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Development of an integrated hydrological-irrigation optimization modeling system for a typical rice irrigation scheme in Central Vietnam

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ABSTRACT

In Central Vietnam, farmers report an increasing occurrence frequency of water shortages for irrigation during dry seasons. Particularly during the summer-autumn rice season, water is often insufficient to irrigate the entire rice production areas, and thus restricting rice productivity significantly. In this study, a coupled hydrological-irrigation optimization modelling system is developed to optimize irrigation strategies for a typical rice irrigation system in Central Vietnam. The model consists of a fully distributed hydrologic model, which simulates the inflow to a reservoir, and an irrigation model, which optimizes the rice irrigation technology, i.e. *Alternate Wetting and Drying* (AWD) or *Continuous Flooding* (CF), irrigation schedule and cropping area under given water constraints. Irrigation strategies are derived based on different initial reservoir water levels at the beginning of the cropping season as well as different maximum water releases. The simulation results show that the initial level of water in the reservoir is crucial: Water levels of less than 90% do not provide sufficient water to irrigate the entire cropping area, whereas a level of 70% restricts the cropping area to 75%. AWD is able to reduce the water input, ranging from 4% to 10%. The adoption of AWD therefore has the potential to irrigate a larger area and may help to increase the profit of the farmers. However, the benefits of AWD can only be achieved after significant investment in the canal system and the reservoir outlet. Since the robustness of the optimization results (performance variability) is crucial for decision support, we estimated the impact of different computing environments on the solutions. Only limited performance variability is found, giving confidence in the robustness of the model for decision support.

1. Introduction

Rice is the main staple crop of Asia (Wassmann et al., 2009). In Vietnam, rice production plays an important role for the agricultural sector, which accounts for approximately 21% of the country's economy (Nguyen et al., 2010). Undoubtedly, rice export remains a critical foreign currency income for the country's GDP, as Vietnam is one of the top rice producers and exporters in the world (Pandey et al., 2014). At the same time rice is also a strategic crop for the national food security. In contrast, among others rice production is the biggest water consumer, accounting for 92% and 72% of water withdrawal in mainland and maritime Southeast Asia, respectively (Bueno et al., 2010; Nelson et al., 2015), or 24%–30% of the total world's freshwater withdrawals (Bouman et al., 2007; Lampayan et al., 2015b). However, increasing water stress due to rapid population growth, climate change, the deterioration of water quality and increasing competition from other water users threatens the water availability for irrigated rice production in many Asian countries, including Vietnam (Rejesus et al., 2011). The UN Global Assessment Report on Disaster Risk Reduction (2015) revealed that by 2050, about 40% of the global population is expected to be living in river basins that experience severe water stress, particularly in Africa and Asia. Recently, many rice growing areas in Vietnam such as Cuu Long delta (low Mekong basin), Highland Plateau and Central region have been suffering from water scarcity for agricultural irrigation due to extreme droughts and/or salinity intrusion. Since Vietnam is expected to belong to the most severely affected countries worldwide by climate change, the vulnerability of agriculture will be increased (UNDP, 2007; MONRE, 2012). Therefore, it is of paramount importance to identify suitable agricultural management strategies, which are able to maintain or even increase the yields under reduced water availability.

Increasing sectoral competition for water demands for the development of more efficient water usage in agriculture (Li et al., 2001). Many efforts have been made to develop ways to decrease the water use

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in rice production and increase water productivity (Belder et al., 2004; Bouman et al., 2005). A promising technology for increasing eco-efficiency in rice production is *Alternate Wetting and Drying* (AWD). The AWD technology does not only reduce the total water amount for rice production but also reduces methane emissions from paddy fields without considerable yield losses (e.g. Bouman et al., 2007; Rejesus et al., 2011; Lampayan et al., 2015a). In AWD, the soil surface is allowed to dry for a certain number of days before re-flooding, thus the field is alternately flooded and dried. In a specific form of AWD, the "safe" AWD, the field is allowed to drain out until the water level reaches 15 cm below the soil surface (15-cm-deep water table). The threshold of 15 cm will not cause any yield decline since the roots of the rice plants are still able to take up water from the perched ground water and the almost saturated soil above the water table (Lampayan et al., 2015a). The period of non-flooded soil in AWD between irrigations can vary from few days to more than 10 days in the absence of precipitation depending on soil type and weather/climate conditions (Bouman et al., 2007; Rejesus et al., 2011; Singh et al., 2013; Lampayan et al., 2015a). In contrast, with *Continuous Flooding* (CF) the ponded water is kept at a certain level (usually at 5 cm above the surface) during the growing period from few days after transplanting until few days before maturity.

Water savings without significant yield losses by AWD (compared to CF) have been reported from field studies for Bangladesh (Rahman, 2014), South China (Liang et al., 2016), and the Philippines (Rejesus et al., 2011; Zhang et al., 2012). Apart from similar yields obtained by AWD, a reduction is revealed in e.g. Tabbal et al. (2002) and Belder et al., (2004), while an increase is found in Li et al., (2001). Lampayan et al., (2015a) conducted research on the adoption of AWD for irrigated lowland rice in the Philippines, Bangladesh and Vietnam. The results showed that AWD can reduce water input for irrigation up to 38% without yield reduction.

Besides field studies, irrigation optimization models are required to test the performance of AWD and CF systematically under various boundary conditions. The number of such studies is limited for Southeast Asia. Hong et al., (2015) developed a water balance model to simulate water level changes in the rice field which accounts for interactions between the rice field and the irrigation system, and evaluated the effectiveness of different irrigation technologies for the Soc Trang province, Southern Vietnam. Results show that AWD is the most effective irrigation technology in terms of water requirements and the number of irrigation events. The number of irrigation events (pumping times) are found to range between 11 and 32 among different considered irrigation technologies.

In Central Vietnam, rice is still grown predominantly under CF. Water is released to the rice cropping areas roughly at the same time, which is speculated to aggravate the problem of water scarcity, particularly the dry summer-autumn season. As a consequence, it is reported of reduced rice yields for this season.

Therefore, our study aims to develop an integrated hydrological and irrigation model applicable for Central Vietnam, which allows to optimize irrigation management, i.e. optimal irrigation techniques, –schedules and cropping area.

2. Materials and method

The Vu Gia-Thu Bon (VGTB) river basin is located in Central Vietnam, between 107°15′-108°20′E and 14°55′-16°04′N. The basin has an area of 10,350 km^2 covering the entire Quang Nam province, Da Nang city and a small part of Kon Tum province (Fig. 1). The elevation of the VGTB ranges from sea level to 2598 m a.s.l.

2.1. Climatic and edaphic characteristics

The climate of the VGTB basin is driven by South Asia monsoon system. It is characterized by relatively warm winters and dry summers (Souvignet et al., 2014). The rainy season, frequently affected by typhoons, lasts from September to December. The VGTB is facing recurrent floods during the wet seasons, but also water shortages during the dry seasons. Rainfall during the wet season amounts up to 80% of the total annual rainfall. The mean temperature varies between 24 °C and 26 °C. The maximum temperature can reach over 35 °C in June and/or July, whereas the minimum temperature can fall below 15 °C in January. In the wet season, the relative humidity is about 85–88% in the lowlands and about 90–95% in high elevated area, while during the dry season this rate is below 80% and 80–85%, respectively.

The basin consists of three distinct landscape types, the uplands, the midlands, and the lowlands. Typically soils in the catchment are Acrisols and poor grey soil, covering most of uplands and midlands, silty soil and alluvial plains along rivers, as well as sandy soil in the low-lying area.

2.2. Agricultural characterization

In Quang Nam province, agriculture is the primary economic sector in terms of labour, it employs over 50% of the population. Total rice cultivation area for entire province is about 87,396 ha for two rice crops winter-spring (WS) and summer-autumn (SA) (Quang Nam Statistical Year Book, 2014).

The lowlands and midlands of the VGTB basin are dominated by irrigated rice paddies. Cash crops are also cultivated in the regions of rice-based cropping systems, but rice is still by far the predominant crop in the region (Pedroso et al., 2016). Further upland, there exist a combination of natural and production forests. Irrigated rice is also present in high plateaus (Fink et al., 2013).

Although AWD has been officially integrated into the guidelines for rice irrigation across Quang Nam province by the Department of Agriculture and Rural Development (DARD) since 2012, CF is still the prevailing irrigation technology. The reasons may vary, but can be summarized as:

- The farmers' traditional beliefs that standing water is required at all stages of rice growing to obtain high yields.
- Farmers have little incentive to reduce water use as the water pricing system is not in place.
- Potential problems with rodents under AWD, particularly when the soil is dried.
- The higher water requirement of AWD at the beginning of each irrigation event, which may potentially lead to temporary water shortages if all fields are prepared at the same time.

Rice productivity is relatively low and unstable due to the high climate variability and due to a weak technical infrastructure and an insufficient amount of water for irrigation, particularly for the SA season. In response to an increasingly unstable water supply, many small-scale reservoirs have been adopted to capture flows at small upstream tributaries. In total, there are 757 irrigation schemes, of which 518 are barrages and 179 are pumping stations. About 73 reservoirs with a volume ranging between 1×10^6 m^3 and over 2×10^6 m^3 were built for irrigation (ADB, 2011). The potential cultivation area to be supplied by the reservoirs is 17,048 ha, which accounts for about 42.5% of the total irrigated area. However, the actual irrigated area reaches < 50% of its designed capacity due to insufficient irrigation systems.

2.3. Case study: selection of a typical rice irrigation scheme in Central Vietnam

We identified the Que Trung rice growing irrigation scheme, located in Nong Son district, Quang Nam province, as typical local rice irrigation scheme in Central Vietnam and suitable for modelling during field surveys. We have elaborated the research needs jointly with local stakeholders from the water and the agricultural sector in the region.

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