An assessment of the data resolution required to run the PESERA soil erosion model at a catchment scale in a high latitude agricultural catchment

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Abstract

The aim of this study is to evaluate the PESERA soil erosion model as a tool for predicting soil erosion at a catchment scale in a high latitude agricultural catchment in eastern Scotland. We investigate the importance of the resolution of soil and terrain data and the sensitivity of the model to rainfall inputs and therefore it's potential to be used as a tool to model the changing risk of erosion posed by changes in rainfall distribution. We show that the model does have the potential to be used as a land use planning tool in an attempt to minimise sediment loss and preserve water quality. We also show that the model has the potential to be used both as a screening tool due to its relatively limited data requirements and at a finer resolution where more detailed data are available, making it a powerful tool for soil erosion research.

Key Words

Soil erosion, modelling, PESERA, water quality, land allocation.

Introduction

The impact of soil erosion on water quality is well known and affects both aquatic ecosystems and the quality of potable water. Scotland is famed for its clean, clear water, which is associated with high quality luxury exports such as Scotch whisky; however, the cultivation of barley required to make whisky can compromise this image. In high latitude climates, cereals such as barley are spring/summer crops, but early rainfall before crop cover is established can lead to locally severe erosion. As well as increasing river turbidity, the sediment also contains phosphorus, which can lead to eutrophication in the relatively nutrient-poor aquatic systems.

Soil erosion risk models are useful to explore land allocation strategies including a shift to winter cereals within catchments in order to minimise erosion and reduce pollution in aquatic systems. Here we present some output from the freely available Pan-European Soil Erosion Risk Assessment (PESERA) model.

The PESERA model is a soil erosion model that has successfully been run at European (Kirkby *et al. 200*8) and national scales (Lilly *et al.* 2009) on a 1 km grid. The dominant processes represented in the model are runoff generation based on a storage threshold model and sediment transport based on runoff, soil erodibility, and topographic potential (Kirkby *et al.* 2008).

PESERA has been tested at plot and catchment scales in Spain (de Vente *et al.* 2009) and Greece (Tsara *et al.* 2005) and at a plot scale in The Netherlands and Italy (Licciardello *et al.* 2009). In general, it has been found to underestimate soil erosion at these scales (de Vente *et al.* 2009, Tsara *et al.* 2005, Licciardello *et al.* 2009). Reasons that have been suggested for this are that the model does not account for individual high impact events (Licciardello *et al.* 2009), gully or channel erosion (de Vente *et al.* 2008). However it is suggested that improvements can be made to the model predictions using higher resolution data than was available for these studies (de Vente *et al.* 2009, Kirkby *et el.* 2008).

Methods

Model

We explore the use of PESERA model as a tool for assessing relative erosion risk in a catchment in Scotland. In particular we consider:

(1) The use of the model with varying resolutions of soil, terrain and land use data
(2) The ability of the model, given high resolution data, to reflect changes in land use
(3) The ability of the model to respond to changes in rainfall that reflect individual years compared to the 30 year average (1971 – 2000)

Study area and soils

The Lunan water catchment (Figure 1) is a 140 km^2 catchment in the east of Scotland (Figure 1), which is under intensive arable agriculture and subject to multiple pollution pressures. These are being extensively studied as part of a monitored priority catchment partnership involving research and environment protection agency staff. The dominant arable crop is spring cereal, then winter cereals and spring sown root crops, predominantly potatoes.

The soils in the catchment are Brown Earths (Cambisols), Humus Iron Podzols (Podzols), Noncalcareous gleys (Planosols) and mineral alluvial soils (Fluviosls) (Scottish and FAO soil taxonomy; Soil Survey of Scotland Staff 1984; FAO 1990) (Table 1).

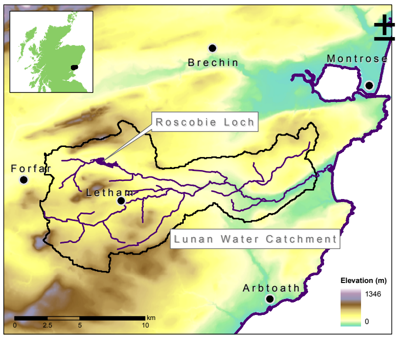

Figure 1. The Lunan Water catchment in north-east Scotland. Based on Ordnance Survey Landform PROFILE ® data. © Crown copyright. All rights reserved. MLURI 100019294 (2009)

Table 1. Soils in the Lunan Water catchment

Series	Cover (km^2)	Major soil sub-group	Drainage	Parent Material
Balrownie	39	Brown earths	Imperfectly drained	Water sorted material generally < 60 cm overlying the above till
Forfar	22.4	Humus Iron podzol	Imperfectly drained	Water sorted material generally > 60 cm overlying till derived from O.R.S. sediments
Aldbar	18.3	Humus Iron podzol	Freely drained	Till derived from Lower O.R.S. sediments mainly sandstone
Corby	14.1	Humus Iron podzol	Freely drained	Water sorted and morainic gravel
Garvock	11.9	Brown earths	Freely drained	Till derived from Lower O.R.S. lava and sediments
Vinny	9.5	Humus Iron podzol	Freely drained	Water sorted material generally > 60 cm overlying till derived from O.R.S. sediments
Undiferentiated Alluvium	8.8	Mineral alluvial soil	Poorly drained	Riverine alluvium
Mountboy	4.6	Noncalcareous gley	Imperfectly drained	Till derived from Lower O.R.S. lava and sediments
Boyndie	2.2	Humus Iron podzol	Freely drained	Fluvioglacial sand

Data

The data available to run the model are:

- 1km European scale Digital Terrain Model (DTM)
- British Ordnance survey PROFILE® (the UK mapping agency) 10 m DTM
- 1:25,000 scale soil series maps
- 1km Grid of the dominant soil series in each grid square
- Predicted soil hydrological information for each of the soil series derived from pedotransfer functions derived from British soils
- Modelled crop rotations for individual fields based on Scottish Integrated Administration and Control System (SIACS) data

Results and Discussion

Soils and terrain inputs

When the resolution of soils data was combined with different resolutions of DTM (Figure 2) it was found that increasing the resolution of the soils data, from the dominant soil series in a 1km grid cell to the soils represented on the 1:25,000 scale map of the catchment (Figures 2b, d and f), highlighted areas close to water courses that are highly susceptible to erosion.

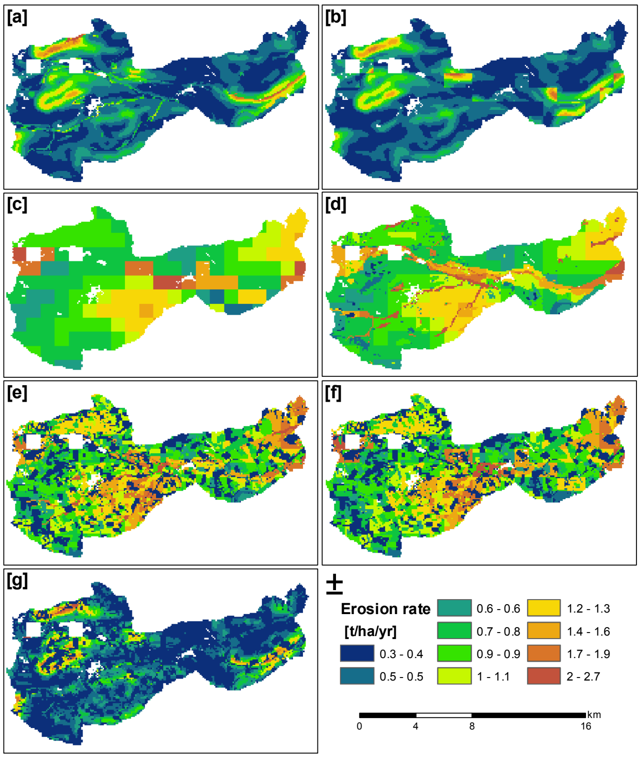

Figure 2. (a) 1:25k soils and OS 100 m DTM, (b) 1 km soils and OS 100 m DTM (c)1km soils and 1 km EU DTM (d) 1:25k soils and 1km EU DTM with SIACS Crops (e) 1 km soils and 1km EU DTM with SIACS Crops (f) 1:25k soils and OS 100 m DTM with SIACS Crops

However ensuring that the terrain input is accurate representation of the terrain in the catchment is vitally important when running the PESERA at a catchment scale. Here we show that the areas with the steepest slope in the west of the catchment, and modeled to have the greatest erosion using a high resolution DTM are not the same areas of the catchment that are modeled to have the highest erosion rates when using the 1 km DTM. Further investigation will look at the link between the input terrain parameter and how this represents the average slope in the catchment.

Using realistic cropping patterns for individual fields based on SIACS data modifies the erosion pattern in the catchment, compared to that based on soils, climate and terrain alone. This suggests that the model can be used as a land allocation planning tool within catchments (Figures 2e, f and g).

Further investigation into the application of the model as a planning tool to minimize soil erosion in a catchment will attempt to integrate the PESERA model outputs with spatially targeted cropping systems. Further investigation, by modeling the whole catchment under one crop, showed that the model was sensitive to the soil texture parameter and that coarse textured soils respond minimally or positively to a change in crops from winter to spring sown, where as medium textured soils respond negatively with increasing erosion rates of up to 30%. Further investigation is currently been undertaken to investigate refining the texture-based erodibility parameters to parameters that are based on the soil's aggregate stability.

Rainfall inputs

Rainfall inputs were changed from the 30 year average (1971-2000) to the values for the individual years 1984 and 1995 to further investigate into the model's sensitivity to changes in rainfall intensity and annual rainfall patterns. The rainfall pattern in 1984 has rainfall peaks in January, March and November, when soil moisture deficits are at their least whereas the 1971 to 2000 average invariably has a much more consistent pattern across months. The results show that there are significant changes (between 45 and 120%) in modelled soil erosion when rainfall inputs are changed from the average to the 1984 values (Figure 3). However when the rainfall pattern for 1995 are used, the erosion is consistently decreased (by a maximum of 30%) compared to the 1971 -2000 average rainfall (Figure 3). The 1995 rainfall pattern is such that a large soils moisture deficit occurs throughout the growing season. These changes occur and appear to be reflecting the rainfall patterns as there is a much smaller percentage change in the annual totals (Average, 770 mm, 1984: 919 mm and 1995 866 mm).

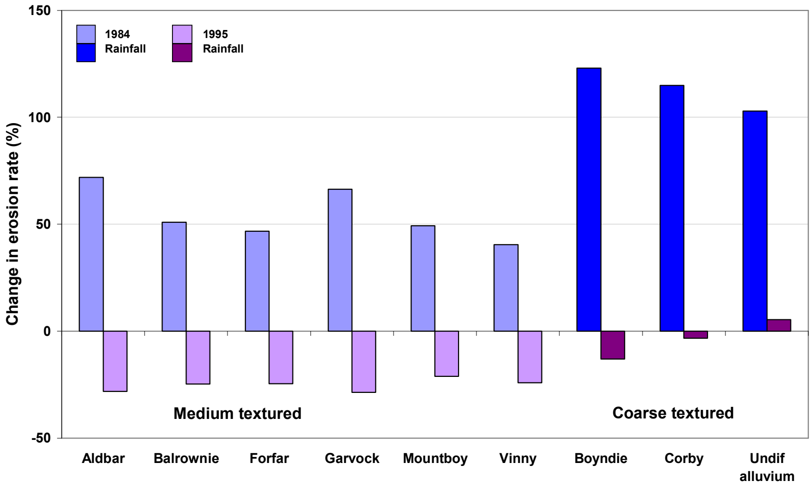

Figure 3. Percentage change in erosion rates using 1984 and 1995 rainfall compared to the 1971-2000 average

Conclusion

This study has shown that the PESERA model can be used as a broad scale screening tool for soil erosion as it has minimal data requirements. However we show that with higher resolution data inputs it has the potential to be used as a land use planning tool at a catchment scale. In addition, the model is sensitive to changes in rainfall patterns and has the potential to be used to assess the risk of soil erosion under future climate scenarios, where rainfall is predicted to change.

We also show that the model is very sensitive to the terrain parameter and that misrepresentation of this can give a skewed representation of erosion within a catchment. In addition increasing the resolution of soils data shows important improvements in the soil erosion predictions.

Future work will seek to further examine the potential of the model to be used as a land use planning tool to minimise soil erosion and to link the soil erosion estimates to measured suspended sediments as a partial validation exercise. We also hope to improve the representation of erodibility within the model based on measurements of aggregate stability.

Acknowledgements

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