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Sustainable Development of Irrigation Infrastructure in Vietnam: A Theoretical Framework

Thanh Nguyen-Duc[1]*, Dat Tran-Tho[2]

[1] *Faculty of Construction Economics and Management, Hanoi University of Civil Engineering, No. 55 Giai Phong Street, Bach Mai Ward, Hanoi, 10000, VIETNAM*

[2] *Council of Science and Training, National Economics University, No. 207 Giai Phong Street, Bach Mai Ward, Hanoi, 10000, VIETNAM*

*Corresponding Author: thanhnd@huce.edu.vn
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Abstract

Investing in the sustainable development of irrigation infrastructure is the best way to address the issue of climate change, which is still uncertain in Vietnam. A convenient sampling was conducted to gather relevant literature for analysis. 150 publications including journal articles, books, book chapters, conference papers and technical reports have been collected and analysed in this research study. The keywords found were visualised with VoSViewer. By integrating the keywords' shared interests, the publications can be arranged to three clusters based on keyword frequency: (1) sustainable development and investment; (2) irrigation infrastructure investment; and (3) irrigation infrastructure investment efficiency. The study confirms the need to examine the investment efficiency of these projects by providing a summary of previous research on the sustainable development of irrigation infrastructure. Subsequently, a theoretical framework is constructed on the efficacy of sustainable irrigation infrastructure development, which is influenced by nine key factors: (1) Natural conditions; (2) Institutions and policies; (3) Politics, socio-culture; (4) Economy; (5) Science and technology; (6) Human; (7) Management; (8) Project finance; (9) Operation. A future research on the sustainable development of irrigation infrastructure can focus on one or a combination of the factors. A holistic research study may need to address all of the factors.

1. Introduction

After some three decades of renovation, Vietnam's economy has undergone many significant changes. In particular, agriculture still plays a major role in our country's economy, and the development of irrigation systems plays a very important role. However, according to the report of the General Department of Irrigation in recent years, irrigation work continues to face new challenges and higher requirements to serve socio-economic development in a sustainable way.

Climate change is having an increasing impact on human life. Climate change and changing habitats create the conditions for bad actors and dangerous epidemics to multiply and spread. As reported by the United Nations Office for Disaster Risk Reduction (UNDDR), “over the past two decades, the number of natural disasters worldwide has increased by approximately 75%" [1]. The most recent data of Vietnam Government indicates that the direct impact of the storm and the circulation of storm Yagi resulted in "345 people died and went missing (323 died, 22 went missing), 1,978 people were injured; 283,383 houses were damaged, roofs were blown off;

122,415 houses were flooded; 286,660 hectares of rice were flooded and damaged; 63,350 hectares of crops were flooded and damaged; 39,242 hectares of fruit trees were damaged; 190,230 hectares of forest were damaged; 36,310 hectares and 11,835 aquaculture cages were damaged and swept away; over 44,500 livestock and over 5.7 million poultry died. There were 803 dike and irrigation incidents in 15 provinces and cities; 2,283 irrigation works and 1,318 clean water works were damaged. Total economic damage is estimated at over 81,703 billion VND" [2]. These disasters have resulted in over one million deaths and affected more than four billion people, causing economic losses of nearly three trillion dollars. It is notable that Vietnam is among the five countries most affected by global climate change, as evidenced by the increasing frequency of extreme weather events. "In the past two decades, natural disasters in Vietnam have resulted in over 13,000 deaths, USD 6.4 billion in property damage, and have placed approximately 60% of the country's land area and over 70% of its population at risk" [3]. These disasters include typhoons, floods, and landslides. This demonstrates that while the irrigation system is gradually improving, it is not yet capable of responding to such anomalies. The impact of climate change in Vietnam is becoming increasingly evident, placing mounting pressure on our country's irrigation system. Consequently, investment in irrigation development is considered a matter of urgency and must be accorded the highest priority.

Irrigation projects accounted for a large proportion of projects serving people's livelihoods, public works, disaster mitigation, climate change, etc. The capital used for these projects is mostly state budget capital and is currently on a downward trend. In addition, with regard to investment in the development of irrigation systems in particular, and development investment in other areas in general, the capital required for this investment activity is often very large, the implementation time is long, the payback period is long, rapid degradation, high risk.. Therefore, the effectiveness of the project is a top concern, plays a very important role to avoid wasting resources, improve the impact of these projects on local socio-economic development, minimise the impact of climate change, for such reasons, The investment efficiency of the position and role in this field is extremely important.

In view of the above shortcomings, in order to develop the irrigation industry in general and the irrigation system in our country in particular, it is necessary for policy makers to have specific information, systematic studies and the study of factors affecting this investment to play a relatively important role. There have been many scientific research projects on the factors influencing investment activities, but they have mainly stopped at considering the current state of investment in industries and have not deeply explored the specific field of investment in the development of irrigation systems. Scientific research on irrigation is often focused on solving irrigation engineering problems, such as developing techniques for building dikes, canals, pumping stations, reservoirs, sea dikes, ..., finding solutions to natural disasters and mangroves to a defined object, ... In addition, there have not been many studies to quantify and establish the relationship between factors influencing development investment activities, such as the level of influence of factors on investment decisions, investment results for irrigation system development.

This study aims to identify research gaps and provide a theoretical framework for future studies on the sustainable development of irrigation infrastructure by gathering, categorizing, and synthesizing material and research findings connected to the aforesaid topic.

2. Methodology

The structure that explains and supports a theory is called a theoretical framework. A theory is a collection of related ideas and definitions that, by outlining the connections between the variables used to explain occurrences, offer a methodical perspective on them. After a protracted research procedure, a theory is created to explain why a research problem exists in a study. By providing a structure for organizing data and drawing conclusions, a theoretical framework aids researchers in interpreting their findings and guides the research process, much like a study roadmap [4].

A theoretical framework is a crucial part of a research publication and ought to be introduced in the first section. It aids in defining the research's scope and shows comprehension of the ideas and concepts relevant to the study.

A four-stage method was used to produce the research, starting with the discovery of keywords relevant to the study's goal. The author used some relevant keywords to accomplish the research goal of "Sustainable Development" of Irrigation Infrastructure," such as: The phrases ‘Sustainable Development’, “Irrigation Infrastructure”, “Irrigation Infrastructure” were found to be important search terms.

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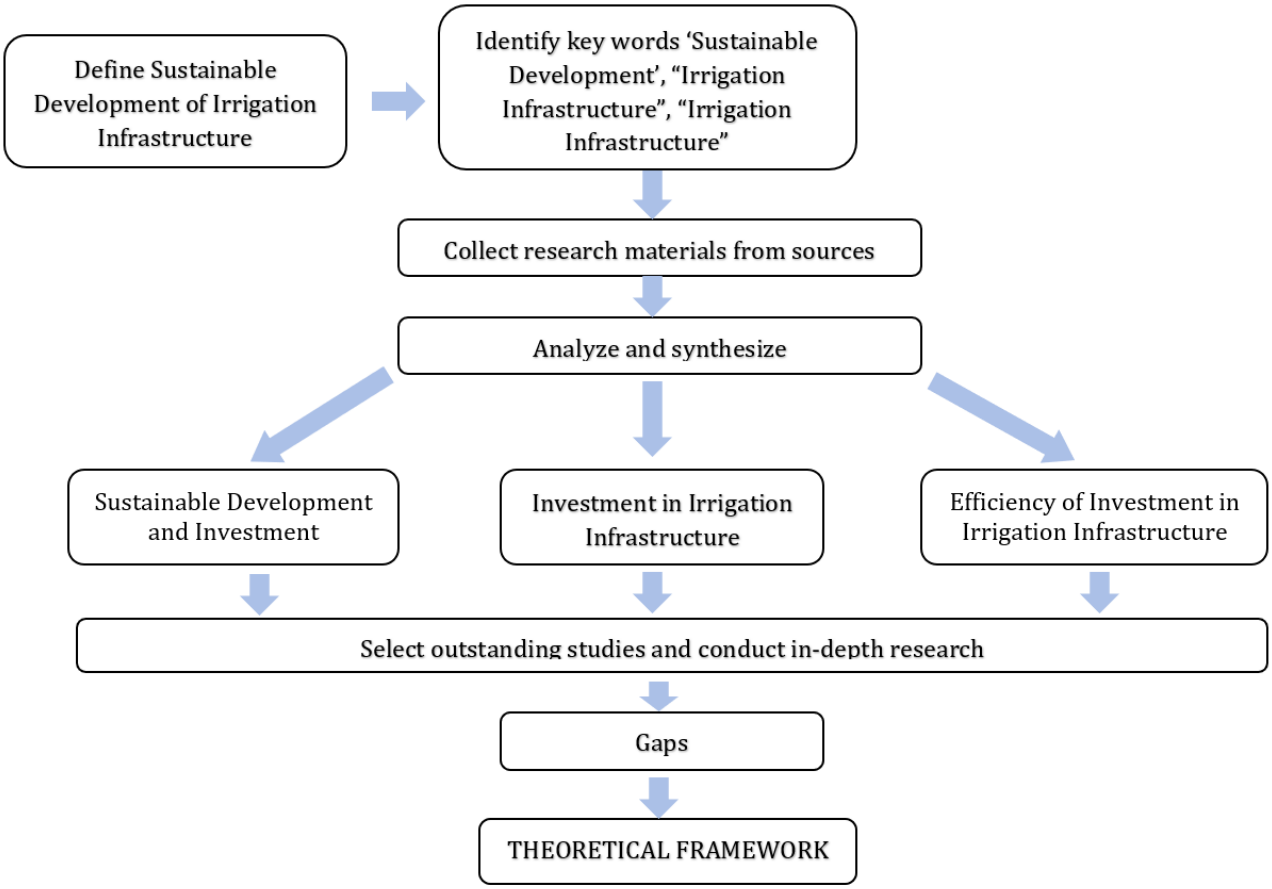

Fig. 1 *Overview of research process*

Finding and compiling documents related to the research topic was the second step in the procedure. This was accomplished by using online resources like Google Scholar and ResearchGate as well as databases that were available at Vietnamese academic libraries. The chosen keywords were then used to further refine the scope. 150 studies with good statistical power, including 98 articles from international journals, were chosen by the research team. Furthermore, 10 conference papers, 13 review papers, 8 books, 4 book chapters, and 17 reports have all addressed the research subject.

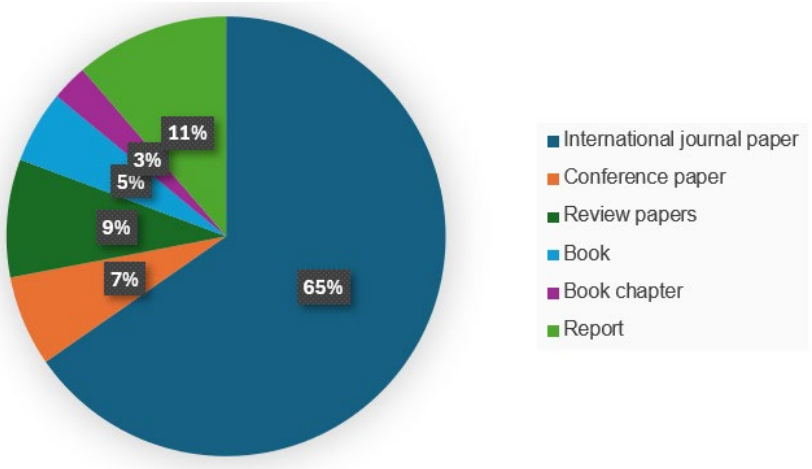

Fig. 2 *The type of distribution of selected articles*

The majority of the studies were gathered during 2010 to 2024. The primary keywords that have been the focus of research throughout the previous 15 years are depicted in Figure 3. It is clear that topics like public

investment, the development of irrigation infrastructure, economic growth, quality, progress, and cost have been relevant for a long time but are still relevant today. Sustainable development, climate change, attracting private financing, project management, and BIM construction information systems are just a few of the topics that have been the subject of recent research.

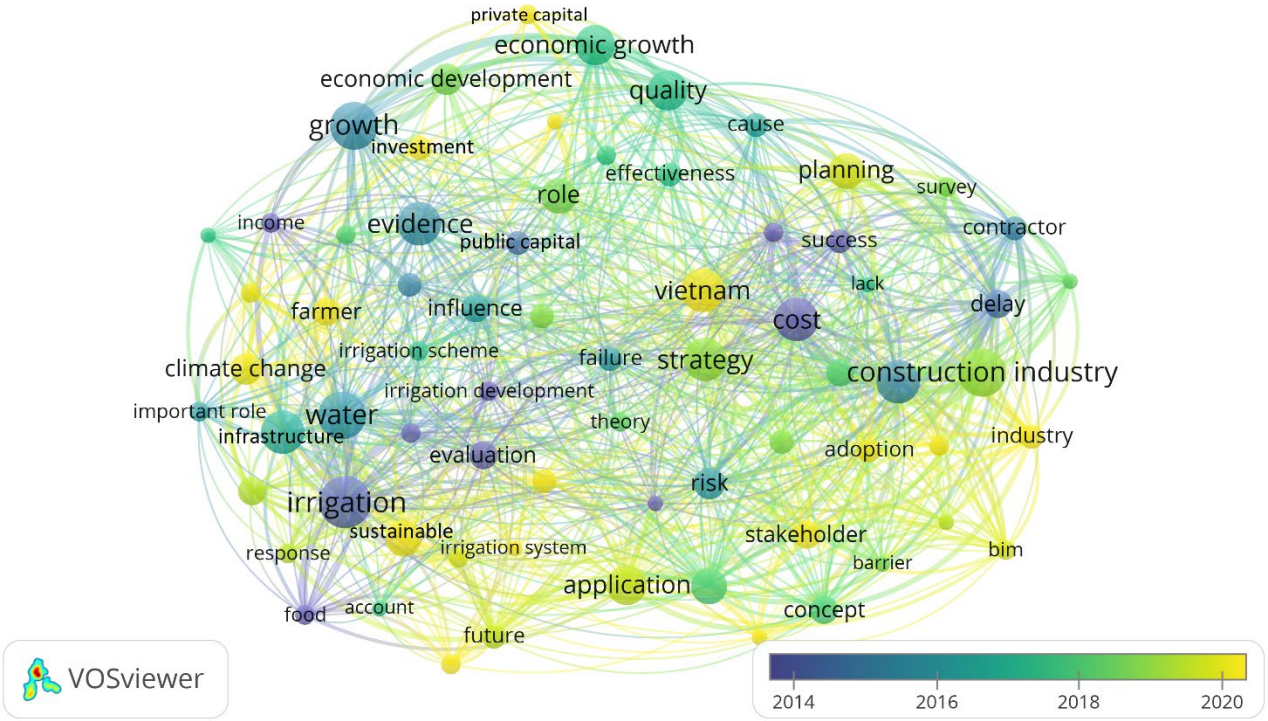

Fig. 3 *Keywords sorted by timeline*

Irrigation, sustainable building, economic growth, investment, climate change, quality, cost, and risk were the most commonly used terms, according to the analysis of the chosen papers (Figure 4). By integrating the keywords' shared interests, we were able to divide the chosen publications into three clusters based on keyword frequency: (1) sustainable development and investment; (2) irrigation infrastructure investment; and (3) irrigation infrastructure investment efficiency.

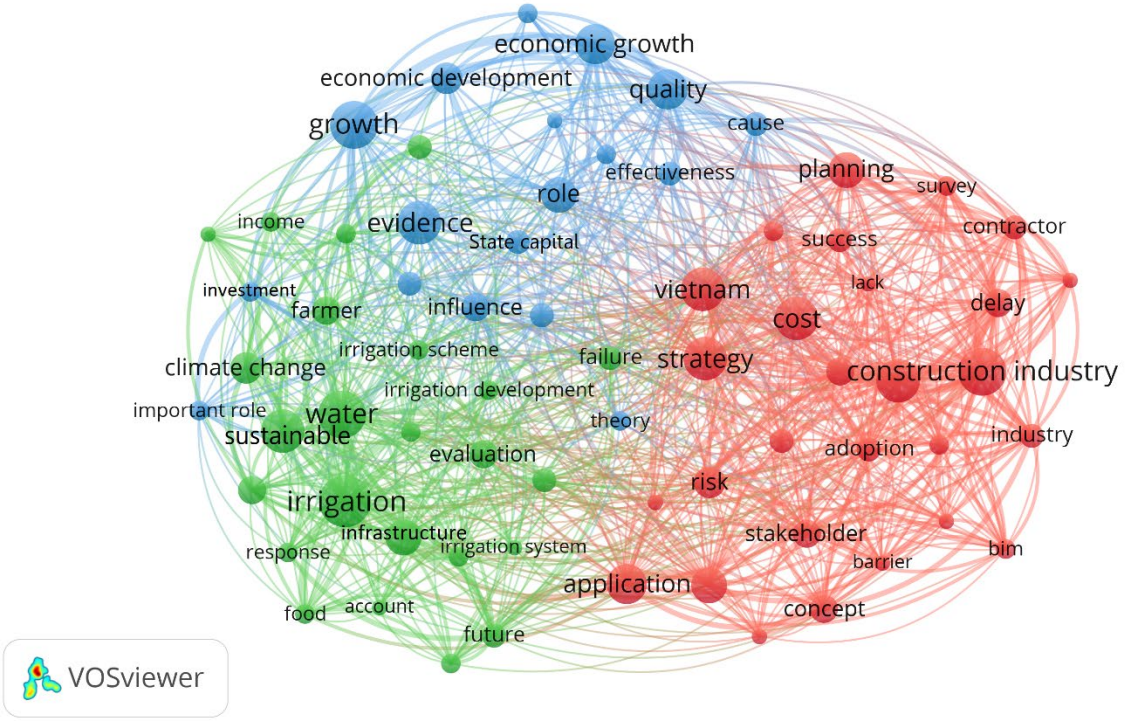

Fig. 4 *Keywords co-occurrence mapping*

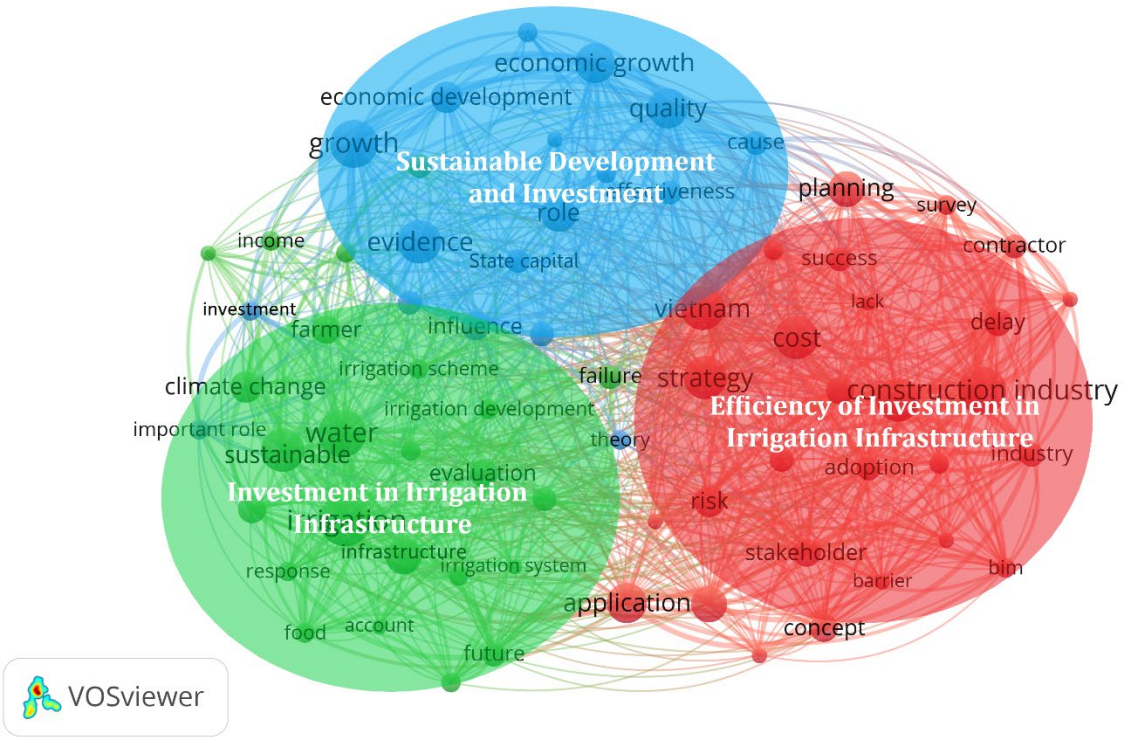

Fig. 5 *Keywords cluster analysis visualization*

Third, 50 relevant studies were selected, thoroughly examined and critically evaluated. In order to make the study coherent and goal-oriented, the literature was also divided into three categories listed in the second stage.

Finally, the articles were comprehensively discussed and evaluated, thereby exploring research gaps and identifying research questions, and constructing a theoretical framework.

3. Results

3.1 Research Studies on Sustainable Development and Investment

Investment is characterized as a national economic activity, a component of a company's production and business operations, and a life issue that affects every family and individual when there are opportunities to boost income and enhance their material and spiritual well-being. Economic growth is officially attributed to investment, and the nature of this relationship has been the subject of several theoretical and empirical investigations.

The term "development investment" is defined as the investment of material assets and labor power by which individuals with financial resources allocate capital to activities that enhance or create new assets for themselves and, simultaneously, for the broader economy. This process increases the potential for production and business activities, as well as other forms of economic growth. It is a primary driver of job creation and an essential factor in improving the quality of life for individuals within a society. This entails the expenditure of capital for the construction and maintenance of residential and irrigation infrastructure, the procurement and deployment of machinery, the training of human resources, and the fulfillment of the routine expenses associated with the operation of these assets. This is done with the objective of sustaining or enhancing the operational capacity of existing facilities, supplementing existing assets, and increasing the potential of all areas of socio-economic activity within the country [5].

Researchers and policymakers alike are now concerned about sustainable development investment, and the funding sources for these initiatives are very varied and include corporate capital, foreign direct investment capital, official development assistance capital, budget capital, and more. The most prevalent qualities of development investment are shared by a variety of diverse fields, each of which has its own unique traits. Projects, work items, or other implementation strategies can be used to carry out development investment activities.

Public investment is crucial to Vietnam's sustained economic growth since it not only directly boosts GDP but also fosters the growth of economic sectors by funding social infrastructure like roads, schools, railway stations, irrigation, and power. Many academics are now studying state budget capital, which is one of the most crucial sources of funding for investments in sustainable development when taking infrastructure and public investment into account. As a result, there are numerous thorough and coherent theories that offer precise and broad perspectives on this capital.

First, a 2024 World Bank study found that public investment spending, in general, and spending on infrastructure, education, and health in particular, have a favorable impact on growth [6]. According to Kose et al. (2022), increasing public investment by 1% of GDP can boost output by up to 1.2 percent over a five-year period [7].

It is often known that a major driver of economic growth can be a rise in public investment spending. According to the evidence now available, public investment in long-lasting assets like infrastructure, healthcare, and education can boost societal well-being and productivity, which in turn promotes long-term economic growth. Evidence suggests that public investment, especially in emerging nations, has long-term implications on output and employment in addition to stimulating immediate economic activity [8]. Rapid output growth and unemployment reduction can be facilitated by public investment, especially in economies that already have slack and monetary accommodation. Public investment gradually boosts labor productivity and sustains economic growth, with notable impacts seen in areas like health and research. The effectiveness of public investment depends on how well it is implemented. More significant economic advantages are linked to higher levels of public investment efficiency. However, the potential for corruption in the distribution of public investment dollars could hinder its effectiveness and lead to less-than-ideal economic results.

Furthermore, optimizing utility and reaching desirable socio-economic outcomes depend on the best possible allocation of spending across a range of purposes. To improve efficiency and effectiveness in public spending, healthcare, and system reliability, this calls for the strategic allocation of resources. Maximizing utility and economic growth requires the best possible balance between capital and current spending. Governments, however, frequently struggle to achieve an efficient allocation, suggesting the need for better methods to evaluate the efficacy of spending [9].

Government capital has a mixed effect on economic growth. Because of past cuts made for political and other reasons, government budgets are tight and public investment is more limited than current spending, which has caused economic development to go more slowly than it otherwise could. Since then, Heller (2005) has recommended that the government focus more on public investment, particularly in infrastructure, provide funding for it, and show that public investment works [10].

Because of these limitations, borrowing from outside sources results in ineffective infrastructure investment initiatives. The contribution of debt-financed public investment to growth and exports also influences external

borrowing limits, even though a nation's capacity to borrow is largely determined by its macroeconomic policies, tax collection capabilities, financial management system, and public debt.

At the same time, previous financial crises have acknowledged the critical role fiscal policy plays in promoting growth and recovery. In many nations, fiscal stimulus mainly consists of budgetary capital intended to increase future growth.

The necessity of using the state budget was also recognized by author Mabel L. Walker in the 1930s. In her research, the author examined how budget expenditures were allocated and examined and analyzed the budget spending concept. In order to develop and formulate a new theory centered on the allocation of expenditures using the state budget, Mabel synthesized theories related to public spending. Over time, theories of the state budget have advanced from the method of managing budget resources according to items to the method of managing budget resources according to work, according to program, and finally according to outputs [11]. Although each of these budget management techniques has pros and cons of its own, they are all characterized by the fact that they have been refined throughout time by the management practices of many nations. The output budget management method is superior, according to Martin et al. (2010), who compared and clearly demonstrated the advancements in budget theories. This method also addressed the question that budget managers frequently ask: how to determine how to allocate a certain amount of money to one activity rather than another? [12]

Spending on fundamental building investments is one of the state budget's most significant expenditure categories. Fundamental building investment is crucial to every nation's socioeconomic development plan because it promotes economic expansion, employment creation, and the resolution of social issues. Researchers and policymakers have studied the state of public investment because they have demonstrated that ineffective management of public investment causes bad debt in nations. the successes and shortcomings in order to provide guidance and solutions for the most effective management of public investment items. As a result, the state can take a significant role in the management of financial assets. The research team of Benedict Clements et al. (2003) has examined the connection between public investment, economic growth, and social effect. The authors have reviewed the theories that are relevant to the research subject, provided an economic growth model, The author illustrated the connection between public investment and economic growth using quantitative techniques. Utilizing quantitative research techniques, the author gathered data in a number of low-income nations, including Ghana, Vietnam, Guinea, Zambia, and Nepal [13]. The authors Edward Anderson et al. (2006) examines the role of state budget investment in the process of reducing poverty by utilizing quantitative models in data processing, public investment theories, and secondary data collection techniques. By using metrics that show how well public investments contribute to growth, productivity, and social balance, the author illustrates the social role of state-funded investment capital. In order to accomplish social objectives, the authors also provide strategies for assessing public investment initiatives and determining the best distribution among regions [14].

P.E.D. Love's (2002) research on the management of investment projects has demonstrated that in order to assess the quality of a construction project, a project model that controls the quality cost system must be developed. Additionally, the project operations should be separated into work areas, executed by several industries, and run separately when basic construction investment projects are being implemented from budget funds. The project's cost management procedure is also significantly impacted by the division of project kinds and modes of operation [15]. The author uses a defined construction investment project to provide commentary on the problems with the cost management of investment activities. The author also examines the role of parties in the management of basic construction investment capital.

3.2 Research Studies on Investment in Irrigation Infrastructure

3.2.1 Investment in Irrigation is Essential for Economic Development

Since it increases agricultural productivity and guarantees food security, irrigation is the most crucial element of sustainable economic growth and helps to reduce poverty [16]. Competition for access to precious and limited water resources is intensifying due to the fast-growing demand for water, particularly in the agricultural and environmental sectors. Therefore, it is crucial for every nation in the globe to choose a suitable strategy for the distribution, management, and allocation of water resources in order to achieve sustainable agriculture. Irrigation is the most well-known technology for storing or preserving water, and it is also a key component of agricultural progress.

In every nation in the world, agriculture provides food and is nearly the primary source of income, particularly in developing nations where the population is expanding at a rate of 3% annually. “The world population is estimated to reach approximately 9.6 billion by the end of 2050, necessitating a 70-100% increase in food production to mitigate the food crisis” [17]. The need for food rises in tandem with the population. Furthermore, agriculture can be thought of as a capital-saving activity. This means that a nation that is agriculturally self-sufficient will need to import fewer goods, which should result in high national savings and a large source of capital

to support the industrial and service sectors, among other things. Simultaneously, the agricultural sector can be viewed as a capital saving, meaning that a nation that is agriculturally self-sufficient will require fewer imports, resulting in large national savings. In addition, the agriculture sector provides labor to other businesses. "Approximately 30% of the region's working population is employed in agriculture, many of them as smallholder farmers with low productivity", according to a 2022 International Labour Organization report [18]. Because of this, people in rural communities usually relocate to urban regions or look for additional job in non-farm activities in order to improve their standard of living. Some economists have attempted to comprehend the importance of farm labor in industrial development [19]. They contend that the agriculture industry has a significant amount of labor or manpower that can be moved to other industries without having an impact on the original industry. Cheap labor can therefore help industry by lowering production costs and increasing profits. Furthermore, as agricultural products make up the majority of developing nations' exports, agriculture is viewed as a source of foreign exchange. Because emerging nations must import new agricultural equipment, tools, industrial machinery, and other items to boost production efficiency, it also generates a market for industrial goods.

Therefore, investment in irrigation development is so crucial for a nation where the vast majority of people rely on agricultural output. Ninety-eight percent of the world's rice output comes from Asian countries, including China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, and the Philippines [20].

Good infrastructure, power grids, and irrigation systems are necessary for increased productivity in agriculture, livestock, aquaculture, crop production, and other industries, including food supply and commercial output. Since water is essential for both life and production, the nation views investing in irrigation development as a critical job. After that, it is feasible to concentrate on agricultural growth and upgrade irrigation infrastructure, which will raise income and reduce poverty [21].

When assessing the effects of irrigation projects on the standard of living of households in Vietnam's most isolated and impoverished regions, Nguyen Cuong Viet et al. (2017) also found that irrigation increases the number of households planting trees each year as well as the area of land each household plants each year, particularly rice and potatoes. Each household owns more forest land as a result of irrigation projects. Additionally, it helps rural households raise more livestock, particularly chickens and pigs. However, each household's area dedicated to perennial crops is decreased. Households may be able to plant more valuable crops that need intensive irrigation if they have better access to irrigation infrastructure. Furthermore, the growth of rice and potato fields will result in increased yields, producing more food for livestock expansion [22].

Purchasing a high-quality, synchronized irrigation system can assist farmers in implementing new technologies and increasing cultivation intensity, both of which can result in increased yields and overall returns. Higher household incomes and an improved standard of living in rural regions can result from this, as well as the creation of new agricultural and non-agricultural job opportunities. In agriculture, irrigation generally plays a significant role in creating revenue. Because of this, significant public investment is required nationwide in basic infrastructure, particularly irrigation [23].

A related study was carried out by Hussain and Hanjra (2003) to investigate how irrigation affects the alleviation of poverty in South and Southeast Asia. In the form of a descriptive analysis, the study, which covered India (1996), Vietnam (1996), the Philippines (1997), Thailand (1998), Sri Lanka (2000), and Pakistan (2000), demonstrated that households with access to irrigation systems generated significantly more output than households in areas with inadequate irrigation systems. Because of this, it is thought to be one of the elements that helps to reduce poverty [24].

Huang et al. (2002) used data gathered in rural China in 2000 to investigate how irrigation affected income, poverty, and income distribution in rural areas. To explain the connection between irrigation and poverty as well as between irrigation and income, they employ descriptive analysis. The results demonstrate that irrigation directly affects poverty and income while also lowering inequality [25].

3.2.2 Irrigation Plays a Major Role in Ensuring Food Security and Responding to Climate Change

According to the 2012 report of the Food and Agriculture Organization of The United Nations (FAO), "over the past 50 years, irrigation has significantly increased agricultural productivity and food security worldwide. Irrigated land, which makes up almost 20% of all arable land worldwide, is currently the site of more than 40% of global agricultural production. Food production must rise by 70% worldwide and 100% in developing nations by 2050 to fulfill the demands of a world population predicted to surpass 9 billion people", with irrigation playing a significant role [26].

Although the consumption profile and anticipated trends differ depending on each nation's level of development, the world's population increase continues to be the primary growth engine. Globally, per capita food spending has gone up, but as a percentage of GDP, especially in middle-income nations, it has decreased. "By 2029, it is anticipated that the average person will consume over 3,000 kcal and 85 g of protein daily, with roughly 60% of the extra calories coming from fat and staple foods. Over the next ten years, fat is expected to expand at by far

the fastest pace, at 9%. By 2029, the proportion of staple foods in the food basket is predicted to decrease for all income categories as the world's diet continues to transition toward more intake of animal products, fats, and other foods" [27].

Poor irrigation infrastructure has a significant impact on domestic agricultural production and is one of the primary challenges in nations at danger of food crises, including the People's Republic of Korea, Kenya, Madagascar, Syria, and Zimbabwe, according to the Global Report on Food Crises (GRFC) 2020. By 2020, "43 million people are expected to experience food insecurity" [28]. "Nearly 282 million people in 59 countries and territories experienced high levels of acute hunger in 2023 - a worldwide increase of 24 million from the previous year. This rise was due to the report's increased coverage of food crisis contexts as well as a sharp deterioration in food security, especially in the Gaza Strip and the Sudan. For four consecutive years, the proportion of people facing acute food insecurity has remained persistently high at almost 22 percent of those assessed, significantly exceeding pre-COVID-19 levels" [29].

As a result, Effective irrigation techniques are therefore crucial for promoting economic growth, especially when it comes to raising global food security, boosting livelihoods, and stimulating more general economic growth in Asia. In fact, it is the cornerstone of civilization in many Asian nations. Furthermore, this function is probably going to continue in the future because irrigation produces a significant amount of the world's food, including most fruits, vegetables, and other crops with high economic value [30].

Hugh Turral et al. (2010) examines the elements impacting irrigation's performance, advancement, and modernization while offering a succinct analysis of the history and state of irrigation worldwide. The study emphasizes how changes in hydrology and water availability brought about by global climate change have a significant impact on irrigation. Furthermore, the need for further improvements in irrigation productivity and efficiency is indicated by the growing demand for agricultural products, diversification, and competition for clean water in the high-tech agriculture sector. The author recommends concentrating on enhancing state administration by refining institutional elements and ongoing technical advancement in order to address this issue [31].

Using the Heckman selection model, Nonvide (2017) investigates how irrigation affects rice yields in Benin and discovers that irrigated households can increase rice yields by roughly 57% as compared to non-irrigated households [32]. Additionally, Bidzakin et al. (2018) recommend that in order to boost rice yields and revenues, rice producers should employ irrigation more frequently [33]. According to Nguyen et al. (2017), irrigation expanded Vietnam's rice, maize, and potato acreage [34].

Anthropogenic climate change impacts both water resources and water demand, according to Doll, P. (2002). Increased water demand may have affected two-thirds of the world's irrigated land in 1995, and for as much as half of the total area, the adverse effects of climate change outweigh those of climate variability. Irrigation systems will play a major role in future water regulation and food security [35]. The study analyzes how climate variability and change affect irrigation water demand using a worldwide irrigation model.

According to a 2015 forecast by Woznicki, S. A., Nejadhashemi, A. P., & Parsinejad, M., the uncertainty in irrigation demand increased between 2020–2039 and 2060–2079. In order to adapt to climate change, agricultural producers and watershed managers require efficient irrigation development investment options [36].

3.3 Research Studies on Efficiency of Investment in Irrigation Infrastructure

3.3.1 Inefficient Investment in Irrigation Infrastructure Development

Irrigation efficiency and agricultural water production need to be significantly enhanced in light of the rising competition for water from high-value sectors of the economy, the need for inexpensive food to feed a growing population and shifting dietary preferences. Continuous adaptation and improvement will be necessary to achieve the goals of better governance, better administration, and the advancement of science and technology. The analysis comes to the conclusion that there aren't many chances for fresh development and that future investments will need to be more focused on certain margins in various economic and agricultural settings. Turral, Hugh, and others (2010) [31].

Several considerations need to be made before investing in irrigation development. There are still insufficient high-quality human resources for project execution, and frequently, finance issues prevent them from meeting project needs. Project restructuring could provide better outcomes, but it hasn't yet improved the responsiveness and appropriateness of investments in a timely way. This is especially true when it comes to a lack of reactivity to changes in land and water resources, irrigation requirements, project scope, goals, and costs. The first change is the start of the project. Management of investment costs is frequently a barrier. Time-consuming processes frequently impede project development and delivery. Although they are crucial to project execution, contract management and tendering have not yet produced the desired results. Corruption, subpar construction, excessive expenditure, and delays are frequently caused by ineffective contract management and tenders.

In the investment process for irrigation systems in Laos, Inthakesone B and Syphoxay P (2021) highlight the inadequacies of the state management system, government policies, farm management techniques, and site selection concerns. Additionally, some irrigation systems cannot be used on a regular basis due to improper maintenance. This raises concerns about the irrigation system's functioning and investment because it is poorly maintained and water consumption is poorly organized. The project's infrastructure depreciates quickly, and when maintenance and repairs are neglected, rehabilitation investment cycles are frequently shorter than ten years and unsustainable. According to the principle of irrigation management transfer, community requirements must guide the selection of sites. Its foundation in Laos, however, is a top-down, donor-driven or supply-driven approach, which may lead to certain issues [37]. Additionally, many of the properties are selected with no clear borders and are extremely close to the city. This has led to a diversity of uses for agricultural land as the population has increased. This explains the progressive deterioration in irrigation system investment efficacy in some locations.

Bernard Myers and Thomas Laursen (2009) summarized the experience of state management of infrastructure construction investment in EU member states by taking into account the experience of state management of infrastructure construction investment in several different countries through the use of state budgets. The author gathered the study's data between 2000 and the end of 2006, with a primary focus on examining the management experience of this investment in the UK and a few other wealthy nations [38]. This can also be a lesson learned for the process of managing basic construction investment activities using the State budget in Vietnam. From there, some of the sharp increase in public debt and inability to control can be avoided. During the author's research period, EU countries made up the group of countries with the largest public debt in the world.

Inocencio, A. B. (2007) examined 314 irrigation projects that were carried out in 50 African, Asian, and Latin American nations between 1967 and 2003. Irrigation projects have become more cost-effective and investment-efficient throughout time. The investment costs of irrigation projects have decreased due to advancements in labor productivity and construction technology, which also considerably lowers the chance of irrigation project failure [39].

3.3.2 Improving the Efficiency of Investment in Irrigation Infrastructure

Increased access to water and competition among water users for more productive and efficient use of water are only two of the numerous obstacles and new demands that will face the worldwide irrigation system's continued expansion and improvement [40]. Furthermore, more dependable, adaptable, and varied water services are needed due to the quick restructuring and change of agriculture. The shift from the first generation of "green revolution" to sustainable intensive agriculture highlights the significance of irrigation solutions that are both environmentally and socially sustainable. Furthermore, the implementation of climate-smart irrigation principles is necessary due to the ongoing effects of climate change [41]

“Since irrigation accounts for 70% of the world's freshwater withdrawals, it is the largest use and management of natural resources” [42]. As such, it necessitates balanced investments in infrastructure, irrigation-related policies and institutions, and water management and governance institutions in order to maximize desired benefits and minimize unintended negative effects on other species or ecosystem services. Modern irrigation systems are increasingly being developed on the foundation of evidence-based innovation and effective irrigation practices.

Bernard Myers and Thomas Laursen (2009) compiled the experience of state management of infrastructure construction investment in EU member states by taking into account the experience of state management of infrastructure construction investment in several different countries through the use of state budgets for this purpose. From 2000 to the end of 2006, the author gathered data for the study, which was primarily concerned with assessing management experience in this investment in the UK and a few other wealthy nations. During the author's research period, EU countries were among the nations with the highest levels of public debt in the world [38]. This can also serve as a lesson for Vietnam's process of managing basic construction investment activities using the state budget, which could help prevent some of the drastic increases in public debt and control issues.

On the other hand, other scholars view public investment as an input into the production process when examining public sector investment. Economic development is positively impacted by public investment, according to research [43]. Scholars who subsequently continued Arrow et al.'s work produced research on public investment, such as Fisher et al. (1998) and Glomm and Ravikumar's (1994) endogenous growth models. A region's growth model assumes that production occurs in just one sector, the private sector, and that labor, private investment, and public investment make up the aggregate production function. Public investment, on the other hand, plays a complementary role in this model, helping the private sector to create economic growth [44][45]. Additionally, resources for public investment are derived from taxes and debt, which the private sector contributes to to some extent when business and production activities are successful. Additionally, Glomm et al.

(1992) confirmed the existence of an optimal public investment plan and proved the presence of a single competitive equilibrium represented by the Euler equation [46].

Research on the economic impacts of public funding infrastructure investment was reviewed by Alfredo M. Pereira et al. in 2010. In order to compare the findings with those of earlier studies, the author gathers data from studies of these impacts conducted in the United States and other countries. Each study technique has its own unique approaches and distinct research outcomes. This research focuses on synthesizing earlier studies on how infrastructure investment affects economic performance. When accounting for the lag of investment, the author's combined findings demonstrate that a variety of research techniques are used, ranging from the linear regression approach to the usage of the VAR regression function [47]. This study approach is more appropriate for comprehending the effects of investments as they frequently have Subsequent study may also be used to execute in Vietnam's development investment industry.

Many domestic scholars have also examined development investment in basic building in Vietnam. In his research, author Hong Trinh-Thi-Thuy (2012) specifically examined the theoretical concerns surrounding fundamental building investment. The author gathered secondary data for the study from departmental year-end reports and official published sources of ministries. Additionally, primary data about basic construction investment activities and expenditures in Binh Dinh Province was gathered through interviews with individuals directly employed by the State management agency. Descriptive statistical techniques and multivariate regression models were employed in the author's data collection to investigate the effects of various factors on the effectiveness of basic building investment expenditures utilizing the State budget. The author's explanation of the necessity of managing state budget expenditures on basic building investment and the demonstration of the necessity of such expenditures are based on an overview of basic construction investment. At the same time, author Trinh Thi Thuy Hong took a budget cycle-based approach to managing state budget expenditures on basic construction investments. The author also compared various approaches to estimating expenditures, which validated the approach to managing state budget expenditures based on results estimation. The results are reliable [48].

Khoai Ta-Van 's (2009) research is from the perspective of each construction investment project utilizing capital from the State budget, in contrast to Trinh Thi Thuy Hong's approach, which is from the perspective of State budget expenditure on fundamental construction investment activities [49].

Additionally, author Mao Phan-Thanh employed the descriptive statistical research technique in 2003 to analyze budget-related difficulties and evaluate the usage of capital building investment capital utilizing the state budget. Author Mao Phan-Thanh also concentrated on analyzing the effectiveness of capital building investment, while author Hong Trinh-Thi-Thuy (2012) carried on and expanded upon this topic in her subsequent studies. The author has developed a set of indicators based on the state budget capital to assess the effectiveness of capital building investments and identify the variables influencing their efficiency. However, Ta Van Khoai's later research and Mao Phan-Thanh 's research primarily concentrate on analyzing the state of capital construction investment, building, and determining the performance evaluation criteria. They also look at the outcomes of capital construction investment using state budget capital. Descriptive statistics and the interpretation of study findings, factors influencing the outcomes, and the effectiveness of capital building investment utilizing state budget capital comprise the author's primary methodology. supplied by the author and hasn't been thoroughly examined to consider how many factors affect capital building investment utilizing funds from the state budget. The authors also gathered secondary data about construction investment activities and information from the General Statistics Office, the Ministry of Planning and Investment, and the Ministry of Finance. Although the studies lack analysis and data collection, capital development utilizing the state budget is mostly seen from the perspectives of investment capital, capital size, and indicators representing investment results and efficiency [50]. Additional dimensions to consider the opinions of many parties directly involved in this capital building expenditure sponsored by the state budget. The studies have created methods to enhance the management of capital building investment utilizing the state budget in the study region based on these research facts, particular analysis, and assessment.

In terms of study topics and research methodologies, there are parallels to author Mao Phan-Thanh 's (2003) work; nevertheless, author Tuan Can-Quang 's (2009) research area is Hanoi city. Like earlier research, Can Quang Tuan has brought up broad theoretical questions regarding basic construction investment and basic construction investment efficiency in this study. Development investment capital is examined from the standpoint of basic construction investment capital that is concentrated from the State budget. The study examined how basic construction investment activities are currently organized and managed, evaluating both the successes and the shortcomings in order to suggest ways to increase the effectiveness of using state budget capital for basic construction investment [51].

In the meantime, Vinh Trinh-Van (2000) has a method for settling works. The author has investigated and examined the settlement report of works that were put up for auction and those that were invested with state funds. In essence, these are finished construction projects (i.e., solely referring to the second stage of the investment project or the stage of investment adoption). Along with systematizing the fundamental reasons of a

financial statement audit and its application to the audit of the final settlement report of the finished basic construction work, the study also examined and defined the function and objective demand of auditing in business economies. By examining the features and fundamentals of the finished basic construction finalization report, the author highlighted the distinctions between the audit of the financial statements and the audit of the final settlement report of the finished basic construction job [52].

In addition to the data directly collected on basic construction investment capital over the years of the research period from the data that has been published by agencies such as Ministries and reports of project management boards, the data has been expanded when the authors have approached, from the perspective of each project, in order to be able to analyze more multidimensionally when researching basic construction investment using the State budget. " These studies haven't, however, used quantitative models to examine the precise effects of various factors on fundamental construction investment activities that use state budget funds, the effectiveness of these activities, or the effects of various factors on the economy and society.

On the other hand, author Khoai Ta-Van approach state management in accordance with the following: "Planning, building a legal framework, promulgating and implementing mechanisms, organization of the apparatus and inspection and control." These authors base their approaches on state management with construction investment projects from the state budget. The legal framework is not synchronous and uniform, the management mechanism is still out of date, and the management capacity has not fulfilled the requirements, among other limitations and inadequacies in the process of state management of state-funded construction investment projects that the study has revealed. Based on this, some suggestions are made to enhance the State's ability to manage investment projects for infrastructure development that are financed by the State.

4. Discussion

4.1 Complexity and Determinants of Effective Irrigation Investment

Vietnam's socioeconomic progress has been significantly influenced by investments in sustainable development. In addition to ensuring food security, preventing natural disasters, and addressing climate change, investments in the development of irrigation works have the potential to support economic growth, agricultural development, and the provision of water resources for daily life. The outcomes of theoretical studies have shown the value of investing in the construction of irrigation infrastructure. Most research focuses on how irrigation development investments affect economic growth, poverty reduction, environmental cleanup, disaster relief, and climate change adaption. Few, though, have thoroughly examined the effectiveness of funding the development of irrigation infrastructure. Quality, progress, cost, contracts, resources, and other characteristics of fundamental construction investment projects are the main topics of most studies on investment efficiency. It is clear that irrigation infrastructure investment projects are intrinsically more complex than traditional basic construction projects due to their multifarious nature, which includes a wide range of building activities.

In order to support the growth of irrigation investment in Vietnam and to provide highly applicable and efficient solutions, it is crucial to carry out research that connects all previous studies on investment outcomes. Numerous elements, such as those influencing the research process, investment decisions, investment implementation process, and operation process, determine how effective irrigation infrastructure investment operations are. Therefore, these components are necessary for the goals to be achieved. Ofosu and colleagues' 2014 study identifies five critical areas that are necessary to achieve irrigation development that is both sustainable and effective. They are as follows: human resources, which include labor, skills, knowledge, and health; natural resources, which include land, water, and genetic resources; social factors, which include gender equality, institutions, rules, and policies; financial resources, which include markets, savings, and loans; and physical resources, which include infrastructure, technology, and equipment. A more thorough characterization of the pertinent components is necessary, as these elements are defined in a too general manner [53].

According to Vishnudas et al. (2007), the following factors are essential for the development of sustainable irrigation: safe access to water and land; suitable technologies; stable and predictable markets for inputs and outputs; advantageous policies and efficient institutions; and a trusted environment for farmer support. The investment in modernizing small-scale irrigation systems, however, is not covered by this study because to factors like inadequately developed supply networks, limited financial resources, high operating and maintenance costs, significant output price risks, and a lack of institutional support [54].

Economic factors, political systems and regulations, infrastructure building technology, and project finance are the main causes of the majority of government irrigation infrastructure investment projects' subpar performance, according to Bjornlund (2020) [55].

It is evident by combining and choosing from earlier research that the following key elements have an impact on investment activities in creating efficient and sustainable irrigation infrastructure systems in Vietnam: (1) Natural conditions; (2) Institutions and policies; (3) Politics, socio-culture; (4) Economy; (5) Science and technology; (6) Human; (7) Management; (8) Project finance; (9) Operation.

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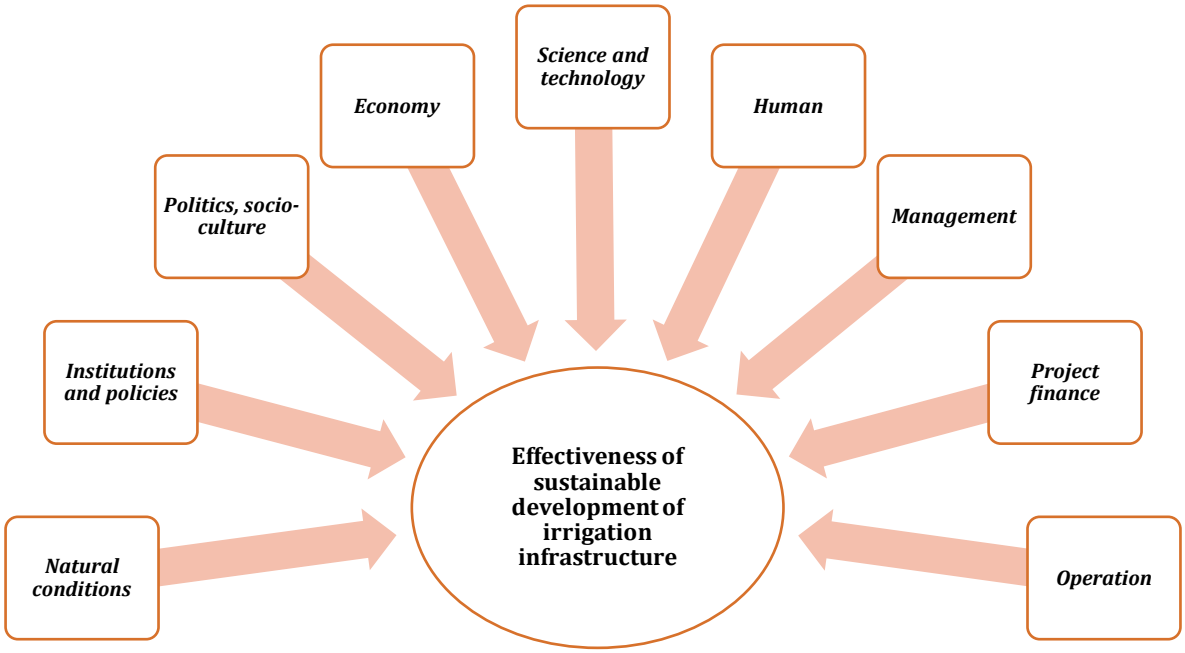

Fig. 6 *Theoretical framework*

The development of sustainable irrigation infrastructure in Vietnam lies at the intersection of environmental resilience, food security, and rural development. The theoretical and empirical analyses in this study affirm the indispensable role of irrigation systems, not only in boosting agricultural productivity but also in mitigating the adverse effects of climate change. Yet, despite significant public investments and policy attention, persistent inefficiencies and underperformance reveal structural shortcomings that this study attempts to unravel.

4.2 Rethinking Investment Effectiveness Beyond Traditional Metrics

A key insight emerging from this study is the need to redefine "investment effectiveness." Traditionally, the success of irrigation projects in Vietnam has been evaluated using cost-efficiency, timeliness, and immediate output indicators (e.g., hectares irrigated or infrastructure completed). However, such metrics overlook vital aspects such as climate resilience, equitable access to water, long-term system maintenance, and integration with broader rural development goals.

In the context of sustainable development, irrigation must be assessed through its contributions to multidimensional outcomes: poverty reduction, livelihood security, biodiversity preservation, and adaptation to hydrological variability. This broader lens aligns with Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action). The proposed framework contributes by offering a structured approach to factor in these dimensions, encouraging planners and decision-makers to think beyond traditional investment appraisal methods.

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4.3 Comparative Lessons from International Experience

International case studies underscore that Vietnam's challenges are not unique. In Sub-Saharan Africa, for instance, Bjornlund et al. (2020) found that poor performance in irrigation schemes often results from weak institutions, inconsistent maintenance funding, and lack of farmer engagement [55]. In South Asia, Hussain and Hanjra (2003) demonstrated that participatory approaches and localized governance mechanisms enhance the success rate of irrigation investments [24]. Meanwhile, China's success in upgrading its irrigation systems shows that alignment with national food strategies, continuous innovation, and decentralized budget allocation are critical for long-term effectiveness.

Vietnam can draw valuable lessons here: institutional reform, community-based water management models, and the adoption of adaptive technology (e.g., precision irrigation, drip systems, and IoT monitoring) can address many existing limitations. Furthermore, integrating irrigation planning into broader regional climate adaptation plans—as seen in India and Thailand—can ensure more strategic, climate-smart investments.

4.4 Systemic Constraints in the Vietnamese Context

Despite strong political commitment and legal frameworks (e.g., Law on Water Resources, National Target Program on New Rural Development), systemic constraints persist. These include:

- Fragmented governance and planning between central and local authorities;
- Over-reliance on state budgets, often stretched thin and subject to rigid disbursement mechanisms;
- Low private sector participation due to unclear incentives and limited risk-sharing mechanisms;
- Lack of long-term maintenance funding, which results in rapid deterioration of assets;
- Weak data systems, limiting monitoring, transparency, and evidence-based decision-making.

Moreover, there is a disconnect between engineering-led project design and actual water needs at the farm level. The study reveals that without feedback loops between users, local governments, and project managers, systems are prone to underutilization or inefficient operation. As a result, investment efficiency remains low despite increasing capital allocation.

4.5 Institutional and Policy Implications

To improve outcomes, a paradigm shift is needed—from a construction-centric approach to a systemic, service-oriented irrigation model. This entails:

- Strengthening cross-sectoral coordination, particularly between agricultural, water, and environmental agencies;
- Mainstreaming climate risk assessments in project appraisal and financing decisions;
- Decentralizing operational management, empowering local irrigation management boards (IMBs) with financial autonomy and technical capacity;
- Developing blended finance strategies, where government, development banks, and private actors co-invest based on clear performance indicators;
- Enhancing accountability, through transparent procurement, independent monitoring, and citizen feedback mechanisms.

These changes must be underpinned by strong political will, legal clarity, and a sustained commitment to capacity building at all levels of government.

4.6 Research and Data Gaps

Despite growing interest, empirical research in Vietnam still lags behind global standards. There is a need for:

- Quantitative studies that evaluate irrigation investment impacts on yield, household income, and vulnerability reduction;
- Longitudinal studies tracking infrastructure durability and climate adaptation capacity;

- Participatory research that includes farmer voices and gender-sensitive perspectives;
- Spatial analysis using GIS and remote sensing to optimize irrigation coverage and minimize environmental trade-offs.

Furthermore, data fragmentation and limited access to official statistics hinder policy evaluation. Establishing a centralized, publicly accessible irrigation investment database could significantly improve transparency and planning.

5. Conclusion

This study offers an overview of the sustainable development of irrigation infrastructure in Vietnam. The concept of sustainable development is an appropriate and beneficial one, offering solutions to numerous issues and fulfilling a multitude of needs within the context of Vietnam. Such investment in irrigation infrastructure development contributes to sustainable agricultural development in a number of ways. Firstly, it secures water sources for daily life and economic development. Secondly, it ensures food security. Thirdly, it mitigates the effects of climate change. Nevertheless, the efficacy of this endeavour remains suboptimal, with numerous unresolved deficiencies.

The effectiveness of developing sustainable irrigation infrastructure in Vietnam is still comparatively low, and research on the subject is usually combined with studies on basic building, producing findings that have little practical relevance. The study has developed a theoretical framework for upcoming investigations into sustainable irrigation infrastructure systems in Vietnam in order to fill this gap.

This study has yielded some noteworthy findings; however, its scope is constrained by certain limitations. The number of previous studies reviewed is limited by time and budgetary constraints. Furthermore, research on preceding studies is required, as there have been few studies in recent times that are genuinely pertinent to the research issue in Vietnam. In subsequent studies, it would be beneficial to expand the research scope to obtain a more comprehensive understanding of the subject matter.

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Conflict of Interest

There is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Thanh Nguyen-Duc, Dat Tran-Tho;* ***data collection:*** *Thanh Nguyen-Duc;* ***analysis and interpretation of results*** *Thanh Nguyen-Duc;* ***draft manuscript preparation:*** *Thanh Nguyen-Duc;* ***Review & Editing****: Dat Tran-Tho. All authors reviewed the results and approved the final version of the manuscript.*

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