Science of the Total Environment 612 (2018) 303–312

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Spatial modeling of sediment transfer and identification of sediment sources during snowmelt in an agricultural watershed in boreal climate

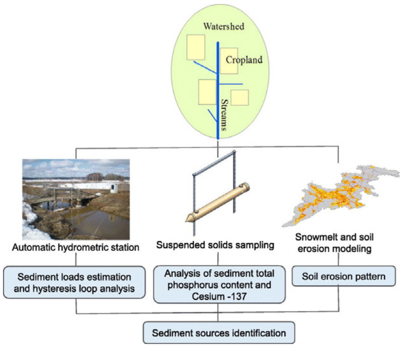
Carlos Gonzales-Inca [a],*, Pasi Valkama [b], Jan-Olof Lill [c], Joakim Slotte [d], Eila Hietaharju [a], Risto Uusitalo [e]

[a] *Department of Geography and Geology, University of Turku, Finland*
[b] *The Water Protection Association of The River Vantaa and Helsinki Region, Finland*
[c] *Accelerator Laboratory, Turku PET Centre, Åbo Akademi University, FI-20500 Turku, Finland*
[d] *Physics, Faculty of Science and Engineering, Åbo Akademi University, FI-20500 Turku, Finland*
[e] *Natural Resources Institute Finland (LUKE), 31600 Jokioinen, Finland*

HIGHLIGHTS

- Using high-resolution hydrometric data, snowmelt sediment transfer was studied.
- Sediment fingerprinting was applied to identify suspended sediment origins.
- Cesium-137 and erosion modeling suggested cropland as main source of sediments.
- Sediment transfer patterns were complex and varied spatially and temporally.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 February 2017
Received in revised form 29 July 2017
Accepted 14 August 2017
Available online xxxx

Editor: F.M. Tack

Keywords:
Snowmelt
Soil erosion
Hysteresis
Sediment fingerprinting
Phosphorus
GIS
LiDAR DTM

ABSTRACT

Sediment transfer patterns during snowmelt were studied in a small Finnish agricultural watershed. Erosion rates were high as a consequence of high runoff volumes over saturated soil that partly lacked vegetation cover. Automatic high-frequency monitoring data of sediment and phosphorus concentrations in stream showed a clock-wise hysteresis loop as a dominant pattern. GIS-based modeling of runoff and soil erosion, using LiDAR DTM data, suggested that runoff and erosion mostly came from cropland that had the highest sediment contribution index. Also sediment fingerprinting with Cesium-137 suggested cropland and stream bank were the most important sources of suspended sediments in streams. Because a major part of annual sediment transfer takes place during snowmelt, it is a critical period for annual losses of pollutants. Management practices that minimize springtime sediment and pollutant losses from cropland would be needed to make a marked impact on annual pollution transfer to stream waters.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Agricultural areas are major diffuse sources of pollutants that end up in aquatic ecosystems, and thus a cause of eutrophication in most parts

---

* Corresponding author.
E-mail address: cagoin@utu.fi (C. Gonzales-Inca).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.142
0048-9697/© 2017 Elsevier B.V. All rights reserved.

of the world (Withers et al., 2014). Water quality protection measures aimed to reduce eutrophication in Scandinavian and Finnish lakes and the Baltic Sea have been primary oriented to reduce sediment-borne pollutant transport from agricultural fields (Ulén et al., 2010; Uusi-Kämppä and Jauhiainen, 2010). In boreal conditions, agricultural fields are covered by snow up to 5 months per year, and the main snowmelt occurs from late March to early April (Bengtsson et al., 1992). This constitutes a critical period of pollutant transfer, because soil erosion is particularly high as a result of prolonged water saturation of soils, reduced vegetation cover and high overland flow on soils thawing from surface (Van Vliet and Wall, 1981; Puustinen et al., 2007). However, erosion rates during snowmelt differ between years, depending on the depth of soil frost and on freeze–thaw cycles during the peak flow periods, which affect water flow pathways and soil erodibility (Van Bochove et al., 2001; Su et al., 2011). Additionally, field characteristic such as surface roughness, slope, vegetation cover and compaction substantially affect sediment losses, e.g. fields with greater roughness trap large particles resulting in an increased relative export of finer particles (Panuska et al., 2008; Panuska and Karthikeyan, 2010). Soil tillage is a major modifier of soil roughness and temporary water storage capacity of agricultural fields (Evans, 1980; Turtola et al., 2007). All these causes of variation make soil losses difficult to predict (Sukhanovskii, 2008).

Fine sediments (<62 μm), particularly clay, are chemically highly reactive and can have a high nutrient content (Naden, 2010). Consequently, agro-chemical pollutant transfer might increase substantially when fine sediments are preferentially mobilized (Alberts and Moldenhauer, 1981; Panuska and Karthikeyan, 2010). Much of the Finnish agricultural soils are clayey in texture and they are sub-drained to improve crop production. Also, channelization has converted natural brooks and streams into straight, deep and uniform cross-sectioned channels that are periodically dredged to maintain drainage ability (Västilä and Järvelä, 2011). Efficient drainage systems accentuate hydrological responses of snowmelt and rainfall, and can also contribute to the amount of sediment and nutrient discharges via channel-bank erosion and resuspension of sediment previously settled on the stream-bed (Kronvang et al., 2012). Stream-bed and -bank may also act as temporary sinks of P, depending on the sediment absorption capacity and soluble P concentration in water (Zhuan-xi et al., 2009).

Several field and watershed-scale models have been applied to quantify soil erosion and to predict P losses from agricultural areas in Finland. The models used include ICE-CREAM (Rekolainen and Posch, 1993), SWAT Model (Tattari et al., 2009), INCA-SED (Rankinen et al., 2010), FLUSH (Warsta, 2011) and RUSLE (Panagos et al., 2015). These models differ greatly in prediction of erosion rate, but they also differ in spatial erosion pattern prediction, as they differ in their mathematical formulation and spatial data representation, being semi-distributed or spatially distributed models. Because most of the modeling tools are used to plan and assess the effectiveness of water protection measures, assessment made with these models is important not only in term of sediments loss quantity, but also the correct identification of sediment sources (Jetten et al., 2002). Therefore, sediment source assessment at a watershed level requires further research and links with empirical evidences that is needed to verify modeling results. As a complement to modeling, sediment fingerprinting provides useful information on the sediment sources and pathways (Uusitalo et al., 2001; Mukundan et al., 2010). If the dominant sediment source in stream can be correctly identified, mitigation measures can be better targeted within watersheds, which increases cost-effectiveness of pollution abatement.

In this paper, the sources and spatial pattern of sediment mobilization during snowmelt in a Finnish agricultural catchment are studied. The specific objectives are: 1) to identify dominant sources of sediment matter collected from a stream channel, 2) to map the spatial patterns of sediment mobilization in overland flow, and 3) to discuss the implications of sediment transfer for P loss control. To this end, high temporal resolution data of river discharge and turbidity is analyzed, and sediment fingerprinting method is applied. Also, soil erosion modeling is carried out in geographic information system (GIS) with LiDAR DTM data.

2. Materials and methods

2.1. Site description

The study area was a head watershed of the Lepsämänjoki River, a tributary of Vantaanjoki River in Southern Finland (Fig. 1). The total area of the watershed is 2237 ha, with elevation range of 30 to 129 m. The land-uses in the study area consist of croplands (38%, mostly spring cereals under minimum tillage), forests (49%) and residential areas (12%). Most of the agricultural fields are located in flat areas (<2% slope) and these are efficiently drained with open ditches and subsurface tile drainage. The dominant soil types in the watershed are marine and lacustrine clays (43%), sandy glaciofluvial till (33%) and impermeable metamorphic crystalline bedrock (16%). The annual hydrological pattern includes two peak flow periods, snowmelt in spring and a rainy period in autumn. The average annual discharge in the study area in 2006–2016 was 0.2 $m^3 s^{-1}$ and the mean annual precipitation 650 mm, with snowfall representing 10–20% of the total annual precipitation. Mean annual air temperature is 4 °C (Rankinen et al., 2013).

2.2. Automatic monitoring data, and sediment sample collection and analyses

Temporal resolution data on an hourly basis on river discharge ($m^3 s^{-1}$) and turbidity (Formazin Nephelometric Turbidity Unit, NTU), recorded by an automatic station, was used in the analyses. The station was installed by The Water Protection Association of The River Vantaanjoki and Helsinki Region (WPA-RVHR), and turbidity was measured with Scan sensors (Scan gmbh, Austria) in one hour interval. The flow velocity and water level was also measured with one hour frequency using an acoustic flow meter (StarFlow, Unidata Pty Ltd., O'Connor, ACT, Australia). Discharge was calculated as a function of flow velocity and cross section area of measured water level, as described by Valkama et al. (2007). Turbidity data was used to estimate Total Suspended Sediment (TSS) and Total Phosphorus (TP) concentrations, with a calibration made with water quality measurements in laboratory. Calibration samples were collected manually and analyzed in the laboratory by WPA-RVHR during 2006–2014. TSS concentrations of the water samples were measured by weighting dried (105 °C, at least 1 h) material retained on pre-weighted glass fiber filters (SFS-EN 872). Total P was analyzed, after acidic peroxodisulphate digestion at 120 °C, by the ammonium molybdate spectrometric method (SFS ISO 6878) with ascorbic acid as the reducing agent.

The following linear relationships were obtained to estimated concentrations TSS and TP from turbidity (Tur) data: $TSS = 0.86 \times Tur + 2.3$, $R^2 = 0.96$, $n = 153$ and $TP = 1.17 \times Tur + 41.6$, $R^2 = 0.91$, $n = 153$. TSS and TP loads were calculated by multiplying concentration by discharge Q ($L s^{-1}$) on an hourly basis. TSS and TP loads during the snowmelt of spring 2012 were computed as the total sum of the 1-h loads. For more detailed load calculations of TSS and TP on the basis of high frequency turbidity data in the study area, see Valkama and Ruth (2017).

To identify the sources of suspended sediment in the stream, the anthropogenic radioactive isotope Cesium-137 (^{137}Cs, half-life 30.2 years) was used. Fallout-derived ^{137}Cs tends to be stratified in the soil depth for decades, having high activity in the topsoil and decreasing remarkably with soil depth, being therefore useful as a fingerprint of sediment sources (Mahara, 1993; Uusitalo et al., 2001; Mukundan et al., 2010). Activity of ^{137}Cs in the sediments was determined by measuring the emission of gamma radiation (661 keV) using a high-purity germanium (HPGe) coaxial detector from Ortec. Resolution of the measuring system was 1.74 keV at 1.33 MeV. The sediments were placed in 30 mL Petri dishes attached to the end cup of the HPGe detector. Calibrated point

Download English Version:

https://daneshyari.com/en/article/5749886

Download Persian Version:

https://daneshyari.com/article/5749886

Daneshyari.com