Benchmarking rehabilitation in the South African opencast coal industry

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Abstract

Opencast coal mining is responsible for the greatest area of land disturbance across all of the commodity types in South Africa. Many thousands of hectares have been rehabilitated to date and, although rehabilitation performance is not always measured or reported, a significant database, spanning 24 years, has now been analysed to identify the main shortcomings holding back rehabilitation sustainability across the industry.

Data from 48 different collieries with rehabilitation performance scores measured from 2000-2024 were analysed. A standardised assessment framework was implemented at all 48 collieries, focusing on aspects of land capability, soil fertility, landscape form and drainage, vegetation species composition and basal cover, implementation of maintenance programmes, and prevalence of invasive alien plants.

The findings show that, although invasive species management, plant species composition, and plant basal cover are often adequate, the implementation of aftercare and maintenance programmes (influencing soil fertility) and deficiencies in overall landform design and drainage systems are most significant in preventing overall rehabilitation progression and self-sustainability. Integrating these during design and rehabilitation execution, followed by intensive maintenance (especially in the first five years post-topsoiling and seeding) will be key for the overall industry performance to improve to acceptable levels. The database is biased towards collieries that actually do undertake rehabilitation and that do measure it, hence the actual industry performance is likely worse than what is presented.

Due to the substantial hectarages involved and the main post-mining land uses being grazing and crop production, the industry cannot afford to keep perpetuating deficiencies in achieving the foundational aspects of rehabilitation that would pave the way for sustained economic future use.

Keywords

land capability, monitoring, landscape form, soil fertility, post-mining land use

Introduction

Open cast mining involves the removal of large volumes of soil and rock overburden to access the workable coal seams. This process results in the destruction of vegetation and soil located above the overburden. A total of 326,022 hectares of agricultural land had been disturbed due to coal mining activities in South Africa up to 2014 (Bench Marks Foundation, 2014). Currently the legal requirement for the mining companies is to comply with the Environmental Management Programme (EMPr), which mainly specifies the land capability, and not necessarily the land use. Although the land capability is still necessary to determine the land use, the focus should primarily be dictated by the end land use. Some of the larger mining companies have variable commitment to monitoring and reporting, while in the smaller mining companies, the lack of monitoring and reporting is prevalent. In mines where an active feedback loop exists between monitoring and maintenance, an increase in the rehabilitation performance can be observed (Agboola et al., 2020). To guarantee uniformity in fieldwork, analyses, and reporting, the methodology employed in this study was carried out using the same procedures that have been in use for the past 24 years.

The purpose of this study is to highlight the current status of the South African open-cast coal rehabilitation efforts and performance in relation to the extent of actual rehabilitation that has taken place, and to provide a standardised assessment methodology that can benchmark rehabilitation performance and provide feedback loops to rehabilitation maintenance and eventual sign-off.

Methods

Assessment criteria

The seven rehabilitation criteria assessed (landscape form, land capability, soil fertility, soil loss, species composition, pasture structure, and vigour) are all interconnected and dependent on each other. The succession of the criteria is presented in Figure 1.

The factors, starting at the lower end, are interdependent, as indicated in Figure 1. Table 1 shows the rehabilitation criteria together with a description of each criterion, whereas Table 2 shows the performance rating or scoring. The landscape form forms the foundation of successful rehabilitation, hence the importance of pre-grass assessments. It includes the civil engineering components like slope length, slope angle, and stormwater conveyance structures, amongst others. The design should be sound and aligned with the mine's closure objectives, any applicable legislative requirements, and best practice guidelines. Once the landscape form is sufficient, it will influence the land capability, which is a factor of slope angle, soil acidity, and topsoil depth. The soil loss is also connected to landscape form but declines with the successful establishment of pasture grasses. Once the areas have been seeded, soil fertility and pasture vigour should be addressed by means of applying fertiliser and undertaking timeous aftercare (two defoliation and two topdressings per annum) for at least the first five years. The degree to which the aforementioned criteria have been addressed will determine the species composition and pasture structure standard.

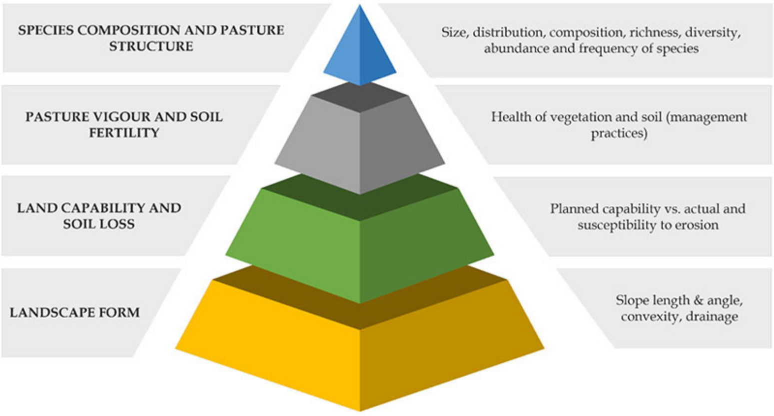

Figure 1—Succession of rehabilitation criteria

Table 1

Rehabilitation criteria

Criterion	Explanation
Land capability	Degree to which actual land capability meets the pre-mining land capability or the land capability prescribed in the Environmental Management Plan, or land capability as otherwise specified.
Landscape form	Degree to which a landscape profile is similar to the pre-mining situation or to the neighbouring unmined situation, or to a stable landscape.
Soil loss	Vulnerability to erosion (joint expression of adequacy of landscaping and revegetation).
Soil fertility	Degree to which soil properties and nutrient resources can support a vegetation that can be managed to restore soil function, or the degree to which soil function is restored.
Species composition	Extent to which plant types conducive to restoring soil function and protecting against erosion are present.
Pasture structure	Size, distribution and frequency of perennial grass plants (proxy for revegetation success).
Pasture vigour	Health of plants as influenced by management.

Table 2

Performance rating

Score	Standard of environmental practice	Explanation – degree to which sustainability is met
5	Best	Excellent, could not be better.
4	Good	Not perfect, but of high standard.
3	Fair	Satisfactory, better than average industry performance.
2	Poor	Flawed rehab not conforming to ethic of sustainability.
1	Very poor	No or little effective environmental management.

Rehabilitation criteria

This section elaborates on the different rehabilitation criteria that are assessed and their applicability in terms of rehabilitation performance.

Landscape form

Landscape form is important because it affects land stability and land capability. For purposes of rehabilitation assessments, landscape form was viewed at three scales: macro, medium, and micro scale.

At the macro scale, there are four main principles of importance and are as follows: drainage to the exterior, drainage density, slope steepness, and hillslope profile. The land should drain to the exterior, and there should be no depressions, hollows, or internal drainage. Ponding of water in rehabilitated areas will lead to the ingress of water into the old mining pit, production of acid mine drainage, and underground leakage or spillage at the surface into neighbouring drainages, resulting in degradation of water quality.

Slope (including slope length and gradient) is an important feature in developing the new landscape. Slope steepness should not exceed the limit at which a tufted grass cover can protect against excessive erosion. If the rehabilitated landscape is too steep, then special measures are required to protect the soil against erosion (e.g., rhizomatous grass cover, such as Pennisetum clandestinum). The new landscape should not be too flat either, otherwise hollows (as a result of differential subsidence of the backfilled spoils) can result in ponding and internal drainage. The ideal hillslope profile is concave at the footslope, with the second choice being an even slope from hilltop to foot while footslope convexity is erosion-prone and unstable.

Conservation structures like stormwater berms, contour banks, and waterways are a concern at the medium scale. The presence of these structures and whether they are appropriately designed and maintained are assessed. There are circumstances where structures are warranted, but the landscape should ideally be designed incorporating geomorphic principles so that formal structures are minimised.

Micro scale refers to surface roughness created by insufficient smoothing during landscaping or by stone, vehicle ruts, rills, and gullies. Roughness at the micro scale impedes access and increases machinery wear-and-tear, during aftercare and future land use.

Land capability

Land capability is an important notion in sustainable land use. Land should never be used beyond its capability, to ensure the resource base is not to be endangered. As a condition of mining, land must be restored to meet a predetermined 'required' land capability.

Five land capability classes were used during the assessment, contrasting with the four classes suggested by LaRSSA, 2019, with the addition of a 'pasture' land capability intermediate between grazing and arable. After wetland, the classes are in descending order of land capability, where arable land is seen to have a higher land capability value than pasture and grazing land. Lower ranking land use can be practised on a higher-ranking land capability, but not the reverse – arable land can be used for grazing, but grazing land should not be cultivated.

In practical application, in mine rehabilitation assessment, the actual land capability was determined on site, and this was evaluated against the land capability as required by the site-specific EMPr (Environmental Management Programme). If the actual land capability equalled or exceeded the required land capability, then 'best' (5) was scored. If the required land capability was not met, then plainly, 'very poor' (1) applied.

Soil loss

In the assessment, soil loss was modelled using the Soil Loss Estimator for Southern Africa (SLEMSA), a locally adapted and simplified version of the Universal Soil Loss Equation (USLE). SLEMSA enables erosion by raindrop impact and overland flow to be estimated. The model inputs are rainfall erosivity (a default value is entered from a published rainfall erosivity map), soil erodibility (a default value is entered, but this may be modified depending on site characteristics), slope length and steepness (determined on site), and vegetal cover (determined on site). There are no standards for soil loss, hence the 'natural' minima and maxima of 2 $t.ha^{-1}.a^{-1}$ and 12 $t.ha^{-1}.a^{-1}$ are used to represent the extremes of the scoring classes. The rate of soil genesis is order of magnitude, 1 $t.ha^{-1}.a^{-1}$, or the addition of 0.1 mm depth of soil annually (Breetzke, et al. 2013), and if the rate of soil loss consistently exceeded the formation rate, there would be no soil.

At high rates of soil loss and soil movement across the land surface, erosion features become apparent to the naked eye (Le Roux, 2008). Because of the slow rate of pedogenesis, the soil is a limited resource. For all practical purposes, nett loss of soil is a permanent impairment on land capability and reparation costs are exorbitant. The situation in South Africa is exacerbated because high potential land, determined largely by soil quality, is critically scarce compared to other countries (CSIR, 2005).

Soil fertility

Soil fertility was determined by taking soil samples at every assessment site submitted for laboratory analyses. Soil fertility is important because it capacitates the restoration of soil function. A key issue is soil organic carbon, which constitutes the life of the soil. During the mining operation, soil organic carbon is lost, and the first function of rehabilitation after the new landscape has been created is to restore the soil organic carbon and reinstate soil function.

The mechanism for restoring soil organic carbon is to grow grass crops repeatedly. When grass grows, the above-ground leaf is complemented by roots. If the grass leaf is removed by grazing, mowing, burning, or the leaf dies, there is a corresponding die-off of the root, which is organic carbon already in the soil. It is recommended that lime be applied to the site's action plan, and if the acidity persists, an investigation is undertaken to determine the source and profile of acidification. High soil fertility is needed to sustain the repeated grass crops, and the standards applied are as follows (Table 3).

The aforementioned requirements should be met at the time of grass establishment, except for the carbon percentage. About 90% of cases of poor grass establishment are because of insufficient soil fertility (FFSA, 2016). If the establishment is poor, grasses are sparse or the 'wrong' species establish, it is costly to try to correct, and the rehabilitation process, and the quality of the rehabilitation product, may be impaired. To facilitate the rehabilitation process, the soil fertility standards should be maintained for five years from the establishment (or until a threshold pasture structure is achieved), during a period of intensive aftercare when nitrogen (N) fertiliser is applied in spring, the pasture is defoliated (mowed or grazed) in mid-summer, the second application of N fertiliser is made immediately, and the pasture is defoliated again in autumn or early winter. Maintaining the requisite soil fertility for five years, having the 'right' grass species, topdressing with N in spring and mid-summer, and defoliating in mid- and late summer constitute the management that is required to increase soil organic carbon and reinstate soil function.

Table 4

Soil fertility standards for pasture production (FFSA, 2016)

Aspect	Units	Standard
P	mg/kg	≥15
K		≥120
Ca		≥300
Mg		≥120
Acid	%	<5
pH	LogH+	5.5<8
Zn	mg/kg	≥1.5
Mn		<20

Species composition

The relevance of species composition is that perennial fertiliser responsive grasses are essential components of the mechanism to restore soil organic carbon and reinstate soil function. If the grasses used are not fertiliser responsive, then increasing soil organic carbon will be slowed, and the fertiliser will not be used efficiently. The grasses must be perennial rather than annual to avoid having to replant. The commonly used grasses that fit these requirements are Rhodes grass (*Chloris gayana*), Smuts finger grass (*Digitaria eriantha*) and Oulandsgras (*Eragrostis curvula*). The step-point method (Evans, Love, 1957) measures the relative proportions of different grasses (and other plants).

Pasture structure

So-called pasture structure is a proxy for pasture establishment and persistence. The ideal is a carpet of densely packed grass tufts approaching a lawn. The two main factors determining pasture structure are soil fertility and defoliation frequency. Infertile soil cannot support plants in abundance, which results in small and widely spaced grass tufts where soil organic carbon does not increase over time. Infrequent defoliation leads to large, widely spaced grass tufts with intervening bare ground or weeds. The idea of the carpet and increased soil organic carbon can be promoted by high soil fertility and frequent defoliation, i.e., meeting the minima in Table 4 and grazing and/or mowing twice per year. Pasture structure is measured by a modified form of the step-point method.

Pasture vigour

This measures grass health as reflected by management intensity. The ideal, for the five years of intensive aftercare following establishment is the maintenance of soil fertility (Table 4), spring application of N fertiliser, defoliation in mid-summer immediately followed by a second application of N fertiliser, and a second defoliation in autumn or early winter. After five years, if the rehabilitation is properly done, all fertilisers may be withheld, and only the defoliation management continued. If, after five years, a threshold pasture structure is not met, usually because of insufficient intensive aftercare, then further intensive aftercare is recommended until the threshold pasture structure is met.

Results

Overall industry performance over time

The results of 299 rehabilitation assessments conducted on South African coal mines using the methodology as described in the aforementioned since 2000 are shown in Figure 2.

The average for the industry is fair+ (3.4). Qualification of this comparison is warranted, as follows:

- ➤ The sample of mines in Figure 2 is probably biased. There is doubtless under-sampling of mines with poor and no rehabilitation. The average rehabilitation performance for the coal mining industry is likely less than shown in Figure 2.
- ➤ The present method of assessing rehabilitation performance dates back to 1996. The method has been revised and improved repeatedly. It is now possibly stricter, so a fair+ (3.4) performance today might have been slightly higher in the past. In the interest of comparability and reliability, the assessment has been made more objective over time. The scoring is currently done by exact algorithms in a computer programme, though there are still some inconsistencies and human error in the data collection phase.
- ➤ The distribution of the annual industry scores from 2000 to date is represented in the box and whiskers plot in Figure 3. The 2024 average industry score remained the same when compared to the 2023 industry average.

Example of a subset of collieries' rehabilitation performance over time

As it is impossible to display the detailed data for all 48 collieries in this publication, an extract of a representative group of collieries is used to show the requisite level of details to inform industry trends in rehabilitation performance. The rehabilitation performance results for this subset of collieries are shown in Figure 4. Of interest, land capability and sol loss thresholds are generally met by most collieries and are consistent over time, however landscape form

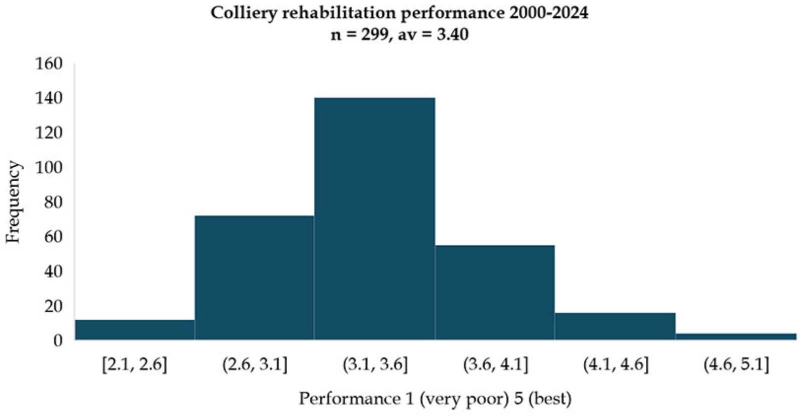

Figure 2—Coal mining industry rehabilitation performance 2000-2024

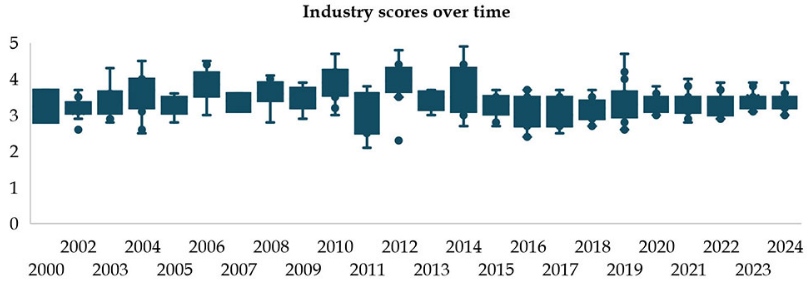

Figure 3—Industry scores over the past 24 years

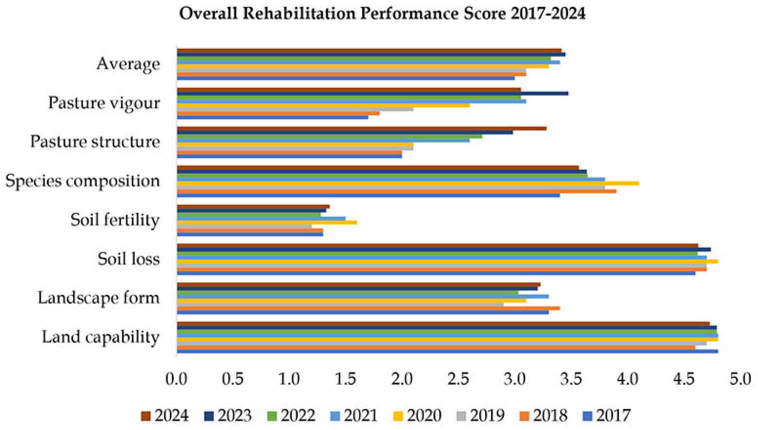

Figure 4—Average rehabilitation performance scores for a group of collieries from 2017 to 2024

Figure 5—Water ponding observed during the site assessments

and species composition tended to perform sub-optimally but consistently. Soil fertility was the weakest performing aspect and did not increase over time, whereas other management intervention aspects, pasture structure, and pasture vigour, increased consistently over time as rehabilitation matured and responded to aftercare. The nett result was a steady improvement in overall rehabilitation performance from 2017 to 2024, however the foundational aspects of landscape form and soil fertility constrained development and attainment of higher scores over time.

General rehabilitation performance criteria requiring attention

Internal drainage and hollows

Internal drainage and hollows were observed at all sites. Hollows in the landscape are notably susceptible to ponding, which is undesirable in coal rehabilitation because it increases infiltration into the underlying spoils and can lead to or worsen the generation of acid mine drainage.

Hollows are mostly relatively small and can easily be rectified by stripping the topsoil, filling in the hollow with subsoil to the desired profile, replacing the topsoil, and reseeding. Internal drainage, as with hollows, also results from differential settlement if the area was initially shaped to be free draining. In this instance, the runoff does not drain to the exterior, causing seasonal waterlogging (Figure 5) of soil, leading to a reduction of pasture structure and land capability. Internal drainage can be remedied by construction of drainage trenches or reshaping.

Soil fertility and acidity

Soil fertility is important because it capacitates the restoration of soil function. A key issue is soil organic carbon, which constitutes the life of soil. During the mining operation soil organic carbon is lost, and the first function of rehabilitation after the new landscape has been created is to restore the soil organic carbon and reinstate soil function. The preferred analytical method is the Walkley-Black method (Walkley, Black, 1934) to determine the soil's organic carbon as opposed to loss on ignition (Heiri et al., 2001). As depicted in Figure 6, the organic matter build-up in the rehabilitation sites had an increasing trend, which is desirable.

The distribution of the overall acid saturation (an indication of the ongoing acidification of soil) over the past few years is presented

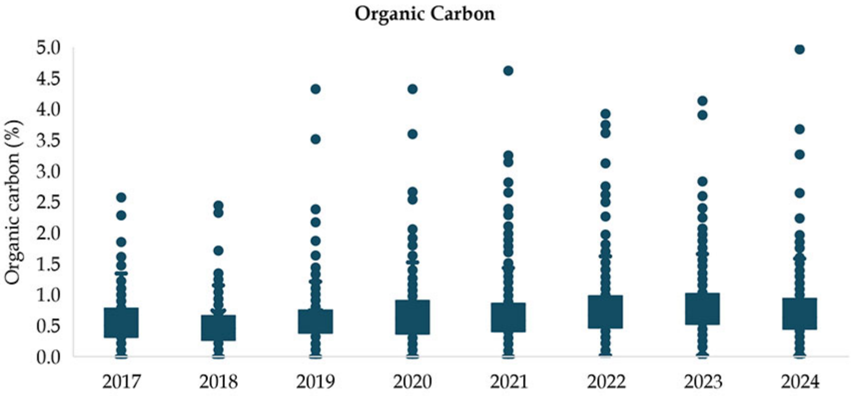

Figure 6—Organic carbon percentages

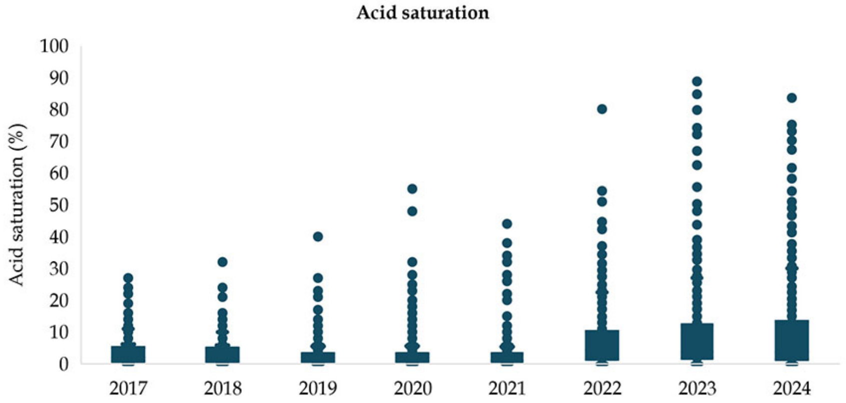

Figure 7—Overall acid saturation percentage

Figure 8—Insufficient aftercare at the rehabilitated areas

in Figure 7. It is evident that the acid saturation is constantly increasing. The sources and extent of acidification of the topsoil should be assessed in order to devise mitigation measures.

Based on the box-whiskers-plot depicted in Figure 7, it is possible that soil acidification is a result of poor drainage, where the acid originates from carbonaceous spoils below and acidifies the topsoil by means of capillary rise. Preferably, acidic soils should be addressed before fertiliser is applied. Lime should be applied two months before the application of fertiliser to ensure that the soil pH conditions are favourable and that the macro nutrients are plant available. When ready to apply fertiliser to an existing pasture, the grass must be short, and it is essential to ensure that the grass is cut or grazed before or during the preceding winter.

Once the source of the acidic soil can be determined, more informed decisions regarding future rehabilitation measures could be made, saving time and money and allowing for more effective rehabilitation and ultimate relinquishment.

No aftercare and invasive alien plants (IAP) invasions

At almost all of the sites, there were areas, or individual assessments sites, which received no aftercare in the past year. One of the consequences of insufficient aftercare, especially in the first five years, is the displacement of desirable grass species with ruderal weeds and invasive plant species (Figure 8). The overall decrease in species composition at the different operations can be attributed to the infestation of annual weeds and IAP (Figure 9) as a result of insufficient aftercare and maintenance.

Non-functional berms

Severe erosion was observed in many areas, mostly because of poorly constructed berms, which tend to cause more erosion than they prevent (Figure 10). Berms might serve a purpose at the outset, but they are a long-term liability as eventual failure is almost inevitable. Berms divert surface runoff as well as dissipate the flow of runoff to protect against erosion. The diverted water should be

Figure 9—Alien invasive plants at the rehabilitated areas (Acacia mearnsii and Cortaderia selloana)

Figure 10—Berm failure that leads to erosion

Figure 11—Severely eroded areas that require immediate intervention

delivered to designed (wide, flat-bottomed, grassed) waterways. Berms need to have a consistent low gradient along their length. Differential settling of underlying spoils leads to an inconsistency in gradient with consequent scouring on steep gradients and sedimentation at places of low gradient. Unless the berms are maintained properly, they fill with sediment and then overtop, causing erosion. Once the pasture structure reaches threshold, the berms need to be closed and grassed.

Erosion

Extensively eroded sites with gulleys and deep scours were widely observed (Figure 11). The gulleys and scours should be filled, and in severe cases, modelling and design works should be considered to control run-on and runoff as a starting point to remedying the significant and ongoing erosion. The area should firstly be surveyed to identify areas where formal water management infrastructure is required.

Conclusion

The results from this study show that collieries that track rehabilitation performance over time are probably in the minority. However, the combined average scores show that a performance score of 3.5 out of a possible 5 should be aimed for in order to reach minimum performance levels and to allow for some self-sustaining post-mining land use.

Industry scores for rehabilitation have shown general improvements since 2000, but have previously been at higher levels, particularly between 2010 and 2014. This is due to the declines in performance of newly rehabilitated areas that have been added to the database, especially since 2017.

For the subset of collieries shown in the example above, there is an active feedback loop between monitoring results and the maintenance activities that are implemented. This is evident from the increase in the average rehabilitation performance score to near compliance levels. However, foundational issues remain that will constrain further development towards sign-off and these relate largely to:

- ➤ Landscape form deficiencies (inadequate or defective stormwater control structures, ponding in hollows, and subsided areas).
- ➤ Topsoil quality concerns (bulk soil stripping yields mixtures of topsoil and subsoil, often of unsuitable nature that are acidic and infertile, lack organic carbon, and have restrictive volumes of plinthite).

- Soil fertility constraints (for establishment of pasture grasses as per the industry standard and due to inadequate amelioration practices at initial establishment or lack of top-up or maintenance fertilisers).

Apart from the foundational issues that constrain rehabilitation performance, the following additional areas of poor performance remain pervasive throughout the industry:

- Lack of rehabilitation aftercare (defoliation via mowing, grazing or burning, followed by seasonal top-up broadcasting of N fertiliser, as well as re-seeding sparse or bare areas).
- Inadequate control of invasive species.

Finally, the following positive trends were observed throughout industry practices:

- Adequate soil volumes are used to achieve required soil depth to meet EMPr-committed land capabilities (although soils may be of poor quality).
- Pasture structure improves over time (however, this is limited to collieries with a monitoring-maintenance feedback loop).
- Species composition improves over time (from initial fertiliser-responsive pasture grasses to later self-colonisation of desirable regionally indigenous species).

With the prioritisation of environment, sustainability, governance (ESG) performance, the ability of a mine or mining group to show shareholders their rehabilitation performance and benchmarking their relative position in the industry should provide a competitive commercial advantage.

Recommendations

The following general recommendations are made, based on assessing rehabilitation performance in the South African open-cast coal industry over the past 24 years, including evaluations of interventions that have been successful, and others less so:

- Pastures need to be utilised in order to maintain cover, avoid them becoming moribund, and to stimulate increases in soil organic C levels. Utilisation levels that are required differ between years and should be informed by monitoring data performance groupings.
- Rehabilitated land should never be used beyond its inherent capability, otherwise, the land use will not be sustainable over time. Novel land uses can be considered, as can a matrix of complementary and-uses to improve sustained economic outputs.
- Native species should be encouraged to increase over time and to eventually displace the majority of fertiliser-responsive pasture grasses. This will reduce the reliance of ongoing expensive and intensive fertiliser applications.
- Geomorphic landform designs should be pursued wherever possible to avoid the need for stormwater control berms that mostly fail over time.
- Monitoring rehabilitation is most probably not implemented at most collieries or is only intermittent. Providing an accurate record of rehabilitation performance over time (preferably with metrics of land use efficiency) remains a recognised and low risk means of building the case for site closure and eventual relinquishment.
- A standardised approach to rehabilitation performance monitoring and evaluation across operations greatly enhances a mining groups' ability to benchmark itself in relation to the industry and to identify where certain operations may be performing poorly, thus guiding the optimal allocation of resources.
- Have a maintenance feedback loop. In evaluating the data from 48 collieries, those that implemented rehabilitation maintenance actions showed increases in rehabilitation performance over time. Those that did not either showed static performance (at best) or declines in performance.
- First address foundational issues (land capability, slope, soil depth, landform design, stormwater controls). Do not establish vegetation until foundational aspects are addressed, as they are difficult and more expensive to fix retrospectively.
- Rehabilitate with the end in mind (especially regarding end land use plans) but do not take shortcuts to achieve these. Establishing pasture is critical to first kickstarting soil chemical and biological processes, prior to establishing crops or allowing grazing (as appropriate).
- Optimise topsoil management by following a stripping plan that, ideally, separates topsoil and subsoils, avoids unsuitable soils (plinthites, wetland soils, etc.), minimises stockpiling impacts, and guides responsible replacement of soils in the sequence that they were stripped.
- Follow the very well-written LaRSSA-Coaltech Guideline for the Rehabilitation of Surface Mined Land (LaRSSA, 2019).

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References

Agboola, O., Babatunde, D.E., Fayomi, O.S., Sadiku, E.R., Popoola, P., Moropeng, L., Yahaya, A., Mamudu, O.A. 2020. A review on the impact of mining operation: Monitoring, assessment and management. *Results in Engineering*, vol. 8 (2020) 100181.

Bench Marks Foundation. 2014. Policy Gap 9. South African coal mining, August 2014.

Breetzke, G.D., Koomen, E., Critchley, W.R.S. 2013. GIS-Assisted Modelling of Soil Erosion in a South African Catchment: Evaluating the USLE and SLEMSA Approach. *Water Resources Planning, Development and Management*, pp. 1–71.

Council for Scientific and Industrial Research and Agricultural Research Council. 2005. National Land-cover Database 2000. Council for Scientific and Industrial Research and Agricultural Research Council, Pretoria.

Evans, R.A., Love, R.M. 1957. The step-point method of sampling-a practical tool in range research. *Journal of Range Management,* vol. 10, no. 5, pp. 208–212.

Fertilizer handbook of South Africa, FFSA. 2016. Seventh revised edition ed. Pretoria, Lynnwood Ridge: The Fertilizer Society of South Africa, South Africa.

Heiri, O., Lotter, A.F., Lemcke, G. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology*, vol. 25, pp. 101–110.

Land Rehabilitation Society of Southern Africa, LaRSSA. 2019. Land Rehabilitation Guidelines for Surface Coal Mines. Land Rehabilitation Society of Southern Africa, Coaltech, Mineral Council of South Africa, 2019.

Le Roux, J.J., Morgenthal, T.L., Malherbe, J., Sumner, P.D., Pretorius, D.J. 2008. Water erosion prediction at a national scale for South Africa. *Water SA*. vol. 34, no. 3), pp. 305–314.

Walkley, A., Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* vol. 37, pp. 29–38.

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