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Modeling seasonal variability of fecal coliform in natural surface waters using the modified SWAT

Kyung Hwa Cho [a], Yakov A. Pachepsky [b], Minjeong Kim [a], JongCheol Pyo [a], Mi-Hyun Park [c], Young Mo Kim [d], Jung-Woo Kim [e], Joon Ha Kim [d,*]

[a] School of Urban and Environmental Engineering, Ulsan National Institute of Science and Technology, Ulsan 689-798, Republic of Korea
[b] USDA-ARS, Environmental Microbial and Food Safety Laboratory, 10300 Baltimore Avenue, Building 173, BARC-East, Beltsville, MD 20705, USA
[c] Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, 130 Natural Resources Road, Amherst, MA 01003, USA
[d] School of Environmental Science and Engineering, Gwangju Institute of Science and Technology, 261 Cheomdan-gwagiro, Buk-gu, Gwangju 500-712, Republic of Korea
[e] Radioactive Waste Technology Development Division, Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon 305-353, Republic of Korea

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SUMMARY

Fecal coliforms are indicators of pathogens and thereby, understanding of their fate and transport in surface waters is important to protect drinking water sources and public health. We compiled fecal coliform observations from four different sites in the USA and Korea and found a seasonal variability with a significant connection to temperature levels. In all observations, fecal coliform concentrations were relatively higher in summer and lower during the winter season. This could be explained by the seasonal dominance of growth or die-off of bacteria in soil and in-stream. Existing hydrologic models, however, have limitations in simulating the seasonal variability of fecal coliform. Soil and in-stream bacterial modules of the Soil and Water Assessment Tool (SWAT) model are oversimplified in that they exclude simulations of alternating bacterial growth. This study develops a new bacteria subroutine for the SWAT in an attempt to improve its prediction accuracy. We introduced critical temperatures as a parameter to simulate the onset of bacterial growth/die-off and to reproduce the seasonal variability of bacteria. The module developed in this study will improve modeling for environmental management schemes.

1. Introduction

Fecal coliforms are introduced to water bodies from various sources that include agricultural runoff, sewage, re-suspension from streambeds, and wild and domestic animal feces (Alderisio and DeLuca, 1999; Cho et al., 2012; Gerba, 2000; Howell et al., 1995; Nah et al., 2010; Pachepsky et al., 2006; Pachepsky and Shelton, 2011; Servais et al., 2007; Won et al., 2010). Although fecal coliforms are not inevitably pathogenic, their abundance in human and other animal waste products can indicate the presence of pathogenic bacteria. Total Maximum Daily Loads (TMDLs) for fecal coliform are implemented at a total of 7800 stream segments in the USA (USEPA, 2005), with the highest percentage as a single pollutant category (21%, *i.e.*, 5600 out of 2700 TMDLs) (Kroencke et al., 2010).

Several studies found that meteorological conditions affect the levels of fecal coliform (Cho et al., 2010a, 2010c, 2012; Gannon and Busse, 1989; Kim et al., 2007, 2010; Marsalek and Rochfort, 2004; Paul et al., 2004; Petersen et al., 2005; Pietikainen et al., 2005; Tani et al., 1995; Won et al., 2010). Previous studies demonstrated the relation between solar radiation and the survival of fecal coliform in natural waters (Auer and Niehaus, 1993; Bellair et al., 1977; Fujioka et al., 1981; Mancini, 1978; Mccambridge and Mcmeekin, 1981; L. Sinton et al., 2007, 1999; Won et al., 2010). Temperature is one of controlling factors affecting soil microbial growth with soil moisture contents (Kirschbaum, 1995, 2000; Lloyd and Taylor, 1994; Paul and Clark, 1996). Pietikainen et al. (2005) observed that the growth rate of bacteria was higher at temperatures ranging from 25 to 30 °C, but it sharply decreased at higher temperatures. Ishii et al. (2007) reported that *Escherichia coli* can survive and grow in soils in temperate climate. Bannister (2010) conducted multiple batch experiments in soils and found that *E. coli* population grew at 20 °C and decreased at 4 °C. Coliform populations in deposited fecal material were shown to grow or to decrease depending on temperature. L.W. Sinton et al. (2007) placed cowpats on pasture and observed growth of *E. coli* concentrations in spring, summer, and autumn, and a steady decrease in winter. Muirhead and Littlejohn (2009) and Soupir (2008) reported *E. coli* die-off in cowpats deposited in winter and autumn but not in

* Corresponding author.
E-mail address: joonkim@gist.ac.kr (J.H. Kim).

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