インドネシア・バリ中央部スンギ流域における棚田地域の SWAT+を用いた水文モデリング

Hydrological modeling of terrace paddy area using SWAT+ in Sungi Watershed, Central Bali, Indonesia.

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1. Introduction

Subak, a traditional Balinese irrigation system, has long been recognized for its sustainable and equitable water management in paddy fields. However, Bali now faces modern challenges including land use and climate change, rapid urbanization, intensive tourism development that threaten this centuries old practice. To asses Subak's resilience in water management, this study employs SWAT+ hydrological model to analysis water balance components in terrace paddy field under Subak traditional irrigation water management.

2. Study area and methods

Study area is located in Sungi watershed, which encompasses Sungi river in central Bali, Indonesia. Originating in mountainous terrain, the river flows from central to southern region Bali. Our research focuses on upper Sungi watershed covering area 3973.9 Ha with elevation ranging from 147 m to 2210 m above sea level. According to Koppen's classification of climate types, the study area belongs to type of tropical rainforest and is dominated by monsoons with temperature ranging from 20.6° C to 35° C and mean temperatures 27.8° C. The average annual rainfall is around 2120 mm.

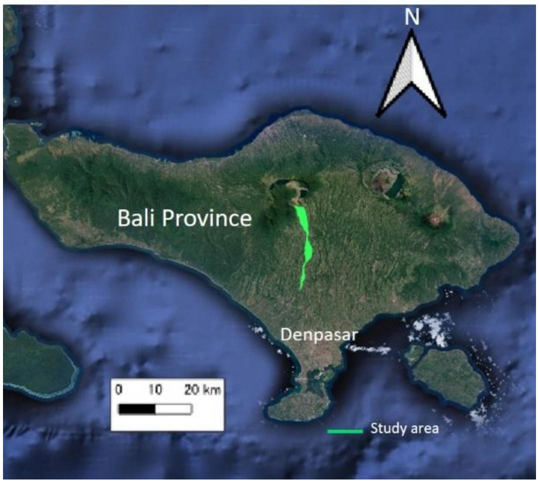

Fig.1 Study area in Sungi watershed

SWAT+, an improved version of SWAT, a continuous, semi-distributed eco-hydrological model. It is a restructured version of the original SWAT, designed to simulate the effects of land management and climate on hydrological processes and water quality. The input data such as Digital Elevation Model (DEM), soil type, land use map, and climate data were required. The hydrological mechanism of the model can be evaluated using the water balance equation which is represented as follow:

$$SWt = \mathrm{SW} + \sum_{i=1}^{t}(Ri - Qi - ETi - Pi - QRi) \qquad (1)$$

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Keywords: terraced paddy, SWAT+, Subak, water balance, hydrological modeling

Where SWt is the final water content (mm), SW is the initial soil water content (mm), t is time in days, R is rainfall in mm, Q is surface runoff (mm) ET is evapotranspiration (mm), p is percolation (mm) and QRi is return flow. SWAT+toolbox with Latin Hypercube technique was used for calibration and validation the model.

3. Result and discussion

Calibration was done using five years' data from 2016-2020 with Figure 2 illustrating the model calibration in 2018. The results showed that the model performance was acceptable in describing hydrological processes in the study area, indicated by KGE of 0.45, RMSE of 2.28%, and PBIAS of -0.028%. Sensitivity analysis identified eight key parameters with perco (+50%) being most sensitive parameter among others. The second parameter was Surlag with a change of -87.5%. Surlag is a parameter that delays the release of surface runoff. Other adjusted parameters included z, cn2, awc, alpha, cn3_cwf, esco.

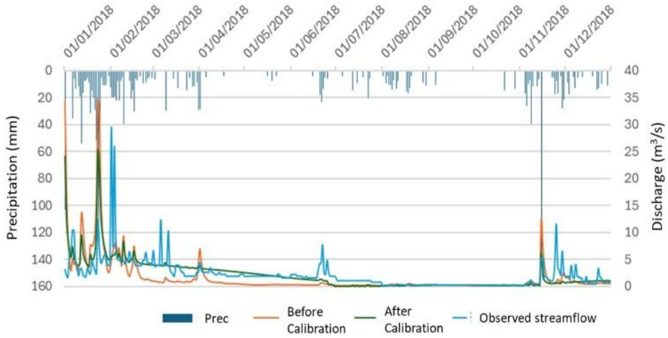

Fig.2 Calibration model in 2018

Table 1 shows the mean annual water balance components during calibration periods. Percolation amount was the largest portion of outflow among water balance components with the value 1246 mm, likely influenced by a high percolation parameter. Surface runoff was relatively small with the value 373 mm, it might be influenced by low in surlag parameter. It means terrace landscape effectively retain water, reduce surface runoff and increasing infiltration. Return flow as base flow contributed to stream flow from shallow aquifers with the value 1134 mm. Despite high percolation high, the recharge to deep aquifer was low with the value 62 mm, suggesting that the most water is stored in the shallow groundwater then release in the downstream.

Table 1. Annual water balance components

Variable	Amount (mm)
Precipitation	2369
Potential evapotranspiration	1083
Actual evapotranspiration	629
Surface runoff	373
Lateral flow	34
Return flow	1134
Percolation	1246
Recharge to deep aquifers	62
Soil evaporation	26

4. Conclusion

Subak terraced paddy fields create an efficient water management system by enhancing infiltration, minimizing surface runoff and maintaining stable base flow for downstream sharing. This study underscores the importance of traditional irrigation system in maintaining water sustainability and resilience in agricultural landscape.