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Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics

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ABSTRACT

It is widely accepted that strong ties exist between land uses and the water quality of adjacent aquatic systems within a watershed. Recently, studies of the relationships between land uses and water quality have also begun to consider the spatial configuration of land uses. Here we investigated the spatial configuration of land uses within watersheds in South Korea and examined how spatial patterns of urban, agricultural, and forest land uses measured at both landscape and class levels, related to water quality in adjacent reservoirs from landscape ecological perspective. The results indicate that water quality of reservoirs is closely associated with both the proportions of land use and the configurations of urban, agricultural, and forest areas. Water quality is more likely to be degraded when there is high interspersion of various land use types and when a large number of different land use types exist within a watershed. For urban land uses, high patch and edge densities, and urban land use as the largest patch, were also associated with water quality degradation, as were higher degrees of patch density and edge density for agricultural land uses. Water quality is likely better if forest patches are unfragmented, have a high value for the largest patch proportion, have complex patch shape, and are aggregated.

1. Introduction

Land uses have direct impacts on hydrologic systems within a watershed (Bolstad and Swank, 1997; Gburek and Folmar, 1999; Lenat and Crawford, 1994; Liu et al., 2000; Omernik et al., 1981; Paul and Meyer, 2001; Tong and Chen, 2002). The types of land use are closely related to the characteristics of human activities, which in turn determine the anthropogenic substances carried into hydrologic systems through drainage or runoff processes. Water quality parameters in various aquatic systems have been closely linked to the proportions or types of land use within a watershed (Lenat and Crawford, 1994; Tong and Chen, 2002). However, previous studies have often focused on the composition of land use types (e.g., urban or agricultural land uses) within a watershed to explain variations in water quality. Few studies have examined the spatial configuration of land use patterns, which could expand the implementations and applications of research findings to landscape planning and land management areas.

Recent studies in landscape ecology, landscape planning, and urban planning have paid particular attention to the spatial structure of landscapes in examining the relationships between land uses and water quality at various scales (Alberti et al., 2007; Uuemaa et al., 2005). From landscape ecological perspectives, the spatial configuration of landscapes may play a critical role in determining natural habitats, hydrological processes, energy flows, and nutrient cycles (Alberti et al., 2007; Grimm et al., 2000; McDonnell et al., 1997). Alberti et al. (2007) emphasized that the spatial configuration, including the extent, distribution, intensity, and frequency of human land uses, is an important factor in understanding the hydrological processes linking land uses and water quality in adjacent aquatic systems. Despite the importance of spatial land use patterns, only a few studies applicable to land use planning and management practices have explored the relationship of land use patterns to water quality at an operational level (e.g., Alberti et al., 2007; Xiao and Ji, 2007).

To evaluate the practical importance of spatial land use patterns for landscape planning and land use management, we investigated the relationship between spatial land use patterns and the water quality characteristics of adjacent reservoirs. From the perspective of water quality, the impact of reservoirs on surrounding watersheds is relatively clear compared to the impact of rivers, which receive continuous water input from upstream. Thus, reservoirs

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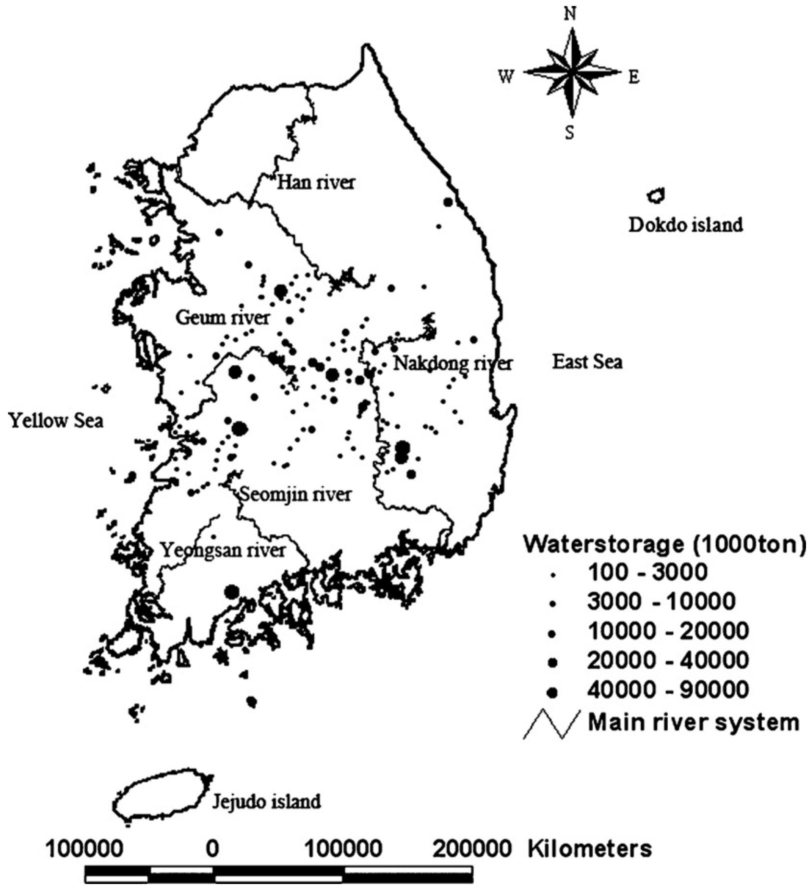

Fig. 1. Locations and relative sizes of sampled reservoirs in South Korea.

provide a unique opportunity to clarify the relationships of land use patterns and water quality. This study was based on the idea that the spatial configuration of land uses, combined with surface conditions, will alter the water quality of receiving water bodies. We measured the spatial configurations (i.e., patterns) of land uses at both landscape and class levels, focusing on urban, agricultural, and forest uses, and correlated these measures with water quality characteristics such as organic matter (e.g., biological and chemical oxygen demand) and nutrient levels (e.g., total nitrogen and total phosphorus). At the landscape level, we measured spatial configurations as a whole, including multiple land use types; at the class level, we measured spatial configurations separately only within single land use types, excluding other land use types. Understanding the relationships between land use patterns and water quality from a landscape perspective is important for watershed planning and management and healthy ecological functioning of landscapes in watersheds. Landscape ecology emphasizes the effects of landscape patterns (i.e., land use patterns) on the processes (e.g., energy flow and runoff; Turner, 1989) and multiple functions (e.g., ecological, hydrological, and psychological functions) of the landscape structure (Naveh, 2000; Opdam et al., 2002). The present study is part of a larger one encompassing the various aspects of landscape structure in watersheds.

2. Methods and data

2.1. Study reservoirs and water quality

South Korea has 18,797 reservoirs that were built primarily for irrigation and flood control (Hwang et al., 2003). The reservoirs are regularly monitored by two government agencies: the Ministry of Environment (MOE) and the Ministry of Agriculture and Forestry (MAF, 2002). Fig. 1 shows the locations and relative sizes of the study reservoirs on the southern half of the Korean Peninsula. We selected 144 of the 450 reservoirs monitored by the MAF, considering the reservoir size, data availability, and hydrologic systems. We excluded reservoirs for which water quality data were missing in the study year. Very small (≤6 ha) or large (≥1000 ha) reservoirs were also excluded. In both of these cases, delineating the watershed boundaries with the given digital elevation model (DEM) resolution would have been difficult because the watersheds were too small or too complex.

In monitoring the study reservoirs, the MOE and MAF collect data on 16 water quality parameters, including water temperature, pH, electric conductivity (EC), biological oxygen demand (BOD_5), chemical oxygen demand (COD), turbidity, suspended solids (SS), nitrogen group (total-N [TN], NH_4-N, NO_3-N, NO_2-N), phosphorus group (total phosphorus [TP], PO_4-P), and microbiological indices including total coliforms, fecal coliforms, and *Escherichia coli* density. However, we analyzed only nutrients (TP, TN) and indicators of organic matter (BOD, COD) measured during the spring (April through May) and fall (October through November) of 2002. Other water quality measures are also important. We chose to use only the above four parameters not because they were more important than other measures, but because they have been widely used in previous studies, and no data were missing for these parameters in the study year.

Reservoirs in Korea are usually full during spring, especially prior to the start of irrigation; after this time, water quality shows seasonal variations (Hwang et al., 2003). According to Kim and Hwang (2004), water quality is similar in Korean reservoirs in spring and fall but worsens slightly in summer and improves in winter. The