A GIS-Based Prioritisation of Coastal Legacy Mine Spoil Deposits in England and Wales for Effective Future Management

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Abstract

Increases in coastal flooding and erosion due to climate change threaten many coastal mine waste deposits in the UK. As such, a robust approach to prioritising sites for management is required. A spatial dataset of 9094 mine spoil deposits in England and Wales was analysed against coastal erosion and flood projections to identify deposits most at-risk. Of these, 58 were at risk of tidal flooding and 33 of coastal erosion over the coming century. Within the 10 highest-priority deposits, 426,283 m^3 of spoil was at risk of release by erosion, with Blackhall Colliery (County Durham) being the largest predicted contributor.

Keywords: GIS, Climate Change, Coastal Erosion, Tidal Flooding, Mine Spoil

Introduction

The long history of mining in the UK has resulted in a substantial legacy of mine wastes within the environment (Johnston *et al*. 2008). As the deposition of many of these wastes predated our contemporary waste management principles, adverse effects are persistent within the environment through the release and transport of metals and mineral fines from spoil heaps. These effects are of particular concern in coastal environments, which have seen extensive deposition of mining wastes in coastal metal ore- and coal-fields in many jurisdictions (Castilla 1996; Dold 2007; Kwong *et al*. 2019). Increases in the likelihood and severity of flooding and erosion due to climate change (Burningham and French 2017) further threaten coastal waste deposits. A robust approach to prioritising such deposits based on environmental risk is required to aid future management, as limited public funds are available to manage and mitigate impacts at these sites.

Given the abundance and widespread distribution of mine waste sites across the UK (Environment Agency, 2008), a case-by-case field-based risk assessment of each individual spoil deposit may become practically and financially unfeasible. National scale GIS-based prioritisation exercises offer a potentially powerful tool to address this issue, and in particular, have previously been used to screen for, and rank, legacy mine sites in terms of their likely negative environmental impact (Mayes *et al*. 2009). In coastal settings, similar approaches have been used for assessing environmental risks posed by a range of former municipal and industrial waste sites (Le Cozanett *et al*. 2013, Irfan *et al*. 2019). By prioritising sites using this approach, which can be readily adapted to suit different requirements, a shortlist of sites may be produced and used as an initial guide to better-direct resources for intensive field-based investigations.

Methods

A spatial dataset of metal and coal spoil areas in England and Wales, originating from digitised historical OS maps (previously collated in Mayes *et al*. (2009)), was analysed against predictive datasets of tidal flood risk and future coastal erosion; key factors which may exacerbate pollutant release. To specify spoil type within this dataset, a spatial join was performed in ArcMap 10.7.1 GIS software, using the British Geological Survey Britpits dataset as reference for historically-mined commodities (Crane *et al*. 2017). A spatial screening was also used to identify spoil deposits which physically intersected areas of predicted coastal erosion over 20, 50, and 100-year timescales (from 2018, the baseline for erosion estimates within the dataset), and high-risk tidal flood zones.

A multicriteria decision analysis (MCDA) approach was applied to prioritise spoil areas based on their environmental risk, specifically in terms of coastal processes likely to be exacerbated by climate change. Adapted from a similar study of historical landfills by Irfan *et al*. (2019), Table 1 details the datasets and data processing techniques used to generate values for MCDA for the following criteria; a) the proximity of sites to the current coastline, b) proximity of sites to sensitive receptors (in this case Sites of Special Scientific Interest (SSSIs)), c) area of spoil at risk of coastal erosion at 20, 50, and 100-year intervals, and d) the area of spoil at risk of tidal flooding.

Due to differences in the distributions and units of values generated (Tab. 1), data were normalised and scaled using the Score Range Procedure such that all values ranged from 0 to 1 (Malczewski 1999). Criteria were then ranked based on their relative importance and weighted using the Rank Sum method (Malcewski 1999). The rank assigned to each criterion was based on the combined expertise of the authors, with the rationale for this, and the normalised weights, presented in Table 2. Following weighting, scaled values for each criterion were multiplied by the respective criterion weight, and summed to produce an overall risk score for each spoil area in the database. This was repeated for each of the three timescales of erosion projections, and used to generate ranked lists of mine spoil deposits.

For sites identified as being higher-priority, estimates were made of the volumes of material at risk of being liberated by coastal erosion processes over the next 100 years. Using a combination of high-resolution LiDAR data, historical maps, and erosion buffer zones (Tab. 1), the volume of mine spoil at risk of erosion within the 10 highest-scoring sites was calculated, as per the methods detailed in Riley *et al*. (2020).

Table 1 *Spatial datasets and data processing methods used in the MCDA prioritisation (Specific ArcMap tool names are written in italics). EA = Environment Agency, NRW = Natural Resources Wales.*

Criteria	Origin Database	Source	Data Processing
Distance from coastline (m)	National Coastal Erosion Risk Management (NCERM)	EA, NRW	Datasets merged to single shapefile, *'Near'* analysis.
Proximity to SSSIs (m)	SSSI designation shapefiles	Natural England, NRW	*'Near'* analysis.
Area at risk of coastal erosion (m^2)	NCERM	EA, NRW	Datasets merged, *'Buffer'* generated for shoreline management plan projections (20, 50, and 100-year, 95% CI), *'Intersect'* analysis on overlapping spoil.
Area at high risk of tidal flooding (m^2)	Flood Map for Planning (Zone 3)	EA, NRW	Datasets merged, and filtered by Tidal Model type to remove fluvial flood risk areas. *'Intersect'* analysis on overlapping spoil.

Table 2 *Ranking and normalised weights of each criterion used in the MCDA prioritisation process (Rank 1 = highest importance).*

Criteria	Rank	Rationale	Weight
Area at risk of coastal erosion	1	Coastal erosion and subsequent transport of spoil fines is considered the primary pollutant release pathway in the coastal zone.	0.4
Area in tidal Flood Zone 3	2	Tidal floods inundate spoil with saline waters and may instigate pollutant release and affect spoil heap integrity, leading to release. Zone 3 has > 1-in-200 annual probability of tidal flooding.	0.3
Proximity to SSSIs	3	SSSIs represent sensitive receptors in the environment, where pollutants will have highest impact.	0.2
Distance from coastline	4	Spoil closer to the coastline typically has greater likelihood of affecting coastal zone than those further inland.	0.1

Results and Discussion

Mine Spoil Database Screening

The mine spoil database contained a total of 9094 spoil areas, accounting for over 528 million m² of spoil distributed across England and Wales. Intersect analysis indicated that of these spoil areas, 58 were at a high risk of tidal flooding, and 33 were at risk of coastal erosion over the next 100 years. A summary of the area of *coastal* mine spoil deposits (defined here as those within 2 km of the current coastline) is shown in Figure 1, which reveals the largest areas to be located in the South West River Basin District (RBD; approximately 9 million m²); a major centre of historical copper and tin mining (Jordan *et al.* 2020). Substantial deposits were also identified in Northumbria (predominantly coal) and Western Wales (lead / zinc mining wastes), with approximately 6 million m² and 4 million m², respectively. Other key regions of interest include North West England, a centre for historical coal and iron mining, and the Dee on the border of England and North Wales (primarily coal and Pb). Modest areas

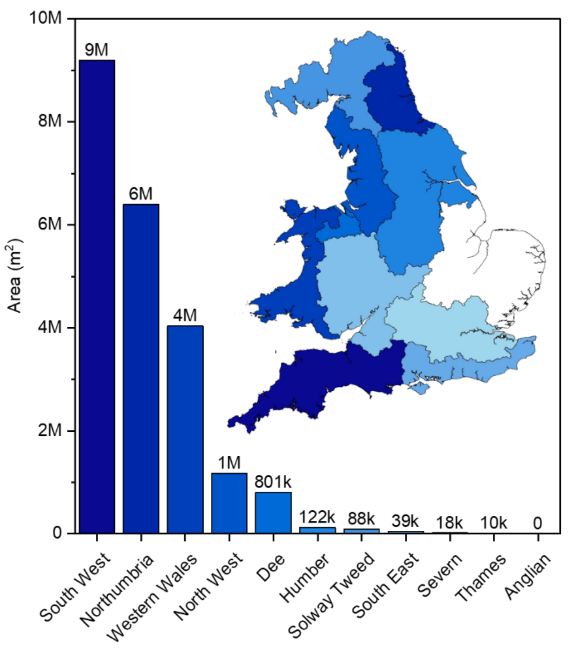

Figure 1 *Calculated areas (m²) of mine spoil within 2 km of the coastline, summarised by RBD.*

of coastal spoil were present in the Humber (primarily ironstone), Solway Tweed (coal and iron), the Thames (coal), Severn (coal), and South East (coal) RBDs.

Site Prioritisation Analysis

During the MCDA, each of the 9094 spoil areas were assigned three risk scores, related to the short, medium, and long-term risks, using the criteria in Table 2. Sorting spoil areas by these scores provides an indication of the sites which present a greater risk to the coastal environment, and is useful for determining higher-priority sites at national and regional scales. Although subtle changes in rank positions were observed when assessing sites over different temporal scales for predicted erosion, Dawdon Blast Beach, an area of extensive historical dumping of coal spoil on the Northumberland coastline, was consistently of highest priority (Tab. 3).

All sites within the top 10 rank positions were comprised of coal spoil, which may be expected given extensive coastal coal mining legacies in both Wales and northern England (Johnston *et al*. 2008). Sites in the South West, despite having the highest areal extent (Fig. 1) were generally of lower-risk in this analysis, likely due to clifftop locations of many historical Cu-Sn spoil deposits in the area (Rainbow 2020), and the protection from flooding offered by elevated settings.

Coastal Mine Spoil Volume Estimation

Assessments of spoil volume at priority sites offered more insight into potential erosive losses and subsequent environmental risk than areal estimates alone. Of the 10 highest-priority spoil deposits, intersect analysis indicated that four of these sites were predicted to be affected by coastal erosion in modelled future scenarios. Of these sites, Blackhall Colliery in County Durham (ranked 2nd for medium-term risk; Tab.3), was the largest spoil deposit in terms of total volume (>4.3 million m^3; Tab. 4). Interestingly, despite consistently ranking in the highest position, Dawdon Blast Beach contained substantially less waste than other sites within Table 4. This could possibly be linked to major waste removal operations at the site during the 1990s (Heritage Coast 2021) which may not be accurately captured in shapefile data. Furthermore, this suggests that future prioritisation analyses should employ the waste *volume* at risk of erosion as a criterion, as opposed to waste *area*, where feasible to calculate.

Coastal erosion projections coupled with volume estimates indicated that in addition to being the largest deposit, wastes at Blackhall Colliery were also most susceptible to coastal erosion, with over 358,000 m^3 of spoil predicted to be liberated over the next 100 years based on current shoreline

***Table 3** The 'top 10' legacy mine spoil deposits identified as being most at-risk in England and Wales within short-term (S: 20-year), medium-term (M: 50-year), and long-term (L: 100-year) timescales.*

Rank			Site Location	RBD	British National Grid Reference	Waste Type
S	M	L				
1	1	1	Dawdon Blast Beach, Seaham	Northumbria	NZ 43556 47893	Coal Spoil
2	3	2	Gas Terminal, Talacre	Dee	SJ 12630 83697	Coal Spoil
3	2	3	Blackhall Colliery, County Durham	Northumbria	NZ 46125 39734	Coal Spoil
4	5	5	Dee Bank, Bagillt	Dee	SJ 21596 75960	Coal Spoil
5	4	4	Wind Farm, Workington	North West	NX 99590 30795	Coal Spoil
6	6	6	Loughor Foreshore, Gorseinon	Western Wales	SS 57087 98795	Coal Spoil
7	8	7	Coast Road, Mostyn	Dee	SJ 16355 80311	Coal Spoil
8	9	8	Jackson Dock, Hartlepool	Northumbria	NZ 51574 32890	Coal Spoil
9	10	9	Port of Blyth, Blyth	Northumbria	NZ 30418 82324	Coal Spoil
10	-	10	Mostyn Road, Greenfield	Dee	SJ 19143 78025	Coal Spoil

Table 4 Volume estimates of high priority spoil areas which intersect coastal erosion risk zones, and cumulative volumes of spoil predicted to be eroded at each timescale.

Site Name	Total Volume m³	20-year Erosion Projection m³	50-year Erosion Projection m³	100-year Erosion Projection m³
Blackhall Colliery, County Durham	4,319,910	97,754	193,182	358,863
Wind Farm, Workington	874,051	0	4,603	35,751
Dawdon Blast Beach, Seaham	301,898	2,108	4,456	26,667
Loughor Foreshore, Gorseinon	188,535	0	971	5,002

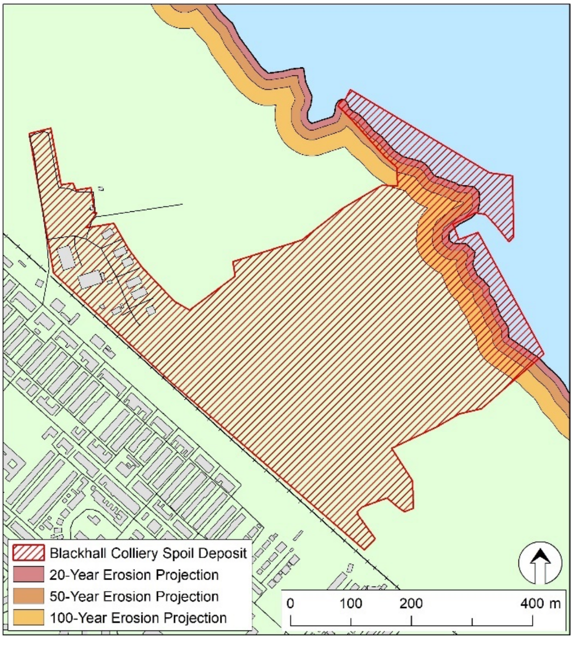

Figure 2 Blackhall Colliery waste deposit in relation to projected 20-, 50-, and 100-year extents of coastal erosion (buffer zones generated using NCERM dataset (Tab. 1) then used in volume estimation as per Riley et al. 2020).

management plans (Tab. 4; Guthrie and Lane 2007). The spatial extent of erosion predicted at Blackhall Colliery is shown in Figure 2, where estimates indicate a coastal retreat of approximately 50 m in the next 100 years. The seaward extension of the spoil deposit boundary is representative of the area of spoil already released via coastal processes.

Both of the Northumbrian sites in Table 4 were predicted to release substantial waste volumes within the next 20 years. The remaining sites, at Workington and Gorseinon, were not predicted to be at risk of coastal erosion in the short-term, but moderate volumes of spoil were deemed at risk over longer timescales, which can also be observed by changes in rank over time, particularly for Workington (Tab. 3). The potential erosive losses identified illustrate the urgent need for risk assessments to inform coastal management practices at these locations.

Conclusions

Legacy mine spoil wastes are present across all regions of the UK and are particularly related to historical coal extraction. The largest areas of coastal spoil were present within the South West, although most regions contained coastal mine spoil deposits. A GIS-based approach to prioritise these deposits in relation to risks posed to the coastal zone was completed, based on several criteria related to physical coastal processes and proximity to sensitive environmental receptors.

Multicriteria decision analysis allowed for ranking of sites, and indicated that coal spoil deposits posed the greatest risk to the coastal environment, predominantly within the Northumbria and Dee RBDs. Despite their abundance, the flood defence offered by clifftop settings of wastes in the South West RBD resulted in lower risk scores. Within the 10 most at-risk sites, 99,862 m^3 of spoil was at risk of erosion within 20 years, rising to 203,212 m^3 and 426,283 m^3 over the next 50 and 100 years, respectively. Of particular importance were Dawdon Blast Beach, the highest-ranked site, and Blackhall Colliery, the site with potential to release the highest volume of waste (358,863 m^3). This work represents the first UK national prioritisation method for screening coastal mine spoil sites in response to projected climate change effects. Such analysis is crucial for ensuring that resources are best allocated for future management of coastal legacy wastes, and is a method that can be readily expanded to cover additional risk factors, and applied elsewhere to a wide range of nationally-important legacy waste stockpiles from other sources.

Acknowledgements

The authors thank the organisers and hosts of the IMWA2021 Conference, in addition to the anonymous reviewers of this manuscript, whose comments have been valuable during the peer-review process. Thanks to Dr Hugh Potter (Environment Agency) for provision of some of the mine-related spatial data that were used here. This work was funded by the Natural Environment Research Council (NERC) under grant number NE/T003022/1 (Legacy wastes in the coastal zone: Environmental risks and management futures).

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