論文の要旨
Summary of the Dissertation

論文題目
Dissertation Title

Sustainable Agricultural Water Resources Management in Afghanistan Using the Hydrological Modelling(水文学的モデリングアプローチによるアフガニスタンにおける持続可能な農業水資源管理)

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Life on earth depends on water resources since every creature needs water for survival. Considering the very small fraction of freshwater globally, providing sufficient healthy water is a matter of death or life for people and ecosystems. Water resources are at risk of degradation, pollution, and scarcity due to rapid increases in consumption. Interdisciplinary solutions to water scarcity and environmental challenges require tools from science and engineering integrated with management tools. The present study presents a series of studies to evaluate water resource availability in data-scarce regions of the world with complex hydrological situations and vulnerability to water scarcity.

The current study evaluated the hydrological dynamics of four watersheds in Afghanistan. The targeted study regions were located in two major river basins in Afghanistan, namely, the Northern Rive Basin (NRB) and the Amu Darya River Basin (ARB), out of five major basins. The NRB is the smallest watershed in the country in terms of surface water availability, and the ARB is the largest watershed in Afghanistan. The Balkhab River Basin (BRB) is representative of the NRB, and the three sub-catchments of Kokcha, Khanabad, and Kunduz are representative of the ARB. The four sub-catchments cover 22367.7, 11993.5, 28023, and 28835.2 km2 in Kokcha, Khanabad, Kunduz, and the BRB, respectively. All the targeted sub-catchments were sourced from high terrain and flow toward flat lands downstream. The flow regime is complicated in the region. Precipitation accumulates in the high mountains during the winter seasons and dominates the discharge flow in the melting season during the early spring with increasing temperatures. The precipitation in the spring season accelerates the melting rate and increases the discharge in the stream, significantly causing flooding. Water infiltrated from snowmelt and rainfall in high terrains will show as lateral flow or springs along the river after a considerable amount of time, contributing to the river flow during the summer and autumn seasons.

This study utilized two computer-based hydrological models to simulate long-term streamflow in watersheds. The models were calibrated and validated against historical discharge records collected by the Ministry of Energy and Water (MEW). The Soil and Water Assessment Tool (SWAT) and hydrological enhancement of Weather Research and Forecast (WRF-Hydro) are two computer-based hydrological models most commonly used by scholars in the field. The BRB hydrological model was developed using SWAT, and the WRF-Hydro model was adopted to model the Kokcha, Khanabad, and Kunduz sub-catchments in the ARB. Statistical indices were used to evaluate the model performance during the calibration and validation periods. Historical data could provide a basic understanding of the water availability in watersheds, but the spatial coverage is low. The main purpose of the hydrological models in this study was to reveal the hydrological dynamics of the watersheds and generate spatial data for further analysis.

A proper understanding of consumption sources is the key to successful water resource management. The agricultural sector of Afghanistan consumes 98% of the country’s water resources, and the remaining 2% is consumed for municipal water supply and industrial usage. Considering that large portions of water resources go to the agricultural sector, irrigation water consumption was estimated using the Penman–Monteith method to estimate the crop water requirement (CWR) for the ARB. Irrigation water usage is a factor of the land area and crop type. Unfortunately, Afghanistan does not have a database for crop type maps. To address data scarcity, remote sensing approaches were adopted to generate spatial and temporal crop type maps for the entire study period. The normalized difference vegetation index (NDVI) products from Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua and Terra were used to generate the crop type map. The NDVI products were classified into major crop types in Afghanistan using an ensemble

of three machine learning algorithms: random forest (RF), support vector machine (SVM), and gradient boosting model (GBM). This study used a voting classifier for the model ensemble and balance weighting to account for the uneven distribution of the different classes in the training and testing accuracy. RF shows the highest accuracy rate among the others, and the ensemble of the three improves the performance accuracy. The models were trained for 2020 based on the availability of observation data and were temporally transferred for 2014 to 2019 over the same spatial coverage. The crop water requirements, crop types and irrigation areas for the BRB were adopted from a previous study and statistical yearbook of Afghanistan.

Finally, the outputs from the hydrological modelling step and estimation of water consumption were integrated into water resource management approaches to assess current management practices in watersheds. The assessment of the BRB revealed severe water shortages downstream and the inequitable allocation of water among users. To address these shortcomings, this study proposed the construction of a reservoir dam in the midstream region of the BRB to store water during late autumn and winter, when surplus water exists in the river and consumption is almost zero in agricultural lands. The location of the dam was determined using the analytic hierarchy process, a multicriteria decision analysis, based on expert opinions. The dam structure can regulate the water by storing it during the surplus flow and releasing the water during the peak irrigation season. The ARB analysis revealed a high availability of water from May to September. The total consumption and available water in the river reach a balance between April and October. As a result of the assessment of irrigation systems in Afghanistan, the irrigation efficiency of the system is extremely low, with almost 50% losses in irrigation canals and agricultural fields. The purpose of this study was to increase irrigation system efficiency by lining irrigation canals and improving the amount of irrigation water applied in the field to the sprinkler to reduce large losses. In the ARB case, lining canals will improve the system efficiency by 9% and can save 14.25% more by changing the irrigation scheme from surface irrigation to a more efficient sprinkler irrigation system. The current study did not use any hard approaches, such as dam construction, in the ARB since all the rivers are transboundary water and Afghanistan does not have a treaty with other shareholders.

The output of these series of studies is a road map for sustainable irrigation water management in Afghanistan. The findings suggest that based on the goals of the Water Affair Management Law (WAML) passed in 2020, a road map for the sustainable management of irrigation water can follow these steps. First, watershed capacity and weakness can be identified using computer-based hydrological models. Water consumption should be estimated according to the current situation as well as the risks associated with climate change. Water allocation among users should be reformed to ensure the equal distribution of water among users upstream-to-downstream. In particular, attention should be given to the rehabilitation of existing infrastructure as well as the development of new infrastructures based on water availability to improve food security and residents' livelihoods by improving system efficiency. The government should increase its interference in water management by replacing the informal traditional system with more centralized modern irrigation systems and enhancing the policy for engaging the private sector in agricultural-related activities. The findings of this study can provide deeper insight into water resource management in Afghanistan for water planners and decision-makers.

Keywords: Hydrological Modelling, Water Resources Management, Irrigation Water, Crop Water Requirements, WRF-Hydro, SWAT, Crop Type Mapping