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Watershed-scale modeling on the fate and transport of polycyclic aromatic hydrocarbons (PAHs)

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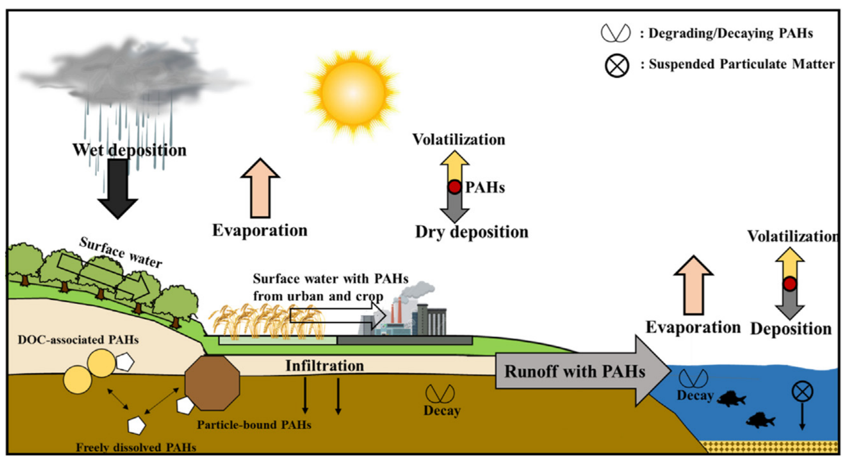
HIGHLIGHTS

- Multimedia model coupled with SWAT was developed as a watershed-scale PAH model.
- Fugacity method was applied for interactions between air-soil and air-water.
- Three-phase partitioning model was used to estimate PAH from soil to water.
- Spatial and temporal distribution of PAH compounds in the watershed was revealed.
- Critical processes that affect PAH compounds in the watershed were determined.

GRAPHICAL ABSTRACT



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ABSTRACT

PAHs are potentially carcinogenic substances that are persistent in the environment. Increasing concentrations of PAHs were observed due to rapid urbanization, thus; monitoring PAHs concentrations is necessary. However, it is expensive to conduct intensive monitoring activities of a large number of PAHs. This study addressed this issue by developing a multimedia model coupled with a hydrological model (i.e., Soil and Water Assessment Tool (SWAT)) for Taehwa River (TR) watershed in Ulsan, the industrial capital of South Korea. The hydrologic module of the SWAT was calibrated, and further used to simulate the fate and transport of PAHs in soil and waterbody. The model demonstrated that the temporal or seasonal variation of PAHs in soil and waterbody can be well reproduced. Meanwhile, the spatial distribution of PAHs showed that urban areas in TR watershed have the highest PAH loadings compared to rural areas. Sensitivity analyses of the PAH soil and PAH water parameters were also able to determine the critical processes in TR watershed: degradation, deposition, volatilization, and wash off mechanism. We hope that this model will be able to aid the stakeholders in: regulating PAH concentrations emitted by various sources; and also apply the model to other Persistent Organic Pollutants (POPs).

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1. Introduction

Economic growth of developing countries has been steadily increasing through the years due to their rapid urbanization and increasing industrial activities [1]. Along with this growth is the increasing number of challenges that are associated with urbanization, such as the decline of public health and the deteriorating urban environment mainly caused by air and water pollution [2,3]. The US Environmental Protection Agency (USEPA) listed priority pollutants that must be regulated and the list includes polycyclic aromatic hydrocarbons (PAHs) that are often associated with urbanization [4–6].

PAHs are potentially carcinogenic substances that are gaining the attention of environmental sectors due to their persistence in the environment and adverse health effects [7]. They are labeled as persistent organic pollutants (POPs), a group of toxic chemical substances that resist degradation and have a tendency to bioaccumulate in the food chain, and have become a public concern due to the significant risks they present to their surroundings [8,9]. Major concerns include emissions from industrial activities and incomplete combustion of fuels since they contribute a large amount of PAHs in the atmosphere and can be widely dispersed to neighboring areas via long-range transport [10–13].

There are existing efforts to mitigate the contamination of PAHs in the atmosphere and surface waters. Monitoring methods have been conducted for several years to perform risk assessments of possible PAH contamination and identify their dominant sources [14–16]. However, chemical analyses of the samples take an excessive amount of time and effort, making it expensive to conduct intensive monitoring activities of a number of PAHs [17]. Water quality models address this problem by using the available data to determine spatial and temporal patterns of PAHs in different media while, mathematical models help simulate PAH concentration at a given time frame using the physical and chemical characteristics of each media. [18]. To simulate the transport processes associated with multiple media, recent studies have applied the modeling approach [19]. The models help compartmentalize complex systems of the environment using boxes that are connected by mass fluxes. Each box represents an environmental medium and can characterize one or more state variables [20]. Greenfield and Davis and Hauck et al. were able to simulate PAH concentrations and evaluate their spatial variability using a multimedia fate model [21,22]. Unfortunately, these existing models are limited to mass transfers and have yet to perform a watershed-scale simulation of PAH transport.

This study addressed the need to have a watershed-scale PAH model by developing a multimedia model coupled with the Soil and Water Assessment Tool (SWAT) for Taehwa River (TR) watershed in Ulsan, South Korea. Ulsan City is the industrial capital of South Korea and has the largest per-capita GDP in the country. The industrial complex in Ulsan is located at the western-most part of city and has more than 200 companies in operation. The plants and factories are mostly involved in steel machinery, petrochemical, and transport equipment, which are expected to be major sources of PAHs. The interactions between the atmosphere, water body, and soil were considered to simulate PAH transport within the watershed, while the SWAT model provided the hydrologic characteristics of TR basin. This study is the first watershed-scale PAH model that was able to investigate the spatial distribution, temporal patterns, and fate and transport of PAHs in a watershed.

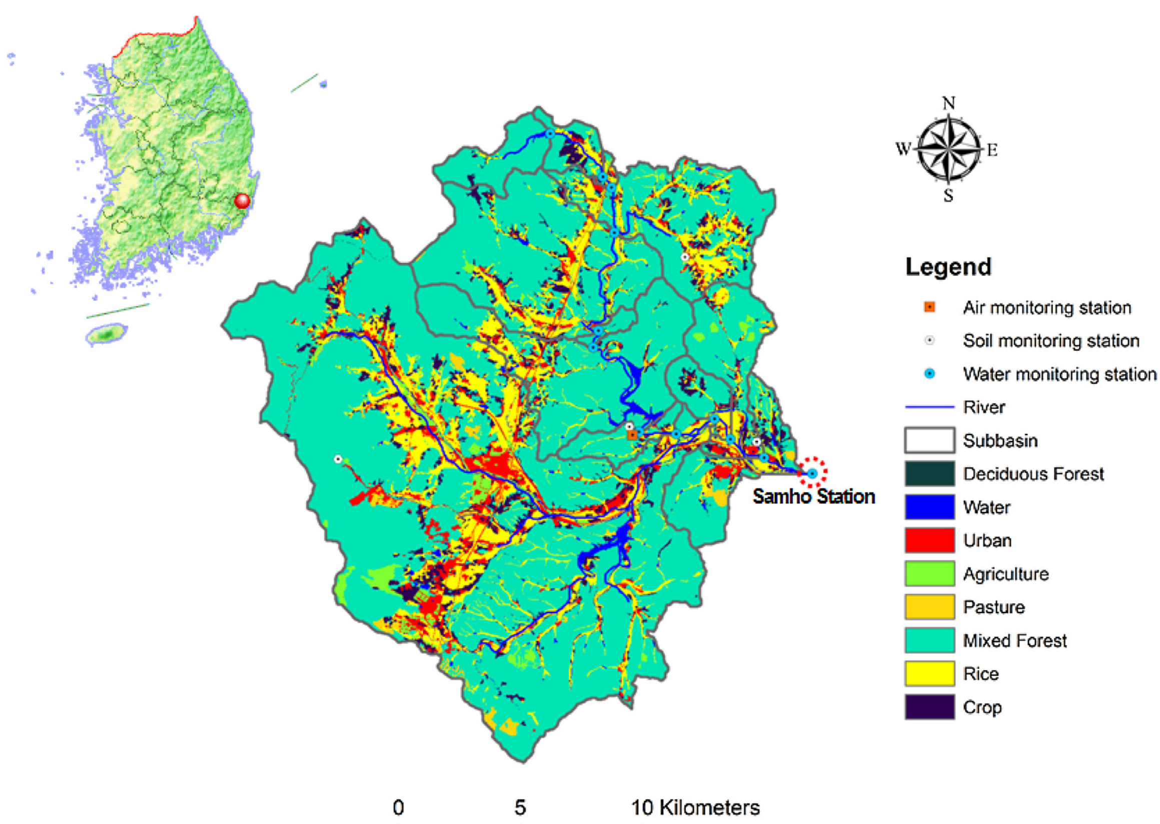

Fig. 1. Landuse map of Taehwa River basin, which includes the air, soil, and water monitoring stations of PAH compounds. This study used the data gathered at Samho Station as the observed data.