Assessment of future climate change impacts on streamflow and groundwater by hydrological modeling in the Choushui River Alluvial Fan, Taiwan

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INTRODUCTION

The interaction between groundwater (GW) and surface water (SW) is an important aspect of water cycle. The assessment of climate change impact on groundwater recharge is a challenge in hydrological researches because substantial doubts still remain, particularly in arid and semi-arid regions (Pulido-Velazquez et al., 2018).

The Soil and Water Assessment Tool (SWAT) (Gassman et al., 2007; Neitsch et al., 2011) simulates the surface runoff and groundwater dynamics, management practices or climate change on water quantity at different geographical locations and scales. Future climate data with five-kilometer **spatial resolution**, provided by TCCIP, were selected to accommodate the future climatic conditions of catchment features.

The **MODFLOW-NWT** (a Newton-Raphson formulation for MODFLOW-2005)(Niswonger et al., 2011) was used as a SWAT sub-routine, simulating groundwater flow processes and all associated sources and sinks on time steps in order to improve the solution of unconfined groundwater-flow problems.







processes (Neitsch et al., 2011) OBJECTIVE

Fig. 2 Location of the Choushui River Alluvial Fan (CRAF), and the delineation in SWAT model.

This study were to apply the **coupled** SWAT-MODFLOW models to estimate **streamflow discharge**, percolation, GW recharge, and water exchange between GW and SW in the Choushui River Alluvial Fan, Taiwan. The research assesses the **impact of climate change** scenarios **influence on** GW recharge in the future.



Table 1 Performance of the statistical indices for monthly runoff at the outlets of sub-basins during the calibration (2005-2011) and validation (2012-2017, bold in brackets) periods with SWAT-CUP calibration.

	Outlets	Pearson correlation coefficient	RMSE (m)	R ²	P _{bias}	NSE
	Tzu-Chiang	0.979 (0.971)	2.742 (1.194)	0.959 (0.943)	-0.003 (-0.131)	0.942 (0.866)
	Chi-Chou	0.959 (0.930)	0.020 (0.114)	0.920 (0.865)	-0.001 (0.010)	0.920 (0.846)
	Tun-Kun	0 865 (0 857)	0.354 (0.056)	0 749 (0 734)	0 289 (-0 029)	0 549(0 469)

Fig. 4 Hydrographs of precipitation, observed and the best-fit monthly streamflow at the outlet of Tzu-Chiang bridge during the calibration period (1989-1994) and validation period (1995-2000). The outlets of Chi-Chou, Tun-Kun, Pei-Kang Bridges during the calibration period (2005-2011) and validation period (2012-2017).

2.5 ·

Table 2 Performance of the statistical indices for groundwater level during the calibration (2005-2011) and validation (2012-2017, in brackets) periods by MODFLOW model

The number of observed heads	NSE (Nash– Sutcliffe efficiency coefficients)	<i>M_{AE}</i> (mean absolute error, meters)	R _{MSE} (root mean squared error, meters)
62	0.98 (0.98)	2.31 (2.16)	2.88 (2.67)

Climate change simulation



 $\times 10^8$ Groundwater flow to the streams Seepage from streams to aquifer





- The simulation results of both models (SWAT, MODFLOW) well fitted the temporal patterns of streamflow and GW head at the hydrology stations during the calibration and validation periods. This is a prerequisite step to apply the climate change scenarios to predict GW recharge in the future.
- During the dry years, the recharge rate seepage from the streams to the shallow aquifer was possible lower than the GW discharge to the streams.

DISCUSSION

Confidence in the calibrated model was enhanced by validation through generally good statistical performance for the temporal pattern of streamflow and groundwater head, with the R^2 , percent bias (P_{bias}), RMSE, Nash–Sutcliffe model efficiency coefficients (NSE), mean absolute error, which helps achieve a reliable simulation of the watershed responses.

The reflects of the concept for SWAT-MODFLOW GW recharge by a lumped module in individual sub-basins contribute to stream network as baseflow. With this simplified implementation of GW dynamics and water exchange between SW-GW (Fig. 5), the spatiotemporal variability of GW recharge for near-term (2021-2040), mid-term (2041-2060), 2061-2080, & longterm period was estimated under the baseline (*Fig. 7*) and four representative concentration pathways (RCPs) (*Fig. 6*).

- GW recharge mainly occurs in the proximal fan area, catching up some high potential recharge locations in previously delineated sensitive areas for GW recharge by Chen et al. (2013) and Central Geological Survey, Taiwan.
 - According to the top-ranking GCM MIROC5 projections procedure for CRAF, the highest and lowest effect rates of climate change on GW recharge in the study region from the 2020s to the 2100s were RCP2.6 (66.36%, -41.92%), RCP4.5 (51.86%, -39.48%), RCP6.0 (56.11%, -40.13%), or RCP8.5 (48.93%, -39.85%). This suggests that even while GW recharge lies in complicated geological heterogeneity and soil profiles, the effects of climate change still substantially influence it. These findings help decision-makers and stakeholders devise sustainable water resource strategies.

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