pollution air and water from mining wastes. Several of the contaminants typically associated with mining are hazardous to human health, including arsenic, cadmium, and lead (Malatse and Ndlovu, 2015). The major oxides in mine tailings are silica, magnesium oxide, alumina, sulphur trioxide, potassium oxide, calcium oxide, and haematite. Although uranium oxide is present at trace amounts (0.0064%) its presence is significant as uranium is radioactive and can present health effects (Malatse and Ndlovu, 2015).

Many of the metal ores associated with mining are present in mine dumps and tailings at concentrations that can present a health hazard (See Table s above for composition of mine tailings, and mining impacted wetlands, soil etc), and there are several ways that humans can be exposed to these hazards. This includes inhalation of contaminated dust and water that contains these metals as oxides or salts, as well as contact with soil from these mining areas (contact can be direct contaminated soil contact when living in proximity to a mining area/ on a previously mined areas, as well as indirect via exposure to air-borne dust and radiation from mining waste soil/sand used for brick-making and road-fill.The safety limits of the contaminants typically associated with mining, the concentrations in the environment, and the degree of exposure will determine the risk to human health and are provided in the following sections.

Exposure pathways and levels of likely exposure for people include inhalation and ingestion of metals as fine dust (typically metal oxides ie SiO_2, Al_2O_3, U_3O_8) as well as ingestion of water and food contaminated with metals and radiation exposure. There may be significant risks from dust ingestion/inhalation and radioactive exposure from mine tailings. In previous studies CSIR investigated wind erosion of dried-out mine tailings impacting on the neighbouring town. Dust samples did not contain radioactivity above background level. Air samples representing a two week period were analysed for the presence of 29 metals. A few metals may cause a possible health risk from air pollution such as arsenic, cadmium, cobalt, manganese and nickel indicating that air sampling needs to be conducted over a longer period. A risk of developing cancer as a result of inhalation of arsenic may be a possible issue and needs to be considered if stone-paper is produced using gold mine tailings.

Each of the contaminants described may contribute to the potential health risk. For example, uranium having both toxic effects and being radioactive, presents additional potential health impacts. There are three main exposure pathways associated with uranium:

- External gamma radiation. Uranium ore contains several isotopes that emit gamma radiation, and persons in the vicinity of ore or concentrates can receive doses as a result
- Inhalation of radioactive dusts. Dusts from ore or concentrates contain radionuclides which if inhaled can lodge in the lung. They may remain in the lung, or be absorbed into the bloodstream and taken to other organs.
- Inhalation of radon decay products. One of the radioactive isotopes in the uranium decay chain is radon which may be inhaled. Radon decays into “radon decay products” (or radon progeny) which may lodge in the lung releasing alpha radiation

Arsenic (As)

Arsenic is classified as a Class A human carcinogen (IARC, 1978; US EPA, 2001; CSP2, 2003; WHO, 2010). Arsenic is a by-product of mining waste from precious and base metal ore deposits. According to Harada (1996) arsenic exposure can result in skin and lung cancer up to 20 -30 years after the first symptoms occurred. Apart from cancer, arsenic poisoning also causes non-cancerous health disorders (Williams et al, 1998). These typically include: dermal conditions, polyneuritis, bronchitis, gastroenteritis, rhinitis, and conjunctivitis. Other human health impacts associated with arsenic exposure are cardiovascular and cerebrovascular diseases, Raynaud’s phenomenon, hepatopathy and nephropathy malignant neoplasm including Bowen’s disease. The US EPA’s (2001) drinking water guideline for arsenic is 0.05mg L^{-1}. Health effects specifically associated with ingestion of arsenic via drinking water include skin damage, circulatory system problems as well as an increased risk of cancer. Exposure to high levels of arsenic can cause death with as little as 70-180 mg of As(III) ingested by an adult being lethal (Abernathy, 1993). Inorganic arsenic can increase the risk of cancers (lung, skin, bladder, liver, kidney, and prostate) while inhalation / breathing of inorganic arsenic causes sore throat, and irritated lungs. Chronic arsenic exposure symptoms include hyperkeratosis (a thickening of the outer layer of the skin), hyper pigmentation, skin malignancies and peripheral arteriosclerosis (blackfoot disease) (Williams et al., 1996). The development of liver, bladder and kidney cancer has been demonstrated at similar exposures through clinical (Sesieni and Cuzick 1993 cited in Williams, 2001) and epidemiological (Chen and others 1994 cited in Williams, 2001) studies. Acute arsenic toxicity causes gastrointestinal irritation, loss of peripheral nerve response and, ultimately, cardiovascular failure.The EPA surface water aquatic discharge standards for chronic exposure to arsenic is 0.15 mg/L, while the acute exposure is 0.34 mg/L. The US EPA (carcinogenic) standard for surface water to have a 1 in a million chance (10-6 risk factor) of health effects is 0.018 mg/L.

Cadmium (Cd)

Cadmium is a heavy metal that is classified by the US EPA as both a carcinogen and a teratogen . Cadmium is regularly found in ores together with zinc, copper and lead. It is found as a trace element in sphalerite and is a common toxic metal associated with AMD (ATSDR, 1999). Cadmium volatilises and condenses during smelting to form cadmium oxide. Cadmium oxide is respirable and enters the air during coal burning or mining operations. There are no known beneficial properties of cadmium. It is extremely toxic even at very low levels to plants, animals and humans and many aquatic species are very sensitive to cadmium (McCluggage, 1991; Lenntech, 2004; Young, 2005). Cadmium toxicity can lead to kidney, bone, and pulmonary damages (Godt, et al., 2006).In addition to these health impacts cadmium also irritates the digestive tract, and causes vomiting and diarrhoea. Cadmium is also a severe lung and gastrointestinal irritant, and breathing high concentrations can lead to obstructive lung disease, “cadmium pneumonitis”, resulting from inhaled dusts and fumes. It is characterized by chest pain, cough with foamy and bloody sputum, and necrosis of the lining of the lung tissues because of excessive accumulation of watery fluids which can cause death. Exposure to low levels over extended periods in air, food and water can cause build-up of cadmium in kidneys, causing kidney and liver damage, anaemia, as well as the loss of sense of smell (McCluggage, 1991; ATSDR, 1999; INECAR, 2000; European Union, 2002; Young, 2005).

Cyanide (Cn)

Cyanide (CN) is a highly toxic inorganic compound composed of carbon and nitrogen. In South Africa around the year 1850, 48 % of the gold production was carried out using the mercury amalgamation process (Marsden and House, 2006). Short term high level exposures result in brain and heart damage and can cause coma and death. Long term exposure to lower levels results in heart pains, breathing difficulties, vomiting, blood changes, headaches and thyroid gland enlargement. Cyanide salts can be rapidly absorbed by inhalation, ingestion, or through the skin. High blood cyanide levels results in weakness of fingers and toes, difficulty walking, dimness of vision, deafness and decreased thyroid gland function (ATSDR, 1997). Cyanide has also been associated with impacts on the quality of life of people in a mining area. The drinking water taps in a small American town close to Montana’s largest cyanide processing gold mine was at one point contaminated with high levels of cyanide. Although this problem was remediated, community members continue to believe that the mine is making them sick. They attribute the increasing rates of diabetes and unusual illness in their community to the mine. The ATSDR (1999) could find no direct correlation between any health impacts and the mines in the area.

Manganese (Mn)

Manganese is another heavy metal often associated with acid mine drainage. It is fairly persistent and can be carried long distances downstream from mining sites. Manganese will precipitate from solution at a pH of above 10 and can be difficult to remove from contaminated water. The specific impact of manganese on aquatic life isn’t very clear since its effect seems to be masked by the interaction with other heavy metals. Earle and Callahan, (1998) found widely varying tolerance levels in different fish species. They also concluded that the toxicity of dissolved manganese was less in water with low levels of hardness. Studies by Wasserman et al. (2006) and Grandjean et al. (2006) reported linkages between elevated manganese exposures of children and learning disabilities as well as hyperactivity.

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Mercury (Hg)

Mercury is classified as a neurotoxin and forms part of the list of 31 priority chemicals of the US EPA. Mercury may occur in three major chemicals forms: as elemental mercury Hg0, as inorganic compounds such as Hg2+, and inorganic compounds, such as methylmercury (MeHg). All of these forms are recognized as highly toxic (UNEP, 2002). Mercury is widely known for its use in extraction of gold in the mining industry. Harada et al (1997) found that approximately 60% of the mercury is released to the air during the purification process. Since mercury is a volatile element, dangerous levels are readily obtained and can be inhaled through air. Once inhaled, mercury bioaccumulates in the human body to attack the central nervous system, resulting in various symptoms such as numbness and unsteadiness in the legs and hands, awkward movements, tiredness, ringing in the ears, narrowing of the field of vision, loss of hearing, slurred speech, loss of sense of smell and taste, as well as forgetfulness. Inorganic forms of mercury have also been linked to spontaneous abortion, congenital malformation and gastrointestinal disorders. Mercury can cause an abnormal irritation or sensitivity of an organ or body part to stimulation, acrodynia (Pink disease, which is characterized by rash and desquamation of the hands and feet), gingivitis, stomatitis, neurological disorders, total damage to the brain and central nervous system and are also associated with congenital malformation (Ferner, 2001; Lennetech, 2004). A broad range of neurological and behavioural disorders may result as the consequence of an exposure to elemental mercury, including tremors, emotional liability, insomnia, memory loss, headaches, respiratory and cardiovascular effects, gastrointestinal and hepatic effects, effects on the thyroid gland, and the immune system, effects on the skin, reproductive and developmental effects as well as performance deficits (WHO, 1991; UNEP, 2002).

Selenium (Se)

Selenium is a semi-metallic trace element classified as a Priority Pollutant by the US EPA. It typically does not occur in pure elemental form, but commonly occurs in mixtures of sulphide ore. Selenium is a common waste product from uranium, bentonite and coal-mining since mining operations often increase the element’s mobility and solubility. Soils, surface waters, and ground waters around mining operations can become contaminated (USEPA, 2002). Selenium is an essential nutrient but too much or too little selenium have adverse human health effects. Chronic and short term effects due to too much selenium exposure include skin lesions, damage to peripheral nervous system, hair and finger nail loss and changes, fatigue and irritability. Short term exposure to high levels of selenium can cause respiratory tract irritation, bronchitis, difficulty in breathing as well as stomach pains (CSP2, 2003).

Silica

There is increasing evidence that environmental factors such as air pollution from mine dumps, increases the risk of chronic respiratory symptoms and diseases. Studies have shown that there is a high level of chronic respiratory symptoms and diseases among elderly people in communities located near to mine dumps in South Africa (Nkosi et al, 2015). They found that there was a high prevalence of asthma, chronic bronchitis, chronic cough, emphysema, pneumonia and wheezing in their study sites. Mine dump facilities are a major source of airborne particulate matter pollution, with dust blowing into surrounding communities and potentially having adverse health effects on human health (Ojelede et al, 2012). Epidemiological studies have shown that living close to mines is a major risk for exposure to particulate matter. Exposure to mine dump dust that is rich in silica has been linked to the development of chronic bronchitis, emphysema and airflow obstruction (Wang et al, 1997).

Uranium (U)

Uranium is a metal with high density. The unstable element is the basis of and parent of almost all releases of radioactivity to the environment by decaying into its daughter products (Busby, 2010). Uranium's half-life is 4,5 billion years. Natural uranium exposure occurs via the mining, milling and ore processing activities as well as consumption of groundwater contaminated with uranium. Dust concentrations of up to 3 700 mg* per m^3 of air were reported from areas adjacent to slimes dams of the East Rand during a windy day (Coetzee et al, 2004). The primary exposure routes are ingestion and inhalation. Uranium is primarily genotoxic. The primary organ at risk from uranium chemical toxicity is the kidney, while chronic radiation can cause damage to the lymph nodes and the bone (United Nations Scientific Committee on the Effects of Atomic Radiation –UNSCEAR, 1988). Exposure to uranium causes genetic and genomic changes and therefore impacts most organs in mammals. When inhaled or ingested, uranium's radioactivity creates risks of lung and bone cancer. Because of the toxic properties of uranium it can also cause damage to the developing foetus and increase the risks of soft tissue cancers (Van Riet, 2009). The mining of uranium, which started at the beginning of the last century, is believed to be linked to the first cases of leukemia potentially caused from a mutation in utero (Busby, 2010). Recent findings on uranium toxicity suggest that, apart from long-known impacts on kidneys, uranium may also damage the brain, impact on genetic information (DNA) and act as an endocrine-disrupting compound (Winde, 2010).
Uranium levels higher than 0.02 mg/L in drinking water can cause kidney damage especially to the proximal tubules (Craft et al., 2004). Other known health impacts caused by uranium are its effect on fertility, foetal growth and postnatal viability reported by ATSDR (1999b). Craft et al. (2004) also reported that uranium may cause malformations in foetuses and that it might be associated with reproductive cancers. Furthermore, uranium tends to concentrate in bone and may interfere with the activity of osteoblasts, possibly contributing to bone cancers and osteoporosis (Craft et al., 2004).
Vakil and Harvey (2009) also reported that uranium from dry piles and mill tailings may be exposed to erosion from wind and water, ending up in the environment. This radioactive material may then be taken up by tree roots and plants and become concentrated (Eisler, 1994; Anspaugh et al., 2002). In turn birds, insects, mice, etc may eat these contaminated plants and may release it via their faeces back into the environment. They also reported that root systems help to bring radon up to the leaves where it can be transpired into the air. A local epidemiological study done by Toens et al (1998) reported that there was a statistically significant correlation between the uranium concentrations found in groundwater sampled from boreholes (used as a source of drinking water by this farming area) and high counts of abnormal lymphocytes in peripheral blood (associated with leukaemia) randomly sampled from 418 people living in 52 different locations in part of the Northern Cape Province

Zinc (Zn)

Zinc is an essential element and is for example needed for male reproductive activity. Zinc is widespread in the environment and can easily dissolve into surface and groundwater from mines and mineral deposits. Exposure to zinc occurs via inhalation or contact with decomposition products, vapours, or substances and can cause severe injury or even death. Zn toxicity can be either acute or chronic and has been reported to cause the same signs of illness as lead, and can be mistakenly diagnosed as lead poisoning (McCluggage, 1991). Zinc is considered to be relatively non-toxic, especially if taken orally. However, excess amounts can cause system dysfunctions that result in impairment of growth and reproduction (INECAR, 2000; Nolan, 2003). Inhalation of zinc dust or fumes causes "metal fume fever". The US EPA (1995) noted high incidence of tuberculosis and lung cancer among residents in zinc mining areas. Chronic, sub-chronic, short-term and acute oral ingestion and inhalation reference/concentration doses are provided for contaminants potentially found in mine tailings in the table 16, below. Carcinogenic potency factors are shown for available data, namely arsenic.

Chemical	CAS	Chronic Oral Reference Dose (mg/kg-day)	Chronic Oral Reference Dose Reference	Subchronic Oral Reference Dose (mg/kg-day)	Subchronic Oral Reference Dose Reference	Short-term Oral Reference Dose (mg/kg-day)	Short-term Oral Reference Dose Reference	Acute Oral Reference Dose (mg/kg-day)	Acute Oral Reference Dose Reference
Aluminum	7429-90-5	1.00E+00	PPRTV Current	1.00E+00	ATSDR Final	1.00E+00	ATSDR Final	-	
Arsenic Salts	NA	-		-		-		-	
Arsenic, Inorganic	7440-38-2	3.00E-04	IRIS	5.00E-03	PPRTV Archive	-		5.00E-03	ATSDR Final
Cadmium (Water)	7440-43-9	5.00E-04	IRIS	-		-		-	
Cyanide (CN-)	57-12-5	6.00E-04	IRIS	2.00E-02	HEAST	-		-	
Cyanide (total complex)	NA	-		-		-		-	
Manganese (Non-diet)	7439-96-5	2.40E-02	SURROGATE. IRIS recommends subtracting dietary exposure	-		-		-	
Mercury (elemental)	7439-97-6	1.60E-04	CALEPA	-		-		-	
Mercury, Inorganic Salts	NA	3.00E-04	SURROGATE. See Mercuric Chloride	-		-		-	
Selenium	7782-49-2	5.00E-03	IRIS	5.00E-03	HEAST	-		-	
Uranium (Soluble Salts)	NA	3.00E-03	IRIS	2.00E-04	ATSDR Final	2.00E-04	ATSDR Final	2.00E-03	ATSDR Final
Uranium, Insoluble Compounds	7440-61-1	-		-		-		-	
Zinc and Compounds	7440-66-6	3.00E-01	IRIS	3.00E-01	ATSDR Final	3.00E-01	ATSDR Final	-	

Chemical	CAS	Chronic Inhalation Reference Concentration (mg/m3)	Chronic Inhalation Reference Concentration Reference	Subchronic Inhalation Reference Concentration (mg/m3)	Subchronic Inhalation Reference Concentration Reference	Short-term Inhalation Reference Concentration (mg/m3)	Short-term Inhalation Reference Concentration Reference	Acute Inhalation Reference Concentration (mg/m3)	Acute Inhalation Reference Concentration Reference	Oral Slope Factor (mg/kg-day)-1	Oral Slope Factor Reference	Inhalation Unit Risk (ug/m3)-1	Inhalation Unit Risk Reference
Aluminum	7429-90-5	5.00E-03	PPRTV Current	-		-		-		-		-	
Arsenic Salts	NA	-		-		-		-		-		-	
Arsenic, Inorganic	7440-38-2	1.50E-05	CALEPA	-		-		2.00E-04	CALEPA	1.50E+00	IRIS	4.30E-03	IRIS
Cadmium (Water)	7440-43-9	1.00E-05	ATSDR Final	-		-		3.00E-05	ATSDR Final	-		1.80E-03	IRIS
Cyanide (CN-)	57-12-5	8.00E-04	Surrogate to Hydrogen Cyanide	-		-		-		-		-	
Cyanide (total complex)	NA	-		-		-		-		-		-	
Manganese (Non-diet)	7439-96-5	5.00E-05	IRIS	-		-		-		-		-	
Mercury (elemental)	7439-97-6	3.00E-04	IRIS	3.00E-04	HEAST	-		6.00E-04	CALEPA	-		-	
Mercury, Inorganic Salts	NA	-		-		-		-		-		-	
Selenium	7782-49-2	2.00E-02	CALEPA	-		-		-		-		-	
Uranium (Soluble Salts)	NA	4.00E-05	ATSDR Final	1.00E-04	ATSDR Final	1.00E-04	ATSDR Final	-		-		-	
Uranium, Insoluble Compounds	7440-61-1	8.00E-04	ATSDR Final	2.00E-03	ATSDR Final	2.00E-03	ATSDR Final	-		-		-	
Zinc and Compounds	7440-66-6	-		-		-		-		-		-	

Table 16 **IRIS The Integrated Risk Information System (IRIS**) is a human health assessment program that evaluates quantitative and qualitative risk information on effects that may result from exposure to environmental contaminants.

PPRTV The Provisional Peer Reviewed Toxicity Values (PPRTVs) derived by the EPA Superfund Health Risk Technical Support Center (STSC) for the EPA Superfund program.

ATSDR The Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk levels (MRLs) were developed as an initial response to The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

CALEPA The California Environmental Protection Agency (OEHHA) Office of Environmental Health Hazard Assessment's Chronic Reference Exposure Levels (RELS) from December 18, 2008 and the Cancer Potency Values (PDF) from July 21, 2009.

HEAST The Health Effects Assessment Summary Tables (HEAST) is a database of human health toxicity values developed for the EPA Superfund and Resource Conservation and Recovery Act (RCRA) hazardous waste programs.

To assess potential health risks associated with exposure to the mine tailings in stone-paper production, a theoretical dose (exposure) needs to be calculated for workers involved in the stone-paper production process and residents in close vicinity of the mine tailings excavation process. This involves assessing dust production which will result in inhalation of dust particles as well as ingestion of dust particle created in the process. Dust is ingested on a daily basis under normal circumstances, where dust is ingested by the inadvertent consumption on hands or food items, and through mouthing objects, Contaminated soil can be brought into homes on the feet of family members and animals. Dust particulates in air can be deposited both indoors and outdoors. Young children playing on the floor have the maximum likelihood of ingesting dust and for dermal exposure to it.The US- ATSDR

(ATSDR, 2005) presents the following equation to calculate potential doses to contaminants in dust to determine possible health risks associated with this exposure (Figure 19).

Exposure doses from ingestion of soil can be calculated as follows:

D = (C x IR x EF x CF) / BW

where,

D	=	exposure dose (mg/kg/day)
C	=	contaminant concentration (mg/kg)
IR	=	intake rate of contaminated soil (mg/day)
EF	=	exposure factor (unitless)
CF	=	conversion factor (10^{-6} kg/mg)
BW	=	body weight (kg)

Default Soil Intake Rates

100 mg/day -	adult, average soil ingestion rate
200 mg/day -	child, average soil ingestion rate
5,000 mg/day -	pica child, average soil ingestion rate *(to be used when assessing acute exposure situations only)*

Note:
mg/day - milligrams per day

Figure 19: Exposure calculation from ingestion of soil (Source: ATSDR, 2005)

An example of an exposure calculation is provided below. A child ingesting dust with an arsenic concentration in dust or soil of 1 milligram per kilogram (mg/kg) (representing the higher concentrations detected in West Rand mine tailings (van Deventer, 2009)) and a daily ingestion rate of 200 milligrams per day (mg/day) as a representative ingestion rate of children (US-EPA, 1997). Assuming a child is exposed to the site 7 days per week, 50 weeks per year, for 6 years the exposure calculation is described as follows:
The exposure factor (EF) is calculated as EF = (F x ED) / AT where F is the frequency of exposure, and AT is averaging time.
EF = ((7 days/week x 50 weeks/year) x 6 years) / (6 years x 365 days/year)
EF = 0.96
The average dose:
D = (C x IR x EF x CF) / BW
D = (1 mg/kg x 200 mg/day x 0.96 x 10^{-6} kg/mg) / 16 kg
D = 0.000012mg/kg/day

This is compared to a reference dose (RfD) in mg/kg/d that is considered to be safe.
The Rfd for arsenic is 0.000015mg/kg/d.
Therefore the hazard quotient is Average Daily Dose / RfD = 0.000012mg/kg/d/ / 0.000015mg/kg/d[1] = 0.8, or 80% of the safe dose, based on toxic effects of arsenic. However, arsenic is also known to be carcinogenic in addition to causing toxic effects.
The risk for developing cancer is calculated as follows:
Risk = LADD * Oral slope factor LADD = lifetime average daily dose and oral slope factor is the chemical specific potency of a carcinogen for the ingestion pathway, or the inhalation concentration if the route of exposure is through inhalation of dust (US ATSDR,2005). No data is available of arsenic concentrations in air near mine dumps, with the exception of a preliminary CSIR study described earlier, which identified a risk of developing cancer as a result of inhalation of arsenic as a possible issue needing to be considered and investigated in more detail.

The possible health effects associated with exposure to mine tailings have been described in the sections above, however no quantitative health risk assessment can be conducted with the limited data available. A few of the contaminants have been identified as having the potential to cause health effects such as arsenic and uranium and would need to be monitored with mitigation measures limiting exposure ensured.

Based on the above discussion with respect to the potential health effects of working with mine tailings and the material from mine dumps, the following salient observations can be made:

- Acid mine drainage, the exposure to dust, radiation and heavy metals from existing mine tailings and dumps is a current problem, and one that is not going to go away, but, in all likelihood, have a greater impact on more people in time going forward due to an increased population and urbanisation, leasing to greater exposure

- Reworking old mine tailing and dump sites does release dust and soils contaminated with radioisotopes, heavy metals and other pollutants or contaminants. It is currently unknown i) what the newly released contaminants are likely to be, and their respective concentration levels, ii) what the health risks would be, and how many people would be exposed, to these new exposures in the event that the mine tailings and dumps be reworked, iii) how to neutralise the undesirable side effects of these on-site and/or before they get disposed and/or dispersed into the atmosphere, and iv) what the cost of managing the health risks would be.
- Mining is likely to continue for at least another three decades or more in Johannesburg. Unless the current mining wastes are utilised and neutralised effectively, it will add to the existing problems concerning land degradation, acid mine drainage, air and water pollution-especially the uranium and heavy metal in soils and water bodies.

It reasonable to suggest that order to mitigate the health risks and the associated liabilities, the focus of stone paper R&D should be on existing mines to avoid future mine wastes. This will, at least in theory, reduce future liabilities and the generation of future mine dumps. Given the uncertainties surrounding the management and the potential impacts of disturbing the historic mine dumps, it is best to adopt the precautionary principle. Much more research and a much more fundamental understanding of the treatment of the pollutants is required before one can embark on mining silica from the existing mine dumps. This recommendation comes in the wake of the fact that a responsible and reasonable government has to take the best decisions with the information available to reduce the risk to society, but, at the same time, also seek to improve the welfare of future generations through ongoing research and development.

5. SUMMARY AND RECOMMENDATIONS

Both rock waste from mining and builders rubble can be converted into a valuable Stone paper product, and in doing so avoid the pollution burdens and land degradation from landfilling these wastes. Stone paper is a durable and water-resistant paper-like product that could be produced locally and can help to avoid the need for the import of packaging as well as the land and water footprint associated with paper made from trees.

There have been huge quantities of mining rock deposited on the land surface in mine dumps and mine tailings from over 100 years of mining- mostly gold in the Witwatersrand and there is **3203 Megatonnes of legacy mining wastes available as a stock accumulated from the mining over the last 100+ years.** The area occupied by mine wastes (mine residues areas MRAs) within the CoJ Municipality is **5764 ha** and ⅔ of these MRAs are gold mining. A large part of the the mining waste within CoJ is present 15 large dump sites that totals at least 400 Megatonnes and occupies 1143 ha land.

In addition, **current and future mining activities will produce another 722 megatonnes rock waste over the estimated 33 years until depletion of the gold resource in 2044**; with an average of 22 megatonnes per annum mined and the degradation and loss of **another** 1500 ha from mine wastes. The current and future mining wastes (as opposed to legacy wastes) are the most appropriate resource as this can tailor the stone paper production to current mining technology and infrastructure, while also ensuring improved rehabilitation of lands upon exiting the mining area that avoid future pollution and burdens on CoJ citizens.

There is approx. **7 Megatonnes Builder's rubble that has accumulated in the existing CoJ landfills**, but it is mixed with other wastes and not seen as readily available (costs of mining landfill for rubble prohibitive). Currently, there is also an **annual flow of at least 197 515 tonnes per annum (0.2 Megatonnes) builders rubble** produced that is destined for the four existing Municipal landfill sites that will amount to 6 Megatonnes in the next 30 years. However, over half is seen as valuable on-site cover for other wastes at the landfill and the rest takes up valuable landfill space. A large portion of rubble is currently illegally dumped and mixed with other wastes around CoJ- a practice CoJ are trying to discourage as it pollutes and degrades natural areas. Therefore, there is at least 44 813 tonnes per annum rubble is realistically available for stone paper.

The other essential component of Stone paper is 20% plastic HDPE (or PET)- a non-renewable resource derived from oil. It would be preferable to use recycled HDPE or PET and data indicates that this plastic forms 1-1.5 % of CoJ waste stream (1.6 million tonnes per annum total)- indicating that there is 15 000 HDPE and 25 000 tonnes per annum PET theoretically available. **Assuming at least 30% HDPE can be recycled and is available for Stone paper, then approx. 4500 tonnes is available. Since HDPE is used at at 20% in Stone paper, this will support 22500 tonnes per annum Stone paper production facility**

There are sufficient resources of waste rock to support a small (4000-40 000 tonnes per annum paper) stone paper production facility using builders rubble, and a medium to large (60 000-120 000 tonnes per annum or more) stone paper production facility using wastes from current and future gold mining. The rock waste resource from both past and near future mining is considerable, with the current and future mining in the next 33 years generating sufficient rock waste for large to very large stone paper production facilities (ie 10 to 20 million tonnes per annum).

However, based on local availability of mining rock wastes and recycled HDPE, it is recommended that a small to medium size Stone paper production facility be established (4000-20000 tonnes per annum). The exact location and costs will depend on the resource and site selection, as well as business model (phase 2 of this project).

The use of Builder's rubble and mining rock waste for stone paper also has **notable environmental and social benefits to CoJ that should be considered in the cost accounting and business model.** Removal of these wastes can avoid many burdens to the environment and human-health, including**:**

- **Land development potential and land degradation.** The mine residues and builders rubble has resulted in landfill with loss of land space, land degradation and the loss of biodiversity. The land area impacted by mining waste is 5764 ha from legacy mine waste and 1500ha from future mining waste (until gold resources are depleted). Similarly, the land area required specifically for builders' rubble waste in landfills amounts to 0.75 ha per year, implying that 22.5 ha of land is required for disposal of builders' rubble over a 30 year timeframe. As such, if the land area impacted by legacy mine rock waste is rehabilitated and developed, then values ranging from R27 billion to R77 billion can be unlocked, depending on the type of land use. Alternatively, if this land were rehabilitated and revegetated, then a minimum value of of R34.4 million per annum could be derived in terms of ecosystem service provision. In either case, however, the costs of rehabilitating the land for the required land use would also need to be taken into account. On the other hand, the value from avoiding future mining waste dumps (in terms of keeping 1500 ha of land available for other development options) ranges from R7 billion to R20 billion; or at least R9 million per year in terms of ecosystem services. Finally, if builder's rubble could be diverted from landfill sites, land with a value ranging between R60 million and R325 million could be preserved for other uses.

- **Biodiversity loss.** Over the history of mining, thousands of hectares of land has been transformed and degraded through mining with significant local biodiversity loss. Currently 89% of the Ecological Support Areas (ESA1 and ESA2) exposed to mining residues, 14 % of mine residues are adjacent to perennial rivers and 38% are adjacent to non-perennial rivers. This highlights the current and ongoing impacts of mining pollution and waste with the important loss of ecosystems and biodiversity and the impacts to water and other natural resources. It also calls for interventions to protect and enhance the biodiversity and ecological infrastructure that provides services, such as regulation and purification of water and air, vital to human well-being and livelihoods.

- **Water pollution and availability.** Stone paper has a water footprint considerably less than conventional tree paper- with a water-saving during production of on uses 41 cubes per tonne paper. In addition, since stone paper does not use wood, it avoids the water needed to grow trees for conventional paper production which saves a further 237 cubes water per tonne paper produced. The overall life-cycle water saving of stone paper instead of tree paper is 278 cubes water per tonne paper or 278L per kg paper. If this water was included in the value of the paper it would save R1002 per tonne paper or R1.00 per kg paper (assumes marginal value of water at R3.60 per cube water) and it also avoids the land area needed for this. Lastly, the use of mining waste for stone paper can reduce the water-pollution associated with mining; such as Acid Mine Drainage (AMD).

- **Soil pollution and air pollution (dust).** The soils impacted by mining (compaction, loss organic matter, leachate and acid mine drainage containing low-PH water with several metals that can cause health impacts, including radio isotopic uranium. The mine dumps and tailings are subject to wind-erosion that carries dust for kilometres and can only effectively be mitigated by removal or vegetation.

The **caveat for achieving these benefits and avoiding unintended impacts** is the use of these wastes in a safe and effective manner. This includes the above-mentioned preference for avoiding the disturbance of existing wastes that have been (partially) rehabilitated and focussing on current flows of mining wastes and builders rubble. This approach can avoid many unintended risks from re-mining dump sites, while helping to avoid current and future flows of mine wastes and builders rubble to going to landfill, and thereby create future land space needed for development (housing, industry, open space). A notable technology risk for the stone paper product is achieving negligible levels of contaminants in stone paper that can present a health hazard. The existing extraction processes are not 100 % effective and even after re-processing, the tailings will still contain about 10 % of the gold and 15% of the uranium present tailings prior to processing. Typical background levels of uranium are in the order of 3 ppm. Average uranium content of slimes (before processing) is around 100 g/t but can range from 50 g/t to over 300 g/t. Thus if 90% is removed you will still have about 10 ppm on average in the final tails-but it could also range from say 5 to 30ppm. There is therefore a significant risk negligible/background levels of uranium can be achieved without exorbitant cost. In the longer-term the rock wastes of the mining areas of the Witwatersrand are a significant and promising rock waste resource, but will require implementation at a much larger scale (millions of tonnes per annum) with prior research and development to ensure radioactive uranium is removed to negligible levels; since even small amounts in stone paper will cause health concerns.

The recommendation for Stone paper production is therefore at the Municipal landfill sites where Builders rubble can be collected together with recycled plastic HDPE; which will reduce illegal dumping and enhance recycling. Stone paper plants generate jobs in the production plants, as well as will also increase secondary jobs and skills in upstream recycling and the downstream production of various paper-products from Stone paper.

Appendix A - Estimation of Volume and Surface Area

Volume

To establish an initial estimate of all the ore that could be available, the ore tonnage milled between 1910 and 2010 was extrapolated from Figure 1[11]. The process involved digitizing the graph in order to approximate the annual quantity of ore milled for individual years.

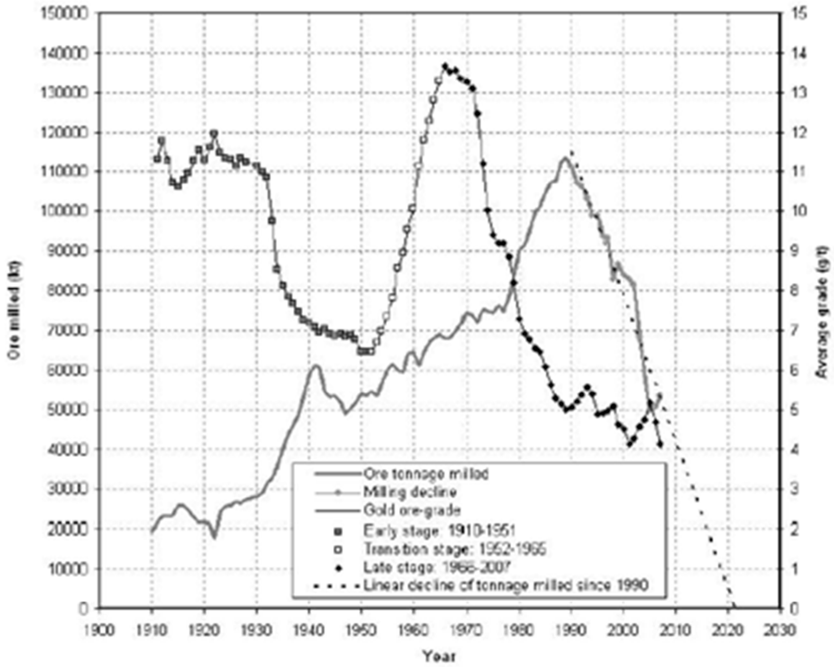


Figure 1. Combined historical graph of annual quantity of gold ore milled

This produced a total probable mass of 6 108 544 kilotonnes of ore milled between 1910 and 2007 or $\boldsymbol{m = 6\,108 \times 10^9\ [kg]}$.

Measurements of settled dry densities of processed ore (in general) range between 1250 and 1650 kg/m^3 as a function of depth, so a value of $\rho = 1450\ [kg/m^3]$ is used for general design purposes[10]. Once these two properties are known the total volume of ore can be calculated by:

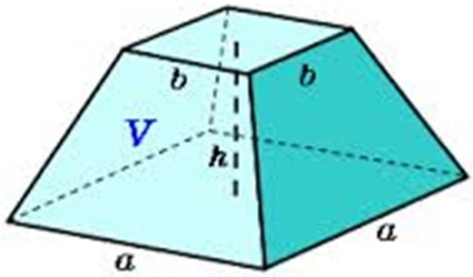
$$V = \frac{m}{\backslash rho} = \frac{6108 \times 10^9}{1450}$$

$$V = 4\,121\,413\,793\ [m^3]$$

Surface Area

In order to quantify the aforementioned volume of mining material, it will be equated to a single mine dump with proportions comparable to existing dumps. The shape assumed was that of a square frustum (truncated pyramid) as in Figure A2. In South-Africa it is common practice to design mine dumps with a final height in the order of 30 – 40 m[10]. For the purpose of this assessment a height of 35 meters was assumed. The repose angle of a material refers to the steepest angle of descent relative to the horizontal plane, to which material can be piled without slumping. For mine dumps this angle typically ranges between 35°and 40°, assumed 37°in the following calculation. It follows:

$$h = 35\ [m]$$
$$\phi\ =\ 37°$$



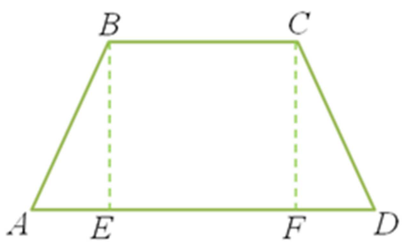
The volume for a truncated square pyramid is defined as:

$$V = \frac{h}{35}(a^2 + ab\ + b^2) \qquad \text{(Eq. 1)}$$

Where:

- **V** denotes the total volume.
- **h** denotes vertical difference between the two parallel planes.
- **a** denotes the length of each side of the base square.
- **b** denotes the length of each side of the top square.

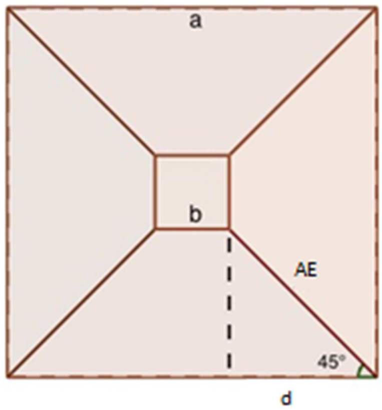
With the total volume (V), height (h) and slope angle(ρ) known, it is necessary to determine a relation between the lengths of *a* and *b* in order to solve Eq. 1 for the respective lengths and subsequently the surface area covered. When considering a view perpendicular to a plane that would intersect the frustum diagonally, the shape would result in an equilateral trapezium and would look something like Figure A3 below:



Where angle BǍE represents the assumed angle of 37°and the heigh t by line BE = 35 m. By using the following trigonometric relation the length of line AE can be found.

$$sin(37°) = \frac{BE}{AE}$$
$$AE\ =\ 46.677\ [m]$$

Knowing this, consider then the top view of a square frustum as illustrated in Figure A4 below, where the known length of AE then forms a new triangle, once again with one known angle i.e. 45 as illustrated.



Again using trigonometric relations the length of line *d* can be found by:

$$cos(45°) = \frac{d}{AE}$$
$$d = 33\ [m]$$

Consequently the relation between the length of each base side (*a*) and top side (*b*) can be defined as:

$$b = a - 2d \qquad \text{(Eq. 2)}$$

Substituting (Eq. 2) into (Eq. 1) and solving for *a* yields:

$$a = 10\,884.47\ [m]\ = 10.9\ [km]$$

And

$$b\ =\ 10\,818.47\ [m]\ =\ 10.8\ [km]$$

Finally the total ground surface area (A) that would be occupied is calculated by squaring the base length:

$$A\ =\ a^2\ =\ 10.9^2\ =\ 118.8\ [km^2]$$

Where

A denotes the total area that would be occupied by a mine dump comprised of all the gold ore milled in the Witwatersrand.

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[1] Arsenic reference dose 0.0003mg/kg/d IRIS (1991) and 0.000015mg/kg/d (CALEPA). The carcinogenic slope factor via ingestion is 1.5 per mg/kg/d and 0.0043 per ug/m^3 via inhalation (IRIS, 1995)