Mapping the impact of mining across the SADC landscape using Landsat 8 imagery

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Abstract

Mining activity has been identified as one of the major contributors to landscape change in southern Africa. In order to assess the impact of mining, a new spatial data that quantifies the extent of current mining activities has been generated from Landsat 8 satellite imagery. Mapping the current extent of mining activity across southern Africa provides a unique, baseline reference dataset to use for monitoring future and comparing historic mining impacts.

Keywords

mining, southern Africa, mapping, reporting, baseline reference, impact assessment

Introduction

Mining has a significant impact on the landscape. This can be in terms of direct physical changes in land-cover, or indirectly as a driver of change in surrounding land-use and associated demographic patterns; influences on other resources such as water and air quality and associated health risks; or as a catalyst for infrastructure development and job creation. The ability to be able to spatially quantify the current extent of mining in a regional context is therefore an important component and often a pre-requisite in many regional assessment or monitoring procedures where spatial intelligence is required in support of decision making.

Using the latest generation of zero access cost Landsat 8 imagery, we have been able to map and quantify the precise spatial extent of current mining activity across eleven countries in southern Africa, from the gold mines in the heart of South Africa to the copper-belt mines in southern DRC. The dataset is thus current and valid, has been generated with minimum development cost, and has high spatial intelligence value to both academic and business end-users. The mine dataset provides, as intended, a unique regional perspective on the extent, distribution and size of mine activities across the sub-continent, rather than detailed information on individual mine characteristics.

The need for a mine activity reference base

A key question to ask however is whether or not now is a suitable time to establish a baseline representation of mining activity in the region, against which historical change and future change can be monitored and referenced? In a recent report on the status of mining in Africa (Deloitte, 20151) it was stated that mine development is slowing across the continent, and may remain so for the foreseeable future, especially if commodity prices are considered. However the DRC / Zambian copper-belt region is a potential high activity anomaly to this pan-African perspective. Establishing a spatially defined mining activity reference base at this low point in mine development may actually be preferential since it represents the status of regional mining activity at a period of minimal development, hopefully prior to future growth and expansion. Or under a worse-case, no future growth scenario, could also assist with understanding the implications of regional mine closure and remediation / reclamation activities.

Approach

The mine activity dataset is a spatially precise, up-to-date inventory of all mining activity in southern Africa, covering Angola, Botswana, Malawi, Mozambique, Namibia, Lesotho, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe, and the DRC’s copper-belt region.

The dataset has been generated from recent, 30 m resolution Landsat 8 satellite imagery, acquired primarily in 2014/2015. The dataset represents all non-vegetated, bare ground areas resulting from mining activities, including extraction pits, tailings dumps, dust-impacted areas and surface infrastructure, which are represented collectively as a single mining activity “footprint”. The mine footprints include both active and decommissioned mines, ranging from small roadside “borrow-pits” and quarries to large commercial operations. Currently no distinction is made between active or decommissioned mines, although the mine footprints are broadly classified into the following sub-classes, namely: “mine water” i.e. flooded pits or ponded tailing dams, (evaporative) salt mines, (road-side) “borrow-pits and small quarries” and all “other” mines, mainly representative of the larger commercial operations. Road-side borrow-pits and small quarries are defined in the context of this dataset as mine features smaller than 5 ha within 500 m of a road. Table 1 lists that full mine activity sub-classes that are contained with the dataset, and the associated class definitions.

<table>
<thead>
<tr>
<th>Class name</th>
<th>Class definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mine other</td>
<td>All mine activity areas, as represented by bare ground surfaces larger than 5 ha in extent, with the exclusion of (evaporative) salt mines. Typically these are associated with the larger commercial mining operations. The mapped footprint represents the combined spatial extent of all extraction pits, tailings dams and associated surface infrastructure.</td>
</tr>
<tr>
<td>2. Mine other water</td>
<td>All water surfaces associated with bare ground mine activity areas larger than 5 ha in extent, with the exclusion of (evaporative) salt mines. Typically this represents either flooded pits and/or ponded tailings dams. The water extent may be permanent or seasonal.</td>
</tr>
<tr>
<td>3. Borrow-pits</td>
<td>Small road-side borrow pits and quarries typically associated with road (or similar) construction activities. Defined as features smaller than 5 ha within 500 m of a road line.</td>
</tr>
<tr>
<td>4. Borrow-pits water</td>
<td>All water surfaces located within road-side borrow-pit features. Typically this represents flooded pits, where the mapped water extent maybe permanent or seasonal.</td>
</tr>
<tr>
<td>5. Salt mines</td>
<td>All mine activity areas associated with evaporative salt extraction, typically using shallow evaporative ponds. This class represents the dry pond areas.</td>
</tr>
<tr>
<td>6. Salt mines water</td>
<td>All mine activity areas associated with evaporative salt extraction, typically using shallow evaporative ponds. This class represents the flooded pond areas.</td>
</tr>
</tbody>
</table>

Table 1: Mine information classes contained in the regional mine dataset.

The full regional dataset, covering the eleven countries between Tanzania and South Africa contains in excess of 37 000 individual mine activity footprints. This is illustrated in Fig. 1. As is clearly evident in Fig. 1, the highest density of mining activity across the region is in South Africa.

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2 The South African extent of the mine dataset is based primarily on 2013/2014 imagery, since this data component was the precursor to the wider southern African data coverage, for which more recent 2014/15 imagery was then available and used.
Fig. 1: Overview of full mine coverage, showing all mine sub-classes including (road-side) borrow-pits and small quarries.

If the high number of (road-side) borrow-pits and small quarries are removed from the dataset, the distribution of mines across the sub-continent is still dominated by South Africa. This is illustrated in Fig. 2, which shows the effect of removing more than 20 000 road-side borrow-pits from the total mine dataset that contains over 37 000 mining footprints. What is still clearly evident is that even with the removal of the road-side borrow-pits, the highest density of mining activity across the region is still within in South Africa.

Fig. 2: Overview of mining extent after excluding all road-side borrow-pits.

Mine mapping

The spatial extent of the mine activity bare ground areas, i.e. the mining “footprint”, has been precisely defined using digital image classification procedures, whilst validation of the bare ground surface being representative of a mining activity has been confirmed by visual analyst interpretation. A combination of automated spectral modelling and unsupervised classification algorithms were first used to define all permanent bare ground surfaces in the landscape; after which those bare ground surfaces associated specifically with mining activity
were identified and delineated using visual, on-screen manual mapping procedures, in order to separate them from other permanent bare ground areas associated with non-mining activities or landscape processes.

The automated spectral modelling process was used to initially identify all areas of seasonally permanent bare ground, using a combination of vegetation-cover sensitive spectral indices, generated from a combination of seasonally representative image acquisition dates per image frame. This modelling procedure was an integral part of the wider GTI southern African land-cover data generation process, whose objective was to create a separate but associated regional vegetation cover dataset (GeoTerraImage, 2015). Both the regional land-cover data and the new mining information where derived from the same Landsat 8 source imagery. The combination of basic land-cover detail and the new regional mine footprint information is illustrated in Fig. 3.

![Image](image.png)

**Fig. 3:** Zambia-DRC Copper-belt mines (shown in red) imbedded within the basic GeoTerraImage regional land-cover data.

The copper-belt mining footprints as illustrated in Fig. 3 also clearly shows which excavation pits and/or tailings dams contain or are covered by water. It is not inconceivable, that in support of analytical purposes, that this information, could be used as an indirect indicator of mine status and a determination of whether a mine is still active or has been decommissioned.

Subsequent to this automated modelling process and outcome, an unsupervised classification approach was then applied on the most suitable, single date, maximum biomass / minimum cloud image per frame, in order to generate a more precisely defined representation of the same bare ground area. This alternate approach was used due to the greater sensitivity of unsupervised algorithm on each individual image frame dataset compared to the more generic, and thus more generalised modelling outcomes.

**Map data presentation**

While the original southern African mine dataset is based on 30 m raster cells, equivalent to the source Landsat imagery format, an alternate, spatially generalised vector dataset has been created that provides a more homogenised representation of regional mine extent and coverage. This alternate, simplified dataset has been created by aggregating all individual mine features into larger “super-clusters”, based on a grouping distance of 400 m, which are more representative of the larger commercial mining operations. Within this process, all small road-side edge borrow-pits and quarries (defined as mine features smaller than 5 ha within 500 m of a road), are allowed to be incorporated into the aggregated feature, if the modelling rules require this. Fig. 4a illustrates the individual mine footprints, including the borrow-pits, before a distance aggregation spatial cleaning process is performed. Fig. 4b shows the result of this vector aggregation and shows how the individual footprints are now solidified into larger, more spatially homogeneous mine area footprints.

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Fig. 4a: Original mine footprints before spatial cleaning and homogenisation using distance-based vector aggregation.

Fig. 4b: Final mine are footprints after spatial cleaning using distance based vector aggregation.

The larger “super-clusters” created by the spatial simplification process still contained the original mine information sub-classes, namely: Mine other, Mine other water, Borrow-pits, Borrow-pit water, Salt mines and Salt mine water. The mine water classes were derived from the GTI regional land-cover dataset, and represent any permanent or seasonal water mapped as part of this land-cover dataset that was located within a mine activity footprint.

**Mining impact on the landscape**

A mine index has been created based on the sum of the number and area of mine features in a given region that provides a useful tool for assessing and comparing mine activity (i.e. number of mines x area of mines). The index is designed to reflect both mine activity distribution and spatial extent, such that a region with a high number of small mines will score lower than a region with a similar number of larger mines; and likewise a
region with a small number of large mines may score the same as a region containing a wide distribution of small mine areas, if the total area of the smaller mines is comparable to the total area of the larger mines.

This index has been applied to the spatially aggregated dataset with the following results.

Looking at a generic country level, the mine index map reflects the highest mining activity in South Africa, representing 63% of the total SADC mining activity; followed by Angola, Namibia, and Zambia. Lesotho, Swaziland, and Malawi have the lowest mining activity index values in the southern sub-continent. Note that the country index has been calculated based on the full mining footprint dataset, which includes road-side borrow-pits. This is illustrated in Fig. 5.

![Fig. 5: Mine activity index values per country.](image)

A more informative spatial pattern arises if the mining activity index is assessed at the more detailed administrative level 1 level, comparable to provincial boundaries in South Africa. At this level a clear indication of the distribution and dominance of mine activity becomes apparent, with areas such as South Africa’s coalfields, bushveld complex and gold fields; the DRC / Zambian copper-belt and the Great Dyke in Zimbabwe starting to show prominence. This is illustrated in Fig. 6.

![Fig. 6: Mine activity index values per administration level 1.](image)

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4 Regional Administrative Level 1 boundaries sourced from www.DIVA-GIS.org, sourced from GADM
Mine activity distribution has also been analysed and compared based on regional hydrological boundaries\(^5\), due to the impact mines can have on water resources. At a broad level, based on hydro basin level 1 the mine index indicates that the catchments most impacted on a regional basis by mining activity are the Orange, Limpopo and the Zambezi catchments. The regional catchments with the lowest mine activity impact are the Rift Valley basins in Tanzania, closely followed by the coastal basins of Angola, Namibia and Mozambique. This is illustrated in Fig. 7.

Fig. 7: Mine activity index rankings for hydro-basin level 1 boundaries.

At a more detailed level, based on hydro basin level 2, the mine indices provide a more revealing localised pattern of mining activity on regional water resources at sub-catchment level. The catchments with the highest mining activity index values are the Kasai 3 (Angola), Lulaba 3 (DRC), Kabompa (Zambia), and the majority of Orange River catchments in South Africa. This is illustrated in Fig. 8.

Fig. 8: Mine activity index rankings for hydro-basin level 2 boundaries.

\(^5\) Regional hydrological boundaries sourced from http://fao.org/nr/water/aquamaps
However, in order to see the true potential distribution and level of mine activity impact on regional water resources it is necessary to combine the information for both hydro-basin levels 1 and 2, in order to see both the level 2 hydro-basins that are immediately affected by mining activities, and all the level 2 basis downstream of these primary affected areas. Only then is it possible to identify those level 2 hydro-basins that are potentially least impacted by mining activities across the sub-continent. This is illustrated in Fig. 9. It is now evident that over 33% of all hydrological sub-catchments in the region are potentially impacted by high levels of mining activity. Outside of South Africa there are a significant number of sub-catchments that are relatively unaffected by mining activity, especially in Mozambique, Malawi, and western catchments of the far western Zambezi. This is illustrated in Fig. 9, where the mine activity index value calculated for any given sub-basin is copied to all subsequent downstream sub-catchments, if it is higher than the calculated index for those downstream sub-catchments.

![Fig. 9: Downstream standardised mine activity index rankings for hydro-basin level 2 boundaries.](image)

**Conclusion**

Mapping the mining activity footprints provides baseline reference data that can be used by both academic and business-end users in decision-making. Having the current mining footprints for the sub-continent region creates a base dataset to monitor future mining activity in the region, both in terms of expansion, closure and rehabilitation. The current mine dataset clearly shows the potential impact of mine activities on water resources across the sub-continent, with over 33% of all hydrological sub-catchments in the region are potentially impacted by high levels of mining activity. Outside of South Africa there are a significant number of sub-catchments that are relatively unaffected by mining activity based on the mining activity index as presented. Repeatable and standardised mapping methodologies and the use of cost effective free-access imagery creates an opportunity to develop and maintain this mining dataset both in terms of future mining activity and expansion of geographical coverage across the rest of the continent.

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