Water Consumption Assessment of Mangosteen: A Bottom-Up Approach

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Abstract: A water consumption assessment using a bottom-up approach is applied in this research; the smallest level of water consumption assessment shows the water consumption behavior at the farm level of 55 mangosteen farms in the Khlung District of Chanthaburi Province, Thailand, in the production year 2019. The findings revealed that the average water footprint (WF) was 774.60 m^3/ton, which was divided into a green water footprint of 519.04 m^3/ton and the blue water footprint of 255.56 m^3/ton. Stage 5 was the mangosteen's growth stage that had the highest WF: this stage was the fruit's maturation period, whose WF was equivalent to 41.16% of the yearly water consumption. The WF of mangosteen data for the production year 2019 is a crucial baseline that will enable farmers to understand the actual water consumption in mangosteen production at the farm level. It will be feasible to determine the trend of changing water use, particularly if the mangosteen WF data is regularly gathered each year and it has led to appropriate water consumption planning per the needs of the mangosteen. Furthermore, this research also raised farmers' awareness concerning the water consumption of mangosteen production.

Key-Words: mangosteen, bottom-up approach, farm level, water footprint, water consumption, climate change

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1 Introduction

The global water demand is increasing as the result of urban expansion, climate change, economic development, and population increase, [1]-[3]. Increased demand but limited water supply, [4], is likely to result in water scarcity in the future; therefore, water shortage is a major threat to the sustainable development of many countries, [5]-[7], especially the inadequate supply of fresh water for population consumption due to climate change, [8]-[9]. Agriculture is a sector requiring large quantities of fresh water, i.e., approximately 90% of the global water consumption, [10]-[13]. It is anticipated that the amount of water used for food production will continue to increase in the future, [14], as a result of increases in population and changes in food demand, [15]-[16].

Stemming from the concern for global water resources, the water footprint (WF) has been proposed to evaluate the water consumption for the production of goods, including crop cultivation, [17]-[18]. The WF of a product is the total water consumption throughout that product's supply chain, [10]. The WF for crop cultivation is divided into the green WF, including rainwater consumption, the blue water footprint (blue WF), including surface and groundwater consumption, and the grey water footprint (grey WF), including the freshwater required to assimilate water pollution, [10], [19]-[20]. The results from the WF assessment can indicate the quantity of water used and where that used water has come from, [21].

The WF concept has been applied to the water consumption assessment for various crops such as grains (rice, wheat, and corn), [22]-[25], [7], oil crops (palm and corn) for ethanol production, [26]-[28], vegetables, [29], fruits (apples and grapes), [30]-[32], and other crops (sugar cane and cassava), [33]. There have been no WF studies on fruits in Thailand because fruit trees last many years and have a long harvest period. Therefore, it takes longer and it is more difficult to keep records for grain and field crops. Hence, this study focuses on the WF of the mangosteen production of the Tambol Troknong Community Enterprise (TTCE), Khlung District, Chanthaburi Province using a bottom-up approach, [4], which encompasses the smallest water consumption assessment at the farm level. This assessment covers the water consumption of the mangosteen production throughout 2019. The results of the study revealed the quantities and origins of the water consumption in mangosteen production at the farm level, and this can be used to manage and plan water consumption in mangosteen production to achieve the highest level of sustainability and the greatest benefit during the current climate change and any future water shortage trends.

2 Materials and Methods

2.1 Study Area

TTCE is located in the Troknong subdistrict, Khlung District, Chanthaburi Province. It has a total area of 4,361 ha, with 55 TTCE members participating in the research project. The Troknong subdistrict is an excellent area for mangosteen production, and approximately 70% of the mangosteen produced is exported. Additionally, the Troknong subdistrict is an agricultural area that has been selected as one of Thailand's green agricultural cities.

The process of creating the boundary of the mangosteen farms began with the downloading of a satellite image from Google Earth in 2019 that covered the Troknong subdistrict area and the assigning of coordinates to that image.

The next step involved exploring the boundary of the 55 mangosteen farms in the area, and the data obtained from this area were used to draw the boundary of the mangosteen farms using the satellite image as a base map. Finally, attribute data were created for the mangosteen farms, including farmers' names, addresses, areas, numbers of mangosteen trees, quantities of production, and water consumption data. The boundary of the study area is shown in Fig. 1

2.2 Scope of Analysis

WF is divided into green WF and blue WF, [10]. In this research, WF was calculated from the mangosteen production, where the green WF was the amount of rainfall used in the mangosteen production. The rainfall data were obtained from the rain gauge station, namely Wangsapparos SAO Station, Khlung District, Chanthaburi Province, from August 1, 2018 to July 31, 2019, [34]. The blue WF was the amount of water from natural and irrigated water sources used in mangosteen production. The data were obtained from in-depth interviews with 55 farmers in 2020. The WF calculation in the 2019 production year covered all the stages of mangosteen production from shoot development (August–October 2018), inflorescence development (November–December 2018), flowering (January–February 2019), fruit development (March 2019), and fruit maturation (April–July 2019).

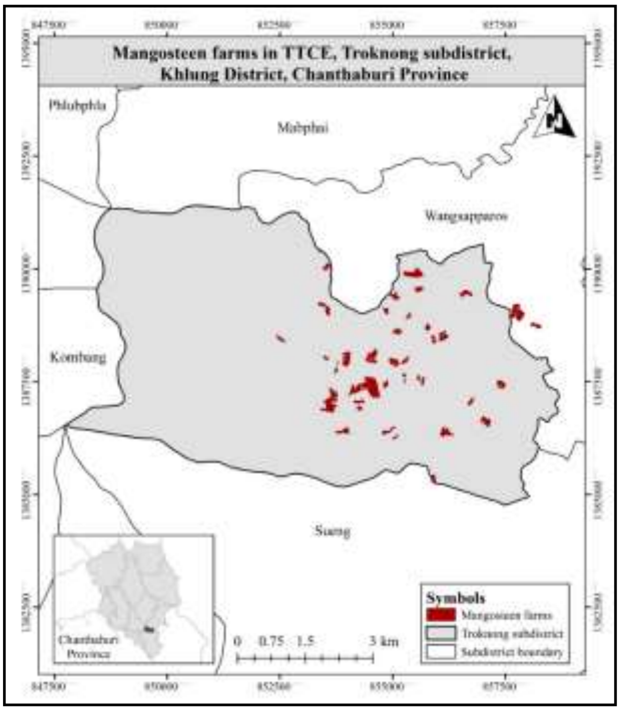


Fig. 1: Study area: 55 mangosteen farms in Tambol Troknong Community Enterprise in Troknong subdistrict, Klung District, Chanthaburi Province, Thailand

The criteria for selecting the 55 farms specified that all the participating farms had to have fruiting trees. Additionally, during the study period, no activity was to be carried out on the farms that affected the land use, such as cutting mangosteen trees or growing other crops other than mangosteen.

2.3 Water Footprint Calculation

The WF calculation for mangosteen production per farm started with the evaluation of mangosteen evapotranspiration (ET) using the crop coefficient (K_c) multiplied by the reference crop evapotranspiration (ET_0), as shown in equation (1), given that K_c was equal to 0.75 and ET_0 was the water consumption of the crop by the Penman–Montieth method, [35].

$$ET_{crop} = K_C \times ET_0 \quad (1)$$

where ET_{crop} was the evapotranspiration of the mangosteen (mm/day), K_c was the coefficient of the mangosteen (mm/day), and ET_0 was the reference crop evapotranspiration (mm/day).

Then, the mangosteen's crop water use (WU_{crop}) was calculated as in equation (2).

$$WU_{crop} = 10 \times \sum_{d=1}^{lgp} ET_{crop} \quad (2)$$

where WU_{crop} was the water consumption of the mangosteen, obtained by the sum of ET_{crop} (mm/day) multiplied by 10 to convert mm to m^3/ha, and lgp was the length of the growing period of the mangosteen (in 365 days), starting from the first day (d = 1) until the 365th day (d = 365).

ET_{crop} was classified into rainwater and the irrigation water requirement by calculating the effective rainfall during the mangosteen growth period and comparing the evapotranspiration with the effective rainfall. If ET > effective rainfall, it meant that the mangosteen required more water than that from rainfall. By contrast, if ET < effective rainfall, it indicated that the demand for irrigation water was 0, i.e., irrigation water was not required because there was sufficient rainfall, [27]. Later, the green and blue WFs were calculated from the ratio of WU_{crop} (m^3/ha) to mangosteen production (ton/ha), as shown in equations (3) and (4).

$$WF_{green} = \frac{WU_{green}}{Y} \quad (3)$$

$$WF_{blue} = \frac{WU_{blue}}{Y} \quad (4)$$

where WU_{green} was the amount of rainwater (m^3/ton) and WU_{blue} was the amount of water from natural sources and the irrigation water used in the mangosteen production (m^3/ha).

Finally, the WF (m^3/ton) was calculated as the sum of the green WF and the blue WF, as shown in equation (5).

$$WF = WF_{green} + WF_{blue} \quad (5)$$

3 Results and Discussion

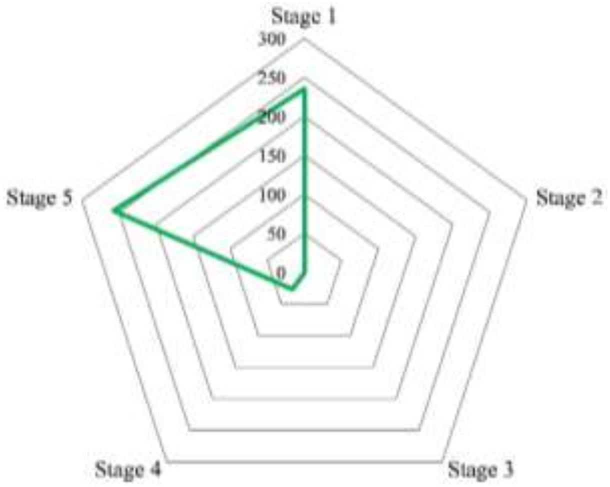
3.1 Basic Information

Mangosteen (*Garcinia mangostana L.*) are large tropical evergreen trees that grow well in tropical climates. The optimum temperature for them is between 25°C–30°C, with a relative humidity of 75%–85%. The soil should have a pH in the range of 5.5–6.5. Mangosteen trees may reach fruit-bearing in as few as seven years, and trees as old as 100 years still produce fruit, [36].

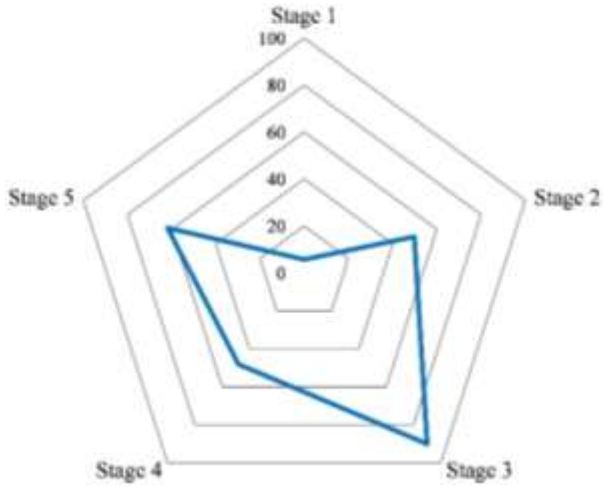
According to the survey in the 2019 production year of all 55 mangosteen farms, a total combined area of 92.74 ha was planted. Farm number 48 had the smallest area (0.16 ha), while the largest farm was farm number 13 (7.36 ha). There was a total of 11,023 mangosteen trees, representing an average planting rate of 118.86 trees/ha. The average age of the trees was 32 years. The youngest mangosteen tree was on farm number 13 (10 years), and the oldest one was on farm number 35 (35 years). The total useful yield was 855,067 kg; however, if fallen fruit (31,120 kg) were included, the average yield was 9,555.85 kgs/ha. Mangosteen cultivation averaged 76.79% in mixed orchards and 23.21% in single plantations. Five types of soils were found on the mangosteen farms: sandy loam (64.29%), loam (21.43%), loamy clay (7.14%), sandy clay (5.36%), and clay (1.78%).

3.2 Average WF in Each Growth Stage of the Mangosteen

In the 2019 production year, the average water consumption of the 55 mangosteen farms in the TTCE in each growth stage was as follows. Stage 1 was shoot development, lasting from August to October 2018. During this period the farmers pruned the branches such that the mangosteen needed water to nourish the branches. It was found that in August 2018, the rainfall was sufficient to meet the needs of the mangosteen trees; thus, there was no need to supply additional water. In September 2018, there was a period of intermittent rainfall that was insufficient to meet the needs of the mangosteen trees. However, after that and until the end of October 2018, there was sufficient rainfall to meet the needs of the mangosteen. Therefore, in Stage 1, the average WF was 241.20 m^3/ton, divided into the green WF of 235.47 m^3/ton and the blue WF of 5.73 m^3/ton. Stage 2 was the inflorescence development, lasting from November to December 2018. During this period, the mangosteen did not need water; this corresponded to areas where there was no rainfall during this period. Although the mangosteen did not need water, the farmers still watered the mangosteen trees because they were used to doing it. If it did not rain, the farmers had to water the mangosteen because they feared that the mangosteen would die. This meant that the water was not utilized. Stage 3 was flowering, lasting from January to February 2019, when the mangosteen needed more water for flowering and yielding. There was no rainfall during this time in the area. The farmers, therefore, had to supply a suitable amount of water for the mangosteen trees. If over-watered, the mangosteen trees could have shed the flowers. The young-fruit development period was in February 2019, when the mangosteen needed more water to nourish the young fruit. As a result, in Stage 3, there was only a blue WF with an average of 90.12 m^3/ton, as shown in Figs. 2a–2b.



(a) The average green WF (m^3/ton)



(b) The average blue WF (m^3/ton)

Fig. 2: The average green WF and the blue WF in each growth stage in the 2019 production year

Stage 4 was the fruit development stage, starting in March 2019, when the mangosteen needed the most water to nurture the fruit. However, the rainfall was insufficient to meet the needs of the mangosteen, so the farmers needed to supply water to the mangosteen. During this period, the average green WF and the average blue WF were 26.57 and 48.08 m^3/ton, respectively. At the end of the production year, Stage 5 was the fruit maturation stage, lasting from April to July 2019. The rainfall was sufficient for the needs of the mangosteen only for one month, May 2019. This month saw the most rainfall in the year, equal to 369 mm, but the mangosteen needed only 95 mm of water. The study found that although this month was rainy, the mangosteen trees in some farms were watered, which was considered excessive. Subsequently, there was a dry spell in June 2019, and there was very little rain in July 2019, resulting in insufficient rainfall to meet the needs of the mangosteen. As a result, the farmers had to supply water to the mangosteen during the last two months before the end of the harvest season. In this last period, the average WF was 318.87 m^3/ton, divided into the green WF and the blue WF of 257 and 61.87 m^3/ton, respectively, as shown in Figs. 2a–2b and Table 1.

3.3 Water Footprint Per Farm

About the WF calculation of each farm, it was found that the farm with the highest WF was farm number 38, with a WF of 2,445.12 m^3/ton. The reason that this farm had a greater WF than the other farms was that it had an area of 0.48 ha and a yield of only 0.75 tons, or 1.56 tons/ha, which was very little compared to that of the other farms with similar areas. For example, farm number 37 had an area of 0.5 ha but yielded 4.6 tons (9.20 tons/ha), and farm number 52 had an area of 0.51 ha and yielded 2.52 tons (4.91 tons/ha). Farm number 38 showed a green WF as high as 2,350.12 m^3/ton, especially during Stage 5 (fruit maturation) when the rainfall was greater than during the other stages. Although the total rainfall was very high, there were dry spells in some months, and the farmers needed to supply water to the mangosteen trees. Therefore, this farm had a blue WF, or irrigation water, equal to 95 m^3/ton. The farms with the second and third highest WFs were farm number 12 (2,354.10 m^3/ton) and farm number 24 (2,042.75 m^3/ton), respectively. These two farms yielded less compared with the cultivated area, resulting in higher WFs compared with the other farms. By contrast, the farm with the lowest WF, 262.58 m^3/ton, was farm number 3. This farm had an area of 0.8 ha and yielded up to 15.25 tons, or 19.06 tons/ha; this was considered to be the farm with the highest yield per area, as shown in Table 1. According to the data collection and the interview with the farmer who owned mangosteen farm number 3, it was found that the farmers were knowledgeable and applied various technologies to take good care of the mangosteen trees, both watering them and using fertilizers. Furthermore, this farm had an abundant water source and had also won the first prize in the Chanthaburi province mangosteen competition. This was a very good indication that this farm could effectively manage the mangosteen plantation.

Table 1 shows the WF for each of the mangosteen's growth stages. It was found that Stage 2 (inflorescence development), which lasted from November to December 2018, was the stage during which the mangosteen did not need water due to flowering. If watered, the mangosteen may have shed flowers, which corresponded to the period when there was no rainfall in the area. However, although the mangosteen did not need water during this time, it was found that the mangosteen trees were watered on 46 farms (83.64%) when considering the blue WF. There were only nine farms, or 16.36%, on which the mangosteen was not watered. This indicated that the majority of the farmers continued to supply water according to their previously practiced patterns and due to their concerns that if they were not watered, the mangosteen could die, without considering any real need and the fact that the mangosteen did not need water. Additionally, the farmers did not take advantage of the weather forecast from the Meteorological Department. If the farmers had used rainfall forecasting data for planning the mangosteen watering, they would have saved water, which would have also helped to reduce production costs. Stage 1 was the shoot development period, lasting from August to October 2018. During this period, there was rainfall in the area, and there was a sufficient supply to meet the needs of the mangosteen. However, 10 farms supplied water to the mangosteen (blue WF), such as farms number 10, 11, and 12, which exceeded the needs of the mangosteen and possibly affected the growth and yield of mangosteen.

Stage 3 was the flowering stage, lasting from January to February 2019. The mangosteen needed water to nourish the flowers and young fruit during this period. However, there was no rain in the area, so all the farms had to supply water to the mangosteen (blue WF), especially farm number 37, with a blue WF of 344.35 m^3/ton. Although this farm had an area of only 0.50 ha, the water consumption was high compared with the other farms in the same stage, indicating a lack of planning for watering the mangosteen. Stage 5 was the fruit maturation period, lasting from April to July 2019 for four months, the longest stage. According to the rain data in the area, it was found that May had had the most rainfall, and it was sufficient to meet the needs of the mangosteen. In other months, the farmers had to supply water to the mangosteen until the full harvest in July (Table 1).

4 Conclusion

This research is a WF estimate of the mangosteen production at the farm level covering all growth stages of the 2019 production, from August 2018 to July 2019. Stage 5 (fruit maturation) had the highest WF of 41.16%, followed by Stage 1 (shoot development) at 31.14%, Stage 3 (flowering) at 11.63%, Stage 4 (fruit development) at 9.64%, and lastly, Stage 2 (inflorescence development) at 6.42%. Considering the details of the WF at each stage, it was found that there were some stages during which the farmers supplied water to the mangosteen, not complying with the needs of the mangosteen. For example, water was not required during Stage 2 (inflorescence development) despite the lack of rainfall in the area. However, it was found that the farmers on 46 farms, or 83.64%, watered the mangosteen nonetheless. This indicated that the vast majority of farmers continued to supply water according to their previously practiced patterns. The interviews with the farmers indicated that they were concerned that if they did not water, the mangosteen would die and not yield fruit. It is important to provide knowledge on water management and planning according to the principles and the needs of mangosteen at each growth stage. It may take time for farmers to adjust their behaviors away from watering according to their habits and toward the water to meet the needs of the mangosteen. Additionally, farmers should be encouraged to use the weather forecast application of the Meteorological Department to help them plan to water according to the climate and to not exceed the needs of the mangosteen. As a result, they could save electricity from water pumping and reduce the production costs, as well as the water consumption, in mangosteen production.

The study on the WF of the 2019 mangosteen production in the TTCE was the first study of its kind, and it has raised awareness for farmers in terms of water consumption in mangosteen production. It has also raised awareness of using an appropriate amount of water as a production resource. Another benefit has been that it has promoted green agriculture and worthwhile water consumption, with a minimum impact on the environment.

Table 1. WF in each growth stage of TTCE in the 2019 production

Farm no.	Area (ha)	Yield (kg)	green WF (m^3/ton)						blue WF (m^3/ton)						Total WF (m^3/ton)
			Stage1	Stage2	Stage3	Stage4	Stage5	Total	Stage1	Stage2	Stage3	Stage4	Stage5	Total	
1	2.82	28,000	167.54	0	0	18.91	182.86	369.31	0	11.79	88.39	70.71	0	170.89	540.20
2	1.28	15,250	139.82	0	0	15.78	152.61	308.21	0	16.79	32.17	20.98	41.97	111.91	420.12
3	0.80	15,250	87.39	0	0	9.86	95.38	192.63	0	10.49	20.11	13.11	26.24	69.95	262.58
4	1.04	7,167	241.73	0	0	27.28	263.84	532.85	0	60.72	60.72	30.36	30.37	182.17	715.02
5	1.47	25,520	96.10	0	0	10.84	104.87	211.81	0	31.35	39.18	19.60	39.18	129.31	341.12
6	0.64	11,900	89.59	0	0	10.12	97.78	197.49	0	16.26	73.17	45.50	0	134.93	332.42
7	2.40	18,020	221.87	0	0	25.04	242.15	489.06	33.30	33.30	33.30	16.64	183.13	299.67	788.73
8	5.00	32,500	256.29	0	0	28.92	279.72	564.93	0	0	30.77	15.38	15.39	61.54	626.47
9	0.64	2,200	484.62	0	0	54.69	528.92	1,068.23	0	227.27	136.37	0	0	363.64	1,431.87
10	1.28	6,600	323.08	0	0	36.46	352.62	712.16	136.36	17.05	136.36	102.27	102.27	494.31	1,206.47
11	1.36	21,300	106.37	0	0	12.00	116.09	234.46	11.17	31.93	25.54	12.77	0	81.41	315.87
12	4.00	8,100	822.65	0	0	92.84	897.87	1,813.36	37.04	148.15	148.15	74.07	133.33	540.74	2,354.10
13	7.36	87,000	140.93	0	0	15.90	153.82	310.65	0	0	36.78	18.39	0	55.17	365.82
14	2.24	32,500	114.82	0	0	12.96	125.31	253.09	0	0	30.52	0	30.53	61.05	314.14
15	0.32	5,555	95.96	0	0	10.83	104.74	211.53	0	86.41	86.41	43.20	100.81	316.83	528.36
16	0.32	3,140	169.77	0	0	19.16	185.29	374.22	5.95	14.86	23.78	14.86	0	59.45	433.67
17	4.16	60,006	115.49	0	0	13.03	126.05	254.57	0	4.33	15.17	10.83	32.50	62.83	317.40
18	1.60	5,500	484.62	0	0	54.69	528.92	1,068.23	0	106.36	141.82	70.91	70.91	390.00	1,458.23
19	0.77	10,460	122.31	0	0	13.80	133.50	269.61	0	11.47	34.42	22.95	0	68.84	338.45
20	0.64	7,300	146.05	0	0	16.48	159.40	321.93	0	31.23	39.04	26.03	0	96.30	418.23
21	1.28	13,060	163.27	0	0	18.43	178.20	359.90	0	49.00	49.00	36.76	0	134.76	494.66
22	0.64	7,040	151.44	0	0	17.09	165.29	333.82	0	90.91	90.91	68.18	0	250.00	583.82
23	1.76	4,500	651.54	0	0	73.53	711.11	1,436.18	0	0	266.67	133.33	133.33	533.33	1,969.51
24	0.72	1,700	705.55	0	0	79.62	770.05	1,555.22	0	125.18	230.59	131.76	0	487.53	2,042.75
25	0.80	10,240	130.15	0	0	14.69	142.04	286.88	0	39.06	39.06	19.54	39.06	136.72	423.60
26	3.20	55,600	95.88	0	0	10.82	104.64	211.34	0	35.97	53.96	26.98	53.95	170.86	382.20
27	0.80	14,080	94.65	0	0	10.68	103.31	208.64	59.09	49.24	78.79	59.09	118.18	364.39	573.03
28	1.28	20,680	103.11	0	0	11.64	112.54	227.29	0	10.52	23.68	13.15	13.15	60.50	287.79
29	0.80	6,100	218.47	0	0	24.66	238.45	481.58	0	65.57	65.57	32.80	122.95	286.89	768.47
30	1.76	23,000	127.47	0	0	14.39	139.13	280.99	0	45.91	91.83	45.91	0	183.65	464.64
31	2.08	26,000	133.27	0	0	15.04	145.45	293.76	0	72.00	96.00	48.00	0	216.00	509.76
32	0.32	2,350	226.84	0	0	25.60	247.58	500.02	0	0	271.28	143.62	191.49	606.39	1,106.41
33	0.26	4,280	99.64	0	0	11.24	108.75	219.63	0	0	119.16	63.08	84.12	266.36	485.99
34	0.56	5,030	185.47	0	0	20.93	202.42	408.82	12.52	50.10	50.10	25.05	0	137.77	546.59
35	0.64	10,200	104.52	0	0	11.80	114.08	230.40	0	37.65	37.65	18.82	43.92	138.04	368.44
36	3.50	25,300	230.46	0	0	26.00	251.53	507.99	0	27.67	55.33	27.67	77.47	188.14	696.13
37	0.50	4,600	181.07	0	0	20.44	197.63	399.14	0	344.35	344.35	172.17	172.17	1,033.04	1,432.18
38	0.48	750	1,066.16	0	0	120.32	1,163.64	2,350.12	15.00	0	15.00	15.00	50.00	95.00	2,445.12
39	0.96	8,060	198.42	0	0	22.39	216.56	437.37	0	49.13	98.26	49.13	98.27	294.79	732.16
40	0.77	6,500	196.83	0	0	22.21	214.83	433.87	0	29.54	29.54	14.77	18.46	92.31	526.18
41	1.60	26,600	100.21	0	0	11.31	109.36	220.88	4.51	24.06	24.06	12.03	0	64.66	285.54
42	0.80	10,500	126.92	0	0	14.33	138.53	279.78	0	11.43	22.86	11.43	15.99	61.71	341.49
43	1.28	8,064	264.42	0	0	29.84	288.60	582.86	0	38.10	76.19	38.10	114.28	266.67	849.53
44	3.30	22,100	248.45	0	0	28.04	271.16	547.65	0	71.68	71.67	35.84	83.62	262.81	810.46
45	4.80	44,200	180.91	0	0	20.42	197.45	398.78	0	52.13	52.13	26.06	60.81	191.13	589.91
46	5.76	46,288	207.30	0	0	23.39	226.25	456.94	0	0	11.95	8.96	6.72	27.63	484.57
47	1.47	22,300	109.96	0	0	12.41	120.02	242.39	0	8.25	41.26	20.63	61.88	132.02	374.41
48	0.16	1,575	169.23	0	0	19.10	184.70	373.03	0	29.63	63.49	31.75	31.75	156.62	529.65
49	1.00	11,050	150.76	0	0	17.01	164.54	332.31	0	21.72	43.44	21.72	21.72	108.60	440.91
50	1.28	5,564	383.24	0	0	43.25	418.27	844.76	0	220.85	441.70	220.85	165.63	1,049.03	1,893.79

Table 1. WF in each growth stage of TTCE in the 2019 production (con.)

Farm no.	**Area (ha)**	**Yield (kg)**	**green WF (m^3/ton)**						**blue WF (m^3/ton)**						**Total WF (m^3/ton)**
			Stage1	**Stage2**	**Stage3**	**Stage4**	**Stage5**	**Total**	**Stage1**	**Stage2**	**Stage3**	**Stage4**	**Stage5**	**Total**	
51	2.56	10,128.00	421.07	0	0	47.52	459.57	928.16	0	121.33	121.33	0	90.99	333.65	1,261.81
52	0.51	2,515.00	339.14	0	0	38.27	370.14	747.55	0	19.09	50.89	25.45	0	95.43	842.98
53	1.12	7,160.00	260.58	0	0	29.41	284.41	574.40	0	87.34	187.15	93.57	93.58	461.64	1,036.04
54	1.78	12,800.00	231.35	0	0	26.11	252.50	509.96	0	50.00	50.00	25.00	93.75	218.75	728.71
55	2.08	3,005.00	266.10	0	0	30.03	290.42	586.55	0	0	359.40	299.50	539.10	1,198.00	1,784.55
Sum	92.74	886,187.00	12,950.85	0	0	1,461.55	14,134.89	28,547.29	314.94	2,737.17	4,956.42	2,644.26	3,402.97	14,055.76	42,603.05
Average	1.69	16,112.49	235.47	0	0	26.57	257.00	519.04	5.73	49.77	90.12	48.08	61.87	255.56	774.60

Remark: Stage 1 shoot development (August–October 2018), Stage 2 inflorescence development (November–December 2018), Stage 3 flowering (January–February 2019), Stage 4 fruit development (March 2019), and Stage 5 fruit maturation (April–July 2019)

This study's limitation is the retrospective farmer interviews on the water consumption of mangosteen, as a result, the data collected might be inaccurate. Consequently, to collect more precise data on the water consumption of mangosteen, the farmers should record the actual water used to cultivate mangosteen in a record form. This will increase the accuracy and reality of the results of the water usage calculation. In addition, durian, a crop that requires a lot of water, is another significant crop in the TTCE. Studying the WF of durian is also worthwhile. TTCE will be able to control water usage appropriately and will have total crop water consumption data. Finally, this study focuses on the water consumption of mangosteen in the production year 2019. Therefore, the annual WF of mangosteen production should be gathered to analyze and plan for the water consumption of mangosteen in the future to cope with climate change.

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