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Research article

Riparian erosion vulnerability model based on environmental features

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ABSTRACT

Riparian erosion is one of the major causes of sediment and contaminant load to streams, degradation of riparian wildlife habitats, and land loss hazards. Land and soil management practices are implemented as conservation and restoration measures to mitigate the environmental problems brought about by riparian erosion. This, however, requires the identification of vulnerable areas to soil erosion. Because of the complex interactions between the different mechanisms that govern soil erosion and the inherent uncertainties involved in quantifying these processes, assessing erosion vulnerability at the watershed scale is challenging. The main objective of this study was to develop a methodology to identify areas along the riparian zone that are susceptible to erosion. The methodology was developed by integrating the physically-based watershed model MIKE-SHE, to simulate water movement, and a habitat suitability model, MaxEnt, to quantify the probability of presences of elevation changes (i.e., erosion) across the watershed. The presences of elevation changes were estimated based on two LiDAR-based elevation datasets taken in 2009 and 2012. The changes in elevation were grouped into four categories: *low (0.5 - 0.7 m), medium (0.7 – 1.0 m), high (1.0 - 1.7 m) and very high (1.7 – 5.9 m)*, considering each category as a studied “species”. The categories' locations were then used as “species location” map in MaxEnt. The environmental features used as constraints to the presence of erosion were land cover, soil, stream power index, overland flow, lateral inflow, and discharge. The modeling framework was evaluated in the Fort Cobb Reservoir Experimental watershed in southcentral Oklahoma. Results showed that the most vulnerable areas for erosion were located at the upper riparian zones of the Cobb and Lake sub-watersheds. The main waterways of these sub-watersheds were also found to be prone to streambank erosion. Approximatively 80% of the riparian zone (streambank included) has up to 30% probability to experience erosion greater than 1.0 m. By being able to identify the most vulnerable areas for stream and riparian sediment mobilization, conservation and management practices can be focused on areas needing the most attention and resources.

1. Introduction

Riparian zones are among the most productive and valuable natural resources in the world because they support numerous ecological services such as high plant species diversity and wildlife habitat (Bentrup, 1998). However, they are also one of the most vulnerable due to their proximity to water bodies that have the capacity to influence their physical, chemical, and biological characteristics. Although erosion and deposition are natural fluvial processes that shape the riparian zones, extreme flooding and human disturbance can hasten the erosion process which can lead to major environmental problems. For example, soil erosion along streambanks and riparian areas can result in streambank instability and failure (Chu-Agor et al., 2008a,b, 2009; Daly et al., 2015) and increased sediment load to streams (Fox et al., 2016). In fact, Wilson et al. (2008), using naturally occurring radionuclide traces, found that streambank erosion contributes about 48% of the suspended

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sediments in streams of the watershed in the present study area (described below). Shields et al. (1995) reported that 480,000 km of eroded streambank in the U.S. produced approximately 450 million of tons of sediment per year. Increased sediment load to streams can result in water quality impairment that can cause human health problems and also threatens the aquatic ecosystem. Lost and degraded riparian zones also translate into destruction of wildlife habitat and consequently the wildlife that inhabits them. Riparian vegetation buffers decrease the impact of nonpoint source pollution by capturing nutrients and sediments from the overland flow (Bentrup, 1998) and reducing the vulnerability of banks to erosion. Conversion of riparian forests into grazing areas or row-crops fields can reduce or eliminate these ecosystem services and accelerate riparian and streambank degradation. Water quality issues and reductions in ecosystem services are some of the many reasons why streambank and riparian erosion are of major concern to environmental scientists, managers, and policy-makers. However, the spatial and temporal variability of the factors and mechanisms (e.g., precipitation, streamflow, elevation, land cover) that affect the erosion process make prevention and mitigation efforts challenging.

The last several decades have seen the implementation of riparian conservation practices to restore the riparian zones and mitigate future degradation of vulnerable areas. A large number of research efforts have been focused on understanding streambank and riparian erosion processes and how to mitigate their effects (Bermhardt and Palmer, 2007; Correll, 2005; Henderson, 1986; Purvis and Fox, 2016; Simon et al., 2011; Zaimes et al., 2004). However, before any conservation measures can be implemented, it is necessary to first identify the areas that are vulnerable to erosion, particularly as it may be exacerbated by climate variability and extremes. Predicting riparian and streambank erosion at the watershed scale is challenging because it requires constant monitoring of soil, hydrologic, and climate variables that can cost more than the conservation efforts themselves.

Erosion at the watershed scale has been addressed from different perspectives. For instance, Fox and Papanicolaou (2007) used nitrogen and carbon isotopes as tracers to identify temporal and spatial variability of erosion processes in a 0.71 km^2 sub watershed. This method required considerable field work and post processing of samples in order to establish rill/interrill and floodplain erosion which limits the suitability of the method to very small watersheds. Distributed models have also been applied to simulate hydrologic event erosion. For example, KINEROS2 (Woolhiser et al., 1990) and EUROSEM (Morgan et al., 1998) numerically solved the sediment mass balance equation using rainfall as input and avoiding the averaging effects of lumped models like USLE and RUSLE (Smith et al., 1995). Again, these models are suited for small watersheds and the erosion is evaluated per specific rainfall event only. On the other hand, Purvis and Fox (2016) estimated the eroded area along the riparian zone by analyzing aerial images of Delaware County, Oklahoma for 2003, 2008, 2010, and 2013 where streambanks were manually delineated using polylines. The effects of the stream power, the riparian vegetation, and the meandering on riparian erosion were studied. The two latter are environmental variables visually detected in the aerial images, while the former was computed from the monitored discharge during the study period. At the watershed scale, erosion vulnerability is commonly assessed using only geospatial analysis of satellite images (e.g., Purvis and Fox, 2016; Chatterjee and Krishna, 2014) instead of numerical models and environmental data. Studies that identify vulnerable areas to riparian erosion at the watershed scale based on the simulation of physical processes are still very limited due to the rigors and expense involved in such endeavors. There is, therefore, a critical need to develop a modeling framework to identify and predict vulnerable areas to erosion along the riparian zones that combines simulations of physical processes and landscape level tools such as watershed scale environmental data.

The specific objectives of this study were to: (1) integrate the hydrologic watershed model, MIKE-SHE, the river model, MIKE-11 (to simulate water movement across the watershed) with the habitat suitability model, MaxEnt, to determine the probability of presence (POP) of erosion along the riparian zone, and (2) determine vulnerable areas for erosion along the riparian zone at the watershed scale. The modeling framework was applied to the Fort Cobb Reservoir Experimental Watershed (FCREW) located in southcentral Oklahoma. By being able to identify the most probable vulnerable areas for stream and riparian sediment mobilization, conservation and managerial practices can be focused on areas that need the most attention and resources.

2. Methodology

2.1. Study area

The Fort Cobb Reservoir Experimental Watershed (FCREW) is a sub-watershed of the Washita River Basin located in southcentral Oklahoma, USA. It drains an area of approximately 800 km^2 to the Fort Cobb Reservoir. The land use in FCREW is predominantly agriculture with approximately 60% of its area used for crop cultivation (USGS, 2016b). The USDA-ARS Grazinglands Research Laboratory (GRL) in El Reno, OK, established the FCREW for participation in the Watershed Assessment Studies (WAS) portion of USDA-NRCS' Conservation Effects Assessment Project (CEAP) (Mausbach and Dedrick, 2004; Steiner et al., 2008). The CEAP WAS was designed to conduct hydrologic investigations for the improvement of watershed models to better assess the impact of conservation practices at the watershed scale. For this reason, FCREW is equipped with a network of climate and hydrologic monitoring stations (Fig. 1) with long-term datasets that can support environmental assessment studies. The watershed has 18 rainfall stations, three observation wells, and three stream gauge stations.

The study area has a sub-humid climate with a bi-modal rainfall distribution (May–June and September–October) which produces an annual rainfall of approximately 800 mm (Starks et al., 2014). FCREW climate is also characterized by wet and dry multiannual periods (Garbrecht and Schneider, 2008) which determine the overland flow and the sediment transport behavior in the watershed. Riparian areas have been affected by livestock grazing expansion, causing active degradation and bank failure in most of the channels in the FCREW (Simon and Klimetz, 2008). Crop production and management has changed in time with some farms implementing newer conservation practices and minimum tillage (Moriasi et al., 2014; Storm et al., 2006). However, the FCREW still experiences water quality problems, specifically transport of sediment and elevated phosphorus concentration, due to intensive agricultural activities and cropland erosion (Oklahoma Conservation Commission, 2009). Despite the fact that approximately 50% of the total suspended sediment load was estimated to come from the streambanks (Wilson et al., 2008), studies identifying vulnerable erosion areas along the riparian zone of FCREW are nonexistent. Erosion related studies conducted in the watershed are mostly focused on quantifying the total suspended sediment load produced in its waterways (e.g., Garbrecht and Starks, 2009; Wilson et al., 2008; Simon and Klimetz, 2008).

The methodology developed in this research was composed of two main parts: the simulation of the hydrologic processes using the models, MIKE-SHE and MIKE 11, and the estimation of erosion