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Interbasin water transfer in the Central Highlands of Vietnam: Impacts and lessons learned

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Abstract: In Vietnam, drought has been occurring persistently and in very complicated patterns, with a great impact on the water, energy, and food security nexus and regional development sustainability. The uncertainty surrounding annual water resources in combination with the low reliability of interbasin water transfer (IBWT) operations is the key driver of water deficits in several affected regions. This study aims to assess the impacts of four big IBWT projects in the Central Highlands of Vietnam, based on a proposed matrix of five evaluation criteria to quantify related impacts and to draw out lessons learned for future development of IBWT. The proposed criteria matrix was formulated on the basis of intensive reviews of IBWT assessments worldwide and relevant Vietnamese laws in force. The impacts were analysed and quantified mainly based on assessment of their operational database and water balance simulations for donor and recipient river basins in current and future states. The results show that the studied IBWT projects did not fully satisfy the proposed criteria set, all project did not meet the criteria of benefit sharing and information transparency; noticeably the Don Duong project fulfilled only one from five. Four lessons were determined for proper planning in river basins, flexibility in system design for unknown future, inadequate environmental impact assessment and delay in enactment of policies for IBWT project management. The results provide sound knowledge to revise the existing projects in the Central Highlands and procedures for impact assessment and approval of new IBWT systems.

Keywords: drought, IBWT project, interbasin water transfer, water resources

INTRODUCTION

Interbasin water transfer systems are mostly used in large to mega-scaled irrigation, and many of them serve multiple purposes, including hydropower generation [SHUMILOVA *et al.* 2018]. Their operation radically changes the natural conditions and socio-economic development of related regions in the donor and recipient basins [MANH *et al.* 2014; SINHA *et al.* 2020; STERNBERG 2016; ZHUANG 2016]. However, these changes are usually opposed in the donor and recipient basins [BUI *et al.* 2020; STERNBERG 2016; YU *et al.* 2018] because water resources are the most essential element when considering inputs into the socioeconomic development of each region. Interbasin water transfer projects are a common solution for water transfer and are often considered for addressing water shortages [GOHARI *et al.* 2013] resulting from agricultural development and urbanization as well as problems related to water resources in the context of climate change.

Currently, 76 large-scale IBWT projects have been built or are under construction worldwide [SHUMILOVA *et al.* 2018]; their aim is to transfer huge amounts of water between regions for different purposes. North America has 34 projects with 24,800 km connection and 1,333 km^3 of annual transferred water; Asia has 17 projects with 28,631 km and 321 km^3; Africa has nine projects with 6,600 km and 233 km^3; Europe has only three projects with 2.1 km^3, and South America has six major projects with 8.2 km^3 transferred water [SHUMILOVA *et al.* 2018].

The majority of IBWT projects in Vietnam are developed in the Central Coast and the Central Highlands, where several hydropower projects functioning as IBWT projects have been built, and around 4.3 km^3 of water volume is transferred between rivers annually [NHUNG *et al.* 2020]. These projects are currently receiving greater attention due to their dominant role in the pattern of drought management and socioeconomic development in the regions [NHUNG *et al.* 2020].

The negative results of IBWT projects have been intensively evaluated [STERNBERG 2016; YU *et al.* 2018; ZHUANG 2016]. The Karakum Canal in Turkmenistan, an example of serious environmental impact, diverts water from the upper parts of two rivers, Amu Darya and Syr Darya, for agriculture use since the 1960s, resulting in serious consequences when in 2007, the Aral Sea had shrunk to 10 percent of its original size due to widespread, wasteful irrigation of the deserts along the Amu and Syr Rivers over four decades [MICKLIN, ALADIN 2008]. The National River Linking Project in India is highly uncertain in water balance due to the most of the water receiving in Northern upstream rivers (which receive water from melting ice from the Himalayas) are difficult to measure accurately [BANSAL 2014]. Megaprojects such as the South–North Water Transfer Project in China and the National River Linking Project in India often have a strong impact on the water balance in river basins and cause saline intrusion downstream of donor basins [ZHUANG 2016]. In addition, IBWT projects also affect local communities when hundreds to thousands of people living in the area have to be resettled [GHASSEMI, WHITE 2007], and they affect areas where water resources are closely linked to beliefs and religion [GURUNG 2015].

Experience and understandings obtained from analysis of existing IBWT projects is important for the development of new projects. The impacts of IBWT are often divided into three types: environmental, socioeconomic, and political [SINHA *et al.* 2020]. When evaluating the environmental aspect, it is essential to clearly classify the impact in each area, including the donor and recipient basins and the transferring process area with monitored parameters including water quality and quantity [JAIN, SINGH 2003]. The environmental impact assessment of IBWT projects includes assessing not only water quality and the maintenance of environmental flows but also biodiversity conservation [ZHUANG 2016].

The criteria for IBWT project evaluation have been studied intensively [COX 1999; GUPTA *et al.* 2008; KIBIIY, MDAMBUKI 2015; RAHMAN 1999; SINHA *et al.* 2020]. According to RAHMAN [1999], there are three criteria to evaluate IBWT projects: the first criterion is concerned with the requirement for a surplus water resources in the donor basin in all conditions, the second relates to an actual water shortage in the recipient basin, and the third regards to minimizing other adverse effects. As proposed in Cox's study [COX 1999], it is necessary to evaluate the effectiveness of an IBWT project through five criteria, with the first and second criteria regarding water surplus in the donor basin and real water shortage in the recipient basin respectively, the third and fourth criteria involve requirements for environmental and social impact assessment, and the fifth criterion deals with the requirement for benefit sharing between donor and recipient basins. In another study, GUPTA and VAN DER ZAAG [2008] also proposed five criteria but adding new terms of planning transparency of IBWT projects and on the existing assessment of risks and uncertainties for different options. Recently, KIBIIY and NDAMBUKI [2015] published three criteria with the specific requirement of clarifying the need for the project, minimizing adverse impacts, and maximizing the efficiency of water transfer. As stated in study of SINTHA *et al.* [2020], there are four criteria; a new term of information transparency is proposed in addition to the conventional criteria mentioned above, to reflect updates on the development of information technology.

In all the studied criteria, the water balance requirement in the donor and recipient basins is essential criteria, it is necessary to carry out the water balance assessment as a basis for ensuring IBWT projects will not significantly impact water shortage, the environment, and livelihoods in the present and the future.

MATERIALS AND METHODS

INTERBASIN WATER TRANSFER IN VIETNAM

In Vietnam, the main reason of drought's frequent occurrences in complex patterns can be attributed to the high uncertainties in water resources, operation of manmade dams in conjunction with increasing water demand in river basins. The impacts of hydropower dams including IBWT projects in the Mekong upstream into the Mekong Delta were extensively reported in many studies [ARIAS *et al.* 2014; MANH *et al.* 2014; RÄSÄNEN *et al.* 2012; YOSHIDA *et al.* 2020]. The big IBWT projects in Vietnam are mainly in the Central Highlands, the region contains four river basins, the Se San River, Srepok River (upstream tributaries of the Mekong River), Ba River and Dong Nai River. The IBWT projects in the Central Highlands were designed for hydropower generation combining with water transfer to the Central Coast where the terrain is mainly lowland area facing water scarcity (Tab. 1). The four big IBWT projects in the region are described below:

1. The Thuong Kon Tum IBWT project, located in the Dak Bla subbasin, cut off 374 km^2 upstream watershed (3%) of the Sesan River basin within Vietnam, storage capacity of 145.5 mln m^3 (7% of total active storage in mainstream Se San River), maximum water transfer capacity of 30 $m^3 \cdot s^{-1}$ to Tra Khuc River basin (Fig. 1).

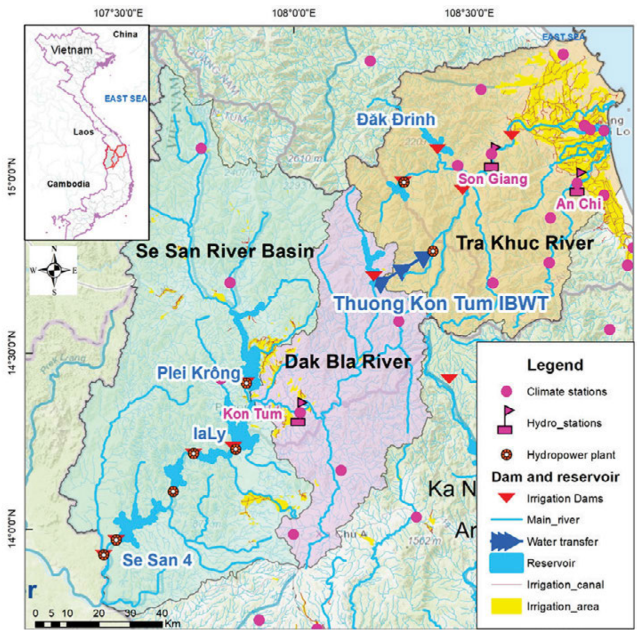

Fig. 1. Map of Thuong Kon Tum IBWT projects in the study area and river networks, subbasins, hydrometeorological stations and irrigation systems in the related rivers; source: Vietnam Institute of Water Resources Planning

Table 1. Specifications of four hydropower projects working as interbasin water transfer projects in the study

Specification	Project							
	Thuong Kon Tum		Kanak–An Khe		Don Duong		Dai Ninh	
	Se San[1)]	Tra Khuc[2)]	Ba[1)]	Kon[2)]	Da Nhim[1)]	Cai Phan Rang[2)]	Da Nhim[1)]	Luy + Quao[2)]
Opening date	2020		2011		1964		2008	
Catchment area A (km^2)	374		1236		775		1158	
– percentage of subbasin	11		36		37		55	
– percentage of entire basin	3	7	9	26	2	27	3	67
Annual discharge Q_o (m^3·s^{-1})	17.4		27.8		22.5		30.2	
– percentage of subbasin	16		36		45		60	
– percentage of entire basin	4	5	8	14	4	70	6	54
Effective storage (mln m^3)	103.1		290.6		155.1		251.7	
Installed capacity (MW)	220		160		240		300	
Discharge $Q_{\text{max release}}$ (m^3·s^{-1})	30		50		39.6		55.4	
Length of tunnel (m)	17500		493		7065		1818	

[1)] Donor river. [2)] Recipient river.
Source: own elaboration.

2. The Kanak–An Khe IBWT project consists of two cascade reservoirs, cut off 1236 km^2 upstream watershed (9%) of Ba River, total storage capacity of 313.7 mln m^3; maximum water transfer capacity of 50 m^3·s^{-1} to Kon River basin (Fig. 2).

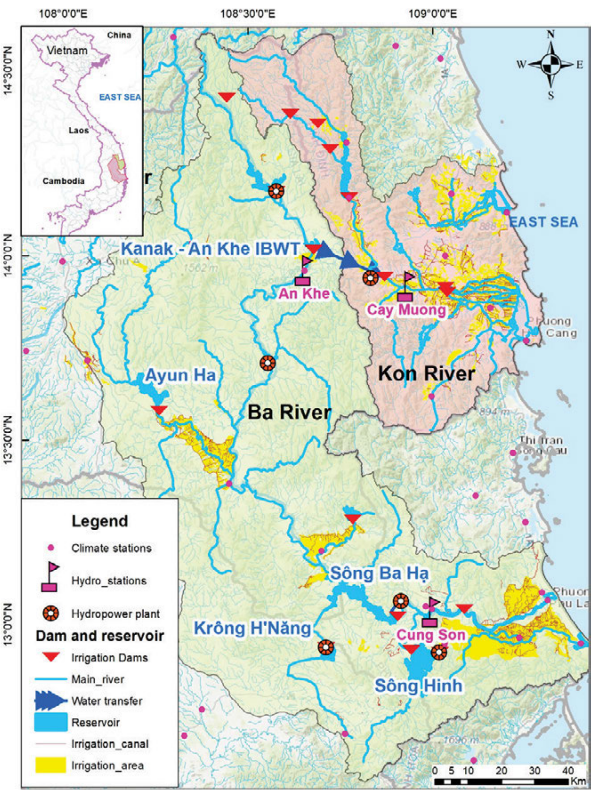

Fig. 2. Map of Kanak-An Khe IBWT projects in the study area and river networks, subbasins, hydrometeorological stations and irrigation systems in the related rivers; source: Vietnam Institute of Water Resources Planning

3. The Don Duong IBWT project, cut off 775 km^2 watershed of Da Nhim subbasin in Dong Nai River basin (cut off 2% of Dong Nai River), storage capacity of 165 mln m^3, the maximum water transfer capacity of 39.6 m^3·s^{-1} into the Cai Phan Rang River (Fig. 3). The dam began operating in 1964, and was designed without any bottom outlet, only spillway for flood control with lowest control level of +11.2 m higher than the dead water level. It is not possible to release minimum flow when the reservoir water level is below the lowest control level of spillway (at 30% active storage).

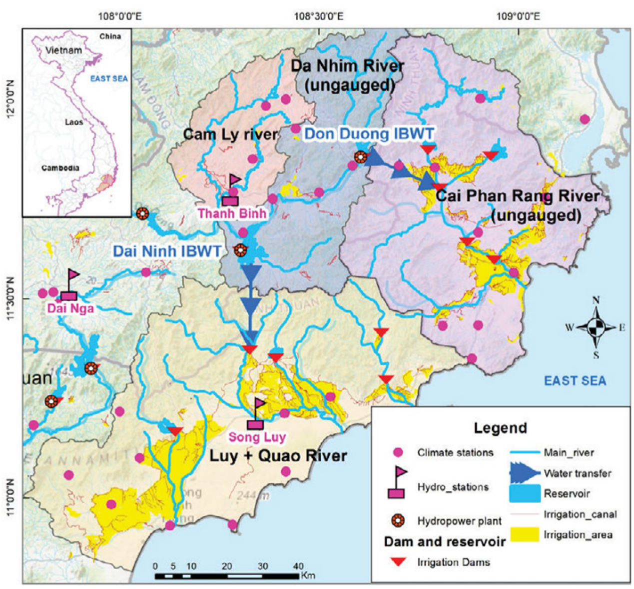

Fig. 3. Map of Don Duong IBWT and Dai Ninh IBWT projects in the study area and river networks, subbasins, hydrometeorological stations and irrigation systems in the related rivers; source: Vietnam Institute of Water Resources Planning

4. The Dai Ninh IBWT project, situated downstream of the Don Duong dam, cut off 1158 km^2 watershed of Da Nhim subbasin (1993 km^2 including Don Duong dam, cut off 3% of Dong Nai River), storage capacity of 319.77 mln m^3, maximum water transfer capacity of 55.4 $m^3 \cdot s^{-1}$ to the Luy + Quao River River basin (Fig. 3).

Summaries of the specifications and designed parameters of each IBWT project are presented in Table 1, including data on transfer catchment and annual transferred discharge to the hydrology of the donor and recipient rivers.

Over decades of operation, the IBWT projects has been transferring massive amount of water to the Central Coast, provided very important water sources for drought management and socioeconomic development in the recipient basins. In recent years, a number of negative effects of those IBWT projects have been reported by the national media, particularly, the Kanak–An Khe and Thuong Kon Tum projects was reported to cause water shortage at their downstream donor basins. However, the positive and negative outcomes of these projects have not been explicitly and thoroughly researched in any publication. It is necessary to identify and evaluate their impacts based on common criteria for IBWT projects for lessons learnt and for future development of that project type.

The aim of this study is to quantify related impacts of four existing IBWT project in the region and to draw out lessons learned for future development of IBWT. To achieve this goal, we propose a matrix of evaluation criteria for the assessment, we assess their monitoring data with operation rule and assess several scenario of water balances for donor and recipient river basins in current and future states. The assessment enables a quantification of the impacts in different aspects in river basins.

DEVELOPMENT OF CRITERIA SET FOR IWBT PROJECT EVALUATION

Given the high variation in criterion sets proposed in publications over time and the provisions from the related Law in Vietnam, this study proposed a set of five criteria for impact assessment of IBWT projects in Vietnam, as follows:

- C1: the donor basin must have surplus water in the present and future;
- C2: the recipient basin must have an actual water shortage in the present and future;
- C3: the social, economic, and environment impacts must be sustainable;
- C4: there must be benefit sharing and information transparency;
- C5: the project must be approved in related sectoral plans.

In which C1 and C2 criteria are proposed in all studies and in Vietnam Law on Water Resources (2012) as critical requirements for any IBWT project. The C3 criteria is formulated from different studies including that of RAHMAN [1999] requires adverse impacts of the water transfer are minimized; the research of COX [1999] suggests that environmental impact assessment must be carried out for donor and recipient basins and a detailed evaluation of social and cultural influence is required to guarantee that the project will not cause any significant interruption, and in study of GUPTA and VAN DER ZAAG [2008], IBWT project should be socially, environmentally and economically sustainable and should be adaptive to natural and social stress; in studies of KIBIIY and NDAMBUKI [2015] and SINHA *et al.* [2020] require minimizing negative impacts and maximizing positive impacts. The C4 criteria is integrated from the fifth criteria in UNESCO publication [COX 1999] and the fourth criteria in studies of SINHA *et al.* [2020]. The C5 is presenting the requirement in Luật số 17/2012/QH13 and also in the third criteria in study of GUPTA and VAN DER ZAAG [2008].

To assess these proposed five criteria, different approaches and methodologies are applied for their purposes, in which the C1 and the C2 criteria on water balance assessment are fully investigated with different scenarios. The C3 criteria is multi-disciplinary, the associated data is difficult to collect. This study, C3 assessment is focused on evaluation of environmental or minimum flow for the downstream donor basins. For the remaining criteria C3 and C4, the evaluation was mainly based on a revision of the relevant technical documentation and comparisons with provisions in related Laws and other regulations.

WATER DEMAND ASSESSMENT

The water demand of all users in basins is estimated using current standards. The crop water demand is estimated according to the national standard based on the CROPWAT model, where the crop's net irrigation requirement (*NIR*) during crop season is equal to its water consumption minus the effective rainfall (P_{eff}). The water consumption of crops is calculated using the following formula:

$$CUW = ET_o K_c + I + a \tag{1}$$

where: CUW = the crop's water consumption, $CUW = ET_o\ K_c$ is the crop's water demand when $I = 0$, for upland crops (I = the infiltration loss), $a = 0$ for upland crops (a = the field water layer), ET_o = potential evapotranspiration, K_c = the crop coefficient.

Water demand for other sectors (domestic, industry, fishery, livestock, tourism, etc.) is calculated according to the related national standards.

In Vietnam, minimum flow is defined as the flow at the lowest level required to maintain a river or river section while ensuring normal development of aquatic ecosystems and minimum operational level of water-related activities by users. However, different ministries provide different guidelines for minimum flow estimation, depending on their level of authority within the river basins. A guideline from Ministry of Natural Resources and Environment (MONRE) defined minimum flow in downstream of dam and reservoir must range between minimum of monthly flow ($Q_{\text{month min}}$) to minimum of three-month average flow ($Q_{\text{3month min}}$). The minimum flow includes the nonconsumable flow for the ecological health of the river (Q_e) and the flow for downstream minimum water demand (Q_{demand}). According to the Ministry of Agriculture and Rural Development (MARD) the value of environmental flow (Q_e) in the downstream of manmade water bodies must be at least equal to $Q_{\text{drymonths90\%}}$ to preserve the ecological environment.

In this study, Q_e is defined either by a maximum value of the range ($Q_{\text{month min}}$, $Q_{\text{3month min}}$, and $Q_{\text{drymonths90\%}}$) or by provided values in interreservoir operation rules (IROR) in river basins. In detail, Q_e for downstream of the Thuong Kon Tum and Kanak–An Khe projects are defined as and 3.3–5.8 $m^3 \cdot s^{-1}$ and 4–8 $m^3 \cdot s^{-1}$

during the low flow season in the IROR for Se San River and Ba River respectively.

In the IROR for Dong Nai River, Q_e for downstream of the Don Duong and Dai Ninh projects is stated to "follow related laws" without any specific values. In this case, the Q_e is estimated as a range ($Q_{month\ min}$, $Q_{3month\ min}$, and $Q_{drymonths90\%}$) based on available measured data in each system (Tab. 2).

Khe station (1350 km^2) downstream of the project (1236 km^2) and Cung Son station covering 12,410 km^2 of the Ba River (13,417 km^2). The model for the recipient basin, Kon River, was set up based on Binh Tuong station, covering 1677 km^2 of the entire 3809 km^2 Kon River.

For Don Duong and Dai Ninh IBWT projects in Da Nhim subriver, because of the small discharge contribution to entire

Table 2. Minimum flows stipulated by operation rules and range of environmental flows Q_e

Project	Operation rule	$Q_{month\ min}$	$Q_{3month\ min}$	$Q_{drymonths90\%}$	Notes
Thuong Kon Tum	3.3–5.8 $m^3 \cdot s^{-1}$ or (60–80)·$10^6 \cdot m^3$	–	–	–	no data
Kanak–An Khe	5–8 $m^3 \cdot s^{-1}$ or (112–160)·$10^6 \cdot m^3$	0.53	–	5.3	based on measured flows at An Khe station, located 1 km downstream of An Khe dam, 1980–2005
Don Duong	undefined but by law	2.17	2.4	4.5	measured inflow of Don Duong reservoir, 1990–2019
Dai Ninh	0.7–2.5 $m^3 \cdot s^{-1}$ or (21–40)·$10^6 \cdot m^3$	1.77	2.2	2.4	measured inflow of Dai Ninh reservoir, 2008–2019

Source: own elaboration.

WATER RESOURCE MODELLING

Rainfall runoff model is applied for this study, for basins with sufficient measured data, the model was set up and verified using DHI's Mike 11–NAM model [DHI Mike 11 2017]; data were updated with observations from 44 rainfall-gauging, 8 meteorological, and 9 hydrological stations (Figs. 1, 2, 3) from 1980 to 2018. The evapotranspiration input was estimated using the Penman–Monteith method for the 8 meteorological stations over the region. For ungauged basins, a common approach is transfer hydrological information from gauged to ungauged catchments based on regionalization of physical similarity, spatial proximity and regression. The physical similarity approach identifies a gauged catchment that is most similar to an ungauged site with respect to its catchment attributes and then transfers a complete parameter set from the gauged site to the corresponding ungauged catchment for hydrological modelling [TEGEGNE, KIM 2018]. In this study, based on the similarity of topography, land use, and soil type in the related river basins, the physical similarity approach was applied to simulate flow in ungauged basins based on validated parameter set of rainfall–runoff model of gauged basins. A summary of the model setup and verification and similar method for donor and recipient river basins is shown in Table 3.

For Thuong Kon Tum IBWT project in Dak Bla subriver, due to small contribution (4% of Q_o) to entire Se San River basin, the model was set up for the Dak Bla tributary (3439 km^2) based on daily measured discharge at Kon Tum station (2968 km^2), and the entire Tra Khuc River basin (4370 km^2) based on daily measured discharge at Son Giang station (2641 km^2) and An Chi station (854 km^2).

For Kanak–An Khe IBWT project, the model setup for the entire Ba River basin was based on two measured stations, An Khe station (1350 km^2) downstream of the project (1236 km^2) and Cung Son station covering 12,410 km^2 of the Ba River (13,417 km^2). The model for the recipient basin, Kon River, was set up based on Binh Tuong station, covering 1677 km^2 of the entire 3809 km^2 Kon River.

Dong Nai River basin (4 and 6% of Q_o), the model setup for the donor basin only considers Da Nhim subbasin (2100 km^2). However, there was no measured flow data; similar catchment method [TEGEGNE, KIM 2018] is applied for Da Nhim subbasin based on measured data at Thanh Binh station in Cam Ly subriver (294 km^2). Modelling for the recipient river basins, Luy + Quao River, was based on measured data at Song Luy station, and the model for Cai Phan Rang River basin was established using the verified parameter sets from Luy + Quao River as the similar catchment approach.

The selected period for calibration and validation at measured stations is before the period of constructed reservoirs with highly regulated stream flow in the basins. Autocalibration method was applied by using autocalibration tool inside the DHI Mike 11–NAM model [DHI Mike 11 2017]. The calibration and validation results at the gauged stations are relatively good, the value of coefficient R^2 ranges from 0.7 to 0.9, and the error of total water volume is less than ±10%; a higher density of gauging stations provides a better value of R^2. As in large-scale modelling for a sparse data region, the results of model calibration and validation are sufficient for water resource and water balance assessment in this study. The estimated parameters of the rainfall–runoff model setup and similar catchment method for the study area are described in Table 3 and Figures 1, 2, 3.

WATER BALANCE SIMULATION

Water balance assessment is essential for evaluating the impact of IBWT projects on water resources in river basins. This assessment requires complex datasets, including baseline and future scenario of inflows, water demands, reservoirs and their operations. An integrated model of water resources and water balance using DHI's Mike Basin model [DHI Mike Basin 2017] was applied for water balance simulation in the identified river basins. The main

Table 3. Setup of rainfall–runoff model and similar approach for river basins in the study area

Area of river basin (km^2)	Method	Gauging station (km^2)	Calibration			Validation		
			period	R^2	ΔW (%)	period	R^2	ΔW (%)
I Thuong Kon Tum project								
Donor: Dak Bla (3439 km^2)	RR model	Kon Tum (2968 km^2)	1982–1990	0.70	3.7	1991–1995	0.70	2.4
Recipient: Tra Khuc (4370 km^2	RR model	Son Giang (2641 km^2)	1981–1995	0.85	6.1	1996–2009	0.86	5.2
		An Chi (854 km^2)	1980–1995	0.90	8.0	1996–2014	0.88	5.8
II Kanak–An Khe project								
Donor: Ba River 13,417 km^2	RR model	An Khe (1350 km^2)	1980–1990	0.80	3.0	1991–1993	0.78	7.0
		Cung Son (12,410 km^2)	1980–1990	0.84	4.0	1991–1995	0.89	3.0
Recipient: Kon River 3809 km^2	RR model	Binh Tuong (1677 km^2)	1980–1995	0.71	4.2	1996–2005	0.82	5.5
III Don Duong and Dai Ninh projects								
Donor: Da Nhim River 2100 km^2	Similar to Cam Ly catchment	Thanh Binh (294 km^2)	1981–1990	0.74	0.5	1991–1995	0.76	0.3
Recipient 1: Luy + Quao River 1718 km^2	RR model	Song Luy + Quao (964 km^2)	1988–1998	0.76	–3.4	1998–2008	0.70	0.1
Recipient 2: Cai Phan Rang River 2824 km^2	Similar to Luy + Quao catchment							

Source: own elaboration.

algorithm for water balancing in the river basin is based on an equation written in the form of the volume of water in the reservoir for the time step (Δt), as follows:

$$W_2 - W_1 = Q_V \Delta t - \ Q_T \Delta t - Q_R \Delta t + X \frac{F_1 - F_2}{2} \ - Z \frac{F_1 - F_2}{2} \quad (2)$$

where: W_1, W_2 = the reservoir volume at the beginning and end of Δt; Q_V = the inflow to the reservoir including surface and underground runoff; Q_R = the outflow from the reservoir including the discharge via the gates and intake; Q_T = leakage and seepage from reservoirs; X = the precipitation that falls on the reservoir surface; Z = the reservoir surface layer being evaporated; F_1, F_2 = the water surface area at the beginning and end of Δt.

The reservoirs and their operation rules are crucial inputs for water balance modelling in each basin. Natural flow in river basins has been highly regulated due to the huge number of irrigation and hydropower reservoir projects that have been built over time. The statistical data of reservoirs in each basin are summarized in Table 4, including the number of irrigation and hydropower reservoirs and their active storage and irrigation areas. The data in baseline conditions were collected and synthesized from the provincial Departments of Agriculture and Rural Development. For the foreseeable future, data of irrigation systems were incorporated from the portfolio of proposed projects according to the latest approval plans. The data on interreservoir operation rules in each river basin were collected based on all approved released versions (Tra Khuc River basin, Sesan River basin, Ba River, Kon River, and Dong Nai River basin). The detailed data of irrigation and hydropower reservoirs in the donor and recipient basins is summarized in Table 4.

The water balance model in river basins was set up to simulate all hydropower and irrigation systems; however, due to a huge number of existing small reservoirs in the river basin, groups of small irrigation reservoirs were combined into a single system for each subbasin. A monthly time step was established for the entire modelling basin to reduce the complexity of the requested input data. The input data included catchment data, inflow data, water use nodes, reservoir nodes including operation rule, return flow, and minimum flows. Water demand was ranked according to priority in decreasing order of domestic, tourism, industry, livestock, and crop cultivation.

Scenario simulations of water balance are defined as four cases for all donor–recipient river basins (Tab. 5). Baseline is up to 2018 when the data in river basins is the most up-to-date. The foreseeable future extends to 2030 when the IBWT projects are still working in normal condition and almost all planned irrigation projects in the region will be completed.

Baseline scenarios (BLS1 and BLS2): the inflow is daily time series from 1982–2018, all existing irrigation projects are operational with water demand as in 2018 and the IBWT projects are no operation and full operation.

Table 4. Data of irrigation and hydropower reservoirs in donor and recipient basins

River basin	Quantity (reservoir)		Total active storage (mln m^3)		Irrigated area (ha)
	irrigation	hydropower	irrigation	hydropower	
Dak Bla	28		31	4.6	1,702
Tra Khuc	109	6	340	235	25,500
Ba	282	12	464	789	33,898
Kon	97	10	504	387	13,719
Da Nhim	34	2	48	406	3,995
Cai Phan Rang	12	5	148	0	7,113
Luy + Quao	4	1	39	0	6,034

Source: own elaboration.

Table 5. Scenarios for water balance simulations

Scenario	Baseline, 2018		Scenario	Foreseeable future, 2030	
	IBWT project	all existing irrigation projects		IBWT project	all existing + planned irrigation projects
BLS1	no operation	full operation	FFS1	no operation	full operation
BLS2	full operation	full operation	FFS2	full operation	full operation

Source: own elaboration.

Future scenarios 2030 (FFS1 and FFS2): the inflow is assumed no significant change in comparison with the baseline inflow, all existing and planned irrigation projects are operational with future water demand of 2030 and the IBWT projects are in no operation and full operation.

RESULTS AND DISCUSSION

EVALUATION OF IBWT PROJECT OPERATION

The results in this section are for evaluation of C3. The operation evaluation is based on the analysis and comparison between requirement from IRORs and recorded data including hydropower plant operation, spillway operation, bottom outlet release from 2012–2019 in each IBWT system.

In terms of minimum flow return to donor basins, later-built projects are better designed to ensure the minimum flow for downstream donor basins; specifically, the Kanak-An Khe reservoir returns to the Ba River 12% of its annual flow during the dry season and, likewise, 3% from Don Duong and 2% from Dai Ninh reservoir (Tab. 6).

A comparison between the practical operation and required minimum flow shows that An Khe reservoir had the highest release in 2017 with an average discharge of 6.1 m^3·s^{-1} (equivalent to 130 mln m^3; Fig. 4), and about 5.5 m^3·s^{-1} (117 mln m^3) in 2018, which are both higher than their estimated value $Q_{\text{drymonths}90\%}$ of

Table 6. Assessment of operational water release from interbasin water transfer (IBWT) projects to donor and recipient basins, by seasons during 2012–2019 period

IBWT	River basin	Season	Water volume (mln m^3) in the year								Average (%)
			2019	2018	2017	2016	2015	2014	2013	2012	
An Khe	Ba[1)]	dry	87	117	129	101	102	84	84	104	12
		rain	45	44	356	583	32	33	771	52	28
	Kon[2)]	dry	39	408	527	124	238	366	295	451	35
		rain	163	155	311	395	158	212	231	134	25
Dai Ninh	Da Nhim[1)]	dry	17	28	48	5	7	0	0	0	2
		rain	9	9	408	377	0	18	77	27	14
	Luy + Quao[2)]	dry	405	378	605	173	306	418	364	441	46
		rain	140	212	591	424	189	301	373	374	39
Don Duong	Da Nhim[1)]	dry	37	1	122	0	0	0	0	22	3
		rain	0	63	345	305	0	0	60	95	14
	Cai PR[2)]	dry	410	365	459	317	322	365	348	392	49
		rain	229	204	336	258	246	229	292	286	34

[1)] Donor river. [2)] Recipient river.
Source: own study.

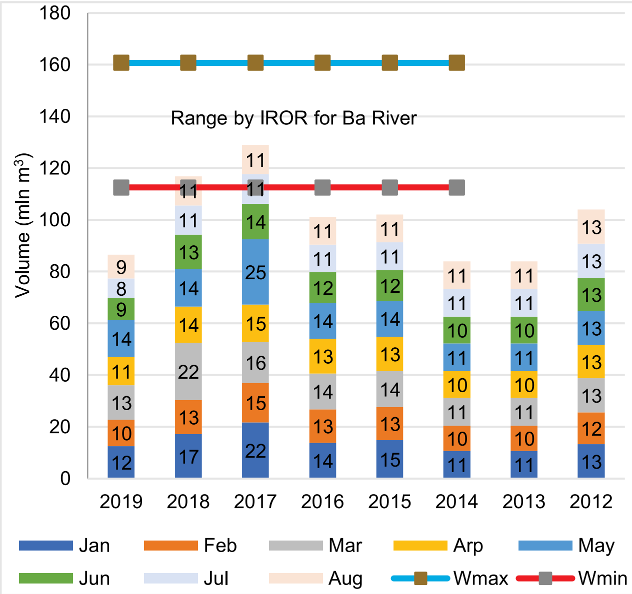

Fig. 4. Comparison of actual release to donor basin and stipulated by interreservoir operation rules in Kanak-An Khe project; source: own study

5.3 $m^3 \cdot s^{-1}$. In other years, this value varied in the range of 3–4 $m^3 \cdot s^{-1}$, smaller than the lower range of minimum flow of 4–5 $m^3 \cdot s^{-1}$ (112 mln m^3) required by the rules, but still higher than the estimated value $Q_{monthmin}$ of 0.53 $m^3 \cdot s^{-1}$ (Tab. 2). For Dai Ninh reservoir, 2017 was the only year when release reached 2.6 $m^3 \cdot s^{-1}$ (49 mln m^3, Fig. 5), higher than the $Q_{drymonths90\%}$ of 2.4 $m^3 \cdot s^{-1}$, while the release was lower than the $Q_{monthmin}$ of 1.77 $m^3 \cdot s^{-1}$ in other years. For Don Duong reservoir, as it can only release via flood spillways when the water level allows, the release is only for a short time (Fig. 6), so it cannot meet the requirement for environmental flow at $Q_{monthmin}$ of 2.1 $m^3 \cdot s^{-1}$ or $Q_{drymonths90\%}$ of 4.5 $m^3 \cdot s^{-1}$ as the estimated value of Q_e in Table 2.

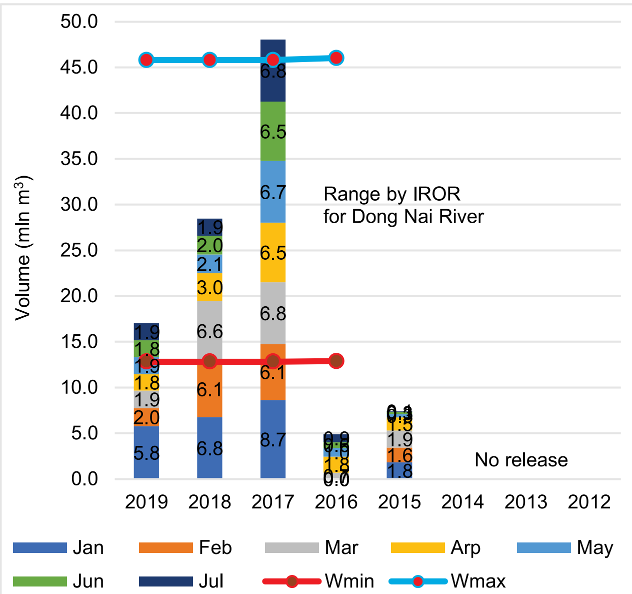

Fig. 5. Comparison of actual release to donor basin and stipulated by interreservoir operation rules in Dai Ninh project; source: own study

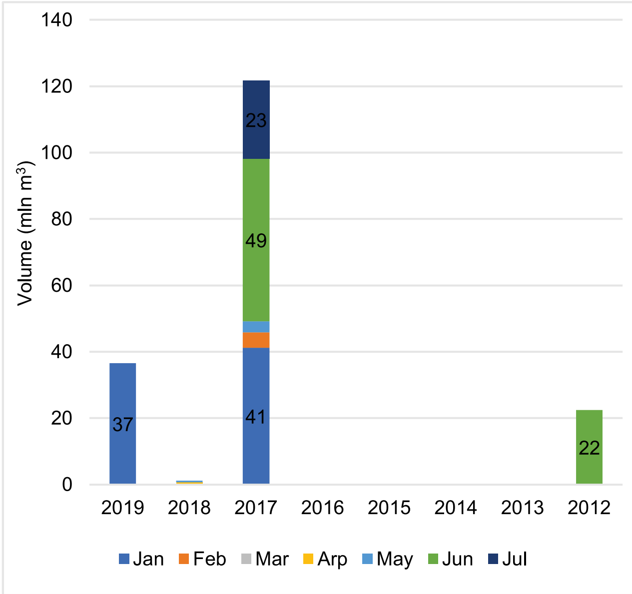

Fig. 6. Actual release to donor basin in Don Duong project; source: own study

Regarding to the ratio of release by season, the Kanak-An Khe system releases annually, on average, about 40% of total inflow to the downstream donor Ba River, including 12% in the dry season and 28% in flood season, and the remaining 60% is transferred to the recipient Kon River, with 35% in the dry season and 25% in the rainy season. The contribution of Dai Ninh reservoir to the downstream Da Nhim River is insignificant, with a total dry season discharge of only about 2%, or even without release in some years; most of the water is transferred to Luy + Quao River, accounting for 85% of the annual flow and about 46% of the dry season flow. Similarly, for Don Duong reservoir, the project only releases about 17% to the downstream Da Nhim River, only 3% of which is in the dry season, and with no release in both dry and flood seasons for many years (Tab. 6). The change in the annual rainfall pattern of rainfed areas might be the key driver of this variation in regulation of water to donor and recipient rivers. The variation differs from system to system. In the higher annual rainfall period of 2016–2017, all the systems had higher release to donor basins, while during the low rain period of 2014–2015, had nearly no release to donor basins from the Dai Ninh and Don Duong reservoirs.

In comparison of actual release with requirement by IROR, the recorded data of dry season downstream release in the Kanak-An Khe is about 112.5 mln m^3; however, in the eight years of real operation with available monitoring data, there were two years, 2017 and 2018, when the total release met the requirement of IROR, and these were wet years. In other years, the total release in the dry season was lower than the IROR requirement, particularly in 2013 and 2014, the driest years; their release to downstream was the smallest. Data of the monthly released flow in those years are summarized in Figure 4.

Similar evaluation for Dai Ninh (Fig. 5) and Don Duong (Fig. 6) systems shows that the required total volume release to the downstream Da Nhim River according to their IROR is smaller than other systems. Over four year of operation based on approved IROR, there were three years from 2017–2019 that Dai Ninh system met the requirements on minimum flow, only in

2016, a severely dry year that it did not meet the requirement. During the same operation period for Don Duong system, as there is no bottom outlet, water can only be released via flood spillways when the reservoir water level is higher than the spillway level, and this is a significant deficiency when trying to reallocate water sources. Regarding the measured data in the Don Duong reservoir, from 2012 to 2019, there were five years when there was no release at all during the dry season: from 2013 to 2016 and in 2018. Although the total release to downstream was the biggest in 2017, at 122 mln m^3 (Tab. 6), however, the released discharge remained very small in April and May led to the actual annual release to downstream of the reservoirs was insignificant and did not meet the requirement for environmental flow.

In summary, the comparison between practical release and estimations based on approved IRORs and minimum flow reveals that all reservoirs rarely achieved both values of operation rule requirements and estimated minimum flows. This is important in evaluating the fulfilment of criterion C3 for each studied system. In the next section, the results of calculated water demand and water balance analyses for each region are presented to clarify the extent of water deficit or surplus for better assessment of the impact of each project on each donor and recipient basin (criteria C1 and C2).

RESULTS OF WATER BALANCE SIMULATION

The results in this section focus on the evaluation of criteria C1 and C2 for all selected IBWT projects in terms of water balance in four scenarios: no operation (BLS1) and full operation (BLS2) under baseline conditions and no operation (FFS1) and full operation (FFS2) in the foreseeable future.

Thuong Kon Tum project

a. Donor basin: Dak Bla subriver

The water balance results (Tab. 7) show that no water shortage happens in the donor basin under baseline conditions (BLS1); the total annual water demand is only 299 mln m^3, while the total annual available water is 2.480 bln m^3 with 85% reliability ($W_{85\%}$: 85 years over 100 years of $W \geq 2.48$ bln m^3) and $W_{85\%}$ during the dry season is around 505 mln m^3, including 31 mln m^3 stored in the irrigation reservoirs. Similar to BLS1, there are no water deficit events in future scenario FFS1 with no water transfer operation in the Thuong Kon Tum IBWT project. The water balance for this scenario shows the water availability in natural and future irrigation systems of about 34 mln m^3 per year, which means there will be a water surplus for future demand of 431 mln m^3 per year, mostly for irrigation.

For the scenarios of fully operational Thuong Kon Tum as designed, around 329 mln m^3 water will be transferred to the Tra Khuc River basin during the crop periods (December to August next year) in both present and future scenarios, which will result in a water shortage in the Dak Bla River basin. In BLS2, the maximum water deficit occurs in April with a probability of 9% of the total calculation years, and in FFS2, the maximum water deficit occurs during the same period with a probability of 84% when water demand increases from the baseline of 299 mln to 431 mln m^3 in the future.

b. Recipient basin: Tra Khuc River

Overall, the recipient river basin has more available water resources and a much larger active storage capacity than the donor basin. Even though the water demand of the recipient, Tra Khuc River basin, is higher than that of the donor basin in both baseline and future scenarios, the results of water balance show that the recipient basin always has a surplus of water in all scenarios or, in other words, water transfer is not significant factor in determining water balance in the recipient basin. The detailed results of the balance are shown in Table 7.

Kanak-An Khe project

a. Donor basin: Ba River

The results for assessment of water resources and water balance (Tab. 8) show that water deficit occurs in all scenarios without operation or with full operation of the Kanak-An Khe IBWT system.

Table 7. Assessment results of Thuong Kon Tum interbasin water transfer (IBWT) project by water resources, water demand, and water balance in donor and recipient basins

Scenario	Annual $W_{85\%}$ (mln m^3)	Dry season $W_{85\%}$ (mln m^3)	Active storage (mln m^3)	Transfer water (mln m^3)	Water demand (mln m^3)	Water balance	Deficit frequency (%)
I Donor basin: Dak Bla River							
BLS1	2481	504	31	–	299	surplus	0
FFS1			65	–	431	surplus	0
BLS2			134	−329	299	deficit	9
FFS2			168	−329	431	deficit	84
II Recipient basin: Tra Khuc River							
BLS1	8204	2126	576	–	758	surplus	0
FFS1			609	–	973	surplus	0
BLS			576	+329	758	surplus	0
FFS2			609	+329	973	surplus	0

Explanation: $W_{85\%}$ = water at 85% reliability.
Source: own study.

Table 8. Assessment results of Kanak-An Khe interbasin water transfer (IBWT) project by water resources, water demand, and water balance in donor and recipient basins

Scenario	Annual $W_{85\%}$	Dry season $W_{85\%}$	Active storage	Transfer water	Water demand	Water balance	Deficit frequency (%)
	mln m^3						
I Donor basin: Ba River							
BLS1	6721	1103	1174	0	2025	deficit	40
FFS1	6721	1103	1595	0	2683	deficit	57
BLS2	6721	1103	1471	−350	2025	deficit	46
FFS2	6721	1103	1892	−350	2683	deficit	65
II Recipient basin: Kon River							
BLS1	4394	915	682	0	922	deficit	83
FFS1	4394	915	705	0	1083	deficit	81
BLS2	4394	915	682	+350	922	deficit	71
FFS2	4394	915	705	+350	1083	deficit	76

Explanation: $W_{85\%}$ = water at 85% reliability.
Source: own study.

For the BLS1 scenario. The $W_{85\%}$ of annual water resources is around 6.72 bln m^3 and during dry season is around 1.103 bln m^3, the active storage of all reservoirs in the basin is about 1.174 bln m^3, and the total annual water demand in the whole basin is about 2.025 bln m^3 (estimated for 2018). The results of water balance show that the donor basin faces water shortage many times in a year from February to August, with a frequency of water deficit from 20 to 70% (40% on average).

For the FFS1 scenario. When water demand in the entire Ba River basin increases from 2.025 bln to 2.683 bln m^3 per year, mainly for irrigation, and the storage volume of the reservoirs increases from 1.174 bln to around 1.471 bln m^3, the results reveal that water shortage remains in the donor basin in the future, with a frequency of water deficit from 20 to 80% (57% in the river basin, on average).

For the BLS2 and FFS2 scenarios. When the Kanak-An Khe project diverts 350 mln m^3 of water to the Kon River, the donor basin faces water shortage in both cases, with higher frequencies of 46 and 65% for the present and by 2030, respectively.

b. Recipient basin: Kon River

Under baseline conditions without water transfer operation, the recipient Kon basin is affected more severely by water deficit than the donor Ba River in terms of water shortage frequency due to the longer dry season production period, when the water transfer operation adds 350 mln m^3 to the Kon River in the dry season; the water deficit, however, is less but still severe; the frequency is 71% at baseline and increases to 76% in the future.

In terms of water resources, the recipient basin is not as abundant as the donor basin, with total available annual water resources of 4.4 bln m^3 with 85% reliability, of which the irrigation reservoirs can store about 675 mln m^3, while the total annual water demand is 922 mln m^3 (estimated for 2018). In this scenario, the results for water balance show water shortage in the basin. For the future scenario, when the water demand increases to 1.083 bln m^3 per year, mainly for irrigation, and the capacity of the irrigation reservoirs is about 698 mln m^3, the water balance results show that the Kon River basin still faces a small water deficit even if it receives 350 mln m^3 from the Ba River basin; the frequency of water shortage is 74% under current conditions and 68% in the future.

The water balance results show that even if there is no water transfer project, water shortage still occurs in both donor and recipient basins. When the project begins operation and releases water, the donor basin will face more serious water shortage than the recipient basin in terms of total deficit, time, and frequency.

Don Duong and Dai Ninh projects

Because the Don Duong and Dai Ninh reservoirs are both located on the same donor basin, the Da Nhim River, their hydropower plants are located upstream of the recipient basin. In this assessment, the evaluation considers the Da Nhim River basin as one donor providing water for two recipient basins: the Cai Phan Rang and Luy + Quao-Quao River basins.

a. Donor basin: Da Nhim River

The watershed of the Don Duong reservoir is a tropical forest without any water demand. Water demand in this basin is mainly from the river section downstream of the Don Duong dam to the Dai Ninh reservoir, where the soil is fertile and flat, favourable for agricultural production. The water demand downstream of the Dai Ninh dam is mainly for environmental flow for a 14 km length of the Da Nhim River before entering the mainstream of the Dong Nai River, where the river flow is strongly regulated by a series of mainstream dams with active storage of 5.3 bln m^3.

The water resource assessment shows that the $W_{85\%}$ of annual water resources is around 1.265 bln m^3 and during the dry season is around 260 mln m^3, the active storage of all reservoirs in the basin is about 455 mln m^3 and nearly unchanged in the future. The total annual water demand is about 220 mln m^3 (estimated for 2018) and slightly increases to 283 mln m^3 in the future.

Without water transfer to the coastal region in the BLS1 and FFS1 scenarios, the water balance results (Tab. 9) show that the basin has a surplus of water in both present and future scenarios.

With full operation of both reservoirs transferring water to the Central Coast (BLS2 and FFS2), the total transfer is around

Table 9. Assessment results of Don Duong and Dai Ninh interbasin water transfer (IBWT) projects by water resources, water demand, and water balance in donor and recipient basins

Scenario	Annual $W_{85\%}$	Dry season $W_{85\%}$	Active storage	Transfer water	Water demand	Water balance	Deficit frequency (%)
	mln m³						
I Donor basin: Da Nhim River							
BLS1	1265	260	455	0	220	surplus	0
FFS1			455	0	283	surplus	0
BLS2			455	–893	220	deficit	26
FFS2			455	–893	283	deficit	27
II Recipient basin 1: Cai Phan Rang River							
BLS1	874	127	192	0	597	deficit	100
FFS1			393	0	500	deficit	89
BLS2			192	+420	597	deficit	71
FFS2			393	+420	500	surplus	0
II Recipient basin 2: Luy + Quao River							
BLS1	1453	203	193	0	799	deficit	100
FFS1			313	0	871	deficit	100
BLS2			193	+473	799	deficit	46
FFS2			313	+473	871	deficit	35

Explanation: $W_{85\%}$ = water at 85% reliability.
Source: own study.

893 mln m^3, taking into account 71% of $W_{85\%}$ of annual water in the Da Nhim catchment. The water balance results show that water deficit occurs in both scenarios, with an increased frequency of water shortage from 26% at present to 27% in the future. The conclusion based on this evaluation is that the Da Nhim donor basin faces significant water shortage with full operation of the Don Duong and Dai Ninh projects.

b1. Recipient basin 1: Cai Phan Rang River

The water resource and demand assessment of the recipient Cai Phan Rang River shows the $W_{85\%}$ of annual water resources is around 874 mln m^3, but is small during the dry season, around 127 mln m^3, due to very little rain. The active storage of all reservoirs in the basin is about 192 mln m^3 and will change rapidly to 393 mln m^3 in the future when some irrigation projects are under construction (Tan My reservoir with 210 mln m^3, Song Than reservoir with 80 mln m^3), while the total annual water demand is about 597 mln m^3 (estimated for 2018), slightly decreasing to 500 mln m^3 in the future due to changes in land use planning, crop shifting, and the development of high-tech irrigation.

Because of its dependence on transferred water resources from the Don Duong hydropower plant for an extended period (since 1964), the main irrigation in this area depends on the water supply from the IBWT. In scenarios BLS1 and FFS1, when there is no operation of the Don Duong reservoir to the Cai Phan Rang River, there is severe water deficit in the recipient basin, at 100% frequency or every year.

With full operation of the Don Duong hydropower plant in scenarios BLS2 and FFS2, when 420 mln m^3 of water is transferred into the recipient basin during the production period from January to August as supply for the present water demand of 564 mln m^3, the simulation results reveal a severe imbalance of supply and demand, and deficit occurs in 71% of simulated years. For the future, when the water demand decreases and active storage increases by building more irrigation reservoirs, the water balance pattern in the recipient basin is completely changed from deficit to surplus (Tab. 9).

b2. Recipient basin 2: Luy + Quao Rivers

The climate pattern in the Luy + Quao River basins is similar to the Cai Phan Rang River basin, where there is little rain in a longer dry season. The water resource and demand assessment of these recipient basins show that the $W_{85\%}$ of annual water resources is around 1.453 mln m^3, but during the dry season, is around 203 mln m^3. The active storage of all reservoirs in the basin is about 193 mln m^3 and rapidly changes to 313 mln m^3 in the future when some irrigation projects currently under construction will be finished (Song Luy reservoir with capacity of 100 mln m^3, Ka Pet reservoir with capacity of 51 mln m^3), while the total annual water demand is about 799 mln m^3 (estimated for 2018) and slightly increases to 871 mln m^3 in the future due to expanding land use.

The Luy + Quao Rivers have the same situation as the first recipient, the Cai Phan Rang River basin, where the irrigation area is designed to use the water supply from the Dai Ninh hydropower plant. Water shortage happens in every year of the simulation period when the Dai Ninh reservoir does not supply water to the Luy + Quao recipient basins (100%) in both BLS1 and FFS1 scenarios. The deficit period is long, from February to July, when water demand reaches a peak and very little rainfall causes no low flow in most of the small streams in the catchment.

With full operation of the Dai Ninh hydropower plant (BLS2 and FFS2), the water balance result shows water shortage in the region with lower frequency, from 46% at baseline to 35% in the future due to the reduction of water demand (Tab. 9).

In summary, operation of the Don Duong–Dai Ninh system is the key driver of water shortage in the donor basin, the Da Nhim River, representing a crucial water source for present and future water demands in two recipient river basins. Without the IBWT projects supplying water, just about 50% of water demand in the recipient basins is satisfied by other sources, or in other words, the recipient basins have to change their development plan completely because there is no IBWT project in operation while its own water resource is limited.

EVALUATION OF BENEFIT SHARING AND INFORMATION TRANSPARENCY

The benefit sharing is evaluated based on the related management policies and the ownership of the IBWT projects. Currently in Vietnam, most of the big hydropower projects including IBWT projects are state owned or managed by joint stock companies under the Electricity of Vietnam (EVN), only small projects (less than 30 MW or/and smaller than 3 mln m^3) belong to the private sector. The joint stock companies are all financially independent, and some of them are listed on the Vietnamese stock exchange (Don Duong project). Management policies has been stated in many laws relevant to environment, disaster, irrigation, water resources and electricity. Those policies are integrated into IROR for each river basins, that controls all regulations related to management of important reservoirs in a river basin, including operation, share of storage water, and related information. The rules are approved at the top level by the prime minister, and updated regularly every two to four years, depending on the situation in each basin. The rules are adjusted to adapt to the practical requirements and changes of related institutions and policies.

Benefit sharing of IBWT projects is considered as sharing of reservoir water storage in certain conditions. According to approved IROR, the reservoir water storage could be shared with other sectors when the authorities announces drought risk at level two or higher and flood risk warning at level one or higher. That means the share is possible but only in case of drought risk and flood risk rather than sharing annual benefit.

In terms of information transparency, currently information on the operation of all hydropower projects in general and water transfer hydropower projects in particular has been linked to the general database of the Ministry of Industry and Trade (https://hochuathuydien.evn.com.vn/ and from http://hothuydien.atmt.gov.vn/), and the data on inflows and release to donor and recipient basins are updated daily or even hourly. However, information on benefit or profit is not disclosed in any publication, and it is very difficult to obtain data on daily or hourly electricity generation for an independent and accurate evaluation of the effectiveness of the systems in the basins as a whole.

In summary, all IBWT projects failed to satisfy the criterion C4 on benefit sharing and information transparency due to the limitation of current policies; this might be improved if IBWT projects are considered as multi-purposes projects rather than hydropower projects as current status.

EVALUATION OF PLAN APPROVAL

Among the selected IBWT hydropower projects, the oldest construction, Don Duong project, operated starting since 1964 (during Vietnam war); the project was built to address water demand and power generation as first project in Da Nhim River basin without any basin planning.

The remaining IBWT projects were built in the 2000s, and these projects were studied, proposed, approved, and built according to the sectoral plans of hydropower and irrigation; they were first planned by the energy sector and approved by the top level (the prime minister) in period of 2001–2007, and subsequently updated and approved by the irrigation sector in 2007 at ministry level (MARD). In detail, the Thuong Kon Tum, Kanak-An Khe, and Dai Ninh projects were proposed and approved in the National Electricity Development Plan with the main purpose of generating electricity for energy security, in which the Dai Ninh and Kanak-An Khe projects were approved in the national plan in 2001, and the Thuong Kon Tum project approved in 2007.

Later in 2007, MARD approved a series of irrigation plans in river basins, to which the Thuong Kon Tum project was included in 2007, and the Kanak-An Khe project was included in the same year. All were approved at the top level by the prime minister.

It is clear that IBWT projects were designed and planned by the energy sector with the main purpose of power generation. The projects were designed to serve the primary goal of generating electricity for national energy security and with secondary goal to meet the “minimum flow” requirement instead of the full development water demand in donor and recipient basins.

SUMMARY OF CRITERIA EVALUATION AND LESSONS LEARNED

A summary of the satisfaction level of proposed criteria of the IBWT projects is shown in Table 10. The results show that no project meets all five criteria in which criterion C4 was not achieved by any projects. The Don Duong project only meets criterion C2 on real water shortage in the recipient basin while the Dai Ninh project has highest satisfaction level, meeting four over five criteria. Because the benefit sharing criterion C4 is related to the government’s macroeconomic policies at the national level in the past, if C4 is excluded from the evaluation, the Dai Ninh project would be considered the best IBWT project in the region. The Thuong Kon Tum and Kanak-An Khe projects only meet three of five criteria; the Thuong Kon Tum project transferred water to Tra Khuc recipient basin without real water shortage and Kanak-An Khe project transferred water to Kon recipient basin cause of water depletion in Ba donor basin.

Regarding the Don Duong project, at the initial stage when economic in the donor basin was not yet developed, the construction of the Don Duong reservoir ignored the long-term water needs in the downstream. However, after more than half a century, the water demand in the donor basin increased, while the project design is not favourable for releasing flow to the downstream, resulting in a conflict of interest between the donor and recipient basins. An alternative water source for economic development could not be found for the donor basin because the location of the Don Duong reservoir is the most suitable site in the basin to construct reservoir. In contrast in the recipient basin,

Table 10. Summary of criteria evaluation in four interbasin water transfer (IBWT) projects

Project	Criterion							Total
	C1		C2		C3	C4	C5	
	present	future	present	future				
Upper Kon Tum	yes	yes	no	no	yes	no	yes	**3/5**
Kanak–An Khe	no	no	yes	yes	yes	no	yes	**3/5**
Don Duong	no	no	yes	yes	no	no	–	**1/5**
Dai Ninh	yes	yes	yes	yes	yes	no	yes	**4/5**

Source: own study.

after more than 50 years of receiving the water source, a large irrigation system was established, which is completely dependent on transferred water sources. For sustainable development in the region, it is necessary to reallocate the water resource in both donor and recipient basin; this should be based on economic, technical, and political efficiency to minimize the impact of the Don Duong reservoir on both basins.

For Kanak-An Khe, the project diverts water from a water-deficient basin to a less water-deficient basin resulting conflict of interest. The unbalanced water condition in the donor basin show that this project has hindered development opportunities in downstream of the Ba River basin. Hence, it is necessary to changes this project into a multi-purposes project with the main goal of supplying irrigation water combined with generating power instead of generating power combined with supplying irrigation, as it is at present.

Based on the design of each IBWT system, the results of impact assessment, and the level of fulfilment of the proposed evaluation criteria, four lessons were learned from these projects, as follows:

1. Lessons on planning preparation and approval: all water transfer projects should be proposed in a regional master plan with multiple objectives, or at least in water resource, hydraulic work, or related sectoral plans. In fact, the existing IBWT projects in the study area did not follow the procedures in the region; they were first approved in the energy sector by highest level of authority and, afterward, other sectors could only update the proposed projects for their sectoral plans as they had already been approved at the highest level.
2. Lessons about the unknown future: as example of Don Duong project, future water demand forecasted over the long term has very high uncertainty, especially considering climate change. Even if the donor basin does not have real water demand at any stage, it is necessary to design projects in flexible way so that they can accommodate donor basins to avoid the loss of future development opportunities for donor basins, although future water demand cannot be fully predicted in existing calculations.
3. Lessons on inadequate impact assessment: failure in C1 for An Khe-Kanak project is cause by inadequate consultation with relevant sectors and communities on the river basins before project construction; it is a direct cause of livelihood and environmental impacts on donor basins at present and might be continue in the future without adequate solution. Thus, it is vital to perform full impact assessment any new proposed IBWT project to avoid waste of capital and potential environment effects.
4. Lessons on slow updating practices of policy: when all the IBWT projects starts to operate, they did not release environmental flow downstream and only started to release after several years according to approved interreservoir operation rules in river basins by the central government (Kanak-An Khe had no release during 2012–2014 and Dai Ninh had no release during 2009–2016). This means the related policies need to be approved before opening of IBWT projects.

CONCLUSIONS

This study evaluated the level of satisfaction of IBWT projects in Vietnam based on the proposed matrix of five criteria. The assessment for C1 and C2 criteria was performed based complex models for water resources and water balance in the donor and recipient river basins, the C3, C4 and C5 criteria is assessed based on an intensive analysis of monitored data, related information of each system. The assessment result shown no project that meets all proposed five criteria and no project satisfy the fourth criteria of benefit sharing and information transparency (C4), especially the Don Duong project, only meets C2 criteria where the recipient basin, a very low rainfall area, has an actual water shortage in the present and future. There are four lessons learned that draw out from the assessment analysis: (1) IBWT projects is not derived from integrated river basin planning; (2) lack of flexibility in system design for unknown future; (3) inadequate impact assessment on social, economic and environmental aspects; (4) management policies launched after project operation opening.

In recipient basins, which are mostly in water-scarce areas except for the Tra Khuc River basin, transferred inflow from IBWT projects plays a crucial role during the dry seasons, providing water for development activities and the prosperity of the region, such as in the Cai Phan Rang River basin and the Luy + Quao River basins. However, water resource is not abundant in the donor basin in the present or future. For a trade-off benefit between donor and recipient, it is essential to develop a regional master plan for water resources in the related basins based on optimization techniques for water rebalance.

In Don Duong project, it was designed without a bottom outlet to release environmental flow to the downstream of the donor basin. It is recommended to build an additional bottom outlet for the Don Duong dam to ensure it can satisfy the C1 and C3 criteria. For the fulfilment of C4 and C5 that requires not only the effort of project owners but also the determination of central and local governments.

Regarding all IBWT projects that cause water shortage in donor basins, since they were originally designed as hydropower projects with irrigation supply as a secondary task, it is necessary to transform them into multipurpose projects that are designed so that water supply during high demand periods or in drought conditions has a priority equal to or higher than power generation, and water supply for the donor basin should always be the first priority.

Given the low level of satisfaction in the evaluation, our results call for urgent reconsideration of the hydropower projects related to IBWT in the Central Highlands and Central Coast of Vietnam. Our findings deliver valuable lessons as a starting point for reconsideration of IBWT project development and mitigation measures for exist projects.

REFERENCES

Arias M.E., Cochrane T.A., Kummu M., Lauri H., Holtgrieve G.W., Koponen J., Piman T. 2014. Impacts of hydropower and climate change on drivers of ecological productivity of Southeast Asia's most important wetland. Ecological Modelling. Vol. 272 p. 252–263. DOI 10.1016/j.ecolmodel.2013.10.015.

Bansal S. 2014. National River Linking Project: Dream or disaster? [online]. [Access 21.10.2020]. Available at: https://www.indiawaterportal.org/articles/national-river-linking-project-dream-or-disaster

Bui D.T., Asl D.T., Ghanavati E., Al-Ansari N., Khezri S., Chapi K., Amini A., Pham B.T. 2020. Effects of inter-basinwater transfer on water flow condition of destination basin. Sustainability. Vol. 12(1), 338 p. 1–20. DOI 10.3390/SU12010338.

Cox W.E. 1999. Determining when interbasin water transfer is justified: Criteria for evaluation. In: Interbasin water transfer. Proceedings of the international workshop. A contribution to the world water vision consultation process. Eds. J.J. Bogardi, S. Bruk, C. Vienot, J.M. de La, F. Gonzáles. International Hydrological Programme (IHP-V). Technical documents in hydrology. No. 28. UNESCO, Paris, 25–27 April 1999. Paris. UNESCO p. 173–178.

DHI Mike 11. 2017. Reference manual: A modelling system for rivers and channels [online]. [Access 21.10.2020]. Available at: https://manuals.mikepoweredbydhi.help/2017/Water_Resources/Mike_11_ref.pdf

DHI Mike Basin 2017. Mike Hydro basin: River basin management and planning [online]. [Access 21.10.2020]. Available at: https://manuals.mikepoweredbydhi.help/2017/Water_Resources/MIKEHydro_Basin_UserGuide.pdf

Ghassemi F., White I. 2007. Inter-basin water transfer. Case studies from Austrialia, United States, Canada, China, and India. Cambridge. Cambridge University Press. ISBN 978-0521869690 pp. 462.

Gohari A., Eslamian S., Mirchi A., Abedi-Koupaei J., Massah Bavani A., Madani K. 2013. Water transfer as a solution to water shortage: A fix that can Backfire. Journal of Hydrology. Vol. 491 p. 23–39. DOI 10.1016/j.jhydrol.2013.03.021.

Gupta J., van der Zaag P. 2008. Interbasin water transfers and integrated water resources management: Where engineering, science and politics interlock. Physics and Chemistry of the Earth. Vol. 33 p. 28–40. DOI 10.1016/j.pce.2007.04.003.

Gurung P. 2015. Inter-basin water transfer: Is this a solution for water scarcity? [online]. [Access 21.10.2020]. Available at: https://www.researchgate.net/publication/280132947_Inter-basin_Water_Transfer_Is_this_a_Solution_for_Water_Scarcity

Jain S.K., Singh V.P. 2003. Water resources planning. Chapter 9. In: Water resources systems planning and management. Ser. Developments in Water Science. Vol. 51. Elsevier p. 505–553. DOI 10.1016/S0167-5648(03)80063-1.

Kibiiy J., Ndambuki J. 2015. New criteria to assess interbasin water transfers and a case for Nzoia-Suam/Turkwel in Kenya. Physics and Chemistry of the Earth. Vol. 89 p. 121–126. DOI 10.1016/j.pce.2015.08.005.

Luật số 17/2012/QH13 của Quốc hội: Luật tài nguyên nước quốc hội [Law No. 17/2012/QH13 of the National Assembly: Law of water resources] [online]. [Access 21.10.2020]. Available at: https://chinhphu.vn/default.aspx?pageid=27160&docid=162986

Manh N.V., Dung N.V., Hung N.N., Kummu M., Merz B., Apel H. 2014. Future sediment dynamics in the Mekong Delta: Impacts of hydropower development, climate change and sea level rise. Global and Planetary Change. Vol. 127 p. 22–33. DOI 10.1016/j.gloplacha.2015.01.001.

Micklin P., Aladin N.V. 2008. Reclaiming the Aral Sea. Scientific American. Vol. 289 p. 64–71. DOI 10.1038/scientificamerican0408-64.

Nhung D., Manh N.V., Hong L., Nghiem D. 2020. Nghiên cứu đánh giá cân bằng nước liên vùng, liên lưu vực sông khu vực Tây Nguyên và Nam Trung Bộ [Research on inter-basin water balance assessment in the Central and Highlands region – Vietnam]. Journal of Water Resources. Vol. 4 p. 1–14.

Nhung D., Nghiem D., Hoang N., Tuan N. 2020. Nghiên cứu đánh giá phân bố và mối liên hệ nguồn nước giữa vùng Nam Trung Bộ và Tây Nguyên: Hiện tại và tương lai 2050 [Study on assessment of distribution and relationship of water resources between South Central and Highlands: current and future 2050]. Journal of Water Resources & Environmental Engineering. Vol. 70 p. 78–86.

Rahman K. 1999. Interbasin water transfer: Bangladesh perspective. In: Proceedings of the International Workshop: A Contribution to the World Water Vision Consultation Process. Eds. J.J. Bogardi, S. Bruk, C. Vienot, J.M. De La, F. Gonzáles. International Hydrological Programme (IHP-V). Technical documents in hydrology. No. 28. UNESCO, Paris, 25–27 April 1999. Paris. UNESCO p. 81–94.

Räsänen T.A., Koponen J., Lauri H., Kummu M. 2012. Downstream hydrological impacts of hydropower development in the Upper Mekong Basin. Water Resources Management. Vol. 26 p. 3495–3513. DOI 10.1007/s11269-012-0087-0.

Shumilova O., Tockner K., Thieme M., Koska A., Zarfl C. 2018. Global water transfer megaprojects: A potential solution for the water-food-energy nexus? Frontiers in Environmental Science. Vol. 6, 150. DOI 10.3389/fenvs.2018.00150.

Sinha P., Rollason E., Bracken L.J., Wainwright J., Reaney S.M. 2020. A new framework for integrated, holistic, and transparent evaluation of inter-basin water transfer schemes. Science of The Total Environment. Vol. 721, 137646. DOI 10.1016/j.scitotenv.2020.137646.

Sternberg T. 2016. Water megaprojects in deserts and drylands. International Journal of Water Resources Development. Vol. 32 (2) p. 301–320. DOI 10.1080/07900627.2015.1012660.

TEGEGNE G., KIM Y.O. 2018. Modelling ungauged catchments using the catchment runoff response similarity. Journal of Hydrology. Vol. 564 p. 452–466. DOI 10.1016/j.jhydrol.2018.07.042.

YOSHIDA Y., LEE H.S., TRUNG B.H., TRAN H.D., LALL M.K., KAKAR K., XUAN T.D. 2020. Impacts of mainstream hydropower dams on fisheries and agriculture in lower Mekong basin. Sustainability. Vol. 12 p. 1–21. DOI 10.3390/su12062408.

YU M., WANG C., LIU Y., OLSSON G., WANG C. 2018. Sustainability of mega water diversion projects: Experience and lessons from China. Science of The Total Environment. Vol. 619–620 p. 721–731. DOI 10.1016/j.scitotenv.2017.11.006.

ZHUANG W. 2016. Eco-environmental impact of inter-basin water transfer projects: A review. Environmental Science and Pollution Research. Vol. 23 p. 12867–12879. DOI 10.1007/s11356-016-6854-3.