STUDY ON OPTIMIZING SURFACE WATER ALLOCATION TO LOWER VU GIA – THU BON RIVER BASIN UNDER WATER SCARCITY AND DROUGHT CONTEXT

Than Van Don[(1)], Tong Ngoc Thanh[(1)], La Van Chu[(2)]
[(1)]National Center for Water Resources Planning and Investigation (NAWAPI)
[(2)]Viet Nam Institute of Meteorology, Hydrology and Climate Change (IMHEN)

Received: 8 July 2020; Accepted: 6 August 2020

Abstract: *Over the past few years, water scarcity and droughts have always been occurring in the Vu Gia - Thu Bon River basin, causing conflict water users. Water demand has also increased. Information and data on potential, the amount of water that can be allocated by 11 regions were used for calculating current water demand in 2014 and these by 2030, thereby determining the simulation model method (WEAP model) for allocating surface water resources to households exploiting and using water in the Vu Gia - Thu Bon River basin. The results showed that water demands of households are basically metcorresponding to inflow accounting for 85% (in 1998) of water demands in 2014 and of that by 2030, followed by sets of priority order and percent of water supplies. The total does not meet water demands corresponding to inflows 85% and 99% of water demands are 78.46 mil m^3 and 101.19 mil m^3, which is significantly less than existing water supplies plan with 146.99 mil m^3. This results in the conflicts in water use, decreasing water degradation and maintaining environmental stability of the river.*

Keywords: *Surface water allocation, Water scarcity, Droughts, Vu Gia - Thu Bon River basin.*

1. Background

Water resources in river basins can be seen as the total amount of water that reaches the basin over a period of a year, which should be used for a variety of needs, such as water supply for domestic, industrial purposes, irrigation in agriculture, aquaculture, navigation, recreational activities, and tourism services.

Water resource allocation is an important content of a water resource master plan of a river basin to address problems when this situation occurs. For river basins with abundant water resources with the demand for water being small compared to the potential, the problem of water resource allocation is not very pressing. However, for water-scarce river basins, the issue of water resource allocation is essential to alleviate water use conflicts, overcoming water degradation and maintaining environmental stability. Handling with good care the situation of the water allocation in river basins will contribute to protecting the legitimate water use of users, bringing about social equity and environmental sustainability.

Therefore, it is pivotable to conduct this study on methodology for determining surface water allocation in Vu Gia - Thu Bon River basin in a fair and reasonable manner.

2. Water resource availability, current exploitation status and prospectus issues in Vu Gia - Thu Bon River basin

2.1. Geographic location and hydro-meteorological monitoring network

The Vu Gia - Thu Bon River in Central Viet Nam is one of nine major river systems. Catchment area is 10,350km^2. The basin has 2 meteorological stations (Da Nang and Tra My)

Corresponding author: Than Van Don
E-mail: thandontnn@gmail.com

working from 1976 to date, and 8 hydrological stations, 2 of which (Thanh My and Nong Son) measuring the flow and water level, 6 of which (Hoi Khau, Ai Nghia, Giao Thuy, Cau Lau, Cam Le and Hoi An) measuring water level, operating from 1976 to date [1].

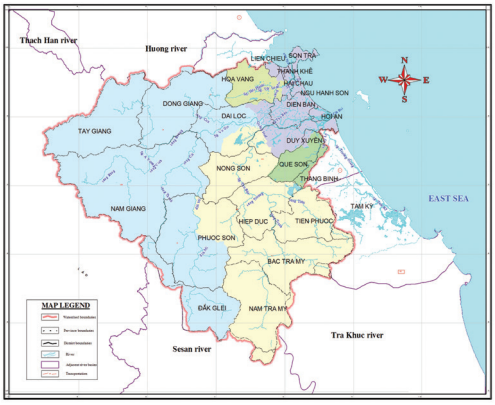

Figure 1. Vu Gia - Thu Bon River basin

2.2. Surface water availability of major tributaries

Thu Bon River from upstream to Giao Thuy has a catchment area of 3,825km^2. The upstream area of the river flows within the high mountains of Phuoc Son, the center of heavy rain of Tra My. In Tien Phuoc and Ngoc Linh, the average rainfalls in the basin for many years reaches 3,300mm, the module of the annual flow in the whole basin reaches M_o=75.3l/s.km^2, Q_o=290 m^3/s. Total annual flow up to Giao Thuy W_o= 9,25x109m^3. Vu Gia River from upstream to Ai Nghia has a catchment area of 5,180km^2, annual rainfall reaches 2,420mm, annual flow module reaches M_o= 52.3 l/s.km^2, Q_o=271m^3/s. The total flow amount at Ai Nghia W_o=8.55x109m^3. The rest from Ai Nghia and Giao Thuy, Thu Bon River to the outlet in Da Nang and Hoi An have annual rainfall of 2,000mm, the total volume of water in the region reaches W_o=1.65x109m^3. Ly Ly River has a catchment area of 275km^2, Q_o=12.3m^3/s and the total volume of water in the region reaches W_o=0.39x109m^3. Tuy Loan River basin area of F_{lv} = 309km^2, Q_o=12.0m^3/s, total annual flow W_o=0.38x109m^3 [2].

2.3. Current exploitation status

In the river basin, there are 820 projects, of which: 72 reservoirs, 546 dams, 202 pump stations with the design capacity: 45,359 ha, actual capacity: 28,569 ha, accounting for 62.98% of capacity. design. Mainstream has 10 hydropower projects generating a significant amount of electricity for the Central region, helping flood, drought control, and water supplies to water users in downstream [1]. Speaking of the amount of water supplied for domestic and industrial purposes, there is Cau Do water plant with a capacity of 120,000m^3/day.night, Son Tra water plant with a capacity of 5,000m^3/day.night for Da Nang city, Hoi An water plant supplied to the Hoi An city and Dien Nam - Dien Ngoc industrial park with a capacity of 6,000m^3/day. night. In rural areas, there are about 30,100 wells and 44,760 wells supplying for about 394,610 people, the rest people often use rivers and streams for food and drink in the form of gravity [1].

2.4. Prospectus issues in Vu Gia - Thu Bon River basin

Due to the rapid socio-economic development, mechanical population growth, and especially the current massive development of hydroelectricity on the Vu Gia - Thu Bon River system in the years has changed the flow patterns, water supplies for areas in the river basin. This has caused controversy and disputes in the distribution and sharing of water resources among regions, typically the case of DakMil 4 hydropower plant.

The current method of water exploitation

and use is still unsustainable because too many small-sized dams on the middle and upstream tributaries are developed to get water for irrigation in the wet season, which depletes the flow of many river branches during the dry season.

The exploitation and use of water resources is still separate by branch, and there is no coordination with each other. Especially, large-sized reservoirs do not have coordination in the whole system, during the time when rivers lack water like in limited years (2013, 2015, 2018, 2019), there is no coordination and cooperation between water use sectors to prevent drought, push salinity and consider ensuring water for environmental flow.

The efficiency of water works is low (irrigation canals, reservoirs,...) due to water loss in large canals, many deteriorated works have not been repaired in time, and actual irrigation capacity of the works is only 75% of the design.

The water resources development plans are still monophyletic, due to each branch.

Lack of coordination and cooperation between localities and sectors in integrated basin management.

3. Scientific basis of optimizing surface water allocation to lower Vu Gia - Thu Bon River basin under water scarcity and drought context

3.1. Scientific basis for determining method of water allocation

Based on data information on surface water resources, land cover, structural systems and water use of structures;

Based on water allocation of sub-basins in Vu Gia - Thu Bon River basin;

Based on the current situation of water exploitation and use of water supply works for domestic, agricultural, industrial purposes and socio-economic development orientation of Quang Nam province and Da Nang city to 2020 and vision after year 2030;

Topographic and geomorphological conditions in the entire river basin; Principles of allocation and sharing of surface water sources for households exploiting and using surface water sources in river basins;

The order of priority among households and industries using water (Living, Environment, Industry, Agriculture, Aquaculture and Power Generation);

On these basics, the authors proposed to apply the mathematical modeling method (WEAP) to allocate surface water resources in the Vu Gia - Thu Bon River basin. This decision is based on: Availability of information and data on meteorology, hydrology and water resources in the basin; the suitability of research basins selection along with the ability to approach the deployment of model tools; feasibility when constructing water source development scenarios in the basin by model and finally the ability to test the application of principles, rate, and priority order of distribution of water resources to water users. proposed for the problem of surface water distribution in the Vu Gia - Thu Bon River basin in the future.

3.2. Numerical model method

The simulation model is an important tool when allocating water resources to households exploiting and using water. The simulation method does not find the solution by the optimal model but uses the simulation model to find the optimal solution, unlike the optimization method, the simulation method uses the simulation model to find the largest (maximum problem) or smallest (minimum problem) among possible options by directly comparing calculated values. The solution of the problem is perhaps not to coincide with the mathematical optimal solution (the solution of the optimization method), so it is just a near-optimal value and is often called a reasonable solution.

3.3. Principles in water allocation

The allocation of water resources for households to use is based on the following principles:

Principle 1: Prioritize water supply according to the highest economic efficiency of water use: After having reserved enough water for domestic use (priority 1), minimum flow (priority 2), estimated remaining quantity priority will be given to those sectors with the highest water

use efficiency (priority 3, 4, etc.) on the basis of a unit of water volume (m^3) or water surface area (ha).

Principle 2: Prioritize water supply according to the guaranteed water supply level (or design frequency): After sufficient water has been supplied for domestic use, the remaining amount of water will be allocated according to the design guaranteed level of water supply on the basis of the frequency of the incoming water. Thus, any industry with a low level of guarantee for water supply must accept the risk.

Principle 3: Proportion of allocated water supply: Once sufficient for domestic use and minimum flow, the remaining amount of water will be proportionally distributed to water users on a proportional basis which has been already specified in the situation of sufficient water.

Principle 4: Prioritize water supply targeted political stability - social and poverty alleviation.

The above-mentioned priority principles of water allocation can be applied separately or in coordination depending on each specific case of the water source, at a certain time to suit the socio-economic conditions. specific areas and sub-regions are planned.

3.4. Determining priority order and proportion of supplies

3.4.1. DAME software

Decision Analysis Module for Excel (DAME) is a commonly used hierarchical analysis tool approach to assist decision-making to solve problems. There are many programs and software that use that approach, but they are commercialized and do not support intermediate computation. In that case DAME has the advantage of being able to work with scenarios or multiple decision-makers and display intermediate computations.

Users can structure their decision model into three levels - scenarios, criteria and variants. All levels above can be assessed by weights or pair-wise comparisons.

3.4.2. Determining criteria

The study identified 4 main criteria including: (1) Amount of water used by each object; (2) Production value to 2030; (3) Proportion; (4) Growth. There are other criteria: Ensuring social security; The importance of water users to socio-economic development of Quang Nam province and Da Nang city.

These criteria and their weight are determined through consultation with water resources experts and representatives of water management, exploitation and use departments in Quang Nam province Da Nang city during the survey and workshops.

3.4.3. Determining requirement

These criteria should satisfy the constraints to achieve the general purpose of the optimal allocation among water users listed below in DAME model as follows:

Table 1. The criteria and constraints in DAME

Criteria	**Water used**	**Production value**	**Importance**	**Growth rate**
Target	Minimum	Maximum	Pairwise comparison	Pairwise comparison

To clearly analyze the right to allocate an water resources of the Vu Gia - Thu Bon River basin flowing through Quang Nam and Da Nang provinces with scenarios weights based on the competitiveness index (PCI) of Quang Nam and Da Nang with the average series of PCI values from 2015 to 2019 as follows: Quang Nam 0.48; Da Nang 0.52.

Table 2. PCI values

PCI	**2015**	**2016**	**2017**	**2018**	**2019**	**TB**
Quang Nam	61.06	61.17	65.41	65.85	69.42	64.582
Da Nang	68.34	70	70.11	67.65	70.15	69.025

Table 3. Results of decision-making power among provinces in Vu Gia - Thu Bon

Quang Nam	Da Nang		
Names of criteria:			
Water used	Production value	Importance	Growth rate
Names of variants:			
Water used	Production value	Importance	Growth rate
Criteria weights evaluation method:			
Method	Geom. mean		
Scenarios comparison:			
Scenarios	Value		*Scenarios weights*
Quang Nam	64.58		0.48
Da Nang	69.03		0.52

3.4.4. Results of priority orders and weights (proportions)

Based on the current socio-economic situation, water exploitation and use demand of Quang Nam and Da Nang, the availability of water in the basin, the input data into the DAME model includes the following water user sectors: farming, livestock, industry, aquaculture. Table below shows weights of different sectors.

Table 4. Results of weights of criteria with respect to DAME model

	Quang Nam					Da Nang				
Criteria	LDN	GTSX	TT	TTTT	Weights	LDN	GTSX	TT	TTTT	Weights
Water used	1	1	1	1	**0.243**	1	2	2	2	**0.40**
Production value	1	1	1/2	1/2	**0.172**	0.5	1	1	1	**0.20**
Proportions	1	2	1	2	**0.343**	0.5	1	1	1	**0.20**
Growth rate	1	2	0.5	1	**0.243**	0.5	1	1	1	**0.20**

(These criteria and their weight are determined through consultation with water resources experts and representatives of water management, exploitation and use departments in Quang Nam province Da Nang city during the survey and workshops)

Table 5. Results of weights of sectors with respect to DAME mode

Sectors	Quang Nam				Da Nang			
	Water used (m^3)	**Production values (billion VND)**	**Proportions (%)**	**Growth rate (%/year)**	**Water used (m^3)**	**Production values (billion VND)**	**Proportions (%)**	**Growth rate (%/year)**
Farming	0.003	0.067	0.079	0.205	0.003	0.005	0.011	0.124
Livestock	0.986	0.031	0.071	0.305	0.982	0.007	0.011	0.181
Industry	0.008	0.882	0.814	0.335	0.005	0.988	0.973	0.555
Aquaculture	0.003	0.020	0.036	0.155	0.009	0.001	0.005	0.140

Results of priority orders and proportion of allocated water by DAME: (1). Scenario with Quang Nam and Da Nang; (2). General scenario with the whole river basin:

Table 6. Results of weights and priority orders

CZn=	Weight	Rank
Farming	0.058	3
Livestock	0.389	2
Industry	0.509	1
Aquaculture	0.043	4

3.5. Applying model method (WEAP) for surface water allocation in Vu Gia - Thu Bon River basin

3.5.1. Data and modelling

a) The entire Vu Gia - Thu Bon River basin system is divided into 11 calculating regions and nodes as shown in Figure 3.

- Bases for dividing calculation regions on river basins

On the natural features, the division of the respective topography of the rivers; On the work system of exploiting and using water resources, considering the administrative boundary or the unit managing the system of works on the river basin or river branches; On the demand, the characteristics of water source and water supply use, including the direction of water drainage after use.

- Results of division of regions in the river basin

According to the view of dividing the calculated regions as above, the Vu Gia - Thu Bon River basin is divided into 11 regions as shown in Table 7 and Figure 2.

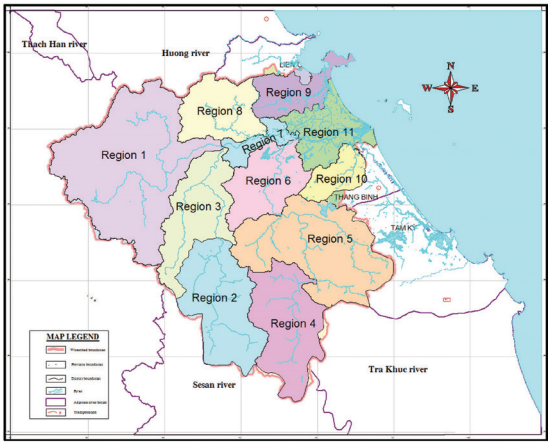

Figure 2. Map of dividing calculation regions on Vu Gia - Thu Bon River basin

Table 7. Results of dividing calculation regions on Vu Gia - Thu Bon River basin

No.	Sub-regions	Area (km^2)	Administration
Region 1	Upper Vu Gia	2,434.71	Nam Giang, Dai Loc, Tay Giang, Dong Giang
Region 2	Dak Mi River basin	1,133.61	Phuoc Son, Dak Glei
Region 3	Cai River basin	927.02	Nam Giang, Phuoc Son,Dai Loc, Dak Glei
Region 4	Tranh 2 River basin	1,082.83	Phuoc Son, Nam Tra My, Bac Tra My
Region 5	Tranh 3 River basin	1,660.49	Tien Phuoc, Hiep Duc, Phuoc Son, Bac Tra My
Region 6	Middle Thu Bon	775.17	Duy Xuyen, Hiep Duc, Phuoc Son, Dai Loc, Nong Son
Region 7	Quang Hue River basin	246.86	Nam Giang, Dai Loc
Region 8	Con River basin	672.95	Dai Loc, Dong Giang
Region 9	Tuy Loan River basin	450.27	Dai Loc, Thanh Khe, Hoa Vang, Hai Chau, Son Tra

No.	Sub-regions	Area (km^2)	Administration
Region 10	Ly Ly River basin	339.43	Thang Binh, Que Son
Region 11	Lower Vu Gia Thu Bon	626.66	Duy Xuyen, Ngu Hanh Son, Dai Loc, Dien Ban, Hoi An, Hoa Vang, Lien Chieu, Que Son
	Total	**10,350**	

b) Data input

- *Meteorological data:* Includes rainfall and evaporation data at stations in the basin. The inflow for the allocated calculation areas is the flow simulated by the Mike - Nam in the period 1991-2015 [4]. Results of calculation of the amount of allocable water to the entire basin corresponding to the frequencies of water up to P = 50% : 7,261 billion m^3; P = 85% : 4,494 billion m^3; P = 95% : 3,862 billion m^3.

- *Land use data:* Includes data on crop area, crop structure and water use demand data for other sectors [2].

- *Reservoir data:* useful capacity, dead capacity, total capacity; The relationship between reservoir capacity - water level W - Z; Discharge capacity of spillway; the design flow for downstream discharge; Coordination process [3].

Table 8. Specification of the reservoirs in the study area

Specification	Unit	Reservoirs				
		A Vuong	Song Bung 2	Song Bung 4	Dak My 4	Song Tranh 2
Catchment area	Km^2	682	337	1467	403	1100
Annual discharge	m^3/s	78.4		166		
High spill head	m	380	690	222.5	820	175
Normal spill head	m	340	645	195	770	140
Total W	10^6m^3	344	230	493.2	251	631
Useful W	10^6m^3	266.5	209.4	320	223	462
Dead W	10^6m^3	77.05	20.6	173.2	28	169
Design capacity	MW	170	126	200	225	135

3.5.2. Calculation of current water demands in 2014 and future 2030

a) Calculation of current water demands

Until 2014, the total amount of water needed to supply sectors in the Vu Gia - Thu Bon River basin is 2,112.69 million m^3/year. In which: That for living is 46.89 million m^3/year, for agriculture (Irrigation + livestock) is 1,774.32 million m^3/year, for aquaculture is 89.65 million m^3/year, for industry is 9.77 million m^3/year and for environmental flow is 192.06 million m^3/year.

Table 9. Current water demands of different sectors in 2014

No.	Sub-regions	Water demands in 2014 (10^6 m^3/year)					
		Domestic	Agriculture	Aquaculture	Industry	Environment	**Total**
1	Upper Vu Gia	1.34	140.32	5.38	0.00	14.70	161.75
2	Dak Mi River basin	0.56	32.22	2.51	0.00	3.53	38.81
3	Cai River basin	0.48	43.19	2.05	0.00	4.57	50.29
4	Tranh 2 River basin	1.12	74.31	3.16	0.00	7.86	86.43
5	Tranh 3 River basin	3.50	199.76	4.61	0.00	20.79	228.66
6	Middle Thu Bon	2.56	171.87	24.55	0.49	19.95	219.42

No.	Sub-regions	Water demands in 2014 (10^6 m^3/year)					
		Domestic	Agriculture	Aquaculture	Industry	Environment	**Total**
7	Quang Hue River basin	1.34	81.45	2.47	0.26	8.55	94.07
8	Con River basin	1.33	90.61	6.08	0.00	9.80	107.81
9	Tuy Loan River basin	16.47	79.59	4.36	1.07	10.15	111.64
10	Ly Ly River basin	3.37	290.45	4.38	2.00	30.02	330.23
11	Lower Vu Gia Thu Bon	14.83	570.54	30.11	5.96	62.14	683.58
	Total	**46.89**	**1,774.32**	**89.65**	**9.77**	**192.06**	**2,112.69**

b) Calculation of water demands by 2030

Based on the socio-economic development orientation to 2030 of Quang Nam and Da Nang provinces and water supply indicators for the water exploitation and use industries in the future, the authors calculated and forecasted total demand. Demand for water use of industries on the river basin Vu Gia - Thu Bon to 2030 is 2,444.07 million m^3/year. Of which: for domestic use is 101.55 million m^3/year, for agriculture is 1,969.35 million m^3/year, for fisheries is 123.44 million m^3/year, for industry is 27.54 million m^3/year and supply to the environment is 222.19 million m^3/year.

Table 10. Forecasted water demands of different sectors by 2030

No.	Sub-regions	Water demands in 2014 (10^6 m^3/year)					Total
		Domestic	Agriculture	Aquaculture	Industry	Environment	
1	Upper Vu Gia	2.59	155.75	4.52	0.00	16.29	179.14
2	Dak Mi River basin	1.11	35.76	2.63	0.00	3.95	43.45
3	Cai River basin	0.94	47.94	3.56	0.00	5.24	57.69
4	Tranh 2 River basin	2.09	82.47	5.94	0.00	9.05	99.55
5	Tranh 3 River basin	6.67	221.71	4.00	0.00	23.24	255.61
6	Middle Thu Bon	4.85	190.76	3.38	9.05	20.80	228.85
7	Quang Hue River basin	2.54	90.40	0.89	0.22	9.41	103.46
8	Con River basin	2.54	100.56	5.14	0.00	10.83	119.08
9	Tuy Loan River basin	39.85	88.34	11.01	1.58	14.08	154.86
10	Ly Ly River basin	6.39	322.38	7.42	5.48	34.17	375.83
11	Lower Vu Gia Thu Bon	31.98	633.26	74.96	11.22	75.14	826.56
	Total	**101.55**	**1,969.35**	**123.44**	**27.54**	**222.19**	**2,444.07**

3.5.3. Verification of WEAP

To verify the WEAP model, the authors used a specific series of 1-year data and based on the actual operation of the building system, the actual water use in the basin. Through the process of collecting and analyzing documents, the authors chose 2010 to test the WEAP model according to the actual construction conditions and irrigation water supply. This is the year that documents are collected quite fully about the construction as well as on land use. In 2010, most of the major hydroelectric projects such as DakMi 4 and terraced hydropower projects on the Bung River such as Bung 3, Bung 2, Bung 5, and Bung 6 have not been operated, so the flow on the main stream are less affected by hydroelectric works system. Thus, the data set to test the WEAP model are as follows:

- Actual 2010 water demand data.
- Current status of works in 2010.
- Monthly data with duration from 1/1/2010 to 31/12/2010
- Inflow to 11 regions in 2010 calculated from Mike - NAM [4].

Table 11. Comparison between simulated (s) and observed (o) data sets at Nong Son, Thanh My in 2010

Month	Inflow to Thanh My (Sub-region 3-1850 km²) m³/s		Inflow to Nong Son (Sub-region 5-3150 km²) m³/s	
	Q_s	Q_o	Q_s	Q_o
1	127.69	126.45	200.92	194.90
2	86.75	84.24	121.74	111.26
3	61.41	57.83	95.23	77.98
4	53.72	51.50	92.01	63.01
5	60.20	53.04	98.90	62.95
6	44.96	45.37	88.63	65.40
7	65.23	62.34	102.99	91.25
8	144.70	137.74	191.89	228.32
9	129.20	127.87	188.61	214.37
10	232.05	235.42	481.26	486.16
11	458.16	463.37	1,603.20	1,604.33
12	226.66	219.77	306.39	262.58

The verification results for 2 stations Thanh My and Nong Son in the period from showed that the difference between calculated and measured is in acceptable range and ensure reliability.

3.5.4. Order of priority and proportions of allocation of surface water sources

Order of priority, rate of distribution of surface water sources is determined by region and water use purpose and basing on catchment characteristics, planned area size, priority order, and rate of allocation is determined. According to the following criteria:

1st point: priotize allocating per regions: Based on water use agreements among regions and the decision issued by the competent authorities.

2nd point: the order of priority and proportion of distribution according to the following main water uses: Domestic; Environmental flow; Industrial production; Agricultural production; Aquaculture; Power production.

3.5.5. Results of surface water allocation

a) Scenario 1: Corresponding to the frequency of inflow of 85%, the current water demands in 2014, without priority as all users would get the same proportions.

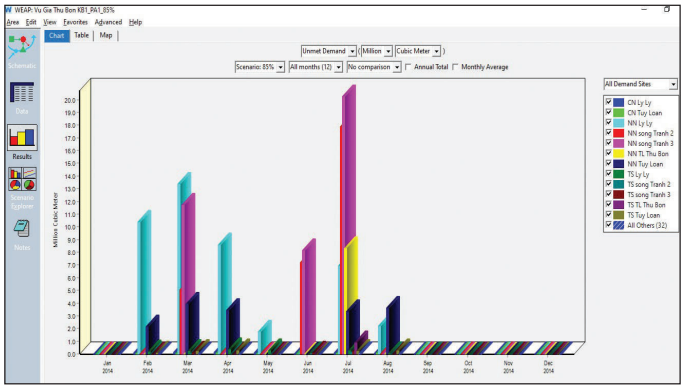

Figure 3. Water shortage in the calculated regions corresponding to the frequency of 85%, current water demand in 2014 and evenly allocated to users

Calculation results of surface water distribution on the river basin showed that total water shortage of industries is 146.99 mil m^3, of which: Industry: 0.86 mil m^3 (Ly Ly: 0.54 mil m^3; Tuy Loan: 0.32 mil m^3); Agriculture: 138.05 mil m^3 (Ly Ly: 43.13 mil m^3, Song Tranh 2: 30.10 mil m^3, Song Tranh 3: 40.70 mil m^3, Upper Thu Bon: 8.31 mil m^3, Tuy Loan: 16.45 mil m^3); Domestic: 4.17 mil m^3; (river basin Tuy Loan); Aquaculture: 3.91 mil m^3 (Ly Ly: 1.33 mil m3, Song Tranh 2: 0.26 mil m^3, Song Tranh 3: 0.38 mil m^3.

Upper Thu Bon: 0.88 mil m^3, Tuy Loan: 1.06 mil m^3). The water-shorted month are concentrated in months 2,3,4 and 6,7, the most water-shorted is in July with 59.39 mil m^3.

b) Scenario 2: Corresponding to water frequency up to 85%, current water demands in 2014, with different priorities and proportions among users. 1) Water supply for domestic use: 100%; 2) Environmental flow: 100%; 3) Water supply for industry: 80%; 4) Agricultural water supply: 80%; 5) Water supply for aquaculture: 80%; 6) Supply water for hydroelectricity according to the operating procedure. Details are shown in Figure 4.

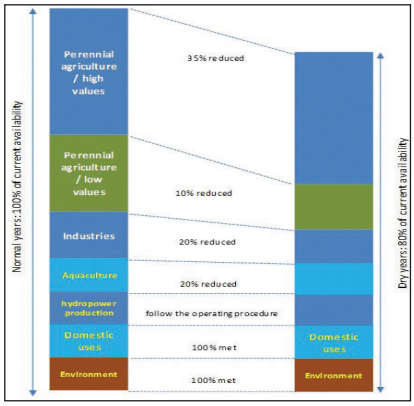

Figure 4. Priority and proportion of water supply to supply in dry years

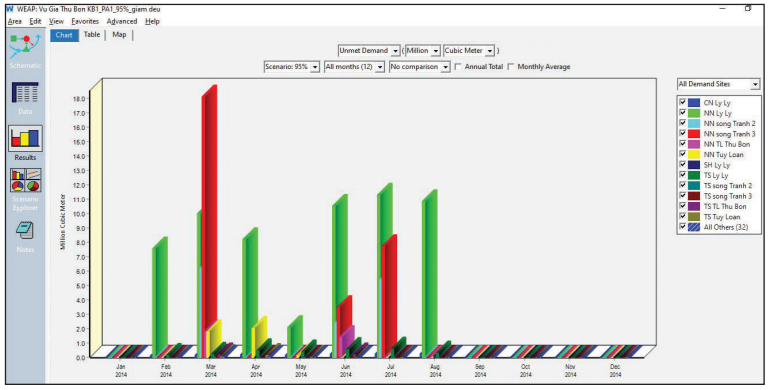

Figure 5. Water shortage on the calculated regions corresponding to the frequency of 85%, the current water demand in 2014 and the allocation of priority order and proportion to households

Calculation results of surface water allocation on the river basin showed that total water shortage of sectors is 78.46 million m^3, and the total water shortage in the whole region is about 78.46 million m^3, of which Industry: 0.84 million m^3; Agriculture: 75.16 million m^3; Aquaculture: 2.46 million m^3.

c) Scenario 3: Corresponding to water frequency up to 85%, water demands by 2030, with different priorities and proportions among users. 1) Water supply for domestic use: 100%; 2) Environmental flow: 100%; 3) Water supply for industry: 80%; 4) Agricultural water supply: 80%; 5) Water supply for aquaculture: 80%; 6) Supply water for hydroelectricity according to the operating procedure. Details are shown in Figure 4.

Calculation results of surface water allocation on the river basin showed that total water shortage of sectors is 101.19 million m^3, of which Industry: 1.88 million m^3 (Ly Ly: 1.28 mil m^3; Tuy Loan: 0.34 mil m^3; Upper Thu Bon: 0.26 mil m^3); Agriculture: 95.52 million m^3 (Ly Ly: 32.08 mil m^3; Song Tranh 2, 3: 42.93 mil m^3; Tuy Loan: 14.68 mil m^3; Upper Thu Bon: 5.82 mil m^3); Aquaculture: 3.79 million m^3. The water-shorted month are concentrated from Feb to Aug, the most water-shorted is in July with 43.59 mil m^3.

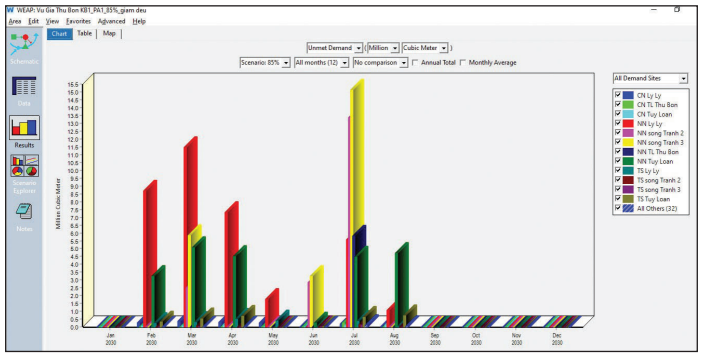

Figure 6. Water shortage on the calculated regions corresponding to the frequency of 85%, the future water demand in 2030 with different priorities and proportions among users

4. Conclusion and recommendation

Vu Gia - Thu Bon River basin is a large river basin in the central region of Viet Nam, supplying water to two provinces of Quang Nam and Da Nang city. Over the years on the river basin, droughts, water shortages have always occurred and resulted in water conflicts between different water users. This shortage phenomenon is due to the socio-economic development and the diversion of water from Vu Gia to Thu Bon through the DakMi 4 hydropower plant, making the downstream Vu Gia River severely short of water, especially Ly Ly River basin, Tuy Loan and Lower Vu Gia River. 10 years ago, Da Nang authority "demanded" hydropower plant to give water back for downstream, igniting a dispute between two localities Quang Nam, Da Nang on one side and hydropower plant owners on the other side. Up to now, this story has not ended yet.

In order to have a scientific basis for rational allocation of surface water sources for the Vu Gia - Thu Bon River downstream, the authors have developed a numerical model (WEAP), computational zoning (11 regions), calculation current water demand in 2014 and future 2030 (based on the socio-economic development orientation of Da Nang city and Quang Nam province), the priority order and resource allocation ratio are determined reasonably under context of droughts, water shortage corresponding to the frequency of water arrival is 85%. The results showed that:

- Corresponding to the frequency of inflow of 85% (the year when the drought or water shortage occurred) with the current water demand in 2014, without priority order, the proportion of water supplies are equal, the total water shortage of all sectors is 146.99 million m^3, of which agriculture is the largest: 138.05 mil m^3, concentrated in the basin Ly Ly basin: 43.13 mil m^3, followed by domestic: 4.17 mil m^3; (Tuy Loan River basin). The water-shorted month are concentrated in months 2,3,4 and 6,7, the most water-shorted is in July with 59.39 mil m^3.

- Corresponding to the frequency of inflow to 85%, the current water demand in 2014 and future in 2030, with different priorities and proportions among users: 1) Water supply for domestic use: 100%; 2) Environmental flow level: 100%; 3) Water supply for industry: 80%; 4) Agricultural water supply: 80%; 5) Water supply for fisheries: 80%; 6) Supply water for hydroelectricity according to the operating procedure. The total water shortage respectively of the sectors 78.46-101.19 mil m^3 has decreased significantly compared with the current plan, the amount of water supplied for domestic use in the regions is not inadequate and at the same time ensuring environmental flow in the downstream area.

In this study, the allocation of groundwater resources has not been considered. Therefore, it is necessary to thoroughly study the potential of groundwater resources in the basin and the possibility of exploiting and using groundwater resources for different uses. Ratios of groundwater to surface water use for each demand.

References

1. The National Center for Water Resources Planning and Investigation: *"Planning on water resources in the central key economic region"*, Ha Noi, 2010.
2. Institute of Water Resources Planning: *"Reviewing and updating calculation of water balance of Vu Gia - Thu Bon River"*, Ha Noi, 2010.
3. Power Construction Consulting Company I: *"Planning terraced hydropower plants on Vu Gia - Thu Bon River, Quang Nam province*", Ha Noi, 2002.
4. Than Van Don (2015), "Study on determination of minimum flow requirement on main river of Vu Gia - Thu Bon, serving ecosystem development", *Journal of Natural Resources and Environment*, No. 08, June 2015.
5. WEAP User Guide, Jan2011 (www.weap21.org/downloads/WEAP_User_Guide.pdf).