Research article

Evaluation of Water Shortages in Agricultural Water Use in the Sangker River Basin, Cambodia

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Abstract The shortage of agricultural water in the Sangker River basin of Cambodia is becoming a severe problem, and the river flow seems to have decreased. The present study assesses the excess and deficiency of irrigation water resources in this river basin for agricultural production. The Soil and Water Assessment Tool (SWAT) is used to analyze the water balance at the main headwork in this river from 2014 to 2018. SWAT was used to estimate the available volume of stream water at the ungauged point of the Kang Hot headwork, and the model performance was evaluated at a gauged point downstream by the Nash–Sutcliffe efficiency (NSE). The model was calibrated manually and automatically by using data from 2007 to 2013. Furthermore, the flow rates in the two main irrigation canals were measured from June 2018 to October 2019 to obtain the actual irrigation water supply, and the evaluation was made by checking the difference between supplied water volume and irrigation water demand. The model output showed good agreement between observed and simulated monthly streamflow during the validation period (NSE = 0.69, RSR = 0.55). From the results of water balance analysis, water shortage rates exceeding 20% of the monthly water requirement occurred mostly between April and June from 2014 to 2017. Furthermore, there was excess water supply in 2018 because of abundant river flow that year. The actual irrigation water supply during the study period showed rates of water shortage of 52% and 41% in the left and right main canals, respectively, at the headwork. This study provides new insights for field technicians to consider irrigation planning for present and future water resources management and development for sustainable irrigation agriculture.

Keywords SWAT, water balance, irrigation, rice paddy, water supply and demand

INTRODUCTION

Many river basins worldwide are facing perceived water shortages because of increasing demands for water from all sectors. In Cambodia, increasing water demands and competitiveness among sectors and between upstream and downstream of the river system are also becoming crucial, and the concern is that the country will face highly restricted water resources (Technical Service Center & JICA, 2014). Accordingly, the shortage of agricultural water is becoming a serious problem in the river basins, and the streamflows appear to be decreasing. Contributing 22% of gross domestic product collectively, agriculture, forestry, and fishing are essential to the growth of Cambodia's economy, and of the 80% of Cambodian people who live in rural areas, 65% rely on those three sectors (USAID, 2019). The Royal Government of Cambodia continues to enhance the management of water resources, develop irrigation systems, and undertake repair and maintenance of the irrigation infrastructure where required. Furthermore, headwork and multipurpose dams have been constructed in the river basins to meet the increased demand for water and flood control. The Sangker River basin in northwest Cambodia is one of the largest agricultural production areas in the nation and faces similar water-resource issues. An irrigation project has been implemented in this area, but improved management is required to solve the water-deficit problems.

The state-of-the-art method for estimating water deficiency is to analyze the balance between the water supply and the demand for irrigation water (IW). Masona et al. (2018) revealed a shortfall in IW use by applying the relative water supply (RWS), the ratio of water supply to water demand; an RWS of 1.6 showed that the targeted scheme received much more water than its IW demands. To assess water deficits in the Heibe River basin of China, Ji et al. (2006) established a model of the balance between water supply and demand based on meteorological, hydrological, land use, and socio-economic data. They found that the water supply was insufficient to meet the water demands of the various irrigation districts, and indeed the Pingchuan irrigation district has already experienced a water supply crisis. By comparing the actual water supply with crop water requirements, Shakir et al. (2010) revealed an annual water shortage of more than 40% in the Upper Chenab Canal of Pakistan. However, with regard to the spatial distribution of operational parameters, calculating the supply-and-demand balance of water resources does not resolve the regional problem of water-resource utilization on a relatively large scale in an inland basin (Bormann et al., 1999). Therefore, the present study considers the water balance of a regional scheme by incorporating a physically based model.

In the present study, the Soil and Water Assessment Tool (SWAT) hydrological model is used because of its widespread use in predicting runoff and sediment yield (Arnold et al., 1998). Herein, SWAT is used to estimate the streamflow at the headwork of the main canals. These streamflow data are then used to evaluate the deficit of water resources in the irrigation project area. The present results could help to identify the root of the water shortages that occur frequently not only in the irrigation project area but also across the river basin.

OBJECTIVE

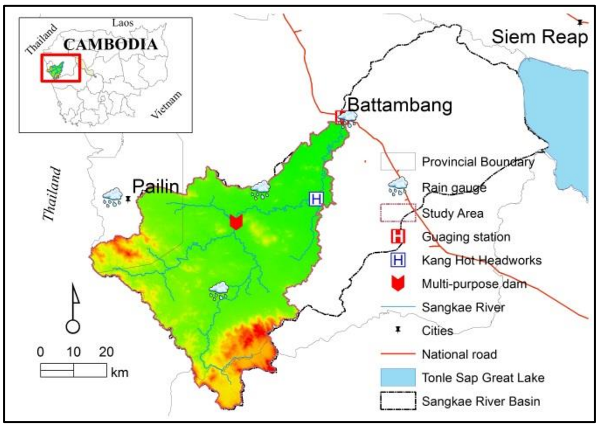
This study aimed to define the available stream water to the irrigation project area and identify the extent to which the water supply of the system is in deficit and/or excess. The specific objectives are (i) to assess the surplus (excess) and deficiency of IW from the Sangker River at the Kang Hot headwork point and (ii) to evaluate the actual IW uses and the demand in the Kang Hot Irrigation Project area.

METHODOLOGY

Study Site

The present study was conducted in the Sangker River basin situated in the Battambang province of Cambodia and with a total drainage area of 6,053 km^2 (Department of Hydrology and River Works, n.d.). The elevation ranges from 13 to 1,400 m above sea level, and the annual rainfall ranges from 695 to 1,787 mm. The focus was on a 3,062-km^2 area to the southwest of the city of Battambang that covers the middle and upper basin of this river system (Fig. 1). The Kang Hot Irrigation Project is only one of the huge numbers of water uses in the study area, with a total command area of 72,000 ha. However, the water is taken from the Sangker River to the project area at the Kang Hot headwork and transported to the paddy fields through the left and right main canals, where the irrigated areas are only 11,200 ha and 42,000 ha (Kodoma, 2018), respectively (Fig. 2).

To assess the surplus and deficiency of IW, the balance between the available water supply from the river and the IW demand was analyzed at the Kang Hot headwork from 2014 to 2018. The actual IW use in the Kang Hot Project area was also evaluated by comparing the difference between the actual volume of water intake from the river and the IW requirement from June 2018 to October 2019.



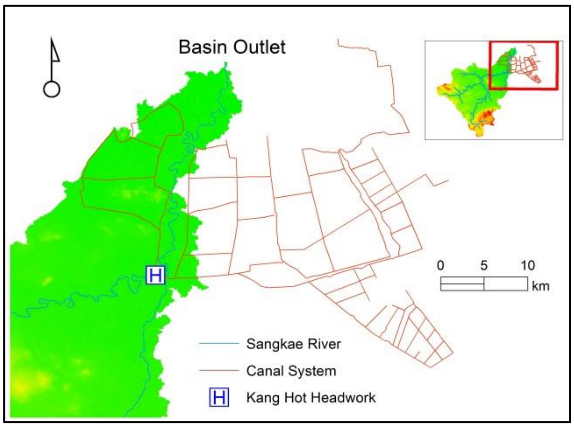


Fig. 1 Location map of study area

Fig. 2 Kang Hot Irrigation Project area

Availability of Stream Water

In the study area, the supply of agricultural water depends on irrigation from the river source. For the latter, the available volume of stream water was estimated using the SWAT hydrological model.

SWAT Modeling

SWAT is a river-basin-scale model developed to predict the impact of land management practices on water, sediment, and nutrient yield, including agricultural activity, in large, complex watersheds with varying soils, land use, and management conditions over a long period of time (Winchell et al., 2013). In the present study, SWAT was set up with the basin outlet at the Samdach Hun Sen Bridge as a gauging station located in Battambang City (Fig. 1). The watershed and sub-basins were delineated within the basin using 30-m-resolution DEM data (ASTER-GDEM 2) in the ArcSWAT2012 interface. The 3,062 km^2 of the catchment area accounts for 51% of the entire Sangker River basin (Fig. 2). A sub-basin was defined as a drainage area with a threshold of 5,000 ha, resulting in 26 sub-basins that were subdivided further into 123 hydrological response units based on slope, soil, and land use, the data for which were retrieved from the FAO-UNESCO Soil Map and the Mekong River Commission (MRC-2010), respectively. The available meteorological data of daily rainfall and temperature data at four stations obtained from the Ministry of Water Resources and Meteorology (MOWRAM) for 14 years (2007-2018) had to be preprocessed by the model. The observed streamflow data collected from MOWRAM at the Samdach Hun Sen Bridge between 2007 and 2018 were used for model calibration (2007-2013) and validation (2013-2018). The SWAT model was calibrated manually by editing the most sensitive parameters based on recommendations by Abbaspour et al. (2015). In addition, the SUFI-2 algorithm packaged in SWAT-CUP was used for automatic model calibration and validation and sensitivity and uncertainty analyses (Abbaspour et al., 2007). The model performance was evaluated using the quantitative statistics of the Nash–Sutcliffe efficiency (NSE) and the ratio of the root mean square error to the standard deviation of measured data (RSR) suggested by Moriasi et al. (2007). After fixing the SWAT for the Sangker River at the Samdach Hun Sen Bridge gauging station, the flow rate at the Kang Hot headwork was extracted from the database of model results.

Irrigation Water (IW) Demands

The IW demands were calculated mainly for rice-based farming in the Kang Hot Project area. Based on its cropping calendar, the unit IW requirement was estimated with a 5-d time step using

$$IR = (ETo \times Kc + PR + Lp - ER) / IE, \quad (1)$$

where (i) IR is the unit IW requirement, (ii) ETo is the crop reference evapotranspiration (calculated using the Penman–Monteith equation with different time steps using meteorological data), (iii) Kc is the crop coefficient following the FAO's guideline for the case of rice paddy fields (Allen et al., 1998), (iv) PR is the percolation rate (because of the absence of field measurement records, this was collected from the Master Plan Study Team of JICA in 2007, which applied a dial gauge and open-ended-cylinder method in the study site), (v) Lp is the land preparation requirement [(needed to saturate the root zone and depends on soil type and rooting depth, which was estimated by assumption (i.e., sandy loam = 250 mm, clay loam = 200 mm, clay = 170 mm)], (vi) ER is the effective rainfall calculated by following empirical relationships developed in Japan (Dastane, 1974), and (vii) IE is the irrigation efficiency, which refers to the conveyance efficiency of the distribution system and was collected from MOWRAM and the Master Plan Study Team of JICA in 2009. The IW demand comes from the unit IW requirement multiplied by the area to be irrigated, which gives a volume of IW needed per unit time. The IW demand is computed as

$$ID = IR \times A, \qquad (2)$$

where ID is the IW demand and A is the area.

Estimation of Actual IW Supply

The actual continuous flow rate for each of the main canals was estimated by three steps. (1) Water-level loggers were installed in the left and right main canals near the Kang Hot headwork during the study period from June 2018 to October 2019. (2) Each canal flow rate was calculated directly from the mean canal-flow velocity (using a current meter over ten time differences) and the flow canal cross-sectional area. The water level in each canal at the moment of measurement was also recorded. These measurements were then integrated into a rating curve (H-Q curve) of the water level and the canal flow rate for each canal (Buchanan and Somers, 1976). (3) By using this H-Q curve, the records of the daily water level were converted into the daily canal flow rate and aggregated at a monthly volume.

RESULTS AND DISCUSSION

SWAT Calibration and Validation

Figure 3 shows the results of the observed and simulated streamflow at the Samdach Hun Sen Bridge gauging station in Battambang City (Fig. 1) with a monthly time step in the periods of calibration (2007-2013) and validation (2014-2018). The graphs show that the SWAT model tracked the observed data accurately both calibration, and validation periods. This was confirmed by NSE values of 0.58 and 0.69 in the calibration and validation periods, respectively (Moriasi et al., 2007). From the SWAT results at the gauging station, the available water resources at the Kang Hot headwork could be estimated for 2014-2018 from the database of the simulation results.

Analysis of Balance Between Available Stream Water and IW Demand

To evaluate the excess and deficiency of IW from the Sangker River at the Kang Hot headwork point, Fig. 4 shows the monthly averages of available stream water and IW demand at the headwork, and Fig. 5 shows the observed deficit rate for the 5-year study period (2014-2018). The results show that the availability of stream water varies over a year and from 1 year to the next. With regard to both the irrigation area and cropping patterns in the Kang Hot Project area during this study period, they were supposed that the IW demands did not change much. If the water shortage is less than 10-20% of the monthly requirement, then the production losses are not very serious (Brouwer et al., 1992).

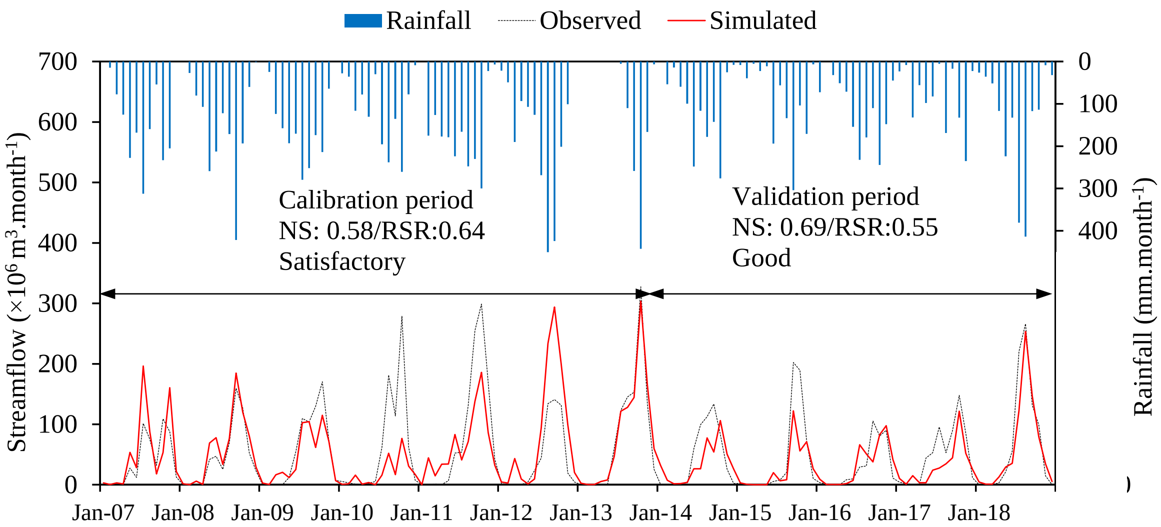


Fig. 3 Monthly simulated and observed flow rate for calibration and validation period in Samdach Hun Bridge gauging station of Sangker River

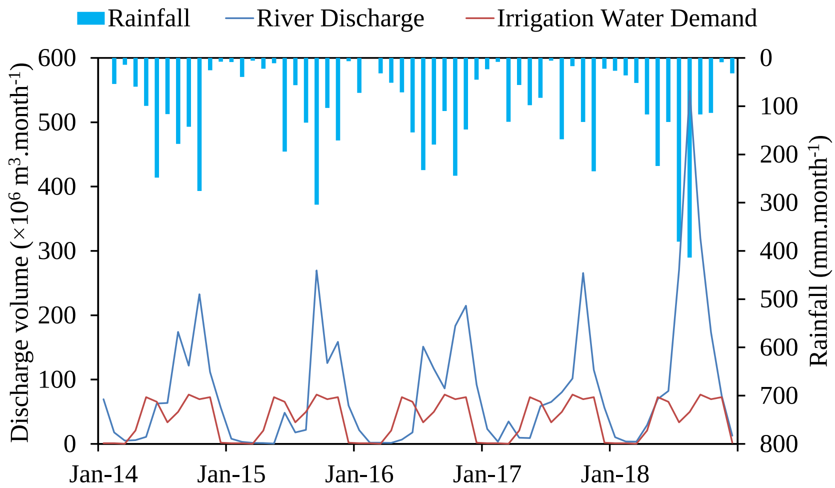


Fig. 4 Balance of available stream water and irrigation water demand at Kang Hot headwork

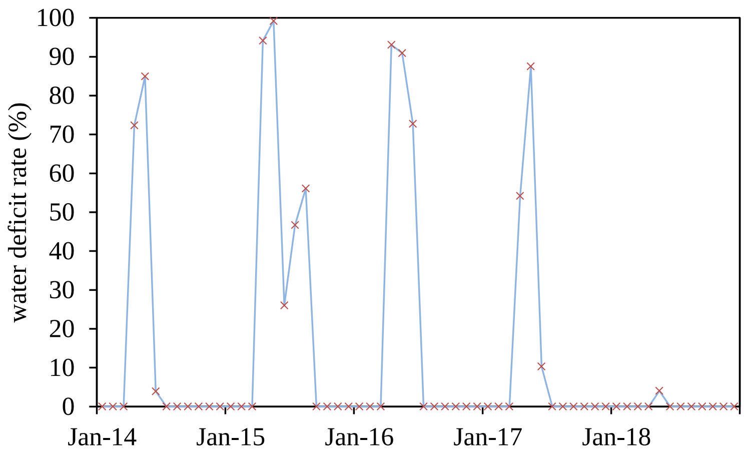


Fig.5 Monthly water deficit rate at Kang Hot headwork

The water balance calculation in Fig. 4 indicates that water deficit always occurred during the April–May dry season every year from 2014 to 2017, with shortage rates of 50-99% of monthly requirements. In the dry year of 2015, the area faced 5 months of subsequent water scarcity (with deficiency rates of 30-99%). Each year, the stream water was surplus in the July-November wet season. In 2018, heavy rainfall increased the streamflow volume, which means that the stream water could meet the IW demand in a given area for the whole year.

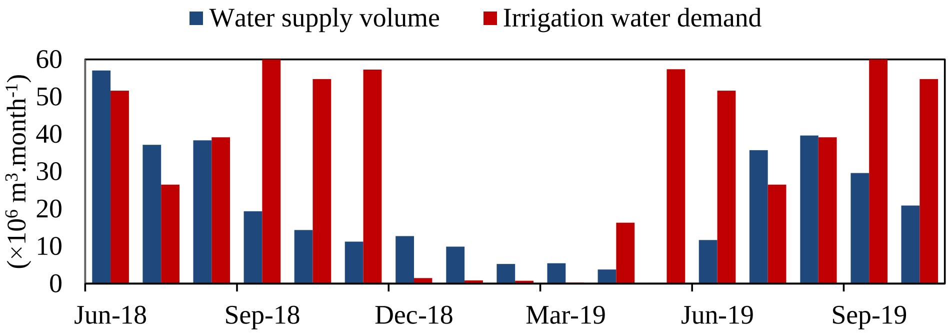


Fig. 6 Actual irrigation water (IW) in right main canal

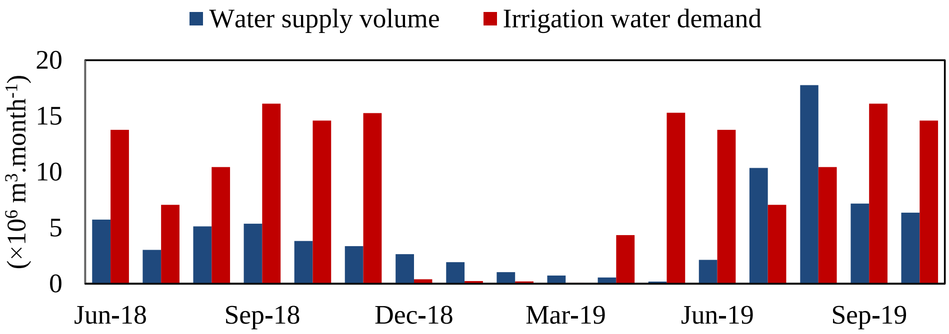


Fig. 7 Actual irrigation water (IW) in left main canal

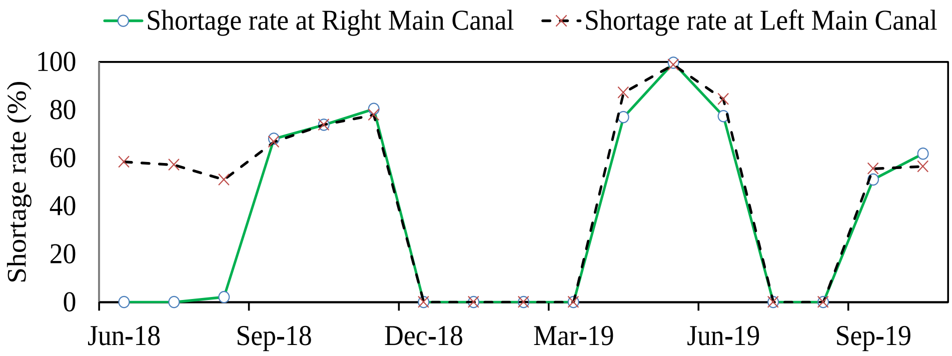


Fig. 8 Water shortage rate in right and left main canals

Evaluation of Actual IW Use

The actual volume of water supply from the Sangker River and the IW demand are shown in Figs. 6 and 7 for the right and left main canals, respectively, as monthly averages from June 2018 to October 2019. Figure 8 shows the water shortage rate in each month for both main canals.

The results for the actual water supply and demand balance for the right main canal (Fig. 6) show a maximum supplied water volume of around 57 × 10^6 $m^3 \cdot month^{-1}$ in 2018, decreasing to 40

$\times$ 10^6 $m^3 \cdot month^{-1}$ in 2019. Meanwhile, the highest IW demand was approximately 60 $\times$ 10^6 $m^3 \cdot month^{-1}$, corresponding to the extreme lack of water in 2019. As shown in Fig. 8, large water shortages occurred in both 2018 (70-78% from September to November) and 2019 (over 77% from April to June). In those 2 years, the water supply was always less than the water demand in September and October, with the shortage rate exceeding 50%. However, the IW demands in every July and August during this study period were met. Overall, we conclude that the right main canal can supply around 59% of the required monthly IW.

Figure 7 shows that the maximum supplied water volume by the left main canal was around 5 $\times$ 10^6 $m^3 \cdot month^{-1}$ in 2018, increasing to 17 $\times$ 10^6 $m^3 \cdot month^{-1}$ in 2019. Meanwhile, the maximum water demand was around 16 $\times$ 10^6 $m^3 \cdot month^{-1}$. Similar to the right main canal, water was also scarce in September and October for those 2 years, with shortage rates of 56-74% (Fig. 8). Figure 7 also shows that water deficiency occurred between June and November, with 50-78% in 2018 and over 80% from April to June in 2019. By 2018, the water supply in July and August was inadequate, with a shortage rate of around 51%. However, compared to that in 2019, it is increased at 7 $\times$ 10^6 $m^3 \cdot month^{-1}$ and 12 $\times$ 10^6 $m^3 \cdot month^{-1}$, thereby meeting the water demands of those 2 months. The water volume of the left main canal can supply only 48% of the requirement.

Cropping Pattern

To minimize the water deficiency, an analysis is conducted by modifying the existing cropping pattern against the available IW. In the revised cropping pattern, the cultivated area is changed as follows: (i) early-wet-season rice is reduced from 40 to 10%; (ii) transplanting-wet-season rice is increased from 60 to 80%; and (iii) direct sowing-wet-season rice is increased from 10 to 20%. The results of this analysis show that the water shortage rate was reduced from 20 to 100% between April and May (2014–2017), which is at the beginning of the irrigation season.

CONCLUSION

The results of this study show that SWAT performed well in predicting the streamflow by providing good agreement between the observed and simulated monthly flow, which is based on the statistics of NSE = 0.58 and NSE = 0.69 in the calibration and validation periods, respectively. With such good performance, SWAT can be used to estimate the river discharge at the Kang Hot headwork point as needed.

The balance between the available volume of stream water and the IW demand at the Kang Hot headwork indicates that the water shortage rate was 50-99% of the monthly requirement, which occurred mostly in April–June, and the excess water was in August–November. This surplus should be controlled to compensate for the deficiencies in other months. By revising the current cropping-pattern calendar, the water deficits could be diminished from 20 to 100% of the monthly shortage rate in those shortfall months.

The actual IW use during the study period was 52% and 41% have experienced the lack of water in the left and right main canals, respectively. Also, water deficits occurred in September and October in both 2018 and 2019.

The results of this study will be useful for policy makers and field technicians for irrigation planning and for developing and managing the water resources in the river basin, in particular for the sustainability of agricultural development.

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