Euro-Mediterranean Journal for Environmental Integration (2019) 4:26
https://doi.org/10.1007/s41207-019-0116-y

ORIGINAL PAPER

GIS-based investigation of historic landfill sites in the coastal zones of Wales (UK)

Muhammad Irfan[1] · **Baptiste Houdayer**[1] · **Hishiv Shah**[1] · **Aleksandra Koj**[1] · **Hywel Thomas**[1]

Received: 28 January 2019 / Accepted: 30 July 2019

Abstract

This paper presents a GIS-based investigation of historic landfill sites (closed) located within the coastal zones of Wales, UK. These sites may pose a potential environmental challenge in future due to rising sea levels and coastal erosion. There are 78 historic landfill sites in Wales, most of which are located in coastal zones. These sites were operational between 1920 and 1999 but under the Environmental Protection Act 1990, the Environment Agency UK is not required to monitor these historic landfill sites. There is potential for exposure of the buried household, industrial, commercial or mixed waste types from some of these sites due to coastal erosion of undefended shorelines by wind and waves. Historic landfill sites were ranked on the basis of potential for exposure due to coastal erosion. A GIS-based landfill site ranking was carried out using the estimated coastal erosion for the next 20, 50 and 100 years and the proximity to the coastline. The results showed that 6 out of these 78 sites may be exposed and become a potential source of pollution as a result of coastal erosion at the current erosion rate, provided no artificial defence line is constructed. This study recommends that waste samples be taken from the identified landfill sites for laboratory analysis. On the basis of the buried waste type, future actions can be proposed such as the construction of artificial coastal defence lines.

Keywords Historic landfill sites · Coastal zones · Environmental pollution · Sea level rise

Introduction

Coastal erosion is a natural phenomenon and a concern worldwide. It is caused by several factors but the most important are the impact of the wind and wave's strength, action time and wave direction. Local geology, soil conditions and land use type also play an important role in the coastal erosion (Adamo et al. 2014).

According to a study in Morocco, 20% and 45% of the beaches could be naturally eroded respectively in 2050 and 2100. To respond to this problem, one of the strategies is to build seawalls to counter erosion. In this case, the first purpose is to protect urban and industrial areas of high value (Snoussi et al. 2009).

Erosion can also be caused or intensified by anthropogenic activities. As in China, with the rapid industrialization and urbanization of the coast without a sustainable coastal zone management plan, some environmental problems were created like flooding and coastal erosion (Li and Damen 2010).

In the UK, more than 100,000 residential properties, 9000 commercial properties and 5000 ha of agricultural land could be affected by coastal erosion, which presents a significant socio-economic problem alongside environmental challenges. Coastal erosion is more likely to occur at locations with a particular geology, like soft soil type, but can be countered by artificial defences (Coastal Erosion 2012).

Editorial handling: Anthony Lehmann, Chief Editor.

✉ Muhammad Irfan
MuhammadI2@cardiff.ac.uk

Baptiste Houdayer
baptiste.houdayer@outlook.com

Hishiv Shah
shahh14@cardiff.ac.uk

Aleksandra Koj
koja@cardiff.ac.uk

Hywel Thomas
thomashr@cardiff.ac.uk

[1] Geoenvironmental Research Centre, Cardiff University, Cardiff, UK

Published online: 10 August 2019

Before modern environmental practices, landfill sites were frequently constructed in low-lying coastal environments, sometimes with an aim to dilute and disperse contaminants slowly within the inter-tidal sediments. These landfill sites were constructed without leachate control. With global weather change and sea level rise, a new challenge has emerged with regards to coastal erosion and subsequent pollution problems from these coastal historic landfill sites (O'Shea et al. 2018). A recent environmental study in England revealed that 1264 historic landfill sites in England are situated in coastal or estuarine areas and present a significant environment challenge due to coastal erosion, rising sea water and extreme weather events. At least one-third of these historic landfills are also in or within 100 m of at least one designated ecological site. Samples taken from two selected sites in Essex, i.e. Hadleigh Marsh landfill and Leigh Marshes landfill, were analysed in laboratory. Significantly high concentrations of trace metals and polycyclic aromatic hydrocarbons (PAHs) were found in the samples (Brand and Spencer 2015).

In a similar study, surface and sediment core samples were collected from brackish marsh and mudflat areas around the former landfill at Lodmoor in Southern England. Geophysical surveys showed that leachate migration of these components is potentially continually occurring from these landfill sites. PAHs could be an important component among the leached contaminants which would need to be followed closely in future studies. That study recommended monitoring in the long term the evolution of lead and the concentration of other contaminants around historical landfill sites (Njue et al. 2012).

Similar to England, Wales also has a record of historic landfill sites. As many as 78 historic landfill sites were operational between 1920 and 1999 (Data.gov.uk 2019). Most of these sites are located close to coastal areas. These sites contain household, commercial, industrial or a combination of waste types, but the details of exact contents are not available which means that some of these historic landfill sites may also contain toxic materials as found in the three sites analysed in England.

Coastal erosion in Wales has been estimated for the next 20, 50 and 100 years by the Environment Agency, UK. These predictions combine long-term monitoring data from relevant local authorities along with the information from a national assessment of erosion supplied by the Department for Environment, Food and Rural Affairs (DEFRA). To estimate the coastal erosion, the Environment Agency utilises the Risk Assessment of Coastal Erosion (RACE) methodology (Environment Agency UK 2019). RACE involves data sets like historical patterns of erosion, the geology and the condition of coastal defences where applicable. It also includes the effects of climate change, e.g. sea level and storms events, etc. (North West England and North Wales Coastal Group 2019; Pembrokeshire County Council 2013, 2018; Severn Estuary Partnership 2016). This information is used as a basic data set in this study to identify the historic landfill sites that could potentially be exposed as a result of coastal erosion in Wales, UK.

Rest of the paper has been organized as follows. "Methodology" section covers the data sets used and the GIS methodology adopted in this study to identify and rank the historic landfill sites in Wales on the basis of potential for exposure due to coastal erosion. Results of the analysis are presented in the "Results and discussion" section. Future work is highlighted and conclusions are drawn in the "Conclusions" section.

Methodology

Figure 1 shows the location of historic landfill sites in Wales. As can be seen, most of these historic sites are close to the coastal regions.

The main objective of the GIS methodology adopted in this study was to identify the historic landfill sites that could potentially be exposed in the future as a result of coastal erosion and sea level rise. A multicriteria decision analysis (MCDA) approach was used for this purpose. Five factors or sub-objectives were identified for the MCDA analysis:

(a) Distance of each site from the current coastline
(b) Coastal erosion predicted for future near the sites
(c) Areas already eroded
(d) Area of each site likely to be affected as a result of coastal erosion
(e) Proximity of each site from critical areas, e.g. environmental conservation areas

These factors or sub-objectives were selected on the basis of literature review and availability of data. Similar parameters were used in other studies, e.g. Cozannet et al. (2013), Lin and Pussella (2017) and Orencio and Fujii (2013). In order to achieve these sub-objectives, key data sets were acquired from different sources and processed in ArcGIS 10.2 Desktop Software. These data sets are given in Table 1.

The two main data sets used in this study are the estimated coastline erosion, calculated by the Environment Agency, and the locations of historic landfill sites in Wales. With the third data set, the coastline management plan, and the erosion estimations, the estimated erosion has been represented with three buffers, i.e. 20, 50 and 100 years. Coastal erosion estimates around the remaining historic landfill sites were acquired from the Environment Agency Web Portal using the nearest postcodes manually. Shoreline provided in the shoreline management plans was

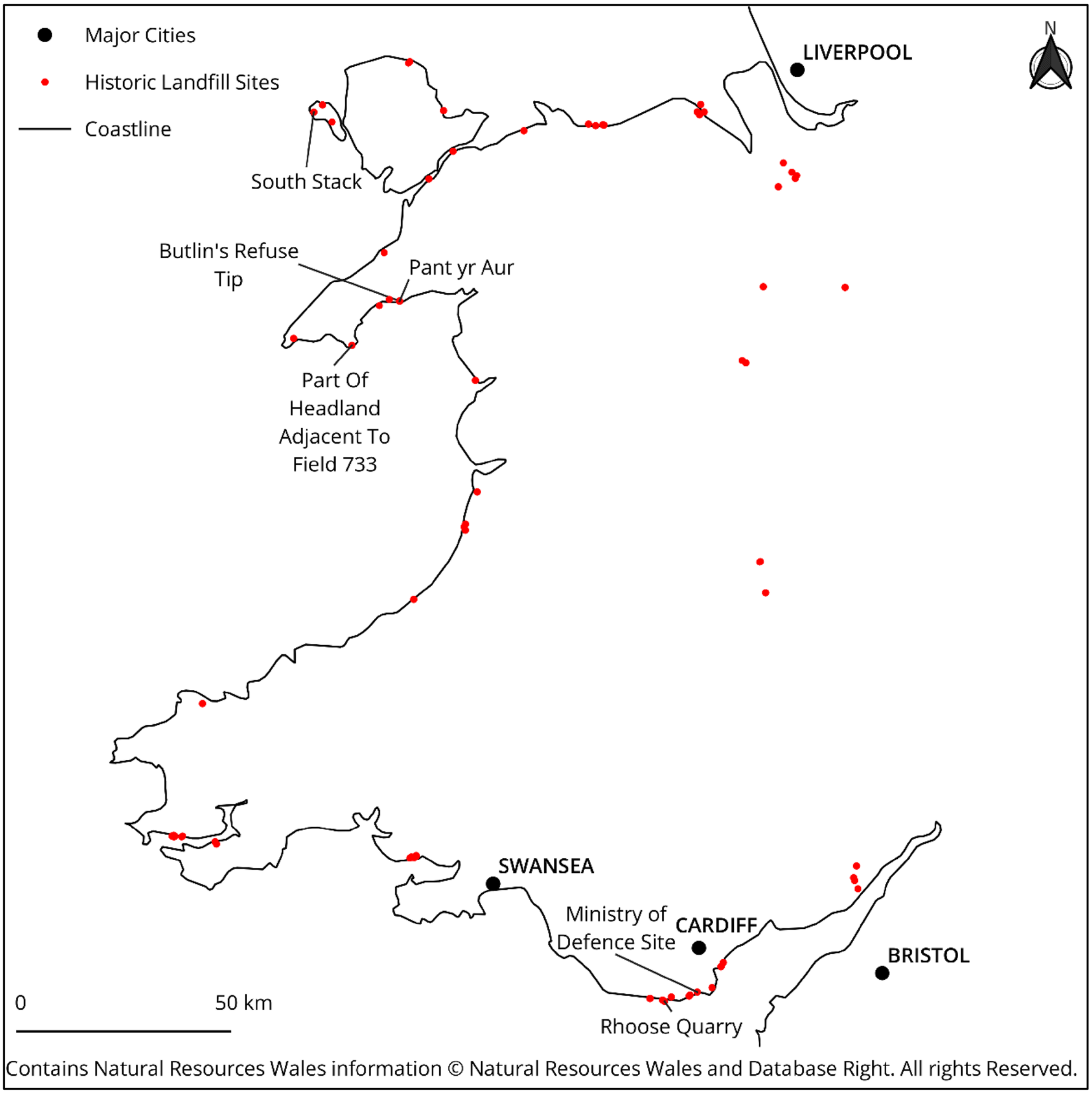

Fig. 1 Historic landfill sites location in Wales

used as the current line and buffers were created inland using the Buffer tool in ArcGIS.

The coastline management plan was also used to calculate the shortest distance between the coastline and each of the 78 historic landfill sites. For this purpose, the Near tool of ArcGIS was used. This analysis also identified if and how much area of a landfill site were already eroded. The distance between the landfill sites and the coastline allowed us to eliminate a number of the historical landfill sites which are not impacted by the erosion predicted for the next 100 years. This is either due to their distance from the coastline or because the shoreline is artificially defended in the surrounding areas. For the remaining sites, the projected eroded area was calculated using the Geometry Calculator tool, after applying the Intersect tool between the erosion prediction buffer zones and the landfill site polygons.

Finally, the fourth parameter was generated by calculating the minimum distance between each of the remaining landfill sites and the critical environmental areas using the Near tool. The critical areas are areas affecting bathing waters, AONB, SSSI, SAC and SPA.

Using primary data sets and the different geoprocessing tools used in ArcGIS, we obtained five parameters: (1) the distance of each site from coastline, (2) the areas of landfill sites already eroded, (3) the eroded zones for the next 20, 50 and 100 years along the coastline, (4) the distance of each site from every critical area and (5) the area of each landfill

Table 1 Data sets used in the study

No.	Data set	Source
1	Shoreline Management Plans, National Coastal Erosion Mapping (NCERM) a. Anchor Head to Lavernock Point b. Lavernock Point to St Ann's Head c. St Ann's Head to Great Orme d. Great Orme to English–Welsh border	Data.gov.uk
2	Coastal erosion prediction a. 20 years b. 50 years c. 100 years	Environment Agency UK
3	Historic landfill sites Wales	Environment Agency UK
4	Strategic environmental areas a. Areas affecting bathing waters b. Areas of Outstanding Natural Beauty (AONB) c. Sites of Special Scientific Interest (SSSI) d. Special Areas of Conservation (SAC) e. Special Protection Areas (SPA)	Welsh Government and Natural Resources Wales data portal

site likely to be eroded in the next 20, 50 and 100 years at current erosion rate and without any intervention.

MCDA technique has been used to rank the remaining sites in terms of potential for exposure due to coastal erosion and the challenges that may pose to the surrounding critical environmental areas. The MCDA approach is very useful because it allows simultaneous analysis of spatial information with different aspects and from different sources. Also, new information can easily be added and the assignment of priorities (with weight) can be revised as much as needed (Kitsiou et al. 2002). Analytical Hierarchy Process (AHP) is a commonly used and well established MCDA method. AHP was originally developed by Saaty (1980). In AHP, the main objective is divided into multiple sub-objectives called criteria. Each criterion is scaled to the same units, usually between 0 and 1. A weight is assigned to each criterion on the basis of its relative importance in achieving the overall objective. Decision makers assign this weight either on the basis of their understanding of the subject or using a technique called pairwise comparison. This method was also developed by Saaty (1980) and it provides a mathematical way of checking the consistency of the relative weights assigned to different criteria. The AHP method has a strong track record of being used for mapping the vulnerability of coastal environments (Le Cozannet et al. 2013; Lin and Pussella 2017; Orencio and Fujii 2013).

AHP-based methodology, adopted in this study to rank the concerned historic landfill sites, is shown in Fig. 2 More weight was assigned to erosion that had already taken place or was predicted for the future as per the shoreline management plans and coastal erosion prediction by Environment Agency UK. Similarly, the distance of the historic landfill sites from critical environmental areas was also emphasised by assigning higher relative weight because if in close vicinity, eroded waste from these sites can cause environmental concerns in the designated environmental areas.

Using the GIS methodology shown in Fig. 2, we ranked the remaining 6 out of 78 historic landfill sites in terms of potential for exposure due to coastal erosion. As explained above, five parameters were first calculated for each site using different geoprocessing techniques. Then the values were scaled between 0 and 1 using the score range procedure (Malczewski 1999):

$$(\text{Benefit})X'_{ij} = \frac{X_{ij} - X_{j}\text{min}}{X_{j}\text{max} - X_{j}\text{min}} \tag{1}$$

$$(\text{Cost})X'_{ij} = \frac{X_{j}\text{max} - X_{ij}}{X_{j}\text{max} - X_{j}\text{min}} \tag{2}$$

After scaling, relative weights were applied to each of the five parameters. The parameter for site areas likely to be eroded in the next 20, 50 and 100 years was assigned the highest weight, i.e. 40%. The parameter for distance from critical environmental areas was assigned a relative weight of 20%. Erosion predicted for future was assigned a weight of 15%. Site areas that had already been eroded were assigned a relative weight of 15%. Distance of sites from current coastline was assigned a weight of 10%. Finally these relative weights were multiplied by the scaled values of each of the five parameters and the resultant values were summed for each site as follows (Malczewski 1999):

$$A_i = \sum_j w_j x_{ij}. \tag{3}$$

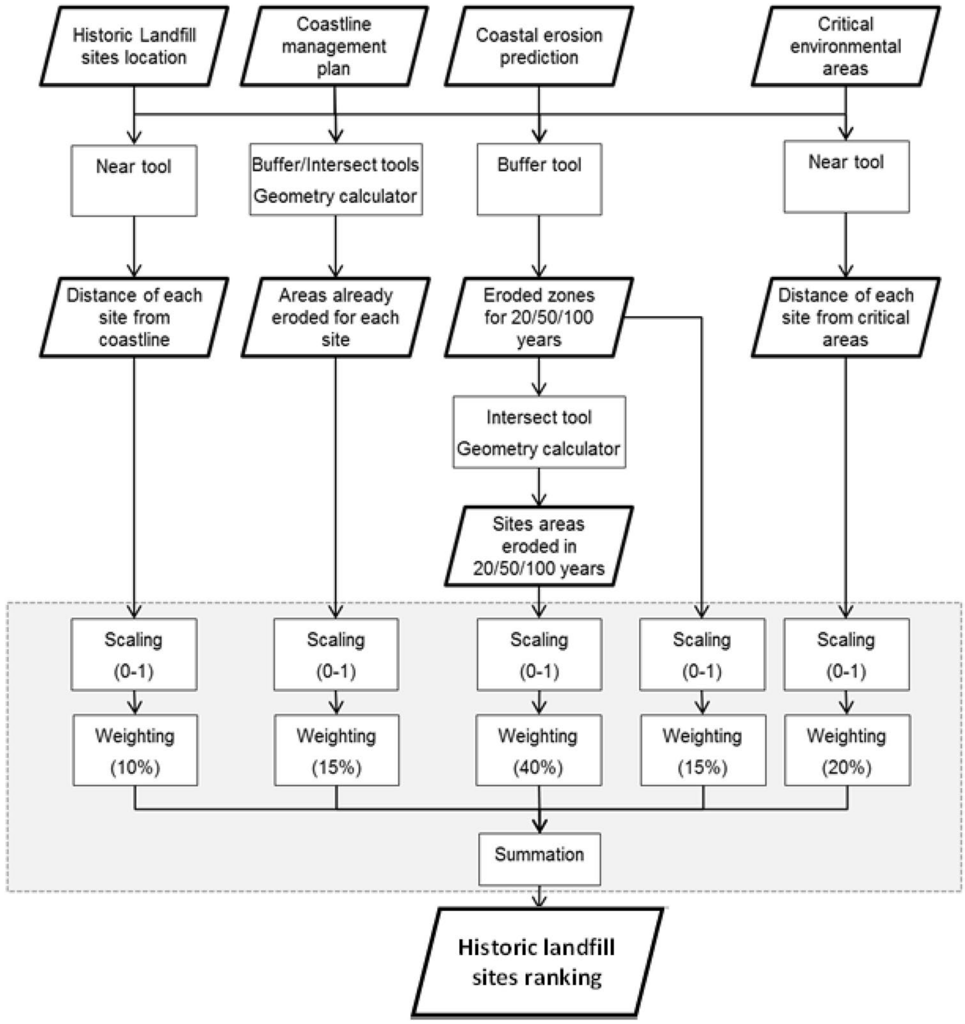

Fig. 2 GIS methodology adopted to rank concerned historic landfill sites

Results and discussion

The six studied landfill sites were ranked by using the AHP technique. The AHP results are shown in Table 2 for each site calculated for erosion potential in the next 20, 50 and 100 years. The Ministry of Defence landfill site is ranked the most affected site for all three periods.

Each of these sites is discussed in the sections below.

Ministry of Defence landfill site

This landfill site belongs to the Ministry of Defence, is one of the oldest sites in Wales and was operational between 1940 and 1950. It is located in the south of Wales and contains industrial and household waste types. The total site surface area is more than 74,500 m^2, which is the largest among the six sites being considered and potentially the largest environmental challenge as well if exposed as a result of coastal erosion. Its area could respectively be eroded at 2%, 4.9% and 10.5% in the next 20, 50 and 100 years at the predicted coastal erosion rate and without any intervention. Figure 3 shows the location of the Ministry of Defence historic landfill site.

Table 2 Ranking of historic landfill sites for potential exposure (from 0 to 1)

Rank	Name	MCDA values for estimated erosion		
		20 years (AHP value)	50 years (AHP value)	100 years (AHP value)
1	Ministry of Defence site	0.74	0.72	0.68
2	Part of headland adjacent to field 733	0.66	0.65	0.61
3	Pant yr Aur	0.38	0.47	0.37
4	Butlin's refuse tip	0.30	0.36	0.40
5	South Stack	0.26	0.26	0.26
6	Rhoose quarry	0.08	0.19	0.23

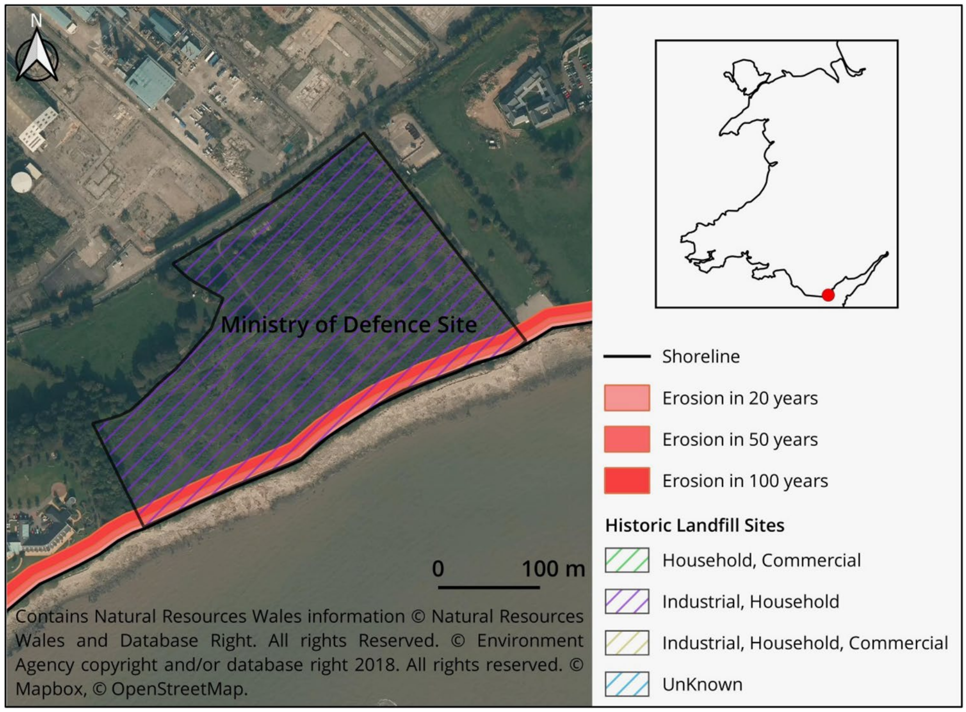

Fig. 3 Location of Ministry of Defence site with predicted erosion buffers

For the Ministry of Defence historic landfill site, which is ranked the most affected site, we also calculated the top soil erosion using digital elevation models (DEM) acquired for year 2006 and 2015.

The DEMs were acquired from the Welsh Government and Natural Resource Wales geo data portal at 2 m resolution (Welsh Government Geo-Portal 2019). Composite DEMs were produced by Natural Resources Wales using light detection and ranging (LiDAR) surveys. In order to estimate the top soil erosion between 2006 and 2015, the Cut&Fill tool of ArcGIS was used. The 2-m resolution is the best available data that could be acquired from the historic archives. Therefore, 2 m DEM was also selected for 2015, despite the availability of 1 m for that time frame. The total net volume loss (top soil loss) between 2006 and 2015 on this site is calculated to be 6107 m^2. The average loss in depth for the entire site is roughly about 8.20 cm. Figure 4 shows the result of the Cut&Fill method on the site.

Part of headland adjacent to field 733

The "part of headland adjacent to field 733" site was used between 1965 and 1987. Its original area was 712.33 m^2 but it has already started eroding by coastal erosion, and it will be almost completely eroded in the next 100 years at current erosion rate and without any intervention.

This site is the smallest in terms of areas but it is potentially very challenging since it has already started eroding and according to records it contains a combination of household and commercial wastes. The erosion rate at this place is very high with 70 m erosion predicted for next 100 years. Figure 5 shows the location of the site with erosion prediction buffers.

Butlin's refuse tip and Pant-yr-Aur sites

These two tips are adjacent to each other with surface areas of about 13027 m^2 and 1963 m^2 respectively. Butlin's refuse tip was used between 1946 and 1975 and it is 9.50 m from the coastline, whereas Pant-yr-Aur was used between 1988 and 1994 and it is only 4.20 m far from the coastline (shoreline management plan).

Combined together, the two sites cover an area of 13,813 m^2, and 0.5%, 7% and 25% of this area could be eroded in the next 20, 50 and 100 years respectively. The Pant-yr-Aur site contains industrial and household wastes, but the Butlin's refuse tip site's content is unknown. Figure 6 shows the location of the two sites in northwest Wales with erosion prediction buffers.

South Stack site

The South Stack site is located in the North West of Wales and it was operational between 1965 and 1975. Its total area is about 8943 m^2. As a result of close proximity to the coastline, this site has already started eroding. However the erosion rate at this location is very slow and predicted to be only 5 m in the next 100 years. At this rate and without any intervention, 2% of the site's area will be eroded in the next 100 years. The South Stack site contains a combination of

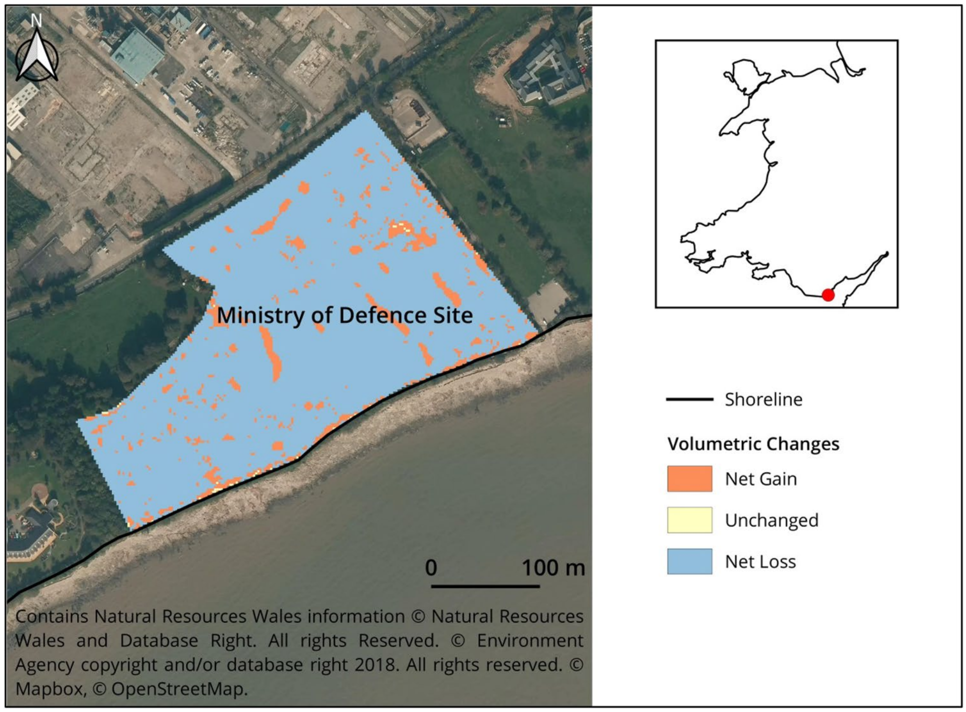

Fig. 4 Topsoil volumetric change (2006–2015) at Ministry of Defence landfill site

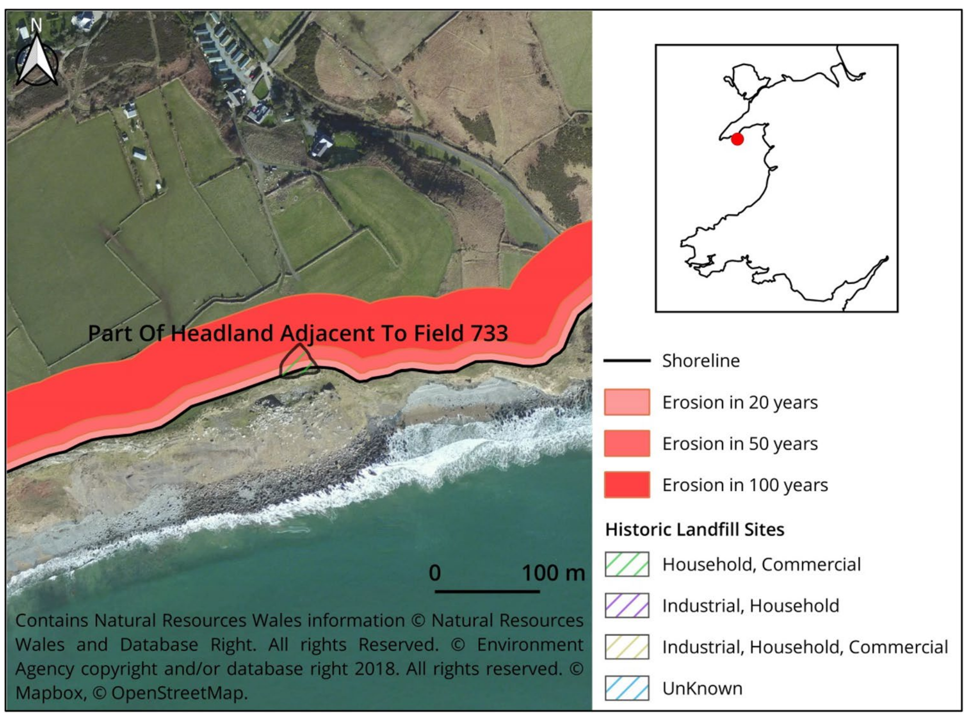

Fig. 5 Location of part of headland adjacent to field 733 site with predicted erosion buffers

industrial and household wastes. Figure 7 shows the location of the site with erosion prediction buffers.

Rhoose quarry

The Rhoose quarry site has an area of about 57,453 m^2. It was operational between 1981 and 1991. This landfill site is only 3.15 m from the coast. According to the estimated erosion, 0.5% and 4% of the site area may be eroded in the next 50 and 100 years respectively. No erosion is predicted within the next 20 years. The contents of Rhoose quarry site are a combination of industrial, household and commercial wastes. Figure 8 shows the location of the Rhoose site with erosion buffers. As can be seen, there

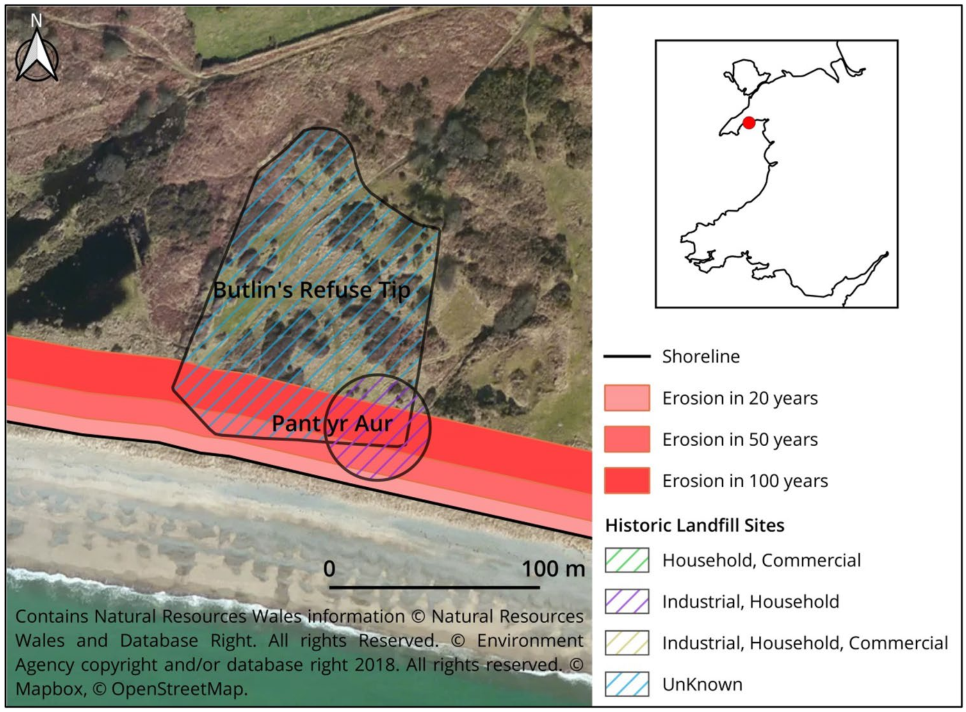

Fig. 6 Location of Butlin's refuse tip and Pant-yr-Aur sites with predicted erosion buffers

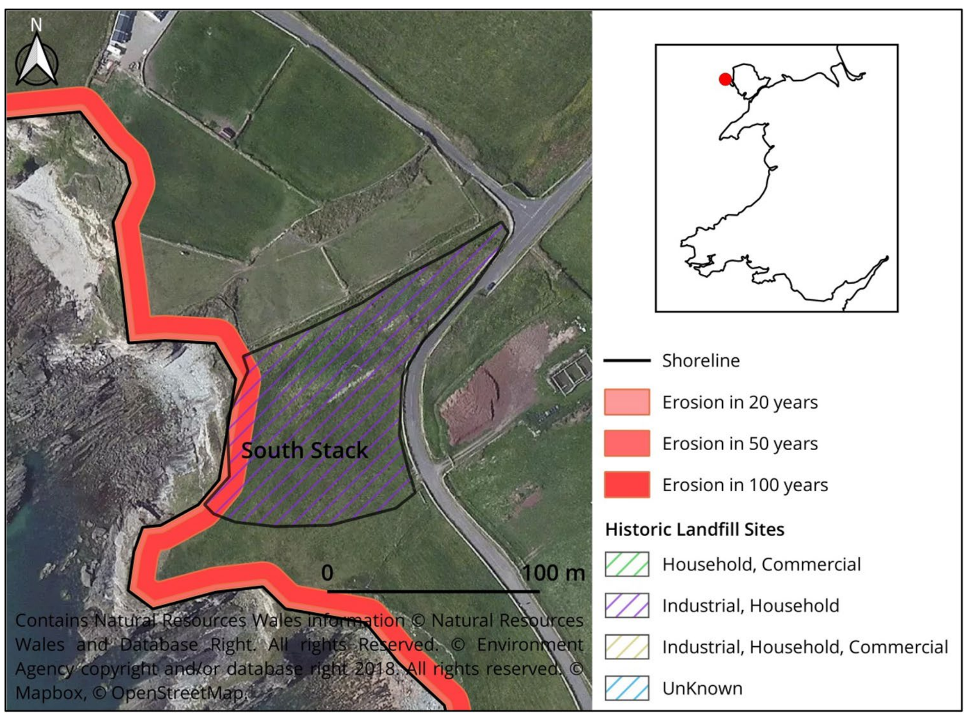

Fig. 7 Location of South Stack site with predicted erosion buffers

is another large historic landfill site in the proximity of Rhoose quarry, but it is not of a big concern since the exposure due to coastal erosion is not predicted for the next 100 years at the current erosion rate.

Conclusions

In this study, a GIS-based investigation was carried out to identify historic landfill sites in Wales that may be affected by coastal erosion. Historic landfill sites' location, erosion

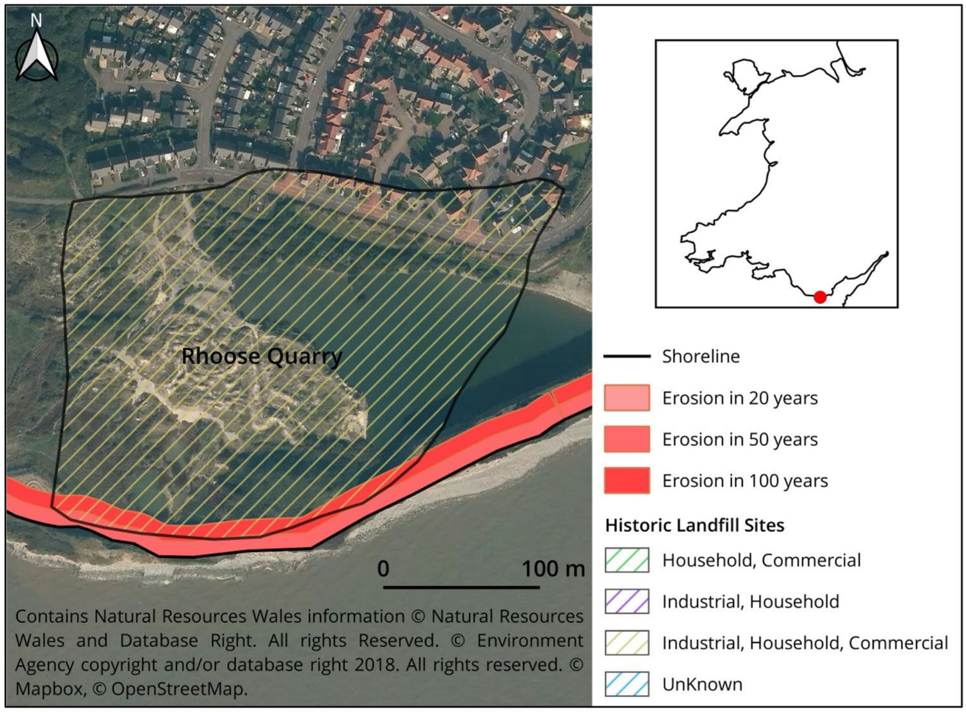

Fig. 8 Location of Rhoose quarry site with predicted erosion buffers

prediction for the next 20, 50 and 100 years, coastal management plans, digital elevation model and critical environmental areas data sets were used in the study. There are 78 historic landfill sites in Wales and most of them are located in the coastal zones. Coastal erosion is a natural phenomenon that occurs as a result of seawater rise, wind, waves, extreme weather conditions and geological parameters. As a result of coastal erosion, some of these historic landfill sites may potentially be affected and this may create environmental challenges. Most of these landfill sites in Wales are situated in the areas where the coast has been defended against erosion. A GIS-based investigation was carried out and after initial screening, six sites were identified as having a higher possibility of exposure due to coastal erosion. Finally, multicriteria decision analysis using AHP was used to rank these six sites in terms of concern of exposure. The Ministry of Defence historic landfill site near Barry in South Wales was identified to be the most susceptible site on the basis of the GIS methodology adopted in this study.

These historic landfill sites contain household, commercial, industrial or a combination of waste types, although the exact contents are unknown. According to two other studies carried out in England, samples taken from three different historic landfill sites were found to have contained high concentrations of trace metals and PAHs. Therefore it is recommended that samples be taken from these six sites and analysed in the laboratory to investigate the exact composition of waste types. Also a geophysical scan is recommended for each of these sites to better understand the three-dimensional volumetric information of the sites. These two parameters will help decision makers in defining countermeasures that can be taken at these sites in order to further defend them against coastal erosion.

Acknowledgements The work described in this paper has been carried out as part of the FLEXIS project (FLEXIS Project 2019), which is part funded by the Welsh European Funding Office (WEFO).

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Adamo F, De Capua C, Filianoti P, Lanzolla AML, Morello R (2014) A coastal erosion model to predict shoreline changes. Measurement 47:734–740

Brand DJH, Spencer PK (2015) Assessing the risk of pollution from historic coastal landfills, Executive summary for the Environment Agency edn. Queen Mary University of London, London

Coastal Erosion (2012) UK Geohazard Note, British Geological Survey https://www.bgs.ac.uk/research/earthHazards/geohazardNotes.html. Accessed 29 Apr 2019

Cozannet GL et al (2013) An AHP-derived method for mapping the physical vulnerability of coastal areas at regional scales. Nat Hazards Earth Syst Sci 13:1209–1227

Data.gov.uk (2019) https://data.gov.uk/. Accessed 29 Apr 2019

Environment Agency UK (2019). https://www.gov.uk/government/publications/shoreline-management-plans-smps/shoreline-management-plans-smps. Accessed 29 Apr 2019

FLEXIS Project (2019) http://flexis.wales/. Accessed 29 Apr 2019

Kitsiou D, Coccossis H, Karydis M (2002) Multi-dimensional evaluation and ranking of coastal areas using GIS and multiple criteria choice methods. Sci Total Environ 284:1–17

Le Cozannet G et al (2013) An AHP-derived method for mapping the physical vulnerability of coastal areas at regional scales. Nat Hazards Earth Syst Sci 13:1209–1227

Li X, Damen MCJ (2010) Coastline change detection with satellite remote sensing for environmental management of the Pearl River Estuary, China. J Mar Syst 82:S54–S61

Lin L, Pussella P (2017) Assessment of vulnerability for coastal erosion with GIS and AHP techniques case study: southern coastline of Sri Lanka. Nat Resour Model 30:e12146

Malczewski J (1999) GIS and multicriteria decision analysis. Wiley, New Jersey

Njue CN, Cundy AB, Smith M, Green ID, Tomlinson N (2012) Assessing the impact of historical coastal landfill sites on sensitive ecosystems: a case study from Dorset, Southern England. Estuar Coast Shelf Sci 114:166–174

North West England and North Wales Coastal Group (2019) http://www.mycoastline.org.uk/. Accessed 29 Apr 2019

O'Shea FT, Cundy AB, Spencer KL (2018) The contaminant legacy from historic coastal landfills and their potential as sources of diffuse pollution. Mar Pollut Bull 128:446–455

Orencio PM, Fujii M (2013) A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). Int J Disaster Risk Reduct 3:62–75

Pembrokeshire County Council (2013) South Wales SMP. http://www.southwalescoast.org/content.asp?id=58. Accessed 29 Apr 2019

Pembrokeshire County Council (2018) West of Wales SMP. http://www.westofwalessmp.org/content.asp?nav=23&parent_directory_id=10. Accessed 29 Apr 2019

Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resource allocation. McGraw-Hill, New York

Severn Estuary Partnership (2016) SMP2 Main Document. https://www.severnestuarycoastalgroup.org.uk/shoreline-management-plan/smp2-action-plan/. Accessed 29 Apr 2019

Snoussi M, Ouchani T, Khouakhi A, Niang-Diop I (2009) Impacts of sea-level rise on the Moroccan coastal zone: quantifying coastal erosion and flooding in the Tangier Bay. Geomorphology 107:32–40

Welsh Government Geo-Portal (2019) http://lle.gov.wales/home. Accessed 29 Apr 2019