CLIMATE CHANGE IMPACT ASSESSMENT ON NUTRIENT LOADING FROM PADDY AREA USING APEX-BASED CLIMATE INDEX SENSITIVITY ANALYSIS

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ABSTRACT

The recent lack of water resources, including irrigation water, has led to relative consideration of water quality issue under the condition where water quantity is sufficient. During the last decade in Korea, the proportion of nonpoint source (NPS) pollution among the total pollutant load has been increased and became greater than the pollutant load from point source. In case of NPS pollution, it is recommended to reduce the pollutant load generated from source area rather than treat the collected pollutants. Irrigation managements are considered as best management practices (BMPs) for reducing pollutant loads such as nitrogen and phosphorus from paddy fields, which account for more than 50% of the total agricultural area in Korea. In this study, we propose a method to evaluate the change of nutrient load from paddy field during the future period according to climate change. Instead of using a direct approach to apply deterministic models to all paddy fields across the country, we used an indirect approach to estimate likely changes in nutrient loads over future periods based on climate indices that are likely sensitive to the nutrient outflows. The APEX-Paddy model was selected to consider the managements and mechanisms in paddy areas. Major indices for each nutrient were derived from 27 climate extreme indices using the model-based sensitivity analysis. Then, we analyzed the future changes in the selected climate extreme indices across the Korean peninsula using the downscaled data from 29 Global Climate Models (GCMs) at 3 km spatial resolutions. Finally, the changes in nutrient loads from paddy fields were estimated based on the changes in the climate indices.

Keywords: APEX, Paddy, Climate Change, Vulnerability, Irrigation Management, Non-point source pollution.

1. INTRODUCTION

The recent conflicts in water use have led to consideration of water quantity and quality issues simultaneously. During the last decade in Korea, the proportion of nonpoint source (NPS) pollution among the total pollutant load has been increased and became greater than the pollutant load from point source. In case of NPS pollution, it is recommended to reduce the pollutant load generated from source area rather than treat the collected pollutants. For example, Irrigation managements are considered as one of best management practices (BMPs) for reducing pollutant loads such as nitrogen and phosphorus from paddy fields, which account for more than 50% of the total agricultural area in Korea.

The NPS pollutants are also known to be sensitive to the changes in precipitation characteristics from spatial and temporal aspect (Wu et al., 2012, Zhang et al., 2011).

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Previous climate change impact assessment have generally focused on streamflow and relatively little research has been conducted on water quality issues (Raneesh and Santosh, 2011; Islam et al., 2012; Kankam-Yeboah et al., 2013). In Korea, a NPS modelling study using the Soil and Water Assessment Tool (SWAT) based on multi-model ensemble (MME) of 10 GCMs showed that TN and TP loads are expected to increase at a watershed scale corresponding to the increases in precipitation (Cho et al., 2016).

However, modeling-based assessment which uses field-scale models in order to consider various irrigation and fertilizer managements at paddy fields as BMPs has some limitations for national scale assessment by considering huge paddy area in Korea. In order to develop national climate change adaptation plans, it is necessary to evaluate the change of nutrient load from entire paddy area on Korean Peninsula according to climate change for future periods. Therefore, the objective of this study is to evaluate the impacts of climate change on NPS pollutant loads from entire paddy areas on Korean Peninsula by considering spatial changes in precipitation characteristics.

2. MATERIALS AND METHODS

2.1 Sensitivity Analysis of Nutrient Outflow Against Climate Extreme Indices

The model parameters from previous study for APEX-Paddy calibration using Icheon's observational data was used for sensitivity analysis (Choi et al., 2017). The 27 Climate Extreme Indices used for reproducibility test in APCC Integrated Modeling Solution (AIMS) (Cho et al., 2018) was selected as proxy variable (Table 1). Downscaled climate change scenarios data extracted from 29 Global Climate Models (GCMs) was used as weather input in order to consider the variability of climate characteristics by creating enough cases for the sensitivity analysis. Annual flow rate, total nitrogen (TN), and total phosphorus (TP) according to changes in climate index was calculated and climate index with a high correlation coefficient and large slope in regression equations was selected as major index sensitive for nutrient outflows.

2.2 Grid-Based Downscaling of Climate Change Scenarios on Korean Peninsula

The Simple Quantile Mapping (SQM) method was selected for downscaling of climate change scenarios at 3 km spatial scale on Korean Peninsula mainly considering the computation time. SQM requires long-term observation data and observational data for precipitation, maximum temperature, and minimum temperature at 3 km resolution for Korean peninsula created using Automated Synoptic Observing System (ASOS) station data (Eum et al., 2018) was used as reference dataset. This data is produced by using Parameter-elevation Regressions on Independent Slopes Model (PRISM) technique considering the altitude (DEM), slope, and distance from the shore using data of 60 ASOS stations managed by Korea Meteorological Administration (KMA). After downscaling of precipitation and temperatures, 21 of the 27 climate extreme indices was calculated and future changes in indices was analyzed at 3 km resolution.

Table 1: List of climate extreme indices used for sensitivity analysis

ID	Variable	Description	Unit
SU	TMAX	Annual count of days when TMAX > 25°C	Days
ID		Annual count of days when TMAX < 0°C	Days
TXn		Annual minimum value of TMAX	°C
TXx		Annual maximum value of TMAX	°C
TX10p		Percentage of days when TMAX < 10th percentile	%
TX90p		Percentage of days when TMAX > 90th percentile	%
WSDI		Annual count of days with at least 6 consecutive days when TMAX > 90th percentile	Days
FD	TMIN	Annual count of days when TMIN < 0°C	Days
TR		Annual count of days when TMIN > 20°C	Days
TNn		Annual minimum value of TMIN	°C
TNx		Annual maximum value of TMIN	°C
TN10p		Percentage of days when TMIN < 10th percentile	%
TN90p		Percentage of days when TMIN > 90th percentile	%
CSDI		Annual count of days with at least 6 consecutive days when TMIN < 10th percentile	Days
DTR	TMAX & TMIN	Annual mean difference between daily maximum temperature TMAX and TMIN	°C
GSL	TAVG	Annual (1st Jan to 31st Dec in Northern Hemisphere (NH), 1st July to 30th June in Southern Hemisphere (SH)) count between first span of at least 6 days with daily mean temperature TG>5oC and first span after July 1st (Jan 1st in SH) of 6 days with TG<5oC.	Days
CDD	PRCP	Maximum number of consecutive days with daily PRCP < 1mm	Days
CWD		Maximum number of consecutive days with daily PRCP ≥ 1mm	Days
PRCPTOT		Annual total PRCP in wet days (daily PRCP ≥ 1mm)	mm
Rx1day		Annual maximum 1-day precipitation	mm
Rx5day		Annual maximum 5-day precipitation (PRCP)	mm
R95pTOT		Annual total PRCP when daily PRCP > 95 percentile	mm
R99pTOT		Annual total PRCP when daily PRCP > 99 percentile	mm
SDII		Annual precipitation divided by the number of wet days	mm/day
R10mm		Annual count of days when PRCP≥ 10mm	Days
R20mm		Annual count of days when PRCP≥ 20mm	Days
Rnnmm		Annual count of days when PRCP≥ nnmm, nn is a user defined threshold (default threshold is 1)	Das

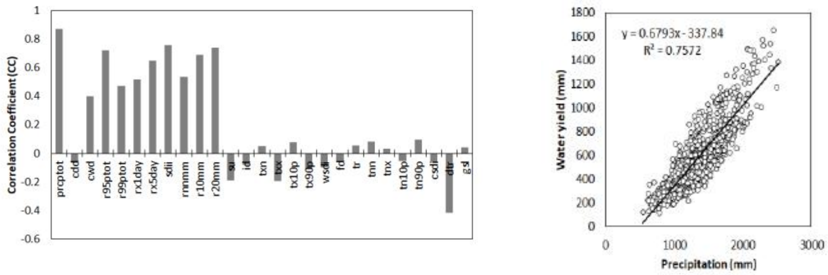
2.3 Analysis of Changes in Nutrient Outflows Due to Climate Change

Estimation of nutrient outflows based on climate indices was conducted using correlation between the selected climate indices in sensitivity analysis and runoff, TN, and TP. Multivariable regression equation was developed based on APEX-Paddy sensitivity analysis against climate indices. This equation was finally used for estimating nutrient loads using climate indices extracted from downscaled precipitation and temperature data at 3 km resolution.

3. RESULTS AND DISCUSSION

3.1 Sensitivity Analysis of Nutrient Outflow Against Climate Extreme Indices

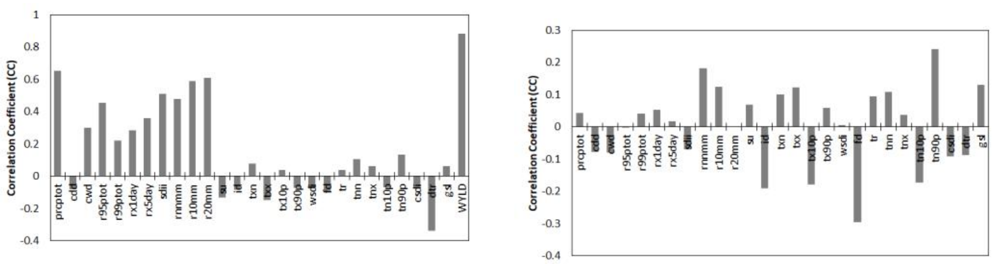
Figure 1 shows the correlation coefficient (CC) for runoff rate against climate extreme indices a scatter plot for the correlation between annual precipitation (PRCPTOT) and runoff rate. Sensitivity analysis results based on calibrated APEX-Paddy model for Icheon field and 27 extreme climate indices estimated from 29 GCMs showed that runoff rate has the highest CC (0.76) with annual precipitation (PRCPTOP) and the second highest CC (0.74) with number of rainfall days more than 20mm (R20mm).



(a) (b)

Figure 1: (a) Correlation coefficient for runoff against climate extreme indices and (b) scatter plot for the correlation between annual precipitation and runoff.

Figure 2 shows the sensitivity results for nutrient outflows against climate extreme indices. Sensitivity of TN against the climate extreme indices was generally similar to the sensitivity of runoff rate and the CC values were slightly lower than those from runoff rate by showing 0.65 and 0.61 with PRCPTOT and R20mm, respectively. About TP, there was no sensitive climate indices with CC values lower than 0.5.



(a) (b)

Figure 2. Correlation coefficient for (a) total nitrogen (TN) and (b) total phosphorus (TP) against climate extreme indices.

3.2 Grid-Based Downscaling of Climate Change Scenarios on Korean Peninsula

Figure 3 shows the multi-model ensemble (MME) based annual precipitation (PRCPTOT) using 29 GCMs according to both representative concentration pathway (RCP) scenarios and future periods. Annual precipitation for historical period (1976 ~ 2005) based on MME average at 3 km resolution are low in southeastern area (Gyeongbuk province) and tend to be low for all future periods. Annual precipitation for three future periods (Near Future: 2010 ~ 2039, Mid-century Future: 2040 ~ 2069, and Far Future: 2070 ~ ~ 2099) is increasing as time moves from the near future to the far future. In addition, the RCP 8.5 scenario tends to have a larger increase compared to the RCP 4.5 scenario.

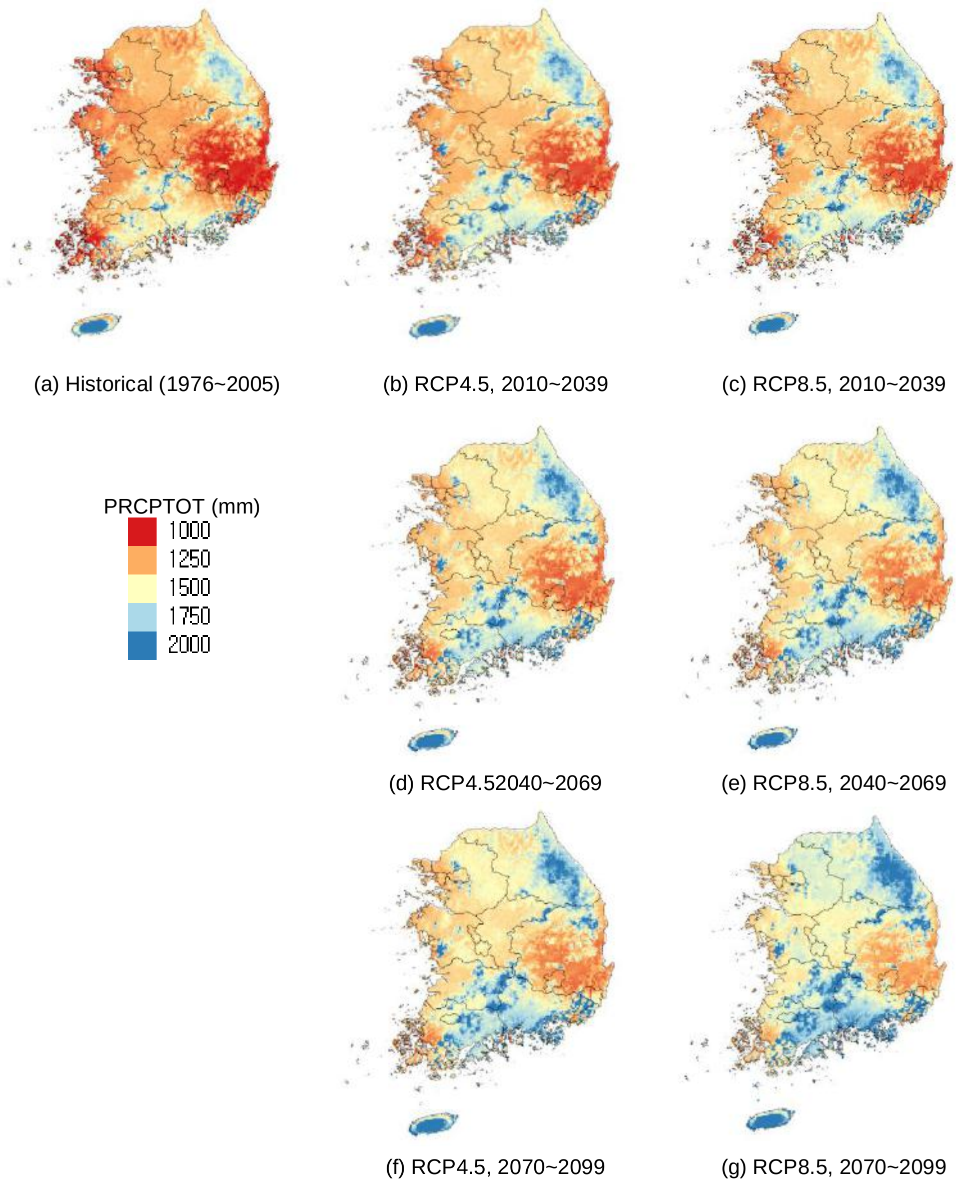


Figure 3. Annual precipitation (PRCPTOT) on the Korean peninsula according to climate change scenarios using 29 GCMs at 3 km resolution.

3.3 Analysis of Changes in Nutrient Outflows Due To Climate Change

We obtained the equation (1) based on multivariable regression analysis using PRCPTOT and R20mm as predicttands for total nitrogen (TN) load. The spatial distribution of total nitrogen (TN) produced by multivariable regression analysis is shown in figure 4.

$$TN = 1.294622 + 0.003277 * PRCPTOT + 0.071088 * R20mm \quad (1)$$

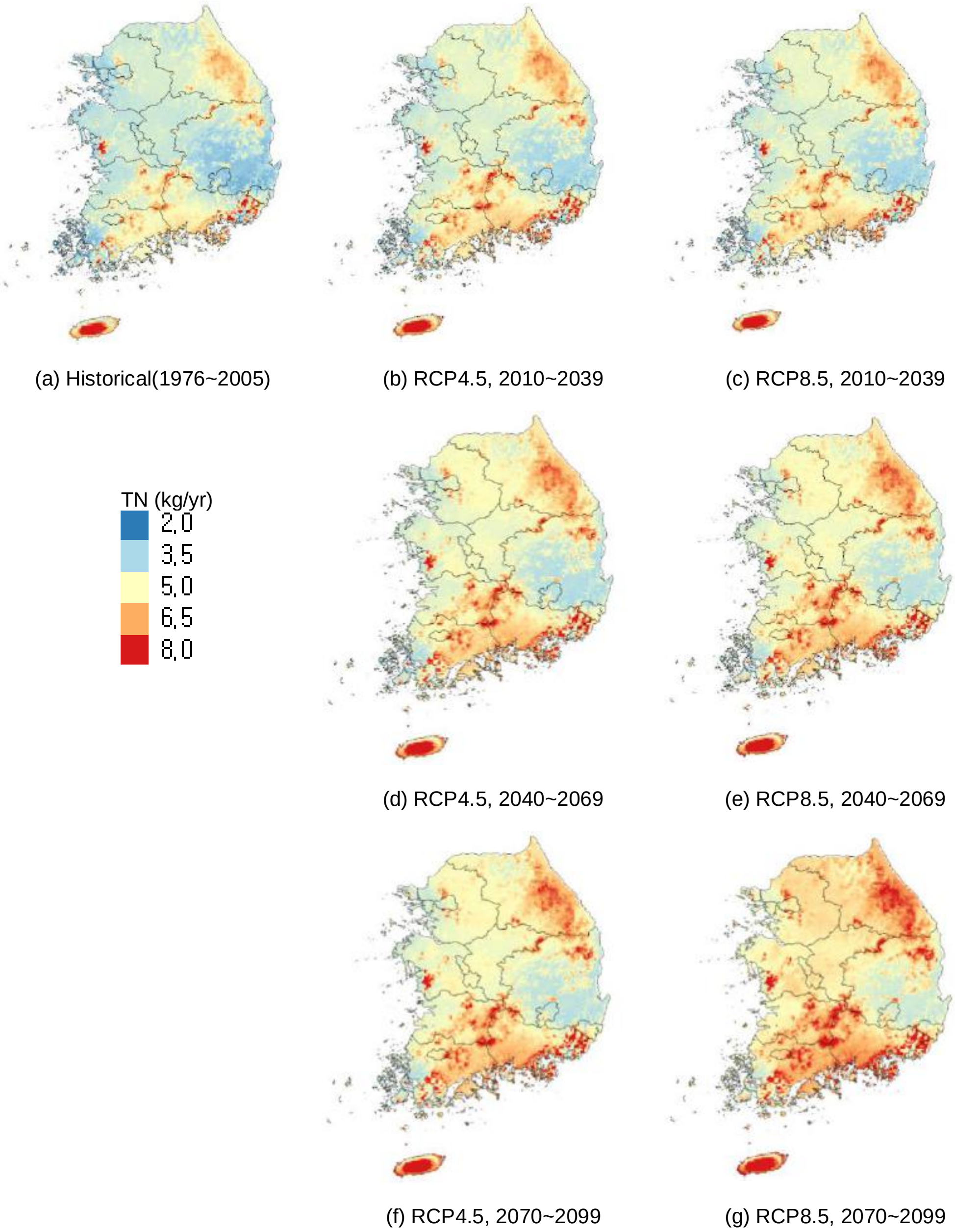


Figure 4. Spatial distribution of total nitrogen (TN) loads on the Korean Peninsula using 29 GCMs at 3 km resolution.

4. CONCLUSIONS

In this study, we propose a method to evaluate the change of nutrient load from paddy field during the future period according to climate change. Instead of using a direct approach to apply deterministic models to all paddy fields across the country, we used an indirect approach to estimate changes in nutrient loads over future periods based on climate indices that are likely sensitive to the nutrient outflows. The APEX-Paddy model was selected to consider the managements and mechanisms in paddy areas. Major indices for each nutrient were derived from 27 climate extreme indices using the model-based sensitivity analysis. Then, we analyzed the future changes in the selected climate extreme indices across the Korean peninsula using the downscaled data from 29 Global Climate Models (GCMs) at 3 km spatial resolutions.

Sensitivity analysis results based on calibrated APEX-Paddy model for Icheon field and 27 extreme climate indices showed that runoff rate has the highest correlation with annual precipitation (PRCPTOT) and number of rainfall days greater than 20mm (R20mm). Sensitivity of TN against the climate extreme indices was generally similar to the runoff sensitivity and the correlation coefficient was slightly lower by showing 0.65 and 0.61 with PRCPTOT and R20mm, respectively. However, there was no sensitive climate indices for TP.

Multi-model (29 GCMs) based downscaled climate change scenario data for precipitation and temperatures on Korean Peninsula at 3 km resolution was produced through this study. Annual precipitation for three future periods is increasing as time moves from the near future to the far future. In addition, the RCP 8.5 scenario tends to have a larger increase compared to the RCP 4.5 scenario. Finally, total nitrogen (TN) loads from paddy fields for future climate change scenarios were produced based on multivariable regression approach using sensitive climate indices. TN load was low in South-eastern area and tend to be low for all future periods mainly due to low annual precipitation.

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