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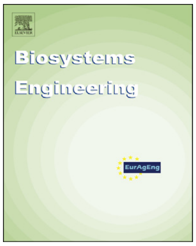

Research Paper

Modelling soil erosion risk for pipelines using remote sensed data

Herbert K. Winning [a,*], *Mike J. Hann* [b]

[a] *CB&I Ltd, 40, Eastbourne Terrace, London, W2 6LG, UK*
[b] *Cranfield University, College Rd, Cranfield, Bedford, MK43 0AL, UK*

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This paper presents a method of using GIS and public domain remote sensed data to perform a preliminary soil erosion risk analysis aggregated into 1,000 m sections for onshore pipeline corridors. The results obtained using this method correspond well with the soil erosion risk assessment carried out in the field, with over 69% in agreement and 95% of the results obtained being within ±1 erosion classification identified by the field data. The areas where this method fails to correctly classify the soil erosion risk are identified and are largely confined to major river crossings and areas of seismic activity, which would require field verification irrespective of the results obtained for these sections using this method. The limitations of the proposed method due to the lack of detailed soil data and strategies to mitigate poor soil data are discussed. Using this method it is possible to identify areas along the pipeline corridor where there is potential for soil erosion risk early on in the project design; this enables the route selection process to consider this important environmental aspect, as well as providing a basis for focusing any subsequent field investigation. The proposed method enables the erosion risk to be quickly reassessed to compare different route options or to revise the proposed pipeline route.

1. Introduction

The aim of the research was to determine the accuracy of predicting the potential soil erosion for onshore pipelines using public domain remote sensed data. The use of public domain data enables the assessment to be carried out during the route selection phase, prior to the acquisition of more detailed remote sensed data. The final assessment would then be verified by subsequent field investigations, targeted using the results of this preliminary assessment.

The importance of minimising soil erosion is well documented, as are the economic and social impacts of soil loss. Erosion control for buried pipelines is important not only to reduce the environmental impact but also to reduce the risk of losing cover over the buried pipe, which increases the risk of mechanical failure (Hann & Morgan, 2006). Once a pipeline has been installed, the pipeline corridor is reinstated and if possible the original ground cover re-established. During this stage of construction soil erosion due to rainfall energy can cause the bio-restoration to fail due to soil loss and washout of young seeds. Furthermore, this type of erosion on slopes will

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* *Corresponding author.*
E-mail address: kwinning@cbi.com (H.K. Winning).

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Nomenclature

ASTER	Advanced spaceborne thermal emission and reflection radiometer
DEM	Digital elevation model
DESA	Department of Economic and Social Affairs
ESRI	Environmental Systems Research Institute
GIS	Geographical information system
NDVI	Normalised difference vegetation index
RUSLE	Revised universal soil loss equation
UNSD	United Nations Statistics Division
USDA	U.S. Department of Agriculture
USLE	Universal soil loss equation
WMO	World Meteorological Organization

cause the formation of rills and gullies on the pipeline corridor which can lead to the pipeline becoming exposed in extreme cases. Erosion at this level will necessitate post installation monitoring and remedial works, adding to the operational cost of the pipeline. Any construction work involving the temporary removal and storage of the topsoil and compaction of the subsoil by machinery increases the potential for soil erosion due to reduced porosity, as the infiltration rate on the compacted soil is reduced, resulting in poorer rates of bio-restoration and in turn greater erosion (Wischmeier & Smith, 1978).

While the application of geographical information systems (GIS) to the modelling of soil erosion is not new, it has largely focused on the determination of individual components of the soil loss equation within discrete watersheds (Alexakis, Hadjimitsis, & Agapiou, 2013) or regional areas of a homogeneous nature (Mathieu, King, & Le Bissonnais, 1997). However, it is only recently that the use of GIS and remote sensed data has been applied to ground and climatic classification specifically for pipeline routes, either based on terrain units (Bayramov, Buchroithner, & McGurty, 2011a, 2011b) or on the prediction reliability and quantitative differences of different soil loss equations (Bayramov, Buchroithner, & McGurty, 2012).

This study covers a pipeline route of almost 450 km traversing Azerbaijan. This area was selected due to the range of 22 different soil types encountered. These range from mountain-meadow soils of the Alpine belt to grey soils of semi-desert and desert areas and yellow soil of Lankaran. This range of diversity is due to geological structure, relief, hydroclimate and diversity of plant cover. In addition, Azerbaijan experiences nine out of eleven world climate types and has elevations ranging from 4466 m above sea level to 26 m below sea level with over 41% of the country being affected by soil erosion (FAO, 2006).

Here a method using public domain remote sensed data to estimate the factors for the universal soil loss equation (USLE) to enable early identification of potential areas of high erosion risk for onshore pipelines is presented. The use of public domain data enables this form of analysis to be carried out prior to finalising the route corridor and the acquisition of more detailed and costly remote sensed data. This allows the erosion risk to be considered earlier in the project design cycle, potentially influencing pipeline route selection, as well as providing focus for any subsequent field investigations.

2. Methodology

While the USLE is described as universal, its database is restricted to the soils east of the Rocky Mountains, although further research has been conducted so that it can be used in other geographical areas (Dabral, Baithuri, & Pandey, 2008; Roose, 1977) and to the application to the construction industry (Gray & Leiser, 1982; Gray & Sotir, 1996). As previous work conducted in Azerbaijan and Georgia was based on the USLE (Eq. (1)), for comparative purposes, this equation has been used for this study (Morgan, 2005), rather than models such as the revised universal soil loss equation (RUSLE) (Renard, 1997) or Morgan-Morgan-Finney (Morgan, Morgan, & Finney, 1984).

$$A = R \times K \times S \times L \times C \times P \qquad (1)$$

Where A is mean annual soil loss, t ha^{-1}; R is mean annual rainfall erosivity factor, MJ mm ha^{-1} h^{-1}; K is soil erodibility factor, t ha h ha^{-1} MJ^{-1} mm^{-1}; S is slope steepness factor, dimensionless; L is slope length factor, dimensionless; C is crop management factor, dimensionless; and P is erosion control practice factor, dimensionless.

The dimensionless factors S, L, C and P are ratios of soil loss observed from a standard U.S. Department of Agriculture (USDA) erosion plot.

While it has been established that the natural sustainable rate of soil erosion is somewhere in the region of 1.5 t ha^{-1} year^{-1} (Wilkinson & McElroy, 2007), it is very difficult to measure the rate of soil formation due to the slow process. Because of this, another approach is to view areas prior to construction as being in equilibrium and therefore the soil

Table 1 – Soil erosion classification (Morgan, 2005).

Erosion class	Field assessment	Soil loss (t ha^{-1} year^{-1})	Description
1	Very slight	<2	No wash marks or scours.
2	Slight	2–5	Shallow rills every 50–100 m.
3	Moderate	5–10	Discontinuous rills every 20–50 m.
4	High	10–50	Continuous network of rills every 5–10 m or gullies every 50–100 m.
5	Severe	50–100	Continuous network of rills every 2–5 m or gullies every 20 m.
6	Very severe	100–500	Continuous network of channels with gullies every 5–10 m.
7	Catastrophic	>500	Extensive network of large gullies every 20 m