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Nonpoint Pollution Potential Assessment in Soyang-dam Watershed

소양강댐 유역의 비점원 오염 포텐셜 평가

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초록

소양강댐 유역의 비점원 오염 포텐셜을 평가하기 위하여 LTHIA/NPS, RUSLE 그리고 ArcView GIS 모델을 사용하였다. NPS 오염 포텐셜(VI)계산은 강우유출(RI), 토양유실(EI), 농약사용량(CI), 가축분뇨(LI)와 상업용 비료(FI) 사용량을 대표하는 지수(Index)를 사용하였다. 유역의 유출심은 4.9에서 34.3cm였으며, 토양유실량은 0.25에서 802 ton/ha/year 범위로 평균은 6.46 ton/ha/year이었다. 농약사용량은 유역에서 판매된 양을 비례법으로 농경지에 분포시켜 지수를 구했다. 가축분뇨의 T-N과 T-P는 각각 0에서 4.33 ton/km²/year, 그리고 0에서 0.90 ton/km²/year이었다. 상업용 질소와 인 비료량은 비료무게로 각각 0에서 717 ton/km²/year와 0에서 321 ton/km²/year이었다. 위의 비점원 오염부하는 오염포텐셜이 작은 1부터 가장 큰 5까지 계량화하여 오염포텐셜을 계산하는데 사용하였다. 각각의 지수에는 임의로 가중치를 부여하였다. 오염포텐셜을 이용하여 오염가능성이 큰 지역과 작은 지역을 공간상에 나타낼 수 있었으며 또한 소양강댐 소유역들의 오염포텐셜을 구하여 오염가능성이 큰 5개의 소유역을 공간상으로 표시하였다. 본 연구기법은 제한된 자원으로 오염관리를 할 때, 오염가능성이 큰 유역을 집중적으로 관리하게 함으로써 경제적이고 효과적으로 유역관리를 수행할 수 있도록 많은 기여를 할 것으로 생각된다.

I. Introduction

Surface water has been used as primary source of drinking water for most areas in Korea. Since 1970's, industrial development in Korea has caused the degradation of surface water quality (Choi, 1997). Government and local agencies have more focused on controlling point source pollution to mitigate surface water degradation because these were the most obvious sources of pollution and the control mechanisms of them were technically and legally available. Controlling point pollutant sources for particular chemical pollutants

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resulted in significant improvement in water quality. However, surface water quality has not been improved to meet the target water quality. The impact of non-point source (NPS) pollution on water quality has surfaced as a major cause of water quality degradation and efforts are being devoted to reduce non-point source (NPS) pollution. It is important not only to know how NPS pollutions are spatially distributed but also to carry out efficient watershed management plans.

Many complex hydrologic/water quality models have been developed and tested to identify NPS pollution. Most of them have been proven to be effective tools for identifying problem areas and determining effective control practices. However, these hydrolo gic/water quality models have limitations in preparing input parameters, which are often huge and sometimes nearly impossible for potential users to prepare.

LTHIA (Long Term Hydrologic Impact Assessment) was developed by Harbor (1994) to assess long term hydrologic impacts of land use changes on runoff. And later, NPS pollution assessment module was developed, incorporated into LTHIA, and integrated with GIS as LTHIA/NPS GIS model for the analysis of spatial runoff and NPS pollutant discharges (Bhaduri, 1998). In the model, land uses are grouped into 8 categories of water, commercial, agricultural, high density residential, low density residential, grass/pasture, forest and industrial areas. Long term daily precipitation data are used to estimate antecedent moisture conditions (AMC) in soil, and the SCS curve number (CN) is adjusted according to AMC. NPS pollutant discharges from both urban and rural areas are computed with event mean concentration (EMC) and runoff volume. LTHIA was further improved to be run on world wide web and named LTHIA/NPS WWW (Lim et al., 1999).

The USLE (Universal Soil Loss Equation), developed by Wischmeier and Smith (1965) has been widely used to simulate annual soil loss for over 30 years. The upgrade version RUSLE (Renard et al., 1997) is integrated into GIS. Rainfall runoff erosivity factor(R), soil erodibility factor (K), slope length and steepness factor (LS), cover management factor (C) and support practice factor (P) are assigned to each cell to compute the amount of annual soil loss. The scheme for estimating the LS was proposed by Moore and Burch (1986a and 1986b). Hamlett et al. (1992) proposed an approach to rank watersheds on a statewide basis for agricultural nonpoint source pollution potential. Four indexes of runoff, chemical use, sediment production and animal waste loading were reflected to rank the watershed NPS pollution potential.

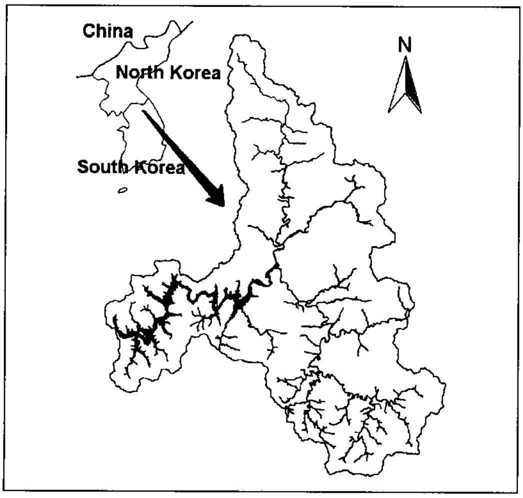
Water quality improvement could be more effectively and economically accomplished if pollution control priority could be put on watersheds with high pollution potential. However, there was no attempt to rank the NPS pollution potential of a watershed in Korea.

The objectives of this study were to analyze the distribution of NPS pollution in Soyang-dam watershed, and to apply a methodology to rank subwatersheds vulnerable to agricultural NPS pollution by assessing vulnerability index which is computed with the five indexes of runoff (RI), soil erosion (EI), chemical use (CI), and nutrient (LI and

FI) originated from animal waste loading and applying LTHIA/NPS, RUSLE and ArcView GIS models.

Ⅱ. Methods

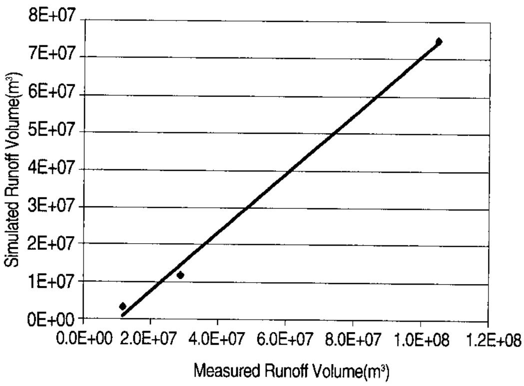
The area of Soyang-dam watershed in Korea is 2,703 km^2 and the main channel length is 166.2 km (Figure 1). The land use of the watershed is composed of paddy (1.8%), upland (5.2%), forest (74.3%), orchard (0.5%) and grassland (18.2%). The top soil of the watershed is mostly sand and sandy loam originated from weathered granite. The soil was classified by the USDA specified hydrologic soil groups based on the soil map and drain characteristics. Hydrologic soil group A took 76.7%, B 23.1% and C 0.2% of the watershed, respectively. The average slope of the watershed is 25 degree. The northern part of the watershed that lies in the north of demilitarized zone (DMZ) was excluded in this analysis. Digitized elevation map (1:25,000DEM) and soil map of 1:25,000 {agricultural area and 1:50,000 (mountains)} were used and a cell size was 100 m square.



〈Fig. 1〉 Location of Soyang-dam watershed in Korea

Runoff index (RI) was estimated from runoff depth simulated by LTHIA/NPS GIS with the input data of land use, hydrologic soil group and long term daily precipitation record. LTHIA/NPS GIS was first calibrated and validated in Pyeongchang river watershed which has a set of long term runoff monitoring data, the similar topography and land use before it was applied to Soyang-dam watershed. Pyungchang watershed was again subdivided into three subwatersheds of 50.5km^2 , 103.8 km^2 and 523.1 km^2, respectively. LTHIA/NPS GIS was then applied to the smallest watershed and calibrated by adjusting CN to fit the simulated runoff to measured runoff. The LTHIA/NPS GIS was applied to the three subwatersheds and simulated runoff was compared with measured runoff (Figure 2). LTHIA/NPS GIS was then, applied to Soyang-dam watershed and runoff depth for each cell was simulated.

Erosion index (EI) was estimated from the annual soil erosion simulated by RUSLE (Revised Universal Soil Loss Equation).



〈Fig. 2〉 Comparison of LTHIA/GIS predicted runoff volume and measured data in Pyeongchang watershed

Rainfall erosivity factor(R) was estimated from the data developed by Cheong et al. (1983) and R factor for the administrative districts in Kangwon province is shown in Table 1. The R factors were interpolated by the inverse distance weighted (IDW) method and assigned to each cell. Soil erodibility factor (K) was estimated with the content of clay, silt and sand in the soil map published by the Rural Development Administration. The estimated K factors ranged from 0.16 to 0.33. Slope length and steepness factor (LS) was computed by using a method proposed by Moore and Burch (1986a and 1986b). Before LS factor was computed, sinks and peaks in the DEM were filled by using the Fill Sink function in ArcView Hydro Extension. Cropping factor (C) was estimated from the table developed by Sim et al. (1996). ArcView RUSLE in which RUSLE was integrated into ArcView (Lim, 1999) was used to simulate the average annual soil erosion of each cell which was used as the erosion index (EI).

Chemical index (CI) was derived from the average annual amount of pesticides sold in the respective administrative district within the watershed. The pesticide data were obtained from Agriculture Cooperative. The amount of pesticide in each district was proportionally assigned to the area of paddy, upland and grass land by the size of area and then, to cells within the area. The size of pesticide assigned to a cell was used to compute chemical index (CI)

Nutrient index (NI) was derived from the amount of fertilizer sold and livestock wastes produced in the watershed. Total nitrogen (T-N) and total phosphorus (T-P) contents of an animal waste per day was multiplied by the numbers of respective livestock to compute the annual T-N and T-P loadings. These T-N and T-P loadings originated from animal wastes were designated as livestock index (LI) while the amount of commercial nitrogen and phosphorus loadings as fertilizer index (FI). The annual nutrient loadings of an administrative district was proportionally assigned to the area of paddy, upland and grass land by the size of area and then, to cells within the area. The size of nitrogen and phosphorus assigned to a cell was used to compute livestock indexes (LI) and fertilizer indexes (FI), respectively.

Ⅲ. Results and Discussion

Runoff depth of each cell in Soyang-dam watershed was simulated by LTHIA/NPS

〈Table 1〉 R factor of each county in Kangwon province

Administrative district	R factor	Administrative district	R factor	Administrative district	R factor
Kangnung-si	297	Kosung-gun	250	Yanggu-gun	350
Samchok-si	215	Sokcho-si	255	Chongson-gun	250
Yangyang-gun	255	Yongwol-gun	350	Pyeongchang-gun	269
Wonju-si	578	Inje-gun	294	Hoengsung-gun	400
Cheolwon-gun	400	Chuncheon-si	464		
Hwacheon-gun	450	Hongcheon-gun	417		

GIS. Average annual runoff depth of the cells varied from 4.9 to 34.3cm. The annual runoff depth of a cell was classified into 5 runoff indexes (RI) using Natural Break classification method, which was a built-in function of ArcView GIS. The 5 runoff indexes were very low, low, medium, high and very high.

The average annual soil erosion of each cell was simulated by ArcView RUSLE and ranged from 0.25 to 802 ton/ha/year with the average of 6.46 ton/ha/year. Again, the annual soil erosion was classified into 5 erosion indexes (EI) of very low, low, medium, high and very high. The same Natural Break classification method in ArcView GIS was used. It should be pointed that because RUSLE can only simulate interrill and rill erosion, gully, channel and stream bank erosions could not be counted in computing erosion index.

The average annual amount of pesticides sold in the respective administrative district within the watershed is shown in ⟨Table 2⟩. The average annual amount of pesticide was proportionally assigned to paddy, upland and grass land by the size of area and then, to respective cell. The amount of pesticide in each cell was then classified into 5 chemical indexes (CI) of very low, low, medium, high and very high with the Natural Break classification method. In adding the different pesticides, toxicity of each chemical was not considered.

The annual loadings of nitrogen and phosphorus which were derived from annual animal wastes produced, and commercial fertilizers sold in each administrative district were computed. Depending on the location and land use, animal nitrogen and phosphorus loadings ranged between 0 and 4.33 ton/km^2/year and between 0 and 0.90 ton/km^2/year, respectively. Commercial fertilizer nitrogen and phosphorus loadings were between 0 and 717 ton/km^2/year and between 0 and 321 ton/km^2/year in gross weight, respectively. These nutrient loadings were proportionally assigned to paddy, upland and grass land by the size of area and then, to respective cell. Animal and commercial nitrogen and phosphorus loadings were classified into 5 livestock indexes (LI) and 5 fertilizer indexes (FI), respectively. Each index grouped into 5 indexes of very low, low, medium, high and very high with the Natural Break classification method.

Vulnerability index (VI) is computed by adding the 5 indexes of RI, EI, CI, LI and FI with appropriate weight factors for respective index.

$$VI = 5RI + 5EI + 5CI + 2.5LI + 2.5FI \quad (1)$$

The 5 indexes of very low, low, medium, high and very high were assigned to 1, 2, 3, 4 and 5, respectively, to compute VI. Higher number stands for greater NPS pollution potential. It is agreed that the weight factors

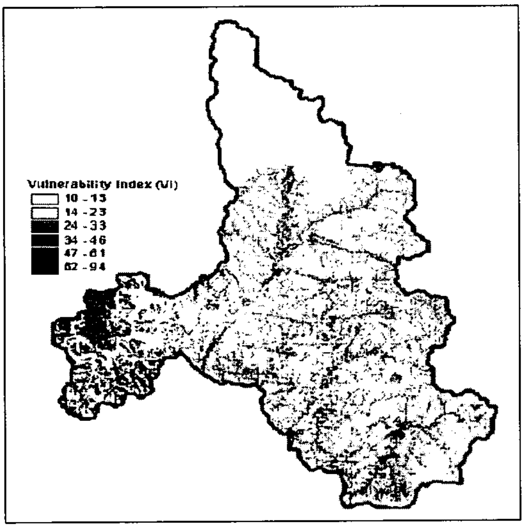
⟨Table 2⟩ The amount of pesticide (kg/year) sold in the administrative districts in Soyang-dam watershed in 1998 and 1999

District	Go-sung	In-je	Yang-gu	Hong-chon	Chun-chon
1998	12,542	15,563	16,998	48,645	34,452
1999	12,953	15,834	12,723	51,857	36,641

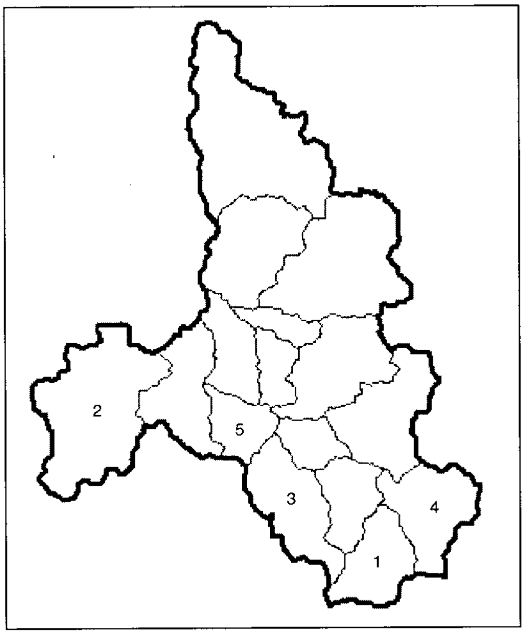
for different indexes may vary depending on the toxicity of pollutants and the impact of indexes on water quality. However, because one of the objectives of this study was to apply a methodology for a watershed ranking with respect to the vulnerability of nonpoint source pollution, weight factors of 5 and 2.5 were arbitrarily assigned based on the research experiences of the watershed. These weight factors need to be sophisticated further by appropriate studies in the future. It was also thought that pollution potential by population, tourists and other factors such as military installation and park should be considered for better prediction of vulnerability index.

Computed VI with Equation (1) ranged from 10 to 94 and was classified into 6 groups by the Natural Break classification method ⟨Fig. 3⟩. Higher number of VI stands for greater NPS pollution potential. Vulnerability indexes in the demilitarized zone and north Korea were not computed.

Korea Water Resources' Corporation (KOWACO) had divided Soyang-dam watershed into 17 sub-watersheds to utilize in planning and managing of water resources in the watershed (KOWACO, 1993). Vulnerability index was extended to the sub-watersheds by adding VI within a subwatershed and dividing it by its area, resulting in a vulnerability index map for subwatersheds ⟨Fig. 4⟩. Again, the 2 subwatersheds in the demilitarized zone and north Korea were excluded. The subwatersheds were ranked from the highest pollution potential to the lowest potential in terms of NPS pollution vulnerability. Five subwatersheds that have the highest NPS pollution potential were marked on the map. The five subwatersheds have relatively larger agricultural fields that cause more soil erosion and runoff and more livestock density than the other subwatersheds, resulting in the higher NPS pollution vulnerability. However, it is noticed that In-je and Won-tong subwater-



⟨Fig. 3⟩ NPS pollution vulnerabilities in Soyang-dam watershed



⟨Fig. 4⟩ Subwatershed rankings in agricultural NPS pollution potential perspective sheds were not ranked as having higher pollution potential ones because population factor was not counted.

Watershed ranking method used in this study is not complete but has shown that it can rank the subwatersheds that have a high NPS pollution potential. By using the map, NPS pollution control can be more economically and effectively achieved with limited resources. However, before this method is put on an application, studies on weighting factors for various indexes are suggested.

Ⅳ. Conclusions

A watershed ranking method using LTHIA/NPS, RUSLE and ArcView GIS to rank the subwatersheds that have a high NPS pollution potential was applied to Soyang-dam watershed. Five indexes of runoff (RI), erosion (EI), chemical (CI), livestock waste (LI) and commercial fertilizer (FI) were developed to compute vulnerability index (VI) which represented the NPS pollution potential. VI ranged from 10 to 94 and was classified into 6 groups from the lowest to the highest NPS pollution potential. VI could also extend to rank the vulnerability of subwatersheds, which made possible to delineate subwatersheds with respect to NPS pollution potential.

Spatial distribution of runoff depth, soil erosion, agri-chemical application, animal waste and commercial fertilizer uses was computed and displayed on subjective maps. Average annual runoff depth of the watershed varied from 4.9 to 34.3 cm. Soil erosion ranged from 0.25 to 802 ton/ha/year with the average of 6.46 ton/ha/year. Animal nitrogen and phosphorus loadings ranged between 0 and 4.33 ton/km^2/year and between 0 and 0.90 ton/km^2/year, respectively. And commercial fertilizer nitrogen and phosphorus loadings were between 0 and 717 ton/km^2/year and between 0 and 321 ton/km^2/year in gross weight, respectively.

It was suggested that the weight factors for different indexes need to be sophisticated by further studies and that population and other factors such as tourists be counted in computing the vulnerability for better watershed rankings in terms of NPS pollution potential.

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