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Contaminated landslide runout deposits in rivers – Method for estimating long-term ecological risks

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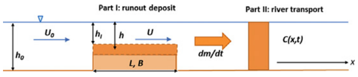
HIGHLIGHTS

- Analysis of effects of contaminant release from landslide runout deposits into rivers.
- A method to estimate long-term ecological risks to rivers and estuaries is developed.
- An addition to existing contaminated site and landslide risk assessment methods.
- Can be considered in integrated water management plans.

GRAPHICAL ABSTRACT



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ABSTRACT

The potential catastrophic event of a landslide bringing contaminants to surface waters has been highlighted in public media, but there are still few scientific studies analyzing the risk of landslides with contaminated soil. The aim of this study is to present a method to estimate the risk of potential long-term ecological effects on water bodies due to contaminated soil released into a river through a landslide. The study constitutes further development of previous work focusing on the instantaneous (short-term) release of contaminants and associated effects. Risk is here defined as the probability of surface water failing to comply with environmental quality standards (EQS). The transport model formulation is kept simple enough to allow for a probabilistic analysis as a first assessment of the impact on the river water quality from a landslide runout deposit containing contaminated soil. The model is applied at a contaminated site located adjacent to the Göta Älv River that discharges into the Gothenburg estuary, in southwest Sweden. The results from the case study show that a contaminated runout deposit will likely cause contamination levels above EQSs in the near area for a long time and that it will take several years for the deposit to erode, with the greatest erosion at the beginning when water velocities are their highest above the deposit. A contaminated landslide runout deposit will thus act as a source of contamination to the downstream water system until all the contaminated deposit has been eroded away and the contaminants have been transported from the deposit to the river, and further to the river mouth – diluted but not

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necessarily negligible. Therefore, it is important to prevent landslides of contaminated soil or waste, and if such events were to occur, to remove the contaminated runout deposit as soon as possible.

1. Introduction

There are few scientific studies on the combination of landslide susceptibility and contaminant spread, although landslides often affect urbanized and/or industrialized areas. Already in 1987, McCahon et al. (1987) pointed out that most studies on landslide impacts emphasize the geomorphological, social or economic aspects, and that ecological impacts are paid very little attention. McCahon et al. (1987) studied the chemical and biological effects of the Pennine peat slide into the headwaters of Langdon Beck and found that the slide caused a large increase in the concentration of suspended sediment and metals, with metal concentrations that reached acute toxic levels for aquatic organisms, but that long-term effects could not be assessed due to lack of data. Since then, little research appears to have been done on this subject. However, related cases have been reported in public media, implying an increased awareness of the potential that landslides can spread contaminants. For instance, public media has reported on a series of unusual landslides in connection with the fracking industry that have brought metal contaminated landslide sludge into the Brenot Creek and the Peace River, Canada (Business Vancouver, 2015; Policynote, 2016). Another example is from the Otago Daily Times that published an article on the Oso Landslide, Washington, US, discussing the potential that this event could cause the release of contaminants from broken sewages as well as the release of propane, household solvents, and other chemicals occurring within and beneath the landslide runout deposit (Otago Daily Times, 2017). In June 2013, the American Geophysical Union (AGU) blogosphere reported on a landslide event in Ecuador that caused a rupture of the so-called Trans-Ecuador pipeline and the leakage of oil, which led to a temporary closure of the Cocoa drinking water supply (Petley, 2013).

Reporting has also been made on the risk of landslides spreading radioactive waste products from the nuclear industry, which since World War II have been dumped in the landslide prone Ferghana Valley area that stretches across Kyrgystan, Uzbekistan, and Tajikistan (Institute of Nuclear Physics NNC RK, 2003; New Internationalist, 2005). Most of the mining facilities in this area were built on unstable slopes. The absence of a suitable location for landfill of wastes led to the dumping of radioactive wastes on floodplains adjacent to rivers (Institute of Nuclear Physics NNC RK, 2003). Underground work and other anthropogenic activities are believed to have caused many of the reported landslides in this area (Institute of Nuclear Physics NNC RK, 2003; UN-SPIDER, 2017). In 1958, a landslide in Mailuu Suu, triggered by earthquakes and heavy rains, caused the burst of a tailing that released 600,000 m^3 of radioactive waste into the nearby river (Institute of Nuclear Physics NNC RK, 2003). Catastrophe modeling of other tailings (tailing dumps and stockpiles) in the Mailuu Suu area has been carried out to analyze possible consequences. The modeling showed that if a tailing is destroyed by a landslide, the contaminated material will most likely be released into the nearby river (Birsen and Kadyrzhanov, 2003). In 2014, Torgoev and Omorov (2014) published a study on the landslide hazards of rock glaciers in the waste material from the Kumtor gold mine, Kyrgystan. They argued that such an event will most likely cause the pollution of the nearby Kumtor-Naryn River basin.

Schreier and Lavkulish (2015) studied the transport and settling of asbestos-rich serpentine sediment dispersed from a landslide area in the Sumas River Watershed in Washington State and British Columbia, and found that the transport of sediment from the landslide to the river is highest during high-flow periods (winter), and that the suspended sediment then moves through the river system in pulses of suspension, deposition, and re-suspension during several storm events. They also found that the sediment zeta-potential impacts the flocculation, coagulation, and deposition of the sediment, which can explain that particles <63 μm settled more rapidly near the landslide area than further downstream (Schreier and Lavkulish, 2015). A study by Johnston et al. (2015) found that landslides may be a significant mobilizer of Fe and Mn from the soil to the aquatic fiordland system, and that the landslides are important for the Fe and Mn cycle in the system.

Other scientific studies that may provide insights into the transport processes that are relevant for the release of contaminants from landslide runout deposits involve contaminant spread from riverbank erosion. For example, Rowan et al. (1995) studied geomorphology and pollution of the Glengonnar Water and found that bank erosion, among others, was an important process that affected the metal content in the river. Foulds et al. (2014) found that erosion in its various forms (surface erosion, rill erosion, bank erosion, and bank collapse) is an important pathway for contaminants to enter a river system. Rhoades et al. (2009) studied the release of mercury (Hg) from riverbank erosion along the South River, Waynesboro, USA. They found that fluvial bank erosion of Hg contaminated soil (from textile manufacturing) was a major source for the Hg load to the water system. Carroll and Warwick (2016) studied the mechanisms of Hg spreading (gold mining) along Carson River, Lahontan Reservoir system in Nevada, USA. They studied Hg loading from diffusion, channel pore water advective flux, bank erosion, and overbank deposition, and found that bank erosion processes were dominant for the Hg load to the river water, for both solid and dissolved Hg. Coulthard and Mackling (2003) modeled sediment and contaminant transport along the River Swale, which is affected by metal mining, in order to predict future conditions. Based on their simulations, they found that it will most likely take several thousands of years of natural erosion to remove all the contaminants from the Swale River channel and its floodplain; meanwhile the contaminants will continue to affect adjacent land and water resources.

So far, we have found no studies on risk assessment that account for contaminant release from landslide events – from hazard identification to risk analysis. To elucidate this hazard, Göransson et al. (2009) used GIS-technique to combine layers for landslide probability with layers for identified, risk-classified contaminated sites along parts of the Göta Älv River valley, in southwest Sweden. The study revealed that out of 31 identified contaminated sites, 8 sites were located in areas with unacceptable slope stability. Out of these 8 sites, 5 were assessed as posing high or very high environmental risk. Two historical landslides in the area that involved industrial sites are the Göta landslide in 1957 resulting in the failure of the Göta Sulphite factory, and the Agnesberg landslide in 1993 causing a large part of the Agnesberg industrial site to slide into the river. Some sediment samples taken from the Agnesberg landslide runout deposit show metal content. In connection with the Agnesberg landslide, the freshwater intake for the City of Gothenburg, located downstream of the slide area, registered elevated levels of turbidity resulting from the initiation slide and the following retrogressive slides at the source area (Göransson et al., 2012). Ströberg et al. (2017) suggested a method to derive a landslide susceptibility index to be used in a GIS-analysis to overlap landslide susceptibility and the location of contaminated sites along parts of the Ångermanälven River, in northern Sweden. They found that 16 of 209 potentially contaminated sites are located in areas with high or very high susceptibility for landslides.

It is possible that the effects of climate change may increase the landslide frequency in areas where precipitation is anticipated to increase. For example, IPCC states that there is a “high confidence that changes