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Water balance for agriculture production in the dry seasons of the Mekong river delta in Vietnam

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Abstract:

Water is the most important component of agriculture production, especially during the dry seasons when all water sources are scarce yet water needs are very high. The Mekong river delta in Vietnam is the largest agricultural and aquacultural region in the country where about half of the Delta's land area is used for rice and upland crop cultivation. One key strategy to address the regional water utility problem is to estimate the net water requirement during the dry seasons. The needs for irrigation water discharge for rice and other upland crops during the dry seasons of the Delta were quantified using the Penman-Monteith equation for estimating reference crop evapotranspiration along with the CROPWAT model for calculating crop irrigation water requirements. In general, the total water taken from the Mekong river flow for irrigation requirements should be approximately 2,300-2,600 m^3/s for normal yields in the current agriculture areas and under local cultivation conditions. Water diversion and upstream hydropower projects are challenging tasks, especially in the context of climate change, to satisfy the water needs for agricultural irrigation in the near future. All water stakeholders among the neighbouring countries that rely on the Mekong river must adjust their regional water-use planning as one of the mitigation solutions for the seasonal drought crisis.

Keywords: **agriculture, CROPWAT model, irrigation water, Mekong Delta, water balance.**

Classification number: **3.1**

Background

The Vietnamese Mekong river delta (MD) is the largest wetland region in the southernmost part of the Mekong river basin and connects more than 700 km of coastal line to the East Sea and the Gulf of Thailand (Fig. 1). The Delta is four million ha in size (12% of total natural land of Vietnam) and hosts more than 18 million inhabitants (about 22% of the entire country's population in 2009). For more than 300 years, the local people have lived close to rivers and streams to facilitate the domestic use of water, such as for agricultural cultivation, fishery, and river transportation. Thus, any change in the water source affects their activities and the ecosystem of the area. The MD is recognized as the largest agriculture and aquaculture production region of Vietnam. The delta supplies more than 53% of the nation's staple food, rice (Fig. 2), 65% of the total fish production, and 75% of the tropical fruit trees. Further, rice production is considered to be the main economic sector, which occupies more than 60% of the labour force in the MD.

The total rice production of Vietnam for the 2014-2015 market year reached 45.18 million tons of paddy rice or approximately 28.24 million tons of milled rice. Since the end of the 1980s, Vietnam has been known as one of the top five milled rice exporters to the world market and more than 90% of Vietnam's rice export comes from the MD. From a series of data obtained from the General Statistical Office [1], the total rice production in the MD exceeded 25.25 million tons in 2014-2015. In this period, about 7.1 million tons of rice was sold to the world food market, which became the record for the largest amount of rice exported from the nation. The cropping calendar for rice and other upland plant cultivation in the MD, in terms of the

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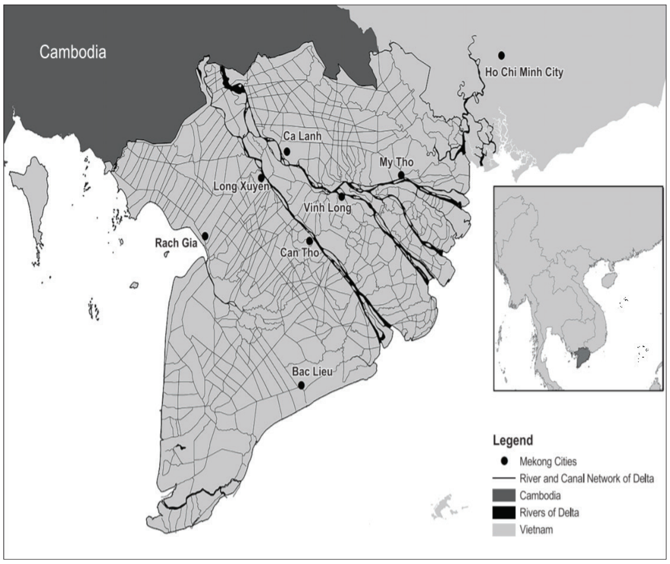

Fig. 1. The Mekong river delta in Vietnam and the delta's network of rivers and canals. Source [2].

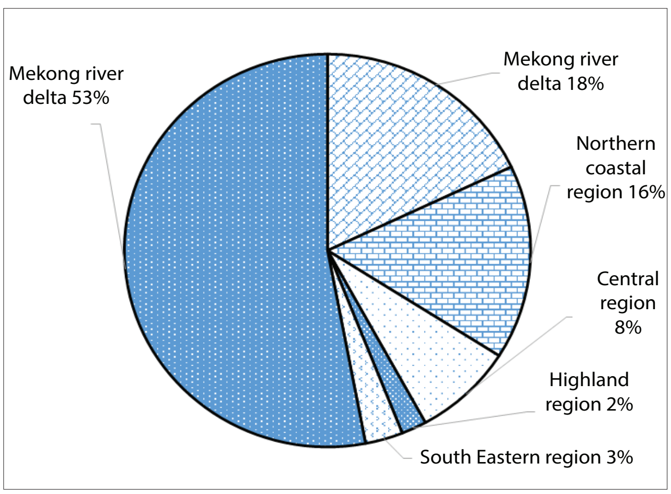

Fig. 2. Contributions to rice production in Vietnam. Data source [3].

growing season duration and the number of crops against the available water conditions in rainfed and irrigated areas, is shown in Fig. 3. From the calendar, a very large water requirement occurs at the end of the dry season, i.e. March and April. However, in March and April, a majority of the seasonal rice has been harvested and those fields are vacated. In a few irrigated areas and saltwater intrusion-free areas such as the An Giang, Dong Thap, Can Tho, and Vinh Long provinces, farmers may plough the lands to prepare for their new rice crop and a lot of water is pumped to the rice fields in March and April.

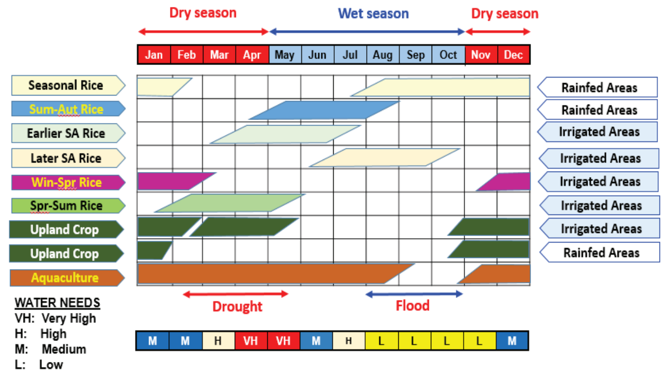

Fig. 3. Agricultural cropping calendar in the Vietnamese MD.

Since 2014, locating fresh water sources has become a huge challenge for agricultural irrigation, especially during the dry season. The available water flow from the Mekong river to the delta has seriously dropped resulting in saline water intrusion of hundreds of thousands of hectares of rice fields. According to the statistics from the Ministry of Agriculture and Rural Development [4], the serious effects of drought and saline intrusion in 2015-2016 caused damage to more than 339,000 ha of Winter-Spring rice paddies, which resulted in a nearly 22% loss of total rice area across the region. Due to limits placed on irrigation water, the Winter-Spring rice crop area dropped by 8.72% in 2016 when compared with the rice area in 2014 (Fig. 4).

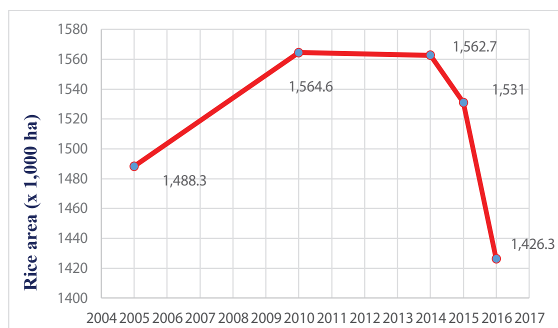

Fig. 4. Change in the Winter-Spring rice areas in the MD due to drought and saline intrusion. Data source [1].

Rice is a major food source for not only the Vietnamese but also for many people around the world. It is well-known that rice cultivation in the lowlands like the MD requires copious amounts of water. At the flowering stage of rice growth, the need for water is high and the rice yield is very sensitive to water deficit, which results in increased spikelet sterility and thus fewer grains. Determining the amount of field water needed to produce one kilogram of rice is a critical issue for water managers. Many experiences have shown that there are large variations in the water need, i.e., to produce one kilogram of rice, about 3,000-5,000 litres of water is required on average, which greatly depends on farming management and weather.

In agro-meteorology, evapotranspiration is a word combining evaporation and transpiration and is one of the most significant components of water balance in crop fields. On average, it takes 1.432 litres of evapotranspired water to produce 1 kg of rough rice [5]. In reality, the water need may go up to 2,500 litres, which includes the outflows of evapotranspiration, seepage, and percolation [6]. Water demand for agricultural cultivation is defined as the amount of water required for crops that compensates for the loss of water due to evapotranspiration and the physical conditions of the soil and land that contribute to water storage as well as the growth stages of the crop. Table 1 presents a rough comparison of water balance for irrigated areas in the countries of the Lower Mekong basin (LMB) versus land area, population, and the Mekong river flow discharge available in the dry season. An estimation of irrigation volume requirements for rice and other upland crops is considered as a regional water security strategy.

Table 1. Land, population and rice production in the Lower Mekong basin, 2014.

Variable	Thailand	Laos	Cambodia	Vietnam	Total
Area in LMB (km^2 x 10^3)	184.0	202.0	161.0	95.0	642.0
Area in LMB (%)	28.7	31.5	25.0	14.8	100.0
Population in LMB (2014) (x 10^6)	24.2	6.1	12.5	23.0	65.8
Population in LMB (2014) (%)	36.7	9.3	19.0	35.0	100.0
Population density (persons/km^2)	132	28	78	279	103
Agriculture area in LMB (ha x 10^3)	10,300	1,900	3,100	4,610	19,910
Paddy area in LMB (ha x 10^3)	1,647	631	1,647	2,606	6,531
Paddy are as % of agric. area	45.1	33.2	53.1	56.5	47.9
Irrigated paddy area (ha x 10^3)	1,425	172	505	1,921	4,023
Irrigated as % of paddy area	30.7	27.3	30.7	73.7	42.2
Paddy prod. (2014) (t x 10^6)	14.7	3.9	8.7	25.2	52.5
% growth of prod. (2000-2014)	2.5	4.5	6.1	3.0	3.4
Average yield (2014) (t x 10^6)	2.6	4.3	3.1	5.9	3.8
Prod. as % of country's total	45	98	94	56	57

Data source [7].

Methodology

CROPWAT [8] is a decision support system software developed by the Land and Water Development Division of the UN's Food and Agriculture Organization for the calculation of crop water and irrigation requirements based on soil, climate, and crop data. The equations for the efficient quantity of crop water are based the guidelines of [9] and the expected crop yield is based on the water use in [10]. The maximum crop evapotranspiration (ET_{crop}) is equal to the reference-crop evapotranspiration (ET_o) multiplied by the crop coefficient (K_c):

$$ET_{crop} = K_c \times ET_o \quad \text{(Eq. 1)}$$

The crop coefficient values, K_c, were provided for a large number of crops and the procedures to determine the ET_{crop} over the growing season were followed. Crop water requirements are defined by the depth of water needed to mitigate water loss through maximum crop evapotranspiration (ET_{crop}) in order to achieve full production potentials under the given crop growing environment. The Penman-Monteith equation is the FAO's standard method for modelling evapotranspiration and is formulated as [8]:

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \quad \text{(Eq. 2)}$$

where ET_o (mm.day^{-1}) is the reference evapotranspiration, R_n (MJ.m^{-2}day^{-1}) is the net radiation recorded at the crop surface, G (MJ.m^{-2}day^{-1}) is the monitored soil heat flux density, T (°C) is mean daily air temperature measured at 2 m height, u_2 (m.s^{-1}) is the wind speed measured at 2 m height, e_s and e_a (kPa) are the actual vapor pressure and saturation vapor pressure such that (e_s - e_a) (kPa) is the saturation vapor pressure deficit, Δ (kPa °C^{-1}) is the slope of the vapor pressure curve, and γ (kPa °C^{-1}) is the psychometric constant.

The water balance equation for a rice field is estimated by Eq. 3:

$$h_{Ci} = h_{0i} + \sum m_i + \sum P_{sdi} - \sum(e_i + K_i) - \sum C_i \quad \text{(Eq. 3)}$$

where all units are mm, h_{ci} is the water depth of the field at the end of calculated period, h_{oi} is the water depth in the field in the start of calculated period, Σm_i is the irrigated water during the i^{th} calculated period, ΣP_{sdi} is the possible precipitation used during the i^{th} calculated period, $\Sigma(e_i + K_i)$ are the water losses during the i^{th} calculated period, and ΣC_i is the drainage water during the i^{th} calculated period. It is necessary to first have an irrigation scheme based on Eq. 3 and then the irrigation water volume to each unit of irrigation land (m^3/ha) is estimated.

For estimation of the water requirement for an irrigation scheme, the coefficient of irrigation (q), defined as the water discharge needed for providing a plant cultivation area unit, is given in Eq. 4:

$$q_{ij} = \alpha_i \frac{m_{ij}}{86.4 \times t_{ij}} \quad \text{(Eq. 4)}$$

where q_{ij} (l.s^{-1}ha^{-1}) is the coefficient of irrigation of the i^{th} plant in the j^{th} irrigation time, α_i is the ratio of the area between the i^{th} plant and the entire irrigation area, m_{ij} (m^3.ha^{-1}) is the irrigation discharge of the i^{th} plant at the j^{th} irrigation time, and t_{ij} (days) is the time for m_{ij} irrigation. Evapotranspiration in the dry season is higher than in

Table 2. Lower Mekong mainstream monthly discharge 1960 to 2004 ($m^3.s^{-1}$).

Sites / Month	Mainstream sites						
	Chiang Saen	*Luang Prabang*	*Vientiane*	*Nakhon Phanom*	*Mukdahan*	*Pakse*	*Kratie*
January	1,150	1,690	1,760	2,380	2,370	2,800	3,620
February	930	1,280	1,370	1,860	1,880	2,170	2,730
March	830	1,060	1,170	1,560	1,600	1,840	2,290
April	910	1,110	1,190	1,530	1,560	1,800	2,220
May	1,300	1,570	1,720	2,410	2,430	2,920	3,640
June	2,460	3,110	3,410	6,610	7,090	8,810	11,200
July	4,720	6,400	6,920	12,800	13,600	16,600	22,200
August	6,480	9,920	11,000	19,100	20,600	26,200	35,500
September	5,510	8,990	10,800	18,500	19,800	26,300	36,700
October	3,840	5,750	6,800	10,200	10,900	15,400	22,000
November	2,510	3,790	4,230	5,410	5,710	7,780	10,900
December	1,590	2,400	2,560	3,340	3,410	4,190	5,710

Data source [11].

the rainy season and the available water discharge from the Mekong river to the delta is lower in the dry season, therefore this paper focuses on the estimation of the water requirement for the Winter-Spring rice crop.

In this study, the meteorological data for a 10-year series of water requirement calculations are collected from the provincial ueather stations of An Giang, Can Tho, and Soc Trang which serve as three rice production regions that represent the flood plain areas, middle areas, and coastal areas, respectively. Hydrological data for water balance analysis during the dry seasons are collected from the Mekong river commission [10, 11]. The monthly discharge from the hydrological stations of the Lower Mekong mainstream from Chiang Saen (in Thailand) to Luang Prabang, Vientiane, Nakhon Phanom, Mukdahan and Pakse (all in Laos) and Kratie (in Cambodia) is presented in Table 2. The mean monthly discharge flows at Tan Chau and Chau Doc (in Vietnam) are available over the period 1979-1996 as presented in Table 3. The soil texture groups of the surveyed fields are from the Provincial Department of Agriculture and Rural Development. Other secondary data, such as reports, papers, and irrigation water utility events from the upstream countries of the Mekong Basin are reviewed for discussion [12-19].

Table 3. Mean monthly flows at Tan Chau (TC) and Chau Doc (CD) Stations ($m^3.s^{-1}$).

St.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
TC	6,220	3,720	2,600	2,010	2,640	7,180	11,270	16,390	21,140	20,340	15,260	10,180
CD	1,360	700	420	330	460	1,450	2,390	3,970	5,200	5,480	4,700	2,710
Tot.	7,580	4,420	3,020	2,340	3,100	8,630	13,660	20,360	25,430	25,820	19,960	12,800

Data source [12].

Results and discussion

Based on the Penman-Monteith equation (Eq. 2), the reference evapotranspiration ET_o calculation results of An Giang, Can Tho, and Soc Trang provinces during the dry seasons are given in Table 4.

Table 4. The reference evapotranspiration in ETo (mm/day) for 6 months of the dry seasons (data taken from 2008-2017).

Province/city	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
An Giang	3.27	3.04	3.28	4.48	5.43	5.82
Can Tho	3.35	3.16	3.43	4.39	5.21	5.73
Soc Trang	3.32	3.08	3.36	4.35	5.06	5.62

Based on the water balance equations, results from calculated irrigation rate from CROWAT for the Winter-Spring rice crop is 9,500±400 m^3ha^{-1} and the coefficient of irrigation is in the range of 1.36-1.39 $l.s^{-1}ha^{-1}$. When compared with the Vietnamese Standards (TCVN 8641-2011) for the Winter-Spring rice crop in the southern region of Vietnam, the irrigation rate during growing periods should be from 7,500 to 8,000 m^3ha^{-1} [20], excluding the irrigation rate for the land preparation period, which is about 900-1,000 m^3ha^{-1}. The higher calculated irrigation rate can be explained by the higher air temperature in combination with stronger air-wind speeds over the last 10 years resulting in higher evapotranspiration rates, which provides evidence of water insecurity compounded by climate variability.

For other agriculture products (upland crops, aquaculture, and animal husbandry), the water needs are experimentally estimated to be 30-35% [19] of the water amount for rice cultivation or 594-693 m^3ha^{-1}. In general, the total water taken from the MD's river system for nearly 1,360,000 ha agricultural land during the dry season is approximately 2,500-2,600 m^3s^{-1}, which is the minimum requirement for normal yields.

Considering the mean monthly flow discharges of the Mekong river that passes Pakse (Laos), Kratie (Cambodia), Tan Chau (Vietnam), and Chau Doc (Vietnam) during the dry season, it is easy to find that the expected water requirement for irrigation in the MD is greater than the inflows of the Mekong mainstream. Thus, this figure indicates that this water source during the dry season is the greatest limitation to the extension of cultivation areas not only in the MD but also to other upstream countries.

Conclusions and recommendation

Lowland rice consumes much more water than any other crops. Although this study is based on a rough water balance equation that only uses three places (i.e. An Giang, Can Tho and Soc Trang) along the Hau river, the calculated results show that it is impossible to satisfy this huge water amount for the irrigation of all the rice areas in the Mekong river delta in Vietnam during the dry seasons.

There are many future uncertainties for which scenario-based studies might be required. For example, increasing air temperature, higher solar radiation, stronger wind velocity, less precipitation distribution, extended drought and salinity duration, as well as the effects of present and future agricultural transformation are main factors affecting rice planting areas and the growth of rice. Rice and other crop productivity can be damaged by an increasing scarcity of water resources for irrigation in the future.

When the extreme scenario of historical drought and salinity intrusion occurred in 2016, the cultivation areas in the MD were narrowed down by more than 35.5%. If upstream countries continue to develop their mega-irrigation projects with 3-fold larger irrigated areas than what exists currently, the water supply capacity for rice and upland crops in the delta will decrease dramatically.

In view of economic and social aspects, rice farmers in the Delta will pay more money to pump water when the water level and flow discharge of the Mekong River decreases. Accordingly, their income will be further reduced as a consequence of climate change, water diversion, as well as abnormal operation of hydropower dam projects. The rice production areas must be reduced as what has already been elaborated in resolution 120 of the Government of Vietnam because water and food security for the downstream nations will be threated.

Water for farming should be used as efficiently as possible; the water productivity (crop per drop) should increase and the water profitability (income per litre) should also be increased by switching from rice to high-value crops. The development of water saving methods for farmers in parallel with farming systems improvement and cropping patterns adjustment is strongly recommended. Furthermore, strategic solutions on hydro-diplomacy and the legal and institutional aspects of water resource governance on international, regional, and local scales should be promoted to share both water benefits and risks among all the Mekong countries.

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REFERENCES

[1] General Statistical Office (2016), *Statistical Yearbook of Vietnam*, Statistic Publishing House.

[2] S. Benedikter (2014), "Extending the hydraulic paradigm: reunification, state consolidation and water control in the Vietnamese Mekong delta after 1975", *Southeast Asian Studies*, **3(3)**, pp.547-587.

[3] General Statistical Office (2015), *Statistical Yearbook of Vietnam*, Statistic Publishing House.

[4] http://english.vietnamnet.vn/fms/vietnam-in-photos/151545/drought-and-saltwater-attack-mekong-delta.html.

[5] S.J. Zwart and W.G.M. Bastiaansen (2004), "Reviewed of measured crop productivity values for irrigated wheat, rice, cotton and maize", *Agric. Water Management,* **69**, pp.115-133.

[6] FAO Irrigation and drainage paper 24 (1977), *Crop Water Requirements*, Food and Agriculture Organization of the United Nations, Rome, Italy. ISSN 92-5-100279-7.

[7] T.L. Cosslett, P.D. Cosslett (2018), *Sustainable Development of Rice and Water Resources in Mainland Southeast Asia and Mekong River Basin*. Tables 5.2, 5.3, 5.4 and 5.5. Springer Nature, Singapore.

[8] M. Smith (1992), *CROPWAT: a computer Programme for Irrigation Planning and Management*, FAO Irrigation and Drainage Paper No. 46, Food and Agriculture Organization of the United Nations, Rome, Italy.

[9] R.G. Allen, L.S. Pereira, D. Raes and M. Smith (1998), *Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements*, FAO Irrigation and Drainage Paper No.56, Food and Agriculture Organization of the United Nations, Rome, Italy.

[10] P. Steduto, C.H. Theodore, F. Elias and R. Dirk (2012), *Crop yield Response to Water*, FAO Irrigation and Drainage Paper No.66, Food and Agriculture Organization of the United Nations, Rome, Italy.

[11] MRC (2005), *Overview of the Hydrology of the Mekong Basin*, MRC, Vientiane, 73pp.

[12] MRC (2009), *The Flow of the Mekong*, MRC Management Information booklet series No.2. 12pp.

[13] F. Molle (2005), *Irrigation and Water Policies in the Mekong Region: Current Discourses and Practices*, Colombo, Sri Lanka: IWMI, 43pp (Research report 95).

[14] F. Molle and P. Floch (2007), *Water, Poverty and the Governance of Megaprojects: The Thai "Water Grid"*, Mekong Program on Water, Institut de Recherche pour le Développement, International Water Management Institute. Chiang Mai, Thailand. 30pp.

[15] F. Molle and P. Floch (2008), *The "Desert bloom" Syndrome: Irrigation Development Politics and Ideology in the Northeast of Thailand*, Mekong Program on Water, Institut de Recherche pour le Développement. International Water Management Institute, Chiang Mai, Thailand, 29pp.

[16] ADB (2011), *Lao People's Democratic Republic: Northern Community-Managed Irrigation Sector Project*, Technical Report, 81pp.

[17] C. Boualapha, O. Philavong (2011), "Water planning in Lao PDR", *Water in the Green Economy in Practice: Toward Rio+20*, Zaragora.

[18] F. Molle, T. Foran and M. Kakonen (2012), *Contested Waterscapes in the Mekong Region: Hydropower, Livelihoods and Governance*, Earthscan publishing, 448pp.

[19] R. Johnston, T. Try and S. Silva (2013), *Agricultural Water Management Planning in Cambodia*, WMI - ACIAR Investing in water management to Improve Productivity of Rice-Based Farming systems in Cambodia Project.

[20] MONRE (2011), *TCVN 8641:2011: Hydraulic Structures - Irrigation and Drainage Techniques for Provisions Crops*.