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Flood-related contamination in catchments affected by historical metal mining: An unexpected and emerging hazard of climate change

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HIGHLIGHTS

- Pb concentrations in flood sediments exceed threshold values, in some samples by a factor of 82.
- Contamination of animal feed caused blood Pb poisoning and mortality in cattle.
- Climate change means that the events of summer 2012 are likely to continue and intensify.
- A geomorphological approach is needed to understand metal flux in fluvial systems.

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ABSTRACT

Floods in catchments affected by historical metal mining result in the remobilisation of large quantities of contaminated sediment from floodplain soils and old mine workings. This poses a significant threat to agricultural production and is preventing many European river catchments achieving a 'good chemical and ecological status', as demanded by the Water Framework Directive. Analysis of overbank sediment following widespread flooding in west Wales in June 2012 showed that flood sediments were contaminated above guideline pollution thresholds, in some samples by a factor of 82. Most significantly, silage produced from flood affected fields was found to contain up to 1900 mg kg^{-1} of sediment associated Pb, which caused cattle poisoning and mortality. As a consequence of climate related increases in flooding this problem is likely to continue and intensify. Management of contaminated catchments requires a geomorphological approach to understand the spatial and temporal cycling of metals through the fluvial system.

1. Introduction

River systems that drain historically mined orefields in the UK and Europe are often contaminated with heavy metals, principally Pb, Zn, Cd and Cu, due to the erosion, transport and deposition of metal-rich sediment from old mine workings and floodplain soils (Wolfenden and Lewin, 1977, 1978; Lewin et al., 1983; Lewin and Macklin, 1987; Macklin and Dowsett, 1989; Macklin, 1996; Hudson-Edwards et al., 1997; Macklin et al., 1997, 2006; Miller, 1997; Dennis et al., 2003; Mayes et al., 2013). Floods are especially effective agents of contaminant dispersal (Bradley, 1984a; Miller et al., 1999; Dennis et al., 2003; Navrátil et al., 2008; Gozzard et al., 2011), leading to sedimentation on agricultural and residential land. This poses a potential threat to the cultivation of crops and grazing of livestock, from large-scale agricultural operations to small-scale 'grow your own' allotments. Despite a lack of accepted Europe-wide contaminant threshold values applicable to metals in river sediment, previous studies have shown that alluvium sourced from historically mined catchments is often contaminated well above UK Soil Guidance Values (SGVs) and other widely used European thresholds (e.g. Dutch target and intervention values) (Dennis et al., 2003; Macklin et al., 2006; Gozzard et al., 2011). The legacy of metal mining in the UK means that many river catchments are characterised by excessive metal flux (Mayes et al., 2013) and thus face serious challenges to meet Water Framework Directive (WFD) targets of a 'good' status related to ecological and chemical parameters. Tackling this problem requires an understanding of the geomorphological processes operating at a variety of scales that condition the entrainment, transport and deposition of fine-grained sediment and associated contaminant load. In this respect, because large floods are relatively uncommon, flooding in June 2012 in west Wales (Foulds et al., 2012) provided an ideal opportunity to study the (re) mobilisation, dispersal and sedimentation of metal enriched alluvium and its environmental impact.

This study focuses on four Welsh river catchments that experienced flooding in June 2012 (Fig. 1) (Foulds et al., 2012). Following these

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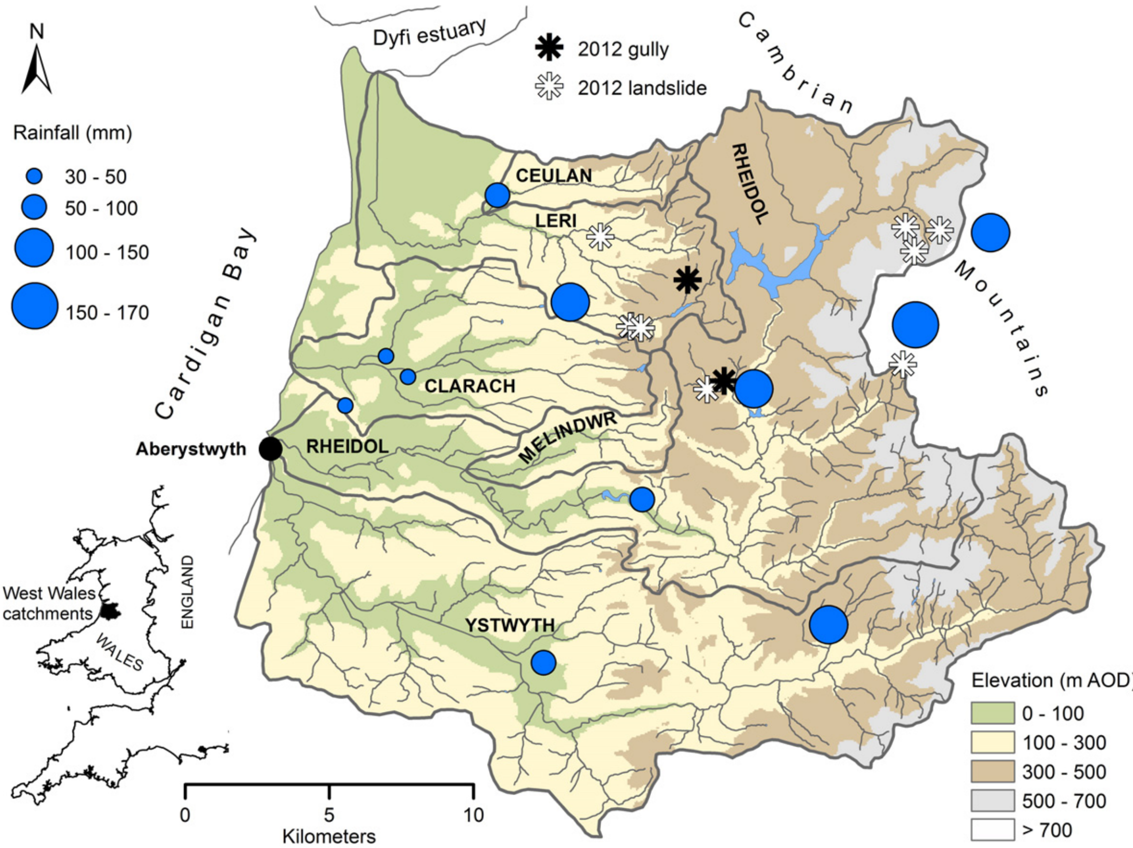

Fig. 1. River catchments in west Wales affected by flooding in June 2012. Graduated circles show daily rainfall totals for 8th June and asterisks mark geomorphological features.

floods it was suspected that a pervasive and chronic hazard may be present in the local area related to the widespread reworking of polluted alluvial units and spoil tips resulting from 19th and 20th century exploitation of the Central Wales Orefield. The principal aims of this research are to (1): characterise the extent and magnitude of flood sediment contamination resulting from flooding in June 2012 and (2): evaluate the wider significance and implications of floodplain contamination in west Wales, with particular reference to agriculture and animal health.

2. Study catchments

The principal rivers affected by flooding in June 2012 were, in decreasing order of severity, the Afon Leri, Afon Rheidol, Afon Clarach and Afon Ystwyth (Fig. 1). All of these catchments drain in a westerly direction towards Cardigan Bay from the Pumlumon massif (752 m AOD), in the Cambrian Mountains. Mean annual rainfall in the uplands is ca. 2600 mm (Grant and Robinson, 2010), associated with a humid-maritime climate and runoff tends to be rapid as upland soils are generally thin, peaty and characterised by natural soil pipes (Jones, 1997). River flows on the Afon Rheidol are significantly impacted by regulation related to Nant-y-moch, Dinas and Cwm Rheidol reservoirs, which produce hydro-electric power. The upper Leri is regulated by Llyn Craigpistyll and there are several small lakes/reservoirs in the Clarach headwaters. River channels in piedmont and lowland areas tend to be gravel/cobble bedded with gradients of ca. 0.002–0.004 m m^{-1}, whereas upland channels are steeper (locally ca. 0.10 m m^{-1}) and more typically cobble/boulder bedded with local bedrock sections. The principal land-use in all study catchments is pastoral farming.

Exploitation of Pb, Zn and Cu ore deposits in west Wales has led to a long history of mining activity, peaking in the early to mid-19th century for Pb and late 19th to early 20th century for Zn. Some mines, however, such as Cymsymlog (Clarach catchment), are known to have been extensively worked since the 16th century and Cu ore extraction began in the Ystwyth headwaters in the Bronze Age (Mighall et al., 2002). Due to the fact that many ore extraction and processing methods involved the use of water, rivers in the UK at the height of the mining era were 'turbid and carried poisonous 'slimes', destroying vegetation, killing livestock and making river banks more susceptible to erosion' (River Pollution Committee, 1874).

2.1. Summer 2012 in the UK

Summer 2012 (June–August) in the UK was the second wettest in a series back to 1910 (1912 was wetter) and June was the equal wettest (with June 1860) in England and Wales in a series back to 1766 (Eden, 2012a). The worst of the summer's weather and flooding occurred in June, affecting different areas of the UK at different times. The first major flood event took place on the 8th–9th June in Ceredigion, west Wales (Fig. 1), related to the deepest Atlantic depression to cross the UK in June since before 1900 (Eden, 2012b), resulting in 24–36 h of low intensity rainfall (5–8 mm h^{-1}; max. 11 mm h^{-1}). Rainfall totals on 8th June 2012 were highest on the western upslopes of Pumlumon where 24 and 36 hour rainfall totals of 146 mm and 183 mm were recorded at Dinas (258 m AOD). At a much higher altitude (529 m AOD), on the eastern side of Pumlumon (in the Wye and Severn catchments), 24 and 36 hour totals were 161 and 208 mm at Eisteddfa Gurig (Fig. 1). Maximum specific discharges (Q/drainage area) and return periods were estimated at 0.8 $m^3\ s^{-1}\ km^{-2}$ and <100 years on the Afon Rheidol, 1.3–4.4 $m^3\ s^{-1}\ km^{-2}$ and >50 years on the Afon Leri, and 0.7 $m^3\ s^{-1}\ km^{-2}$ and 4 years on the Afon Ystwyth. Although large (with the exception of the Afon Ystwyth), this flood was not unprecedented as there is evidence of other severe floods events in Ceredigion, notably October 1886 (Cambrian News, 1886), June 1910, 1919, 1935 (Cambrian News, 1910; Welsh Gazette, 1919, 1935), July 1957 (Cambrian News, 1957), December 1964 (Cambrian News,