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NGO THI NHIP

ASSESSMENT OF WATER RESOURCES IN THE DONG NAI RIVER BASIN FOR SOCIO-ECONOMIC DEVELOPMENT IN THE CONTEXT OF CLIMATE CHANGE

(in the Central Highlands region)

SUMMARY OF DOCTORAL THESIS IN EARTH SCIENCES

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1. Necessity of the thesis topic

Water is an extremely valuable but limited resource. With increasing demand and the impact of climate change, the quality of water resources is facing a decline in both quantity and quality. Vietnam has an abundant water resource system but its uneven distribution across the country that is detrimental to water resource allocation, leading to an insecurity of water resources. The Dong Nai River Basin plays an extremely important role in providing water not only for the provinces of the Central Highlands but also for economic development in the Southern region. Although the upstream area of the Central Highlands accounts for 22% of the entire basin, economic development and exploitation of water resources (WR) in the upstream region affect the quantity and quality of WR in the downstream region. Most of the research topics cover the entire Central Highlands, or the entire Dong Nai River Basin. The studies focus on in-depth research of each part such as surface water resources or underground water resources or focus on assessing quantity, quality or their changes. There are very few comprehensive assessment studies, especially the assessment of upstream water resources in the Central Highlands with consideration of climate change. The thesis "Assessment of water resources in the Dong Nai River Basin for socio-economic development in context of climate change (in the Central Highlands region)" will highlight the impact of natural and socio-economic factors on water resources, calculate and estimate the water balance (WB) in the current and future study area (SA) in 2035 and 2050 under the impact of climate change (CC). The research results will provide additional scientific basis for the management and assurance of water security in the river basin.

2. Objectives of the thesis

- Assess the potential and existing status of water resources in the research area based on the impacts of natural and socio-economic factors affecting water resources in the research area.
- Estimate future water resources and water demand according to socio-economic development trends and climate change impacts; calculate the current water balance of the research area in 2020 and the future in 2035, 2050 with detailed results for 8 sub-basins.
- Propose some solutions for the exploitation and rational use of water resources in detail for the sub-basins, serving the socio-economic development of the research area.

3. Research content of the thesis

From the overview of research on assessing water resources in the world, in Vietnam as well as in the research area, the thesis finds and completes the scientific basis and practical basis for assessing water resources for the research area.

- The thesis assesses the existing status and potential of water resources of the research area based on the impacts of natural and socio-economic factors on water resources. Calculating the current water balance in 2020 and the future (2035, 2050) with consideration of climate change impacts. Their detailed results are shown for sub-basins.
- From the research results, several comprehensive solutions have been proposed in exploiting, using and protecting water resources in the research area according to the sub-basins, serving socio-economic development from the perspective of integrated water resources management.

CHAPTER 1. OVERVIEW OF THE RESEARCH AND ASSESSMENT OF WATER RESOURCES

1.1. Some concepts

1.1.1. Concept of water resources assessment, characteristic factors

There are many different concepts of water resources assessment:

"Water resources assessment is to determine the source, level, reliability and quality of water resources for its use and control". According to the concept of the Global Water Partnership (GWP).

"Water resources assessment is understood as determining the quantity, quality, value, usability and level of their impact on socio-economic development, as well as the impact of socio-economic activities on water resources" according to Nguyen Thanh Son.

Water resources are assessed by three basic characteristics: quantity, quality and dynamics. Thus, water resources assessment is the process of measuring, collecting and analyzing relevant parameters on quantity and quality, changes in water resources over space and time (including rainwater, surface water, groundwater) for the purpose of exploiting and managing sustainable water resources.

1.1.2. The role of water resources assessment in socio-economic development

Nowadays, water is not only important for food and industry but also plays a role in many other fields. After the 6th Congress, Vietnam has achieved many great development achievements, especially from water resources. Hydroelectric projects such as Hoa Binh and large reservoirs have made important contributions to the prosperity and economic development of the country. Vietnamese law stipulates that water is a public asset, water assessment and inventory are very important to ensure the effective use and sustainable development of this resource.

1.2. Overview of the research and assessment of water resources in river basins around the world

Historically, research on water resources and integrated water resources management has been interested since very early time, starting from the end of the 19th century. International organizations have pla resource management an important role in promoting research and management of water, typically the International Water Management Institute (IWMI) and the World Water Forums. Some pioneering countries in this field such as the US,

France, Brazil, and China have issued legal documents and established specialized management agencies to implement integrated water resources management. At the same time, the strong development of information technology has allowed the application of computer models such as NAM, MIKE, WEAP to water resourcesmanagement, contributing to improving the scientific and objective nature of the decision-making process.

The research and assessment of water resources of river basins under the impact of climate change

According to the Intergovernmental Panel on Climate Change (IPCC), the concentration of CO_2 in the atmosphere is increasing, expected to reach a high level by 2100. Global warming causes extreme weather events and deep impacts on the availability and variability of freshwater sources. Recent studies in different regions of the world have shown future reductions in the flow of important river systems such as the Karnali River in Nepal and a gradual decline in other basins. The assessment of climate impacts through the CMIP5-RCP 8.5 scenario provides a detailed view of the flow and temperature changes for the Atlantic Coast river basins of the United States.

1.3. Overview of research and assessment of water resources in river basins in Vietnam

Throughout history, research on water resources in Vietnam has gone through many stages of development. Before 1945, water resources research was limited, mainly focusing on the construction of irrigation structures. From 1945 to 1975, the North had initial basic research on water resources with typical works such as the development of hydrogeological maps, but the South was limited due to war. Since 1975, water resources research has made great strides with large-scale studies such as KC12, KC08-31, 42a, ... focusing on assessment, planning and management of water resources in river basins. Recently, water resources research has focused on integrated management, responding to climate change and

ensuring water security. However, the research still has some limitations that need to be overcome.

In recent years, water resource assessment with consideration of climate change is a trend in last 20 years and has been carried out in major river basins across the country. The goal is to proactively and sustainably manage water resources and proactively adapt and respond to climate change caused in river basins.

1.4. Status of research and assessment of water resources in the Dong Nai River Basin

Research on Water Resources in the Dong Nai River Basin has been conducted in many stages. Before 2005, major studies such as Program 48C (1988), Project KC-12.04 (1993), KC-08-29 (2005), KC-08-05 (2004) were published, mainly by leading scientists such as Prof. Dr. Ngo Dinh Tuan, Assoc. Prof. Dr. Pham Quang Hanh. The studies focused on quantifying the components of water resources and water balance in the Central Highlands.

In the period of 1995-2005, with the development of industrial parks at downstream of the Dong Nai River Basin, projects such as "Environmental protection of the Dong Nai River Basin" were launched. Scientists such as Prof. Dr. Lam Minh Triet has proposed a solution for integrated river basin management to resolve conflicts over water use and basin reservoir operations.

In the period 2005-2010, the studies focused on the current drought status and the development of drought forecasting procedures. The studies are all of great significance in providing solutions for adequate water supply for agricultural development and drought mitigation. From 2010-2020, with the emergence of many hydropower projects and reservoirs, the studies focused on the operation of inter-reservoirs and assessing their impacts on water distribution and use in the Dong Nai River Basin. Sustainable solutions were also proposed. Most recently, the master planning of the Dong Nai River Basin for the period 2021-2030, vision to

2050, has just been announced by the Ministry of Natural Resources and Environment on January 2024.

Some shortcomings in assessing water resources in the Dong Nai River Basin

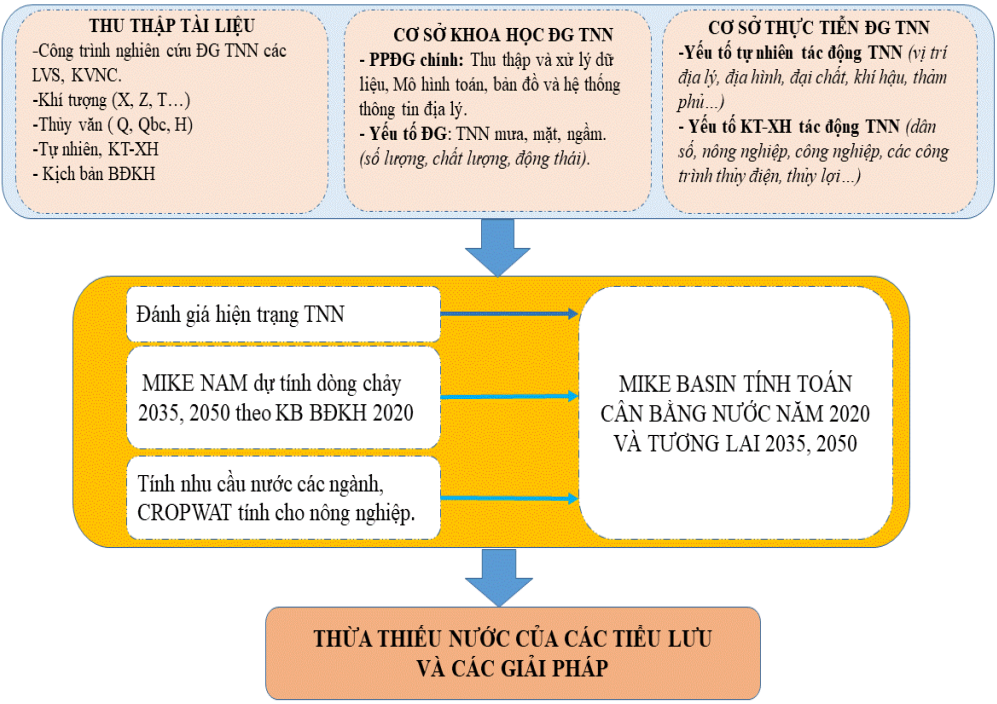

Figure 1.1. *Logical diagram of research steps*

Scientific studies only focus on in-depth research on each type of resource: rainwater, surface water or underground water, many results only evaluate quantity, some works only evaluate quality. The issue of forecasting and estimating water resources is associated with socio-economic development and large-scale territorial planning, estimating future flows according to the old 2012 and 2016 climate change scenarios, it is necessary to pay attention and study the role of minimum flows for water use relationships in the river basin. Solutions focus on specialized

water resource management but rarely mention socio-economic development by sector or by sub-basins. There has been no research, including the latest project, that has assessed in detail the characteristics of natural and social factors affecting the water resources of the Dong Nai River basin in the Central Highlands under the impact of climate change with the 2020 climate change scenario. There have also been no results of forecasting changes in water resources occurring in the study area under the impact of future climate change in detail to the sub-basins. Therefore, the research results of the thesis will be the basis for orienting solutions for using water resources in a reasonable balance and detailed water resources to the sub-basins, serving sustainable socio-economic development. To solve the above problems, the thesis needs to conduct research according to diagram 1.1.

CHAPTER 2: SCIENTIFIC AND PRACTICAL BASIS FOR ASSESSING WATER RESOURCES IN RIVER BASIN

In this chapter, a scientific basis shows clearly the main research methods, databases applied to calculate and evaluate water resources factors. The practical basis has clarified how the natural characteristics and socio-economic conditions of the research area affect the formation of water resources in the research area.

2.1. Scientific basis for water resources assessment

2.1.1 Research methods

2.1.1.1. Mathematical modeling method

After studying the suitability of the models with the research topic the author selected the MIKE NAM model which was applied to estimate the flow on the river basin. CROPWAT software was selected to calculate water demand for agriculture, and the MIKE BASIN model was applied to calculate water balance. To apply the mathematical models for detailed calculations the research area is divided into 8 sub-basins.

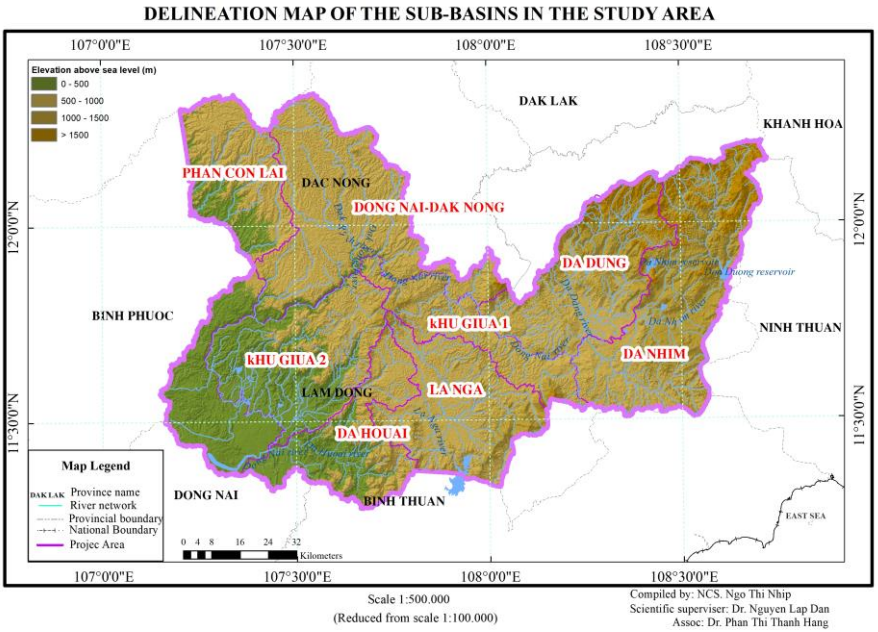

Figure 2.1: *Sub-basin division of the study area*

1. MIKE NAM model

The basic input data of the model includin rainfall, evaporation at Bao Loc, Lien Khuong, Da Lat, Dak Nong, Ta Lai stations... and observed flow data measured at Dai Nga and Dak Nong stations were used to calibrate and verify the model. The initial model parameters were determined during the calibration and validation processes.

The model outputs area flow processes in the basin

2. CROPWAT software

Inputs include factors such as temperature, wind speed, sunshine duration, humidity, calculation period, rainfall, crop information, geographical features and local factors are requested when calculating water requirements.

Outputs are estimated values of potential evapotranspiration (ETo) based on the Penman-Monteith method; water requirements are calculated according to growing period of crops

.

3. MIKE BASIN model

The model is used to calculate the water balance in the study area in 2020 and in the future in 2035 and 2050 under the impact of climate change.

The inputs including all information about the river network, terrain, current status of water exploitation and use are determined directly from the interfaces on the screen in the future. The amount of water coming to each sub-basin in the MIKE BASIN model is calculated from the rainfall that creates the flow (according to the results of the MIKE NAM model) for the sub-basins. Water demand for the sectors for the existing status in 2020 and the future in 2035 and 2050 is also calculated from the model. The synthesis of 5 calculation scenarios is as follows:

Table 2.4 Results of water balance calculation scenarios

Frequency	**Run-off scenarios**				
	Current 2020	**2035.RCP4.5**	**2035.RCP8.5**	**2050.RCP4.5**	**2050.RCP8**
P = 85%	2020	KB2	KB3	KB4	KB5

Water demand: Water demand scenarios for current sectors in 2020 combined with water demand for crop production corresponding to the frequency of ensuring water supply P = 85%. Future water demand scenarios for the period 2035, 2050 according to the frequency of ensuring P = 85% corresponding to the climate change scenarios RCP4.5 and RCP8.5.

The results identify sectors, sub-basins experiencing water shortages, amount of water deficit, and the timing of shortages for each scenario.

2.1.1.2. Statistical and Expert-Based Methods

Inheriting scientific works on assessing water resources in the world and in the country. Especially research projects on assessing natural

resources: State-level scientific and technological projects TN3/T02 (2015), KC.08.29/11-15 (2015), TN16/T01 (2016-2020), TN16/T02 (2016-2020). Ministry-level scientific and technological project 2017, code: 2015.02.14. Groundwater documents of the 704th Groundwater Survey Team, projects KC.02.2009, KC.08.05. Latest documents [83], [88], [95], [96]. Statistics of meteorological and hydrological measurement and observation documents on the NC area, unifying data series and selecting the uniform time series of data 1985 - 2020 for calculation use. Collect additional documents, compare collected documents with field data... In addition, the study applied expert methods to consult scientists to advise the research direction and results of the research process.

2.1.1.3 Map and geographic information system (GIS) methods:

The preferred research method in the thesis is to use geographic information from maps, combined with software such as MapInfo and ArcGIS. By using these tools, maps of the study area, river network maps, as well as maps of annual flow modules, flood levels, droughts, and underground flows have been built.

2.1.2. Computational database

2.1.2.1. Database for assessing rainwater resource

The study used the 1985-2020 rainfall data series at 8 meteorological stations and rain gauge stations: Dak Nong, Bao Loc, Da Lat, Lien Khuong, Dai Nga, Di Linh, Ta Lai, Ta Pao to calculate rainfall TNN in the study area. The study used the method of calculating average rainfall in the basin, the method of rainfall contours. Rainwater quality according to Circular No. 10/2021/TT – BTNMT, dated June 30, 2021.

2.1.2.2 Database for assessing surface water resources

The hydrological stations used for calculation are 4 operating stations, this study selected 4 stations for calculation with a series of measurement data from 1985-2020. The hydrological stations Thanh Binh on Dong Nai River, Dai Nga on Dargna River, Dak Nong on Dak Nong River, and Ta Lai station on Dong Nai River were used to calculate the

characteristics of surface water resources of the study area. The statistical method was applied to calculate the characteristic values of water resources.

Water quality: In the thesis, to evaluate surface water quality, QCVN 08-MT:2023/BTNMT was used.

2.1.2.3. Database for assessing groundwater resources

a. Forecasted groundwater resources

$$Q_{TN} = \frac{V_t}{t} + Q_{bc}$$

Here: Q_{tn} - forecasted groundwater resources (m^3/day);

V_t - water volume stored in aquifers (m^3);

Q_{bc} - total recharge from various sources (infiltration by rainwater, surface water, recharge from underground streams from other places) (m^3/day);

b. Exploitable reserves of underground water

Exploitable reserves are determined by the formula:

$$Q_{kt} = 0,3.Q_{tn}$$

Qkt: Exploitable reserves of aquifers in the study basin, m^3/day;

Q_{tn}: Forecasted groundwater resources of aquifers in the basin, m^3/day.

Groundwater quality: following QCVN 09:2023/BTNMT (abbreviated as QCVN09), issued under Circular No. 01/2023/TT-BTNMT dated March 13, 2023.

2.2. Practical Basis for Water Resources Assessmen

2.2.1. Natural factors affecting water resources

2.2.1.1. Geographical location

The geographical location of Dong Nai River Basin has determined the nature of the tropical monsoon climate of the West Truong Son range, and the special weather pattern. The climate has a deep distinction between the rainy and dry seasons, causing a very uneven distribution of water resources between the two seasons, the rainy and flood season accounts for 76.74%, the dry season 23.26%.

The scope of Dong Nai River Basin stretches from Northeast to

Southwest, on many different types of terrain, creating the ability to collect large amounts of rainwater, but there is a diverse and complex differentiation (the center of heavy rain in Bao Loc is in the West, Southwest, Northwest where the wind is stronger than the East of the River Basin; Rain on the windy mountain slopes is stronger than the plateau, highlands and lowlands).

2.2.1.2. Topography and geomorphology

The terrain and geomorphology of Dong Nai River Basin affect rainfall, rainfall distribution, hydrology and water storage capacity. Rainfall: The River Basin has the largest rainfall among the River Basins of the Central Highlands. Rainfall distribution: The rainfall of the River Basin is concentrated on the windward slopes of the Southern and Southwest mountainous regions with large rainfall in the areas with rain gauge stations: Bao Loc, Dak Nong, Ta Lai with rainfall (2000-2800) mm. On the contrary, the area with the least rainfall in the basin (Da Lat, Lien Khuong) has rainfall (1200-2000) mm. Hydrology: With the terrain sloping from the Northeast to the Southwest, it creates favorable conditions for erosion, forming many streams, rapids in the upstream, small and fast river flows, floods in the basin rise and fall quickly, the dry season in the basin has small flows, the dry season lasts 7 months, many places are short of water. Water storage capacity: The terrain also makes the water storage capacity in the basin poor, water quickly flows downstream of the river basin and flows out to sea.

2.2.1.3. Climate

The climate of Dong Nai River Basin has made the rain have a specific characteristic of being concentrated only in the rainy season (from May to October) accounting for 81.6% of the total rainfall and the remaining 7 months of the dry season account for 19.4%. The spatial and temporal differentiation of rain has led to the difference in forming the flow of the flood season lasting 5 months from July to November (accounting for 76.74%). Precipitation represents the primary driving factor governing

runoff formation in the study area. The rainfall–runoff relationship was systematically examined based on observations from meteorological, pluviometric, and hydrological stations within the basin.

Factors such as high solar radiation, high sunshine, high evaporation, low air humidity in the dry season... have directly and strongly affected the water loss capacity of Dong Nai River Basin. This is the cause of prolonged drought and severe water shortage in the river basin.

2.2.1.4. Hydrological river network

Water resources in the basin are different, the river and stream network forms a mountainous terrain, with many cuts and rapids, so the rivers and streams are typically short and steep. The characteristics of the plateau and red basalt soil lead to the formation of flows in the basin during the flood season, which is often 1-2 months later than the rainy season. The flood season lasts 5 months, the flood rises quickly and easily causes flash floods, landslides, and landslides. In the dry season, the flow accounts for 23.1%, lasting 7 months, and the large amount of evaporation on the red basalt soil causes the natural flow of rivers and streams in the basin to dry up and break up in many places.

2.2.1.5. Geology, hydrogeology

The geology, hydrogeology of Dong Nai River Basin determines the abundance, distribution characteristics and quality of underground water resources. The permeable basalt formations are the most important underground water reservoirs. The basalt cover creates a "phase shift" between the rainy season and surface flow and underground flow. The dry season lasts 7 months on the red soil of Basalt, which evaporates greatly, so the precious underground water source is supplied to the industries in the dry season. Geology, hydrogeology govern both the quantity and quality of surface flow and underground flow, in the South and Southwest of the basin in Da Lat, on the Dak Nong plateau, some high mountainous areas have been polluted with iron with Fe content > 0.3 mg/l.

2.2.1.6. Soil

Due to the characteristics of the soil, the amount of water seeping into the soil layer at the beginning of the rainy season is large, a large amount of surface flow is formed during the rain. Therefore, floods form in the basin more slowly than in other areas, the surface flow contributes a large amount to the formation of flood peaks, flood peaks can appear 2-3 days after rain. The process of forming underground flows is also slower than in other basins, from 1-2 months, some areas 3 months. The soil characteristics make the strength of the region industrial crops, the area and output of the above crops have expanded and grown strongly in the past 10 years. The massive industrial crop area without planning has led to serious degradation of both surface water and groundwater in the dry season.

2.2.1.7. Vegetation

The reduction of natural forests has led to a decrease in groundwater storage capacity, in addition, floods and landslides occur more often, causing great damage to people and property. In addition, deforestation to increase cultivated areas also affects surface water and groundwater resources by increasing the amount of water consumed for irrigation. In many locations, the groundwater level has dropped seriously, the groundwater level has dropped 1-3 m, especially 7-8 m in the dry season compared to before.

The influence of land cover is also a dominant factor influencing water resources, as presented in the author's article No. 1.

2.1.1.8. Impact of natural disasters

With the condition of the buffer surface being thinner due to the decline of natural forests and gradually being replaced by restored planted forests and production forests. Natural disasters: droughts during the dry season are severe, erosion, riverbank erosion causes sedimentation of the channel, reservoir bed, changes in flow... thereby causing land degradation, no flow, drying up and loss of flow, easily causing floods, and also reducing the water storage capacity of reservoirs due to sedimentation.

2.2.2 Analysis of socio-economic factors affecting water resources

2.2.2.1. Population

The total population of the study area has increased continuously in recent years, increasing by 13.6% after 10 years, in 2020 compared to 2010. People's living standards and incomes are increasingly improving, creating pressure on the demand for and use of clean water not only for daily life, but also for other activities related to human activities such as agricultural production, industrial development, processing...

2.2.2.2. Economic activities

Agriculture is the dominant factor affecting both the quantity and quality of water resources in the Dong Nai River Basin. The large demand for water is industrial crops: coffee, pepper, fruit trees: durian, avocado, macadamia... expanding beyond the planning, leading to inadequacies in the ability to meet water resources, conflicts in exploitation, use, and sharing of water resources, especially in the 7 dry months.

Industrial activities are the second largest water users after agriculture. Mineral exploitation, starch processing... use a lot of water. The ability to reuse water is low, if not thoroughly treated and closely monitored, it can easily cause pollution and degradation of natural resources.

Service and tourism industry, Da Lat attracts a large number of visitors every year, requiring high quantity and quality of water supply.

2.2.2.3. Water extraction structures

Positive impacts: the process of storing water and regulating water is very helpful in using the comprehensive benefits of natural resources, hydroelectric projects bring great socio-economic benefits to develop the region.

Negative impacts: creating major changes in the hydrological regime of natural flows to the downstream area in an unfavorable direction. The rainy season increases the possibility of threats, the dry season lacks water, causing the river to break, making the sedimentation and erosion process in the downstream change complexly.

Hydraulic structures - dominant factors affecting river flows, are analyzed on basis of the observed data at hydrological stations over two periods: Period 1 from 1985 to 2000 and Period 2 from 2000 to 2020. The analysis demonstrates that irrigation and hydropower structures have moderated flow variations in the basin, harmonizing flows between the flood and dry seasons. Specifically, mean flows during the dry season tend to increase, while during the flood season, the structures reduces peak floods and regulate river discharge more evenly. -

CHAPTER 3: ASSESSMENT OF WATER RESOURCES IN THE CONTEXT DONG NAI RIVER BASIN OF CLIMATE CHANGE

3.1. Assessment of water resources in Dong Nai river basin

3.1.1. Assessment of rainwater resources

Dong Nai river basin is located in the Southern Central Highlands with an average annual rainfall of approximately 2200 mm. There is a large rain center in Bao Loc - Dak Nong with an average annual rainfall of 2400 - 3000 mm. The average annual rainfall in the area is 2200 mm, in the rainy season (May - October) the average is 1785 mm (81.6% of the annual rainfall). The rainfall in the entire dry season (November - April) is only 403 mm (18.4% of the annual rainfall).

Table 3.2a: Characteristics of rainwater resources in upper Dong Nai river Basin

No.	Sub-river basin	Area (km^2)	Average annual rainfall (mm)	Total annual rainwater volume (Bil. m^3)
1	Upper Dong Nai River to Ta Lai	9364	2200	20.6
2	La Nga	1331	2240	2.98
3	Be river basin	981	2300	2.26
	Total			**25.8**

The quality of rainwater in the upper Dong Nai river basin is relatively good and stable. The pH reflects weak alkaline and slightly acidic

water, varying from 6.88 to 7.14 with an average pH value of 6.98. Rainwater is super light and can be used for drinking, daily activities or irrigation.

3.1.2. Assessment of surface water resources

Assessment of total surface runoff

The flow in the study area is quite abundant with the average flow module over many years reaching values from 32.2 - 52.8 1/s.km^2

Dong Nai River basin up to Ta Lai hydrological station has flood season flow from (July to November) with flood season flow module of 66.5 l/s.km^2, accounting for 76.74%. The dry season usually starts from December, or January lasting until June, July, sometimes until August, accounting for only 20-30% of the annual flow.

***Table 3.6**: Flow characteristics of 5 hydrological stations*

Hydrological station	**River** km	**Area (km2)**	**Qo** (m^3/s)	**Mo** ($l/s.km^2$)	**W_o** (Bil. m^3)	Hệ số CS	Hệ số CV
Dak Nong	Dak Nong	292	15.41	52.8	0.49	0,325	0,39
Thanh Binh	Dong Nai	294	9.47	32.2	0.30	0,21	1,14
Dai Nga	La Nga	347	16.6	47.9	0.52	0,18	0,4
Ta Lai	Dong Nai	9364	340	36.3	10.7	0,21	0,16

***Table 3.8:** Surface runoff generated in the basin*

River basin	**Area F (km^2)**	**Annual runoff module ($l/s/km^2$)**	**Volume W (Bil. m^3)**
Dong Nai (up to Ta Lai)	9364	36.2	10.72
La Nga (within Central Highlands)	1331	47.9	2.00
Be river (within Central Highlands)	981	44	1.65
Total			**14.37**

The results of water quality analysis at 70 monitoring points during the flood and dry seasons are presented in Table 18 of the Appendix and illustrated in Figures 3 and 4 on pages 181–182 of the Appendix. The results show that water quality at most river and lake monitoring sites in the research area is classified as good to very good. However, there are still

many monitoring points on the rivers and lakes of the Cam Ly and Da Dang rivers that show signs of heavy to very heavy pollution in both the flood and dry seasons

3.1.3. Assessment of groundwater resources

Assessment of groundwater quantity:

Table 3.14: Results of determining exploitable groudwater,

TT	Aquifer	Area (km^2)	Total volume (10^6 m^3)	Total recharge (m^3/day)	Total forecasted source (m^3/day)	Total exploitable ground water (m^3/day)
1	qh	423.83	370,1624203	32247.53	69263.77	20,779.13
2	βqp	300.30	2,110,945499	206440.08	417534.63	125,260.39
3	$\beta(n_2$-qp)	4,351.20	30,756.61	2,754,066.52	5,829,728.01	1,748,918.40
4	n_{1-2}	65.02	393.778	38563.40	77941.20	23,382.36
5	k_2	120.10	402.89	5509.00	45798.00	13,739.40
6	j_{1-2}	3,033.10	9,436.62	2.72.317,04	1,215,979.07	364,793.72
Total		**8,293.55**	**43,471.01**	**3,309,143.57**	**7,656,244.67**	**2,296,873.40**

Table 3.15: Water resource potential of upper Dong Nai River basin

Basin	Total annual rainfall 10^9m^3/year	Total volume average surface runoff 10^9m^3/year	Total volume groundwater 10^9m^3/year
Dong Nai river (Up to Ta Lai station)	25.8	14.37	0.84

Water quality: In general, underground water in aquifers is good quality, which is meaningful for water supply. Some places have water samples with iron content higher than national standard. In these places, water users need to build filter tanks to reduce the total iron content in the water before use. In addition, some places have signs of microbiological contamination, these places are often related to the impact of domestic and production wastewater.

3.2. Estimate water resources in Dong Nai River basin in 2035, 2050 with consideration of climate change

3.2.1. Estimate water resources in 2035, 2050

Table 3.17: Meteorological and hydrological stations used for calculation

Result	Nash efficiency (%)	
	Dak Nong station	Dai Nga station
Calibration	80.1%	77.2%
Veryfication	73.1%	81.7%

The result of the MIKE NAM model calibration and verification *table 3.17.*

Table 3.18: MIKE NAM model parameters of stations used for calculation

Station	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF
Dại Nga	12.5	182	0,36	200	49.8	0.3	0.382
Dak Nong	15.5	255	0.412	372.2	46.7	0.965	0.714

3.2.2. Changes in the flow in the Dong Nai River basin to 2035 and 2050 taking into account climate change

Baseline period (HT) (rainfall data 1986 - 2005): The base period selected for comparison is the period 1986 - 2005. (according to the base period in the climate change scenario of the Ministry of Natural Resources and Environment 2020). The period from 2016 to 2035 (2035 period) following two emission scenarios RCP 4.5 and RCP8.5. The period from 2046 - 2065 (2050 period) following two emission scenarios RCP 4.5 and RCP8.5.

For the annual flow in the period 2035-RCP4.5, the mean annual flow (Qtb) of all sub-basins decreased from 1.60% - 5.0% compared to the baseline period; on the contrary, in the period 2035-RCP8.5, all sub-basins had an average annual flow increase from 0.13% - 9.71% compared to the baseline period. By the period 2050, the RCP 4.5 and RCP 8.5 scenarios both increased in most of the basins, the rate in the sub-basins ranged from 3.87% to 11.46%.

3.3. Water Balance Calculations and Proposed Solutions for the Rational Utilization of Water Resources in Support of Socio-Economic Development

3.3.1. Estimate water demand in Dong Nai River basin in 2035, 2050

Table 3.30*: Summary of water demand for various sectors in 2020, 2035, 2050*

(Unit: $10^6 m^3$)

Scenario	Domestic	Industry	Cultivation	Animal husbandry	Fishery	Min. flow	Total
Present status 2020	45.61	50.5	1,550	47.8	45.31	581	2,320
Estimate in 2035	55.28	56.9	1,645	137.8	48.5	581	2,525
Estimate in 2050	79.10	68.3	1,764	192.5	52.8	581	2,737

3.3.2. Calculate water balance for the upper Dong Nai River basin with consideration of climate change.

Table 3.33*: Summary of water shortage in the basin with respect to scenarios* *Unit: 10^6*

Scenario	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	Total
KB1	7.3	37.6	45.8	0.1	1.6	0	0	0	0	0	0	0	**92.4**
KB2	9.6	72.7	100	1.1	1.9	0	0	0	0	0	0	0	**185.3**
KB3	8.5	65.9	97.9	1.1	1.9	0	0	0	0	0	0	0	**175.4**
KB4	9.6	72.7	100	1.1	1.9	0	0	0	0	0	0	0	**205.4**
KB5	12.0	73.9	105	1.0	2.2	0	0	0	0	0	0	0	**194.2**

3.4. Proposed Solutions for the Rational Utilization of Water Resources

3.4.1. Existing problems

- Dong Nai River Basin has abundant water resources but still suffers from drought every year;
- The impact of climate change is increasing and causing serious consequences;
- The level of water shortage by 2035, 2050 will be more serious if there are no suitable solutions.
- Practice shows that for Dong Nai River Basin, drought is the main risk and cause of great damage agricultural production every year. Therefore, if water resources are not used reasonably (meeting the needs of industries), it will not ensure sustainable socio-economic development.

3.4.2. General solutions

Planning adjustment solutions: Adjusting reasonable population planning; Re-adjusting land use planning; Territorial planning in the direction of management according to sub-basins; Establishing organizations such as

management boards or committees, commissions of Dong Nai River Basin; Planning management, increasing watershed forest coverage

Solutions for water resource storage and use: With rainfall of about 25.8 billion m^3/year, generating surface runoff of 14.37 billion m3 while the water demand in 2020 is 2.32 billion, by 2035, it is estimated to be about 2.525 billion m^3 and in 2050 about 2.737 billion m^3, accounting for only 10.87%, 11.6% and 13% of rainfall of Dong Nai River Basin, respectively. Thus, Dong Nai River Basin is not a water-deficient basin. It is necessary to apply engineering measures in storing rainfall in the study area.

Solutions for economic sectors: focus on changing the structure of crop areas in agriculture, smart irrigation, focusing on high-quality agriculture.

Structural solutions: Upgrading and repairing existing irrigation works. Collecting rainwater, surface water, and supplementing groundwater with works. Expanding the Da Nhim hydropower plant on the Dong Nai River.

3.4.3. Solutions for sub-basins

3.4.3.1. Da Nhim sub-basin

(1) Focus mainly on engineering solutions. Details for engineering solutions are in Table 38 of the appendix for Da Nhim sub-basin.

(2) Arrange the crop structure in accordance with the ability to balance water sources.

(3) Prioritize the supply of domestic water, water for livestock farming, and water for irrigation of high-value industrial crops.

(4) Develop small irrigation systems, on-farm irrigation, and water-saving irrigation systems.

(5) Mobilize people to dredge canals, clear streams, dig wells, use long-term drought prevention solutions, continue to plant forests according to planning, strengthen upstream forest protection.

(6) Implement more favorable mechanisms and policies to attract businesses to invest in smart agriculture, increase the area of crops that actively supply water

(7) Allocate investment capital to build new key irrigation works.

3.4.3.2. Da Dung sub-basin

(1) Upgrade and build new irrigation structures, increase active storage in residential areas by ponds, dams, and rainwater tanks. The potential for surface water exploitation on the Da Dang branch is 308.1 million m^3 [83]. On the sub-basins, there is also Da Dang 3 with 7.6 million m^3, Dan Kia Lake (Suoi Vang) with 11.31 million m3, this river section is downstream of Dai Ninh hydropower plant. Therefore, it is necessary to survey and build new surface water collection works, renovate existing irrigation works to reduce losses and improve water use efficiency. The irrigation system is expected to be upgraded and newly built on the sub-basins as shown in Table 39 of the Appendix. Reconsider the transfer of water from Dai Ninh Lake to Luy River, which has seriously affected the water shortage in the downstream area after the dam. If these works are upgraded and operated, the issue of water resource sharing will be reconsidered, which will overcome the water shortage on the sub-basins in the current and future dry season.

(2) Convert crop structure, build high-quality, smart agricultural areas and save irrigation in Lam Ha, Da Lat and Duc Trong districts.

(3) Restore upstream forests: extremely important to regulate water resources, protect the quality of upstream water resources, and supply water to downstream areas.

(4) Ensuring domestic water supply: Ensuring that by 2025, 95 - 99% of rural people will use clean water.

3.4.3.3. Sub-basin of the central area 1

(1) Upgrading and building new irrigation works and reservoirs (Table 40 in the appendix): Communes that often experience drought: Loc Bao, Tam Bo, Loc Lam..., economic efficiency is not high, it is necessary to change the structure of drought-resistant crops: mulberries, fruit trees...

2) Ensuring domestic water supply: Promote and implement investment in the program to upgrade domestic water in communes at risk of water shortage.

3.4.3.4. Sub-basin of Dak Nong - Dong Nai

Converting crop structure towards adapting to climate change and unusual drought. Upgrading and repairing irrigation projects in detail in Table 44 of the appendix. Be proactive in responding to local droughts. Every year, there must be a plan and solution for pumping irrigation to serve production, especially in areas with high risk of local droughts.

3.4.3.5. The remaining sub-basins

Flooding, landslides, and flash floods often occur on this sub-basin, so it is necessary to strengthen proactive response to the rainy and stormy season: strengthen synchronous inspection of drainage systems, clear and dredge ditches, streams... Plant trees and protect forests. Detailed construction solutions for sub-basins in Tables 41, 42, and 43 of the appendic.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusion

(1). The research results have evaluated and clarified the role of natural factors that determine the formation and influence the quantity and quality of natural resources; Socio-economic factors increase water demand, affecting the quantity and quality of water in the Dong Nai River Basin;

(2). The potential of water sources has been assessed, water sources and water demand for industries and sub-basins of the Dong Nai River Basin have been forecasted by 2035 and 2050, taking into account the impact of.

(3). The Dong Nai River Basin has been divided into 8 sub-basins, applying the MIKE BASIN model to calculate water balance. The results show that:

+ Every year, the Dong Nai River Basin is quite rich with about 25.8 billion m^3 of rainwater producing 14.37 billion m^3 of surface water and 0.84 billion m^3 of underground water; Dong Nai River Basin is not a water-deficient basin: According to current calculations, the water demand in 2020 in the Mekong Delta is 2.32 billion m^3, in 2035 it is 2.48 billion m^3 and in 2050 it is 2.74 billion m^3, accounting for 18%, 19.3% and 21.3% of the total surface and underground water in the Mekong Delta, respectively.

+ Due to the deep differeces between the rainy and dry seasons and the increasing demand for irrigation water to growing crops, the large amount

of evaporation in the dry season, in addition to the few, damaged, old and ineffective irrigation works combined with the impact of climate change, 2/8 of the Mekong Delta will experience water shortages in 2020 and 4/8 of the Mekong Delta will experience serious water shortages in 2035 and 2050.

(4). The thesis has proposed some additional solutions to exploit, protect and use natural resources reasonably, mainly focusing on detailed construction solutions for sub-basins.

2. Recommendations

- For the use of natural resources on the Dong Nai River, there needs to be close coordination between sub-basins, carefully reviewing the transfer of water from Dai Ninh reservoir to Luy River and Don Duong Hydropower Plant to Phan Rang River, causing consequences of water shortage and drought behind Don Duong and Dai Ninh dams

- The research results of the thesis are based on scientific basis and the application of appropriate mathematical models, combined with practical investigations, using and updating many reliable related data. This is a highly useful document, the locality can refer to the proposed solution for the problem of using water resources on the river

NEW CONTRIBUTIONS OF THE THESIS

(1). This study has contributed to refining the methodology for water resources assessment by systematically analyzing the impacts of natural and socio-economic factors on the Dong Nai River Basin (in the Central Highlands region), under the influence of climate change at the sub-basin scale.

(2). The approach has been successfully applied to assess water resources in the study area for the present and projected periods up to 2035 and 2050, incorporating the effects of climate change. The results provide a scientific basis for guiding the sustainable exploitation, utilization, development, and protection of water resources to support socio-economic development at the sub-basin scale.

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