Assessment of the Aquacultural Water Demand in the Long Xuyen Quadrangle An Giang, Vietnam

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Abstract Aquaculture in the Long Xuyen Quadrangle-An Giang (LXQ-AG), has drawn a lot of interest due to the favourable conditions of the area and therefore it has experienced significant development by local people. Products from aquaculture are crucial in the healthy nutrition and they possess a great export value, improving the living standard of local people. However, aquaculture may be unsustainable due to many reasons, such as eliminating significant water resources via pollution. In the LXQ-AG, aquaculture competes for the vital, limited water resources with irrigation that supports rice cultivation. This competition has not received proper attention yet. Therefore, the total water demand for the aquaculture sector should be calculated to ensure the sustainability and potential development of both aquaculture and irrigation. The open-water evaporation model of Penman was used to calculate evaporation losses from ponds, various assumptions were made to estimate the water required to flush the ponds. The result shows that the total water demand was 2,188 million $m^3 yr^{-1}$ in 2015. It is estimated that in 2020, aquacultural water demand will be 18,140 million $m^3 yr^{-1}$, an increase by a factor of 8.29. The main reason for this rise is that the local managers expect the catfish farming area to increase by 80%, and farm operators are expected to apply the "VietGAP standards". The study showed that the inevitable evaporative losses are negligible in the total water demand of aquacultural ponds. Therefore, it is straightforward to reduce the future water demand by adopting water-saving operating procedures in the dry season.

Keywords: Vietnam, An Giang Province, evapotranspiration, aquaculture, Penman equation

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1. Introduction

The Long Xuyen quadrangle area (LXQ) situated North of the Mekong delta is the first receiver of the freshwater resources of the Mekong River system as the rivers flow from Cambodia into Vietnam. Flow is split between two major rivers: the Tien and Hau rivers (Figure 1). The general abundance of water resources creates preferable conditions for freshwater fish farming.

The part of LXQ inside An Giang province (LXQ-AG) has a land area of 3,537 km^2. It is quite low and flat, over 80% of the natural area within elevation range of 1m; 10% of the total area classifies as mountainous [1]. LXQ-AG has a vast river and channel network with a total length of 5,500 km covering most of the province. River and channel density of the whole province reaches 1.6 km/km^2. The advantage provided by the sufficient amount of available water resources decreases further from the main rivers, especially the upland area of Seven Mountains. Canals take water from the Hau River to remote areas suffering from the lack of freshwater, yet these do not have the forwarding capacity of the natural stream network. As such isolated areas mean only a smaller fraction of LXQ-AG, aquaculture has good potential in most districts, except in the Tri Ton and Tinh Bien in the Seven Mountains [2]. The consequent development of aquaculture is threatening water resources seriously in recent years, as the growing aquacultural water consumption does not respect the water demands of other sectors and is already out of balance with the regional irrigation planning strategy [3]. Therefore, an integrated approach covering both irrigational and aquacultural water demands is indispensable. The irrigational water demand has been assessed by Tran and Honti [4].

While water resources on the regional and annual scales are at present still sufficient, there are seasonal problems. In fact, the water resources in the dry season are very limited and of declining quality. The cause of this phenomenon is that most of the canal system was planned and constructed for rice cultivation and navigation. The water demand of aquaculture was not considered. Channel design flow capacities cannot keep up with the rapid increase of aquaculture area [5]. Contaminated canals affect the self-purification ability of the system and threaten the sustainability of the fishery. This is a really difficult problem for the water managers in An Giang province.
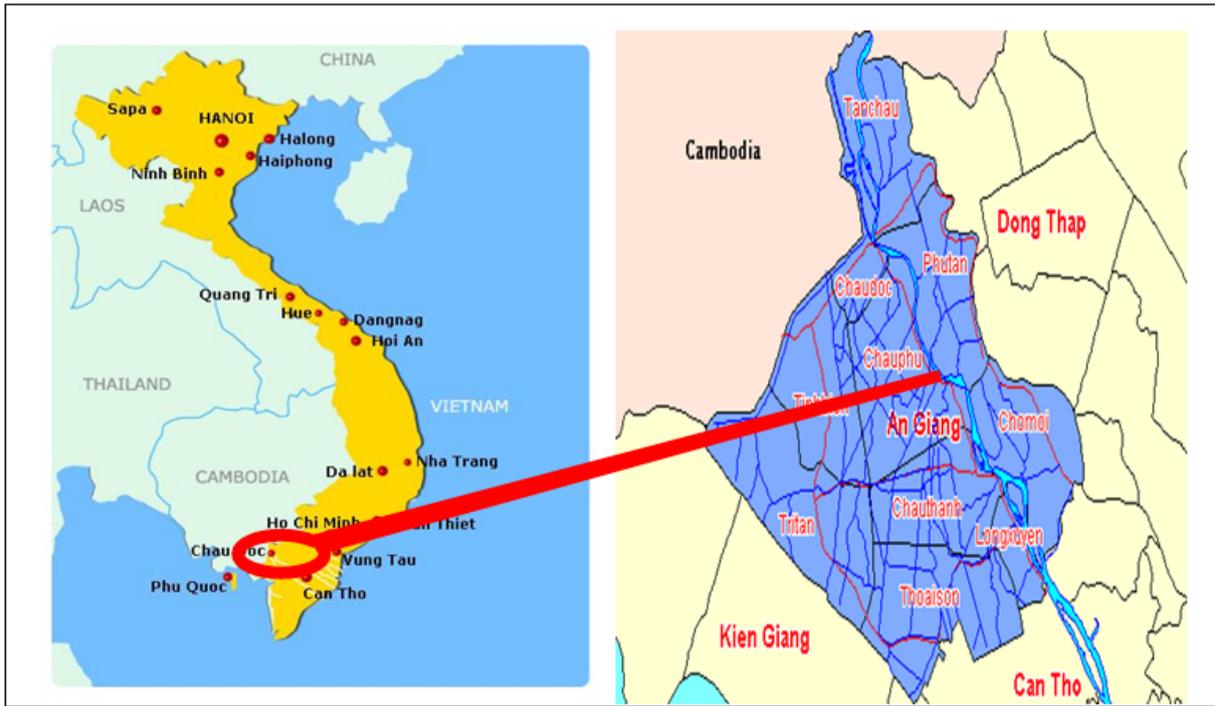
Figure 1. Vietnam (left) and location of LXQ-AG (right)

2. General Situation on Aquaculture in An Giang Province

Over the past 10 years, in the process of modernization and persistence of economic restructuring in agriculture, An Giang province continues to benefit from the development in the aquaculture and related sectors in general. With favorable natural conditions, breeding freshwater fish is not too difficult, and therefore aquaculture in An Giang province has developed strongly and the region is now one of the leading provinces of the nation in terms of output and export revenue of aquatic products, especially catfish (*Pangasius spp.*). From being sold in some domestic markets to exporting into the whole World, "Vietnam pangasius" became a trademark, and is consumed in most of the continent [6].

In 2005, the total area of aquaculture in the province was 1,836 ha, of which 770 ha was catfish farming. In 2015, the total area of aquaculture was 2,456 ha (an increase of 619 ha compared to 2005), of which fish farming for export was 1,845 ha, fish breeding was 610 ha [7]. The water surface area for aquaculture in 2017 was 2,475 ha, the output was 262 thousand tons (increase 5.9% compared to 2016). In 2017 pangasius farming area in the province reached 1,295 ha, increase 1.09% over 2016. Catfish output in 2017 was estimated at 285 thousand tons, an increase of 18 thousand tons compared to 2016 [8].
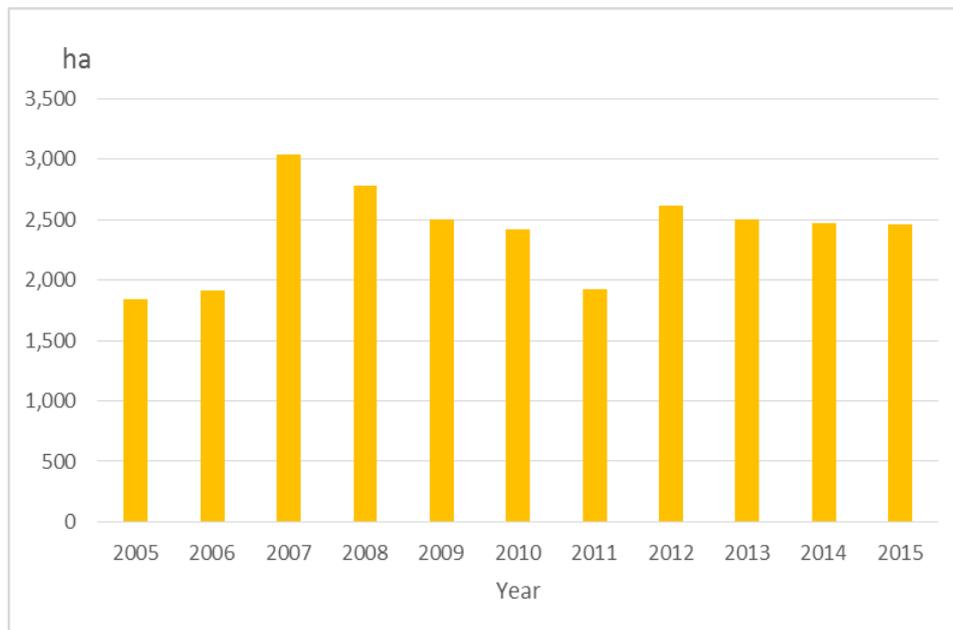

Figure 2. The area of aquaculture in An Giang province in the period of 2005-2015. **Source:** An Giang Statistical Office

However, along with the rapid development, the initial effectiveness and profitability of the aquaculture sector is facing a decline. One of the biggest difficulties is that the polluted water has begun to affect the efficiency of production. The ever increasing pressure on water resources of LXQ-AG highlights the importance of rational planning relying on scientific support. As the boom of aquaculture is a relatively recent phenomenon, planning of new fish farms should ideally strive to avoid resource competition with other, established sectors, such as rice farming, by applying scientifically proven methods to reduce the overall water demand and to reduce pollution. However, such aspects are not considered when decisions are made solely on the basis of economic aspects. The Ministry of Agriculture and Rural Development plans a total aquaculture area of 6,276 hectares by 2020. Of which there would be 1,430 hectares of catfish farming [9]. At present, the provincial People's Committee has promulgated many policies, including the plan of aquaculture production areas of application high technology in the period 2020-2030, indicating that the province should focus on raising aquaculture export, apply advanced fish farming techniques [10]. Therefore, the water demand for the fishery sector is likely to increase significantly more than that of conventional aquaculture.

Therefore, this paper provides detailed water demand calculations for the aquaculture sector in An Giang province, hoping to contribute to local support for the design calculations of upgrading the channel system.

3. Methods

Water demand for aquaculture depends on season, types of fish and farming methods. The majority of farmers in LXQ-AG breed catfish using traditional methods, in 2 growing turns annually, wherein each turn lasts 5-6 months. Fingerling production lasts 90 days. The depth of the pond for catfish and fingerling production is between 1.5-2 m. People who raise fish for export need to refresh the water every 10 days, each time changing 33-50% of the initial volume of water. For fingerling production, water is changed weekly; and every time the 50% of the initial water volume is changed [11].

The VietGAP (Vietnamese Good Agricultural Practice) program was initiated in 2008 and promotes the production of clean and safe food products [12]. This long-term initiative includes the aquaculture sector too, and aims to meet the trend of market requirements, to enhance the value chain for fish farming from the farm to the table, and to contribute to catfish farming development and lasting production stability. It aims to provide steady, guaranteed benefits for farmers as well as the processing and export sectors and is the basis for the requirement for Pangasius farmers in the country to move towards the implementation of international standards such as GlobalGAP, BAP, ASC. From the definition of the VietGAP objectives it is obvious that food safety and economic aspects dominate and environmental sustainability does not even appear among the principal targets.

Currently, 30% of the fish farming area applies the VietGAP model. It requires deeper ponds (2-3 meters), and changing one third of the water every day. These requirements increase the water demand of catfish farming significantly compared to traditional farming practices. In 2020, it is expected that the area applying the VietGAP standards will increase to 80% [13]. To calculate the water demand of aquaculture over the entire LXQ-AG area with the current and expected future extent and practices, a precise breakdown is required. Thus, we assess the following components (each normalised to mm, which is equivalent to 10 m^3 per 1 ha pond area):

The water needed for renovating the pond before stocking: the pond needs to be filled up to a depth of 0.3 to 0.5 meters, left soaking for 5 to 7 days, and finally drained completely.

$$Q_{renovating} = 500. \tag{1}$$

The amount of water required to fill the pond (to 2 m depth):

$$Q_{fill} = 1000H \tag{2}$$

where H is the pond depth [m].

The total amount of refreshing water required during a cultivation turn:

$$Q_{rep} = n.a_i \tag{3}$$

where a_i is the amount of water to be refreshed at once (mm); where n is the number of required refreshments

The total water demand for aquaculture for year (assuming 2 turns annually):

$$Q_{total} = 2[Q_{renovating} + Q_{fill} + Q_{rep}] - H_{rain} + Ei + Sp \tag{4}$$

Where: H rain is the annual rainfall depth; E_i is the evaporative loss per year; Sp is water losses by seepage per year.

The area-specific constituents of total water demand are calculated for both the traditional and VietGAP farming methods. Each is multiplied with the actual/estimated cultivation area to get the total water demand of aquaculture in the entire LXQ-AG. While renovation and refreshing demands depend entirely on the farmer's decision on the breeding method, traditional farming or VietGAP standard, the water required in the pond depends on the pond bathymetry and desired depth, yet these constituents can be estimated quite well based on usual practices. The most complicated term is the loss through evaporation, which requires a model to calculate. We use the Penman model to estimate the evaporative loss.

Open water evaporation serves as a convenient index of the evaporation demand of a particular climate [14] and, plays an important role not only in the water budget of a lake, reservoir or wetland, but also in the energy budget. In these open water bodies, evaporation is the major component of water balance which generally, has rarely been measured directly especially in developing countries [15]. Huge amount of sensible heat flows from adjacent warm-hot dry lands (large amount of advection energy flux density) and increases the evaporation rate of free surface water bodies drastically. Therefore, it is very difficult to estimate evaporation of open water using ordinary methods. In this study, the latent heat flux (mm d^{-1}) of the small wet patch (representing ponds used for aquaculture) is defined by the open water evaporation equation of the Penman (1948) equation:

$$E_p(\frac{mm}{month}) = \frac{\Delta(Ta)}{\Delta(Ta)+Y}R_n + \frac{Y}{\Delta(Ta)+Y}f_u(e^* - e_a) \quad (5)$$

where R_n = net radiation in evaporation equivalents (mm d^{-1}); T_a (K) is the air temperature over the drying land surface, e_a is the actual vapor pressure (hPa), e* is the saturation vapor pressure (hPa) at T_a, and f_u is the wind function, traditionally expressed as [16]:

$$f_u(m/s) = 0.26(1 + 0.54u_2) \quad (6)$$

where u_2 is the wind speed (m/s) at 2 m above ground. We calculate open water evaporation for each month according to both the 2015 conditions and the expected mean weather in 2020 using the climate change scenario of An Giang province in 2020 [1]. Water that is lost vertically through the bottom of the pond, horizontally through the dikes by infiltration, and through the drainage system of the pond is called seepage water. How to calculate water losses caused by seepage for ha/year:

$$S_p(m^3) = R_{Sp} \times 10,000(m^2) \times 360(day). \quad (7)$$

According to FAO, R_{Sp} (m/day) is the rate of seepage losses in millimetres per day (mm/day) from loam in one day will average 14 mm (from 8 to 20 mm/day) or 0.014 m/day [17].

4. Results and Discussion

The amount of annual evaporation (E_p) was estimated as 1,697 mm/year, which is an equivalent of 4.64 mm/day. The months of high evaporation were dry months from February to May, evaporation ranged from 4.9-5.6 mm/day. The parameters used in evaporation calculations is shown in Table 1, the results are shown in Table 2.

The total area of ponds in 2015 in LXQ-AG was 2,500 ha. The total water demand of VietGap standard was 3,117,513 m^3/ha/year, which is 10.48 times higher than that of traditional farming (297,513 m^3/ha/year). The study of Southern Irrigation Institute found, that the water demand for 1 ha of aquaculture was 304,000 m^3/ha/year [18]. This value is equivalent to our results. In 2020, according to the plan of the Ministry of Agriculture & Rural Development, 80% of the water surface area will be managed according to the VietGAP standards, and the projected water surface area for aquaculture will be 7,540 ha. The water need for aquaculture for 1 ha pond area in 2020 will increase the by a negligible 4,000 m^3/ha/year compared to 2015 (Table 3). This increase is mainly due to the change in evapotranspiration from 4.46 mm/day in 2015 and is expected to increase to 5.5 mm/day in 2020. This means that, climate change wouldn't alter the evaporation losses amount significantly.

Table 1. Meteorological parameters used in the Penman equation

Months	Relative humidity (%)	T_a (K)	e*	R_n (mm d^{-1})	Y (hPa K^{-1})	Δ
January	74	297.75	0.326	4.537	0.674	0.143
February	79	298.65	0.309	5.073	0.674	0.144
March	79	300.65	0.345	5.804	0.674	0.159
April	80	301.85	0.362	5.570	0.674	0.167
May	79	301.55	0.366	5.585	0.674	0.168
June	83	301.05	0.332	4.500	0.674	0.162
july	81	301.45	0.336	4.418	0.674	0.160
August	80	301.05	0.342	4.856	0.674	0.161
September	81	301.05	0.336	3.605	0.674	0.160
October	81	300.05	0.336	4.885	0.674	0.160
November	80	301.15	0.310	4.696	0.674	0.147
December	77	299.95	0.313	4.223	0.674	0.143

Table 2. Monthly estimated open water evaporation

Months	u_2 =wind speed m/s	f_u =0.26 (1+0.54u$_2$) (m/s)	E_p(mm/day)	E_p(mm/month)
January	0.104	0.274	4.372	133.101
February	0.127	0.277	4.900	149.154
March	0.127	0.277	5.628	171.319
April	0.115	0.276	5.398	164.327
May	0.138	0.279	5.415	164.847
June	0.173	0.284	4.341	132.134
july	0.185	0.285	4.259	129.640
August	0.138	0.279	4.685	142.612
September	0.162	0.282	3.449	104.997
October	0.127	0.277	4.713	143.459
November	0.127	0.277	4.522	137.668
December	0.127	0.277	4.054	123.403

Table 3. Water demand for the Pangasius farming and Fingerling production (m³/ha/year)

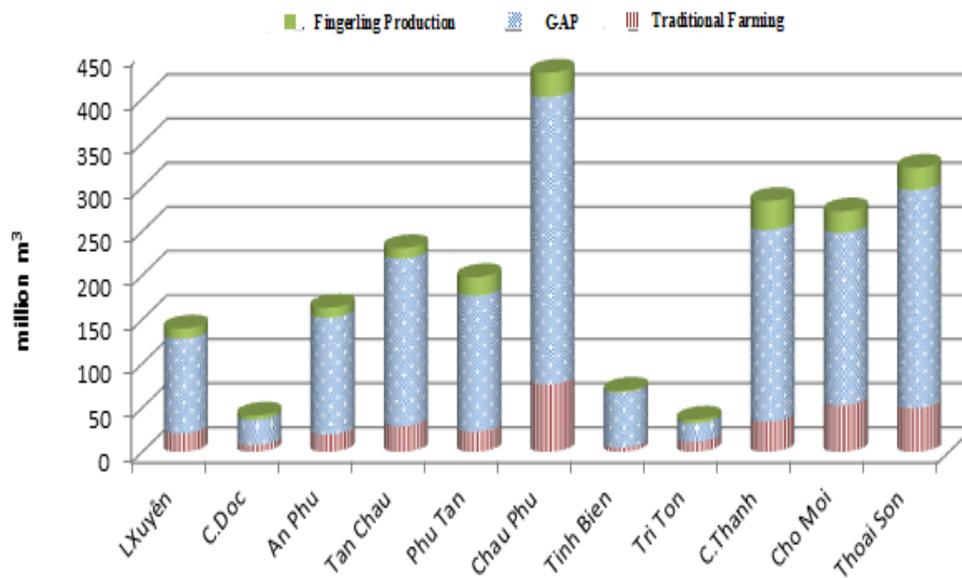|	2015		
	Traditional Farming	**Farming by GAP**	**Fingerling Production**
$Q_{renovating}$	10,000	10,000	10,000
Q_{fill}	40,000	60,000	40,000
E_p	14,113	14,113	8,468
S_p	50,400	50,400	50,400
Q_{Rep}	200,000	3,000,000	240,000
Q_{rain}	17,000	17,000	17,000
Total	**297,513**	**3,117,513**	**331,868**
	2020		
$Q_{renovating}$	10,000	10,000	10,000
Q_{fill}	40,000	60,000	60,000
E_p	18,250	18,250	10,950
S_p	50,400	50,400	50,400
Q_{Rep}	200,000	3,000,000	1,800,000
Q_{rain}	17,000	17,000	17,000
Total	**301,650**	**3,121,650**	**1,914,350**

Figure 3. Total water demand for aquaculture by districts in 2015
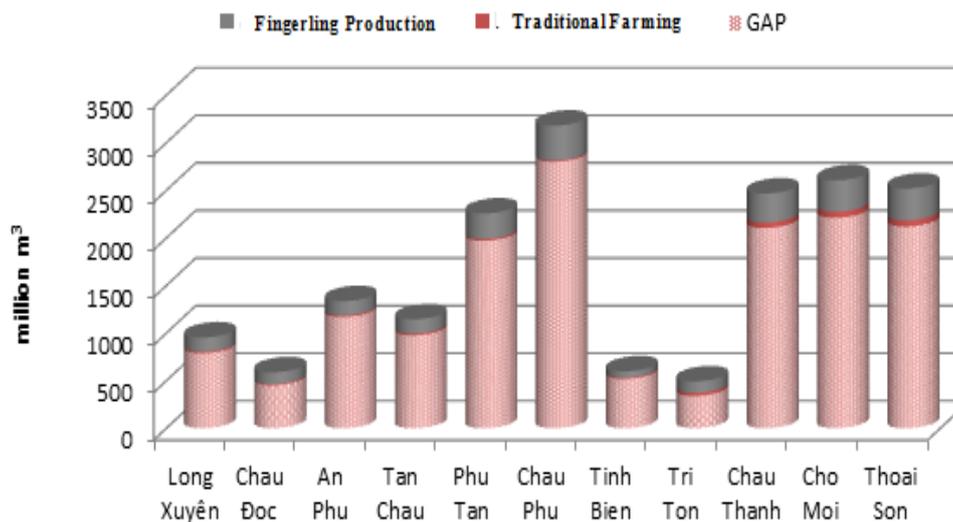

Figure 4. Total water demand for aquaculture by districts in 2020

The district with the highest water need is Chau Phu (429.47 million m³). Most of the households in Chau Phu live by catfish farming. Following Chau Phu district are Thoai Son, Chau Thanh, Cho Moi, and these districts have water demand nearly the equal of volume and are, respectively, 321.88; 284.33; and 272.44 million m³. Next are the Tan Chau, Phu Tan, and An Phu districts and Long Xuyen city, water demand in the range 139.78-230.89 million m³. Three districts have insignificant water demand for aquaculture: Tri Ton, Tinh Bien districts and Chau Doc town. The reason for this is that the canal system does not circulate the water, so flow does not reach the interior canals. Aquaculture is facing many difficulties in these districts due to lack of water (Figure 3).

Figure 4 shows the results of the water demand for aquaculture in 2020 by districts. The district with the highest water demand is still Chau Phu district, total water demand in 2020 is 3,180 million m³, an increase of 7.4 times compared to 2015. Then following Chau Phu are Cho Moi, Thoai Son, Chau Thanh, Phu Tan districts, with water demand 2,605; 2,518; 2,467; 2,257 million m³ respectively, an increase from 7.84 to 11.75 times compared with the water demand in 2015. The remaining districts have water requirements that are lower than these districts, but the water demand will still rise from 4.97-14.28 times more than in 2015.

Considering pond dimensions, pond operation guidelines and the estimated evaporation, the total water demand of aquaculture in LXQ-AG was 2,188 million m³yr⁻¹ in 2015. Out of this huge amount evaporation is responsible for only 2%, so pond operating guidelines are practically the sole determinants of the aquacultural water demand. Total area for aquaculture in LXQ-AG in 2020 is expected to increase to 7,540 ha due to promoted development of this sector. Therefore, water demand of the expanded aquaculture sector with the new Viet-GAP operating standards [12] may exceed 18,140 million m³yr⁻¹, an increase of 8.29 times compared to 2015 (Figure 5).
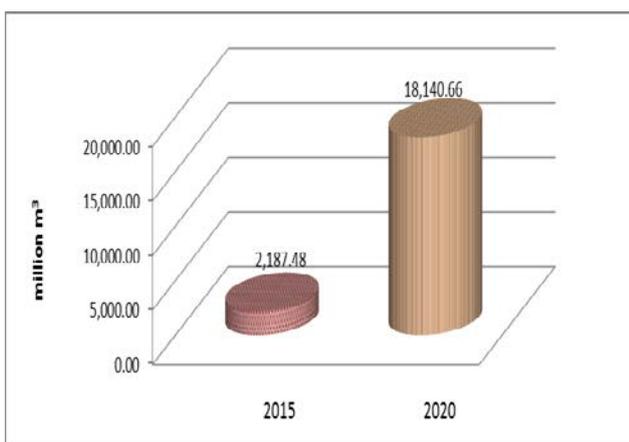

Figure 5. Total water demand for aquaculture in 2015 and 2020

5. Conclusions

Based on the analysis of aquaculture operating procedures, namely the present practice and the Vietgap standards, we showed that evaporative losses are negligible compared to the total water demand of catfish farming ponds. Therefore we concluded that the water demand can be potentially reduced by adapting water-saving operating procedures in the dry season.

Through the calculation of water demand, the province can take the initiative in examining and assessing the conveying capacity of canal systems. From there, there are plans to repair, dredge, and classify drainage and sewerage areas accordingly.

And our suggestion is that new fish farms should be planned into districts where water resource pressure is not critical, or restrict fish farms to the vicinity of large rivers. Our results highlight that sustainability of the aquacultural sector and the water management in LXQ-AG in general should be included in the circle of primary objectives such as economic development and food safety.

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