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KHOA HỌC CÔNG NGHỆ

CLIMATE CHANGE INTENSIFIED RAINFALL EXTREMES IN CENTRAL VIETNAM: CASE STUDY OF DA NANG CITY

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Summary: *Climate change has intensified rainfall extremes. It was well demonstrated during the invasion of Storm Son Ca over Central Vietnam in mid-October 2022. This paper presents the analysis of rainfall extremes in Da Nang City based on climatological observation in the present climate (1983-2022). Conventional trend and frequency analyses were employed to detect the pattern of changes. Results show that the rainfall extremes tend to be increasing over the entire period, but they have been further intensified in the last decades in line with the projection by climate models. These research results are good references to support water engineers and policy-makers in urban planning and development for the promotion of climate resilient infrastructure.*

Keywords: *Climate Change, Rainfall Extreme, Frequency, Da Nang*

1. INTRODUCTION

Climate change has been considered as one of the biggest environmental challenges in the 21st century. Changes in future weather extremes have been projected and recently re-emphasized in the 6th Assessment Report of the Intergovernmental Panel on Climate Change [1]. In the early 2000s, scientists at the Meteorological Research Institute of Japan implemented advanced experiments to diagnose the future characteristics of tropical cyclones [2]. Results from this research are important to inform decision-makers and water infrastructure engineers. It is very likely that the number of tropical cyclones in the future climate will be less than that in the present climate (in the same time slice, e.g., 25 years). But there will be a 40-60% increase in precipitation within a 100 km radius of the tropical cyclone center. Figure 1 illustrates the ensemble mean of the rainfall profile around all simulated tropical cyclones.

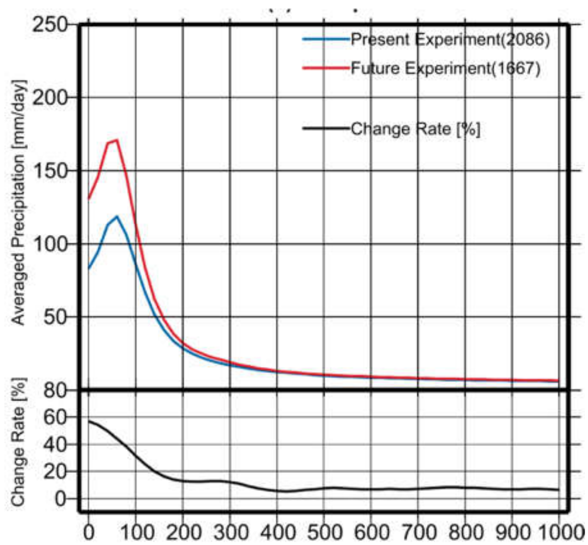

Figure 1: The radial profile of rainfall around all simulated tropical cyclones in the present (1979-2003) and future (2975-2099) experiments. The four digits in parentheses show the number of tropical cyclones. (Adopted from [2])

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With respect to current practices on engineering design, the scales of most water infrastructure have been determined under the consideration of rainfall variability, but variation properties are stationary with time (neglecting future impacts). Design rainfall intensity duration frequency (IDF) curves have been established based on variations of the rainfall recorded in the past. They are perhaps no longer valid under a changing climate; as it has been found that most extreme events occurred in the last several decades were distributed beyond the margins of those observed in the past.

Increased rainfall extremes pose threats to flood defence infrastructure, especially the urban drainage system. This was well elaborated recently in Da Nang City which was severely influenced by the Storm Son Ca during October 14-15th 2022 (Figure 2). Torrential rains induced severe widespread urban inundation causing heavy damage to citizens' properties, public transport infrastructure, warehouses and electricity substations, directly affecting daily life and production activities (Figure 3).

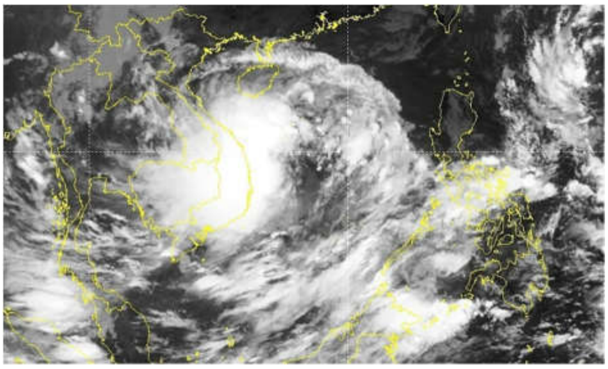

Figure 2: A satellite image of the Storm Son Ca off central Vietnam on October 14, 2022 (Photo source: National Center for Hydrometeor logical Forecasting).

In terms of damages, Storm Son Ca has caused the worst flood in Da Nang City in a decade. Serious inundation was seen in all districts and wards. Most streets and low-lying houses were submerged. There hasn't been an official report on losses, but they were estimated about 60 million USD.

Figure 3: An inundated street in center Da Nang City on Oct. 14th 2022

This paper addresses the trend of rainfall extremes in Da Nang City based on a climatological analysis of the present climate (1983-2022). The study results are considered to be fundamental information in supporting urban planning and development, an urgent adaptation requirement to tackle climate change.

2. DATA AND METHOD

2.1. Data

Climatological data was derived from a daily observation dataset in period 1983-2022 at Da Nang Meteorological station. Additional monitoring rainfall data observed by automatic rain gauges around Da Nang City on October 14-15th 2022 were selected for spatial analysis.

2.2. Method

- *Trend analysis*

The estimation and prediction of trends and associated statistical and physical significance are conventional methods of climate and meteorological studies. With a time-series of rainfall, the trend is defined as the rate at which rainfall changes over a certain time period (time slice). The trend is formulated using either linear or non-linear relationships between predictors and predictands. However, this study adopted a simple linear regression which is most commonly used to estimate the linear trend (slope).

- Frequency analysis

Frequency analysis of extreme rainfall events is useful for determining the scale of water engineering infrastructure and flood risk assessment. This study employed a conventional method presented in the literature [3] and [4] for defining rainfall extremes with chosen return periods (Tr) for the baseline climate. The method employs the Gumbel extreme value distribution fitting of the annual maximum discharge using the L-moments approach [5], as expressed in Equation (1).

$$Q(Tr) = \xi - \alpha\, ln(-ln(1 - \frac{1}{Tr})) \quad (1)$$

where α and ξ are the scale and location parameters of the analytical Gumbel distributions.

3. RESULTS AND DISCUSSION

- Maximal daily rainfall trend

The study area has been recognized as the region that receives the most severe landfalls in Central Vietnam, which is a result of cyclone invasion and topographical effects. This type of rainstorm usually causes rainfall extremes of the year [6]. The daily rainfall data of 40-year (1983-2022) were analyzed to determine the annual one-day maximum rainfall of Da Nang City. Rainfall extreme trend analysis was first performed for the entire dataset. This helps detect a long-term trend of rainfall extremes. Results show that there is an obvious increase in rainfall extremes (Figure 4). The dataset is further divided into 20-year time slices (1983-2002 and 2003-2022). It is found that the trend of rainfall extremes in the former time slice is quite consistent with the trend detected for the last 40-year. However, in the later time slice the trend is found increasing significantly. The recent two largest events are set beyond the historical observation. These imply increases in rainfall extremes recently, both frequency and intensity.

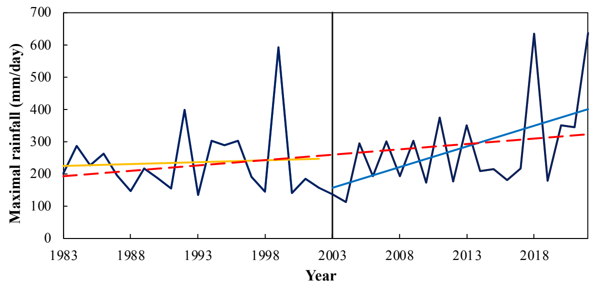

Figure 4: Maximal daily rainfall trend in period 1983-2022 (the red line represents a 40-year time slice; the green line denotes the first 20-year time slice and the blue line denotes the last 20-year time slice)

- Frequency of rainfall extremes

The frequencies of rainfall extremes in the present study were derived based on three time slices, including: the first half (1983-2002), second half (2003-2022), and entire dataset (1983-2022). Rainfall extremes were defined with 2-, 5-, 10-, 25-, 50-, and 100-year return periods. Figure 5 presents a comparison of frequency curves derived from the maximal daily rainfall in different time slices. If the time slice 1983-2022 is selected as reference baseline climate, the results show that the frequency curve derived from the first 20-year of the dataset tends to underestimate rainfall extremes; on the other hand, the frequency curve derived from the last 20-year overestimates the rainfall extremes. These indicates significant increases in the frequencies of extreme precipitation events in the late decades. Table 1 presents the statistics of frequency changes. It can be interpreted as follows. If the rainfall dataset in period 1983-2002 was used to design a drainage system (usually designed with 10-year return period), the design might underestimate approximately 10% of rainfall extremes. In case the rainfall dataset in period 2003-2022 was employed, the design tends to be oversized (approximately 10%); however, under the context of climate change, the rainfall extremes are expected to be further intensified. Thus, additional inputs from climate model projections are critical to inform engineers in designing urban infrastructure.

With regard to serious inundation situation in Da Nang City recently, the Storm Son Ca triggered widespread heavy rainfall in a short-duration (Figure. 6). Many places experienced more than 300 mm of rainfall in 6-hour that exceptionally exceeds the capacity of the existing urban drainage system. As previously mentioned, the system was designed

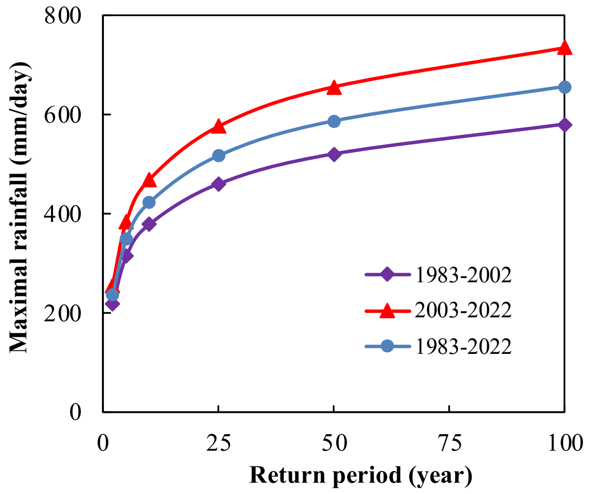

Figure 5: Frequency of rainfall extremes: the blue line was derived from the entire dataset; the purple and red lines were derived from 1983-2002 and 2003-2022 time slices, respectively.

Table 1: Statistics of changes (%) in estimates of rainfall extremes as compared to reference baseline climate (1983-2022)

	Return period (year)					
Time slices	**100**	**50**	**25**	**10**	**5**	**2**
1983-2002	-11.5	-11.2	-10.9	-10.3	-9.6	-7.6
2003-2022	12.1	11.8	11.5	10.9	10.2	8.3

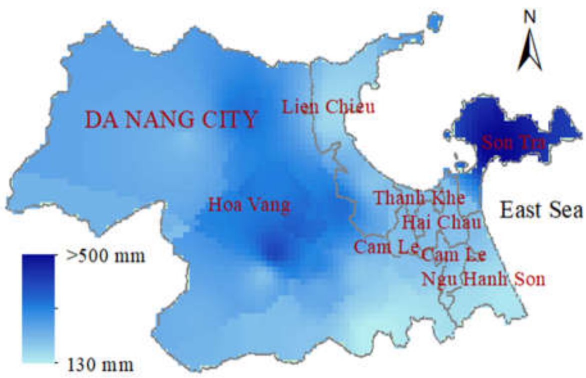

Figure 6: Accumulated rainfall measured by automatic rain gauges around Da Nang City on October 14th, 2022 to drain out local rainfall with the frequency of 10- or 20-year return period.

4. CONCLUSION

Vietnam has been classified among the six countries that most affected by climate change. Meteorological data demonstrates that recent extreme events are beyond the historical observation. Consequences were observed during the influence of Storm Son Ca when the urban drainage system in Da Nang City was completely defeated by the intensified flood. Other urban areas across Vietnam have been experiencing similar inundation problems. Understanding increases in rainfall extremes are crucial to inform adaptation options, including engineering and non-engineering interventions. The former requires physical investment for prioritized infrastructure. Especially, the later urges updates on technical standards to promote climate resilient urban planning and infrastructure which will be further addressed in the next publication of this on going research.

ACKNOWLEDGEMENT

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WATER USE EFFICIENCY IN IRRIGATION SYSTEMS OF VIETNAM

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Summary: *The Water Use Efficiency (WUE) in irrigation system is mainly based on two indicators: (i) irrigation efficiency (IE), and (ii) water productivity (WP). Water productivity in Vietnam reach at $2.57/m3 in terms of GDP, about one-tenth of the global average of $19.42/m3 (World Bank, 2016). The agricultural sector in Vietnam consumes over 80% of water, mainly fed by irrigation systems, while contributes to GDP of the country accounts for only 13.96% (gso, 2019) then improving the water use efficiency in agriculture will increase the value of water to economy. This research shows the water use efficiency indicators in study sites with different forms of irrigation works as well as evaluates the aspects that affected to the water use efficiency in irrigation systems. The research results will provide a basis for proposing solutions to improve the water use efficiency in irrigation systems of Vietnam.*
Keywords: *Water Use Efficency, Irrigation Efficiency, Water Productivity.*

1. INTRODUCTION

Across Vietnam, more than 900 irrigation systems have been built, covering over 200 ha per system, including 110 medium and large irrigation systems, which cover over 2,000 ha per system. There are more than 86,200 irrigation works across the country, including more than 7,100 dams and reservoirs, 19,400 pumping stations, 27,700 sluices/gates, 32,000 small or temporary weirs, and 291,000 km of canals. These irrigation systems supply water to approximately 4.28 million ha of land, equivalent to 36.5% of all agricultural land in Vietnam, including:

Rice paddies, which make up 7.68 million ha of agricultural land in Vietnam. Approximately 95% of this area requires year-round irrigation.

Water supplied for aquaculture covers approximately 686,600 ha.

Advanced water-saving irrigation technology for upland crops only covers 0.288 million ha out of 2.4 million ha (12%).

Approximately 6 billion m3 of water is supplied for domestic and industry through these irrigation systems.

The irrigation systems also support flood prevention and flood control for urban and industry areas and support power generation, navigation, and environmental protection.

As evident, these vast irrigation systems play a vital role in underpinning Vietnam's economic productivity and food security. The distribution of these irrigation systems by region and service area is shown in Figure 1 below. The size, type, and management model of irrigation system varies across the country, according to the changes in conditions and irrigation needs.

One of the most important challenges of the 21st Century is dealing with the water crisis caused by water scarcity, as well as the degradation of ecosystems caused by water pollution. Significant resources have been invested in water development for

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agricultural purposes. However, despite Vietnam's efforts to develop water resources for food security, access to reliable and safe water is still a challenge that disproportionately impacts the poor. In addition, competition from other growing uses, such as residential and industrial, combined with water quality issues, potentially jeopardize the resources available for agriculture. In this context, the efficient use of water resources, especially in agriculture, is a concern in Vietnam, as in many countries around the world. Agricultural water use and management covers multiple scales: crops, fields, farms, irrigation systems, and river basins (national and transboundary).

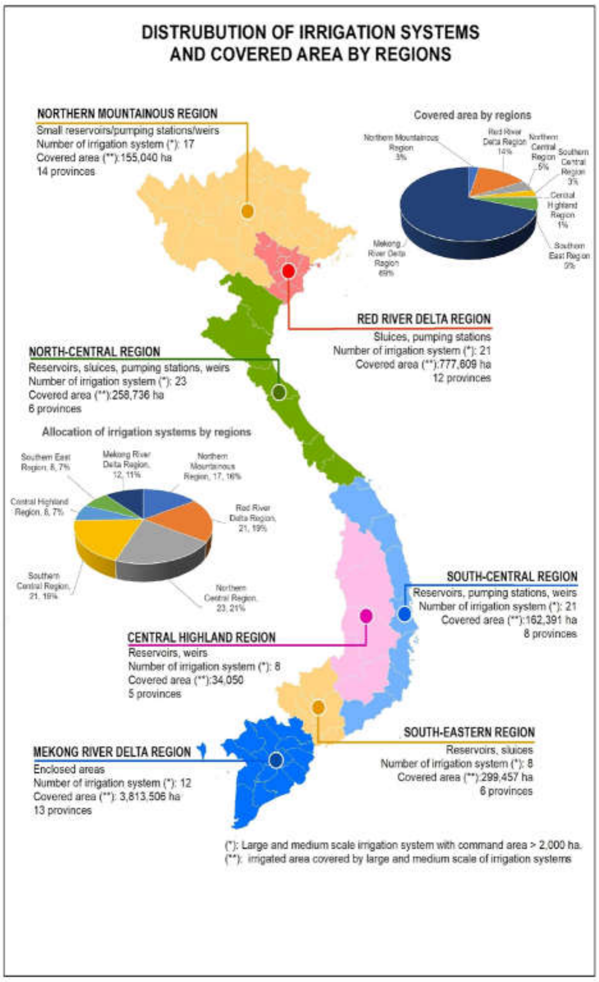

Figure 1: Distribution of irrigation systems by region and service area

In addition, according to the World Bank report "Vietnam: Towards an adaptive, clean and safe water system" (2019), irrigation systems often operate below design capacity. Despite considerable investment in Vietnam over the past 40 years, the irrigation system is of poor quality and can only deliver about 50-60% of its design capacity (World Bank, 2013). As a result, Vietnam is amongst the countries with the highest irrigation costs in Southeast Asia (HCMUAF, 2013). Nationwide, only 26% of channels (by length) can operate at full capacity; this number is slightly higher for primary and tertiary channels, and slightly lower for secondary channels.

In the context of water scarcity and seasonal variability, as well as with limited and unevenly distributed water resources, the efficiency of water use in the agricultural sector must be studied and evaluated. This research is essential to underpin potential solutions for improved efficiency and safety of agricultural water use across Vietnam.

2. STUDY SITES AND METHODOLOGY

(1) Study sites selection

The study is carried out in diffient economic regions across the country, including in the (i) northern mountainous region; (ii) the Red River Delta region; (iii) the north-central region; (iv) the south-central region; (v) the central Highlands; (vi) the south-east region; and (vii) the Mekong River Delta. The illustrates the typical irrigation systems by region, according to the data from the Directorate of Water Resources (DWR) are shown in Figure 1.

In consultation with Irrigation Exploitation and Management Companies (IMC) based on typical form of irrigation system by region, and in consideration of the availability of operational and field data, the total 13 study sites for the research are proposed are shown in Figure 2.

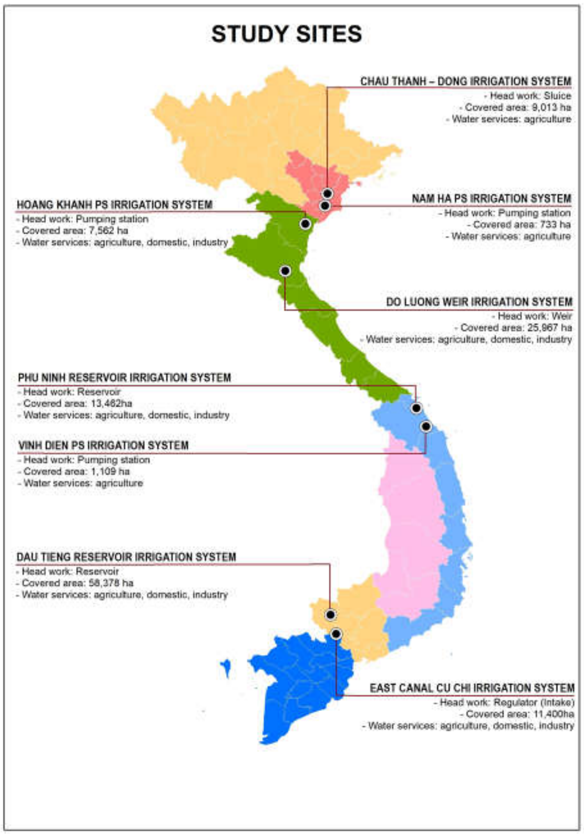

Figure 2: Selected study sites for the research

(2) Methodology

The water use efficiency in irrigation system is based on two indicators: (i) irrigation efficiency (IE), and (ii) water productivity (WP). In order to improve the efficiency of water for agriculture, and for the economy in general, indicators such as WP for water-using sectors and IE are useful to underpin improved management of these systems.

Irrigation efficiency

The irrigation efficiency, as defined by Jensen, 1977, is:

IE = NET/DIV + Er*(1- NET/DIV)

Where:

IE: irrigation efficiency (%)

NET: net evapotranspiration of crop (mm)

NET = ET-Pe

Where:

ET: evapotranspiration (mm)

Pe: the effective precipitation (mm)

DIV: total amount of water withdrawn or diverted (mm)

Er: the rate of reuse (regression) of the lost water

Method of determining parameters:

ET: evapotranspiration of crops (water demand of crops) is determined through: (i) the reference evapotranspiration (ETo) calculated using the CROPWAT software (CROPWAT is a computer programme which was developed by the Food and Agriculture Organization (FAO) for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data.

Pe (effective precipitation): utilise CROPWAT software to calculate Pe from rainfall data for each of the research sites, which is collected from official agencies, combined with the field crop characteristics (root depth in growth periods).

DIV: total amount of water withdrawn from the headwork, which is calculated or estimated from operational data from IMCs and/or WUOs.

Er: Consulting with IMCs and WUOs technical/operation staff to estimate the rate of reuse of lost water.

These parameters are estimated using the CROPWAT software with meteorological and rainfall data, as well as working with regional and local IMCs and WUOs for water accounting at the study sites. **Water accounting** is of **utmost importance** in this research.

Water productivity

Water productivity in the agricultural sector is determined by the formula (Keller et al., 1996):

WP = P/WC

Where:

WP: Water productivity ($/m^3)

P: Value of crop sold at the field ($)

WC: Water consumption (m^3) includes effective precipitation and water withdrawn:

WC = DIV+Pe

Method of determining parameters:

To determine the value of crops sold at the field (P), crop yield data is collected through field surveys (from IMC/WUO) and the price of the product at the field (from farmer).

To determine water consumption (WC), the water accessed by irrigation systems (DIV) is collected or estimated from IMCs and WUOs.

Effective precipitation (Pe) is calculated from rainfall and climate data for the research sites using CROPWAT, combined with crop characteristics (root depth) and the growth periods of crops.

3. RESULTS AND DISSCUSIONS

(1) Irrigation efficency

The irrigation efficiency indicator in the selected sites is shown in Figure 3 below

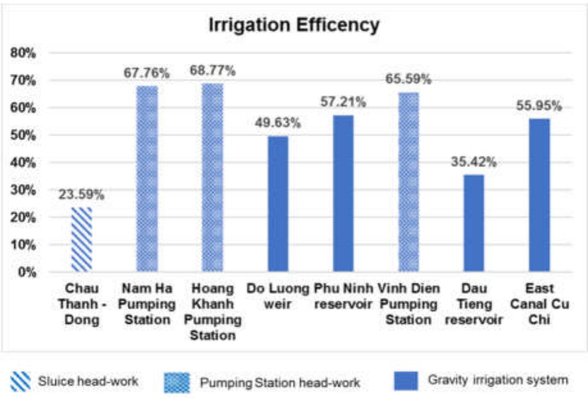

Figure 3: Irrigation efficiency in selected sites of the research

The resulting irrigation efficiencies illustrated in Figure 3 above, show key patterns. Firstly, when splitting the results into the three types of headworks (as shown in Figure 3), it becomes evident that: (i) gravity irrigation systems taking water from the river through sluices at the beginning of a canal (such as Chau Thanh - Dong irrigation system of Nam Ninh IMC) have the lowest irrigation efficiency; (ii) gravity irrigation systems with the headworks as either reservoirs or weirs, and with some coordination of other water storage sources, have higher irrigation efficiency; and (iii) irrigation systems with electric pumping stations have the highest irrigation efficiency, although most of these systems do not have a profesional water distribution plan or measuring method to ensure quality of water provision. High efficiency of these irrigation systems comes from the pressure on IMCs to minimize electricity expenditure, as a result of the operating costs.

It is also important to note that the Phu Ninh irrigation system has been modernized with irrigation improvement projects funded by the World Bank, such as WB3/WB7. The irrigation efficiency of this system reached 57.21%, more than double compared to 2013 (23.05%), when the WB7 project began. This shows the important role that regular updating and maintenance plays in improving the irrigation efficiency in irrigation system.

Finally, The Dau Tieng and the East Canal Cu Chi irrigation systems use irrigation management technologies such as SCADA (Phong et al., 2014). These result in very high irrigation efficiencies compared to other gravity-fed irrigation systems nationwide. This shows the undeniably important role of irrigation management techniques in improving the functionality of these irrigation systems.

(2) Water Productivity

The water productivity indicator in selected sites is shown in Figure 4 below.

The results show that the value of water productivity in the studied irrigation systems in Vietnam reached an average value of 0.18 USD/m3, which is higher than the average value of 0.10 USD/m3 found by the FAO in more than 50 systems studied, as well as the forecasted growth of water productivity in the agricultural sector for the period 1995-2025 of 0.095÷0.127 USD/m3 (Cai et al., 2003).

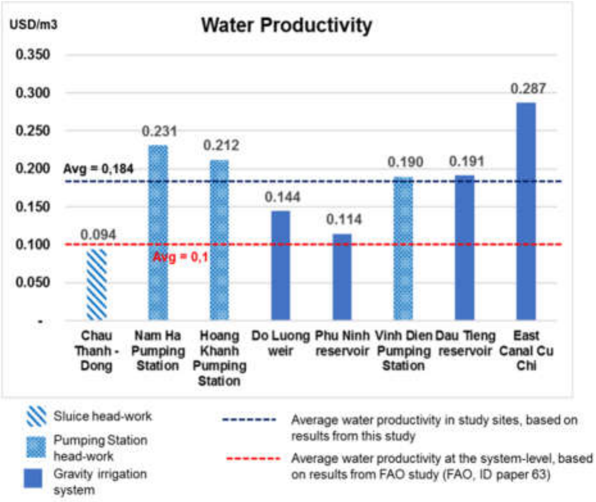

Figure 4: Water productivity in selected sites of the research

(3) Disscusions

For Irrigation Efficency:

Irrigation efficiency at the irrigation systems mainly depends on: (i) coverage area of irrigation systems; (ii) form of irrigation system works; and (ii) irrigation management techniques. Some main finding

Coverage of irrigation systems:

For gravity irrigation systems: Irrigation efficiency tends to decrease where the command area of the irrigation system increases. When comparing the irrigation efficiency across Dau Tieng, Do Luong, and Phu Ninh, which all share similar irrigation techniques and water sources (i.e., gravity irrigation and the main canal system is lined), a direct correlation was found between command area and efficiency. This shows that under the same conditions, the larger the command area, the lower the irrigation efficiency. This is attributed to the increased complexity in water management when the command area is greater.

For pumping station irrigation systems: There is not much difference in the efficiency between the Nam Ha (command area 733 ha and efficiency of 67.76%), Hoang Khanh (7,562 ha command area and efficiency of 68.77%), and Vinh Dien (1,109 ha command area and efficiency of 65.59%). This is probably due to the pressure of operating costs (electricity) resulting in managers or operators stopping the operation of the pumping station when they feel enough water has been distributed.

Form of irrigation system works

Head works

The irrigation systems with **electric pumping stations** are the group with the highest irrigation efficiencies, at an average efficiency of **67.37%,** despite most of these irrigation systems not having a professional water distribution plan or water measurement method to ensure quality of water services. The operation is typically manual and based on local experience. The pressures from electricity costs likely contribute to the higher-than-average levels of efficiency.

The **reservoir-fed gravity** irrigation systems have lower irrigation efficiencies than the systems with electric pumping stations, at an average efficiency of **49.55%**. This could be attributed to the implementation of a professional water distribution plan. In addition, these irrigation systems typically have very effective SCADA equipment for their water distribution.

The gravity irrigation system that distributes water from rivers through **sluices** (such as the Chau Thanh - Dong irrigation system of the Nam Ninh IMC) has the lowest irrigation efficiency, at **25.97%**. This could be attributed to the lack of coordination and oversight on water use allocation and cost pressures.

Canal system

For large-scale gravity-fed irrigation systems with completed and lined reservoirs and/or weirs, such as the Do Luong, Phu Ninh, Dau Tieng, and East Canal Cu Chia systems, higher irrigation efficiency is achieved.

For the Phu Ninh irrigation system (modernized through the WB3/WB7 project), the calculated irrigation efficiency is **57.21%**, more than double its efficiency in 2013, which was **23.05%** (Nguyen Tung Phong et al., 2004).

For the Do Luong irrigation system (upgraded through the JICA2 project), the calculated irrigation efficiency is **49.63%**, compared to **35%** in 2014.

For irrigation systems with electric pumping stations, such as the Nam Ha, Hoang Khanh, and Vinh Dien systems, the irrigation efficiency with lined canal systems is **65.59% - 68.77%**. The irrigation efficiency of these pumping stations depends on the form of the irrigation network and water source. It is clear however that lined canal systems improve efficiency outcomes.

<u>Water management techniques</u>

Normally, IMCs develop irrigation plans for agricultural production for each season specific to each system.

For irrigation systems with reservoirs or weirs, such as the Dau Tieng, East Canal Cu Chi, Phu Ninh and Do Luong systems, large command areas mean that water distribution is complicated, and the irrigation canal system is very long with high rates of water loss. For these systems, the water distribution plan is developed based on water demand for agricultural, domestic, and industrial users. The implementation of the water distribution plan is based on (i) the irrigation plan; (ii) specific weather conditions (rainfall); and (iii) the irrigation monitoring system. In particular, monitoring systems help with the IMCs' water distribution activities, enabling adaptation to different water demands, water quality variability, and resource availability.

For irrigation systems with pumping stations, such as the Nam Ha PS, the Hoang Khanh PS, and the Vinh Dien PS, seasonal water distribution plans are typically developed according to weather conditions and the operator's assessment of water demand. These water plans and their monitoring is very limited, so the quality of water management activities cannot be determined on the basis of science and technology.

For gravity-fed irrigation systems, such as the Chau Thanh – Dong, an irrigation plan exists but is very general and not monitored. Water distribution from this system is operated manually, without electricity cost pressures and limited monitoring.

SCADA systems have gradually been applied in a number of the irrigation systems, specifically:

In the Dau Tieng irrigation system: The water distribution plan was developed using a bottom-up approach (from water users). The SCADA system at Dau Tieng can measure the water level and flow from the Dau Tieng Reservoir to the irrigation system. This SCADA system helps to manage and coordinate the quality and quantity of water supplied from the Dau Tieng reservoir.

In the East Canal Cu Chi irrigation system: SCADA application has reached a higher level following WB3 project support. This includes water demand and distribution from the East Canal Cu Chi irrigation system to different water users (agriculture, industry, domestic).

In the Phu Ninh irrigation system: The current SCADA system monitors water level and flow in order to adjust water distribution in accordance with the system's conditions.

In the Do Luong irrigation system: The application of SCADA has just started under the JICA 2 project and completion and handover to IMC is expected in June 2022. Thus, the effectiveness of the SCADA system cannot be assessed yet. However, considering the current manual operation, it is expected the SCADA will provide a significant benefit to the system's irrigation efficiency.

For Water Productivity:

Through a preliminary analysis of the Water Productivity in the selected site of the research, no relationship was found between Water Productivity and the coverage area. The results of water productivity calculation show that the factors affecting Water Productivity indicator mainly include: (i) form of irrigation head works; (ii) water management techniques; (iii) diversity of water users; and

(iv) crop type and pattern.

Form of irrigation head works

Irrigation systems with **electric pump stations** achieved a relatively higher Water Productivity (higher than the average value of 1.84 USD/m3). This can be explained through cost pressures and the desire to reduce costs and close oversight by manual operators.

Gravity irrigation systems with **Reservoirs/Weirs**, (including the Do Luong, Phu Ninh, Dau Tieng and East Canal Cu Chi irrigation systems) showed uneven Water Productivity and no clear trend. This could be explained, in part, due to diversified water sources from different irrigation systems. (Further analyzed in section 6.2.3)

The irrigation system with gravity-feed sluices generated the lowest value of Water Productivity. This form of irrigation system does not need the coordination of water source and doesnt have as signifcant cost pressures. This leads to a high-water consumption and low productivity.

Water Management Techniques

Water management systems using SCADA showed a higher Water Productivity than those without or low level of SCADA usage.

Irrigation systems with electric pump stations such as Nam Ha, Hoang Khanh and Vinh Dienshowed a higher-than-average Water Productivity due operation cost pressures (electricity bill) rather than water management approaches as there is almost no water monitoring or water mesurement system in place.

The gravity irrigation systems have the lowest Water Productivity) due to the lack of water efficiency practices.

Diversification of water services

Irrigation systems with electric pumping station have similar Water Productivity.

The gravity irrigation systems can be divided into 2 groups: Group 1 mainly servicing water for agricultural production; and Group 2 Servicing water for agricultural production and water for domestic and industry.

Group 1: Do Luong irrigation system and Phu Ninh irrigation system mainly service agricultural production and only a very small percentagedomestic and industrial users, so although Irrigation Efficiency is higher than other irrigation systems in Group 2, the Water Productivity is lower than the average Water Productivity in this form of gravity irrigation systems and much lower than the irrigation systems in Group 2.

Group 2: Dau Tieng irrigation system and East Canal Cu Chi irrigation system have a very high proportion of water for industrial and domestic sector, so the Water Productivity is higher than the average Water Productivity of the studied systems, especially in the East Canal Cu Chi irrigation system, the Water Productivity is higher than 56.8% average value.

This shows that the impact of non-agricultural water services on Water Productivity on irrigation systems is very clear. Calculation results of Water Productivity at irrigation systems also show that Water Productivity for non-agricultural water services (industrial - domestic) is higher than Water Productivity for agricultural irrigation services at 18,45%.

Crop pattern

The main task of irrigation systems is still to provide public irrigation services for agricultural production.

This group of irrigation systems with the form of head works as electric pumping station has a relatively similar Water Productivity and has an average value (for agriculture) at 0.210 USD/m3;

The group of gravity irrigation system with the form of head works as Reservoir/Weir has an average of Water Productivity at 0.174 (USD/m3) for agricultural production,

Thus, at the irrigation system, the cultivated area is mainly paddy rice and vegetables, so there is not much difference in crop pattern, but the factors affecting Water Productivity in agriculture come from the other factors such as: (i) irrigation system characteristics; and (ii) Irrigation Management techniques.

4. CONCLUSION

Climate change is impacting water security and creating significant uncertainty for the agricultural sector. Population growth and increased water demand are compounding this challenge. Tensions between competing water users are on the rise. Efforts to increase irrigation efficiency and agricultural productivity are essential to help Vietnam manage these challenges, ensure food security, and contribute to Vietnam's economic development.

The results of this research on irrigation efficiency and water productivity in the irrigation systems in Vietnam are summarized as follows:

General: The average water productivity of the studied irrigation systems (0.184 USD/m3) was found to be higher than those studied by the FAO (50 irrigation systems in Vietnam), and also higher than the growth forecast of water productivity in agriculture for the period 1995 - 2025 (0.127 USD/m3) (Cai et al., 2003).

Scale of command area: In general, the larger the command area of the irrigation system, the lower the irrigation efficiency, when comparing irrigation systems of similar condition and water source.

Type of headworks: The irrigation systems using electric pumping stations have higher irrigation efficiencies and water productivities due to the financial pressure on operating costs. Systems with reservoirs had medium effiency and productivity, and gravity-fed irrigation systems were the least efficient and productive.

Canal system: Irrigation systems with lined canals showed significantly higher irrigation efficiencies than unlined, earthen canals.

Technical water management: Irrigation systems with good water management techniques, and applications of advanced water management technologies (such as SCADA), have higher water use efficiency. With the application of an effective water measuring system and modern technology, the multi-purpose exploitation of the irrigation system is less complicated and results in a higher water productivity.

Diversification of water services: Irrigation systems with diverse water users (i.e., industrial and domestic) have a higher water productivity than irrigation systems that only serve water for agricultural production. Calculation results show that water productivity in non-agricultural sectors is about 18.45% higher than water productivity in the agricultural sector.

The results of this research will be the basis for proposal of solutions to improve Irrigation Efficiency and Water Productivity in irrigation works systems, contributing to improving the Water Use Efficiency in agriculture sector in particular as well as in the general economy of Vietnam.

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LANDSLIDE HAZARD MAPPING USING ENSEMBLE MACHINE LEARNING ALGORITHM IN BA BE LAKE BASIN

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Summary: *The purpose of this paper is to present a result to build the landslide hazard map using four machine learning models including Logistic Regression (LR), Random Forest (RF), Gradient Boosting (GBC) and Xgboost (XGB) for Ba Be Lake basin. In this study, based on field surveys, the reviewed literature and available data, we considered ten landslide causative factors including slope, soil, plan curvature, normalized difference vegetation index (NDVI), Digital Elevation Model (DEM), geomorphons, distance from the road, distance from the river, density of streams and rainfall accumulation which were extracted and prepared from the spatial database. The Receiver Operating Curves (ROC) and Area Under Curve (AUC) were used to validate the modes. The results of the analysis showed that the RF and GBC models had the highest predictive ability (AUC = 0.88), followed by the XGB models with 0.86 and the last one is LR with AUC = 0.78. The results could be useful to planners in general land use planning and management.*

Keywords: *Landslide hazard mapping, machine learning, landslide.*

1. INTRODUCTION

One of the most serious geological hazards in the world is landslide, especially in mountainous areas. The landslide events are causing widespread destruction of infrastructure, the loss of life and properties [1]. Mountains cover about 65% of land in the area, Ba Be Lake basin is prone to landslide hazard. According to the results of landslide investigation, the area of Ba Be Lake and the surrounding areas has more than 800 landslide points in the period from 2000 to 2014 [2].

Ba Be Lake basin is a small basin with an area of 464.68 km² located in the west of Bac Kan province and adjacent to Tuyen Quang province. Ba Be Lake basin is contributed by the three major tributaries, namely Bo Lu, Cho Leng and Ta Han.

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Ngày thông qua phản biện:16/9/2022
Ngày duyệt đăng: 03/10/2022

Although the main research object is Ba Be Lake basin, in this study area only 36 landslide sites have been collected, so an expanded area is considered to enhance landslide data and rainfall stations surrounds Ba Be Lake area with part of Tuyen Quang province.

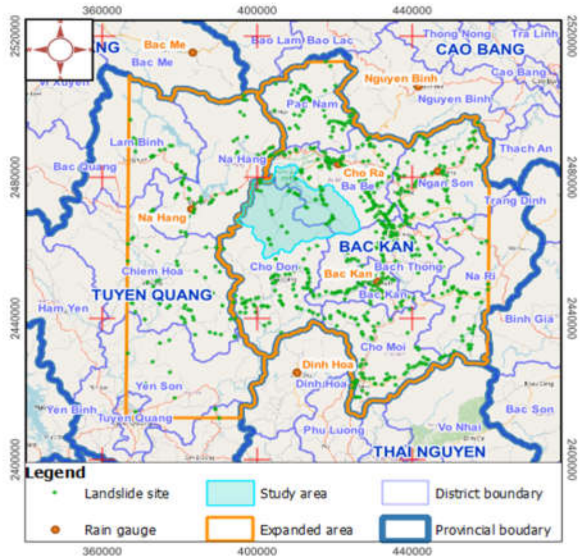


Figure 1: Study area

2. METHODS

Qualitative approach to develop the landslide susceptibility mapping and modelling have been adopted by several researchers [3] [4] [5]. Recently, machine learning techniques such as artificial neural network are applied to landslide susceptibility analysis to remove subjectivity in qualitative analysis [6] [7] [8].

2.1. Data collection and preparation

To carry out this study, the required data were collected and sorted from different data sources such as DEM from Ministry of Natural Resources and Environment (MONRE) with 1/10.000 scale, Satellite image from Google Earth Engine (GEE), Soil from Department of Natural Resources and Environment Bac Kan (DONRE), Road from Open Street Map (OSM), landslide sites from MONRE [2] and field survey, daily rainfall from MONRE.

Table 1: Sources of data

No.	Data	Sources	Note/Details
	DEM	MONRE	1/10.000 scale
	Landsat images	GEE	Period from 2000 to 2020
	Soil map	DONRE	Collected in 2020
	Road map	OSM	Downloaded in April 2021
	Landslide sites	DARD and field survey	Vietnam Institute of Geosciences and Mineral Resources (VIGMR); Bac Kan Provincial Commanding Committee of Natural Disaster Prevention and Control, Search and Rescue (PCDPSR); Field trip in 2020.
	Daily rainfall	MONRE	From 1986 to 2020 for 7 gauges (Bac Me, Bao Lac, Ngan Son, Nguyen Binh, Cho Ra, Na Hang, Dinh Hoa) and Bac Kan for 1996-2020 period.

Terrain analyses include slope, plan curvature, geomorphons, density of streams. NDVI is extracted satellite images from 2000 - 2020 using GEE tool. The resolution of factors analysis is 20m.

The whole factor analysis is done in python language: GIS spatial analysis using GDAL, and GRASS libraries or QGIS toolbox, data series analysis using Pandas and Numpy libraries, charts using Matplotlib and Seaborn libraries. We also use QGIS to present the maps.

2.2. Spatial Database

1. Landslide Inventory database

We have collected data on landslides from 2 sources: (1) from PCDPSR with several landslide locations collected in recent period (with unspecified timeline); and (2) The landslide investigation project which was implemented in Bac Kan by the Vietnam Institute of Geosciences and Mineral Resources in 2014 [2].

The collected landslide sites are reprojected to VN-2000 and removed duplicate points at the two data sources, besides, some unsuitable landslide sites (after review and evaluation) are also removed. In the Ba Be Lake basin and the surrounding area, 808 landslide sites were selected in both Bac Kan and Tuyen Quang provinces in this study.

2. Landslide causative factors

Slope

The force acting on the steep slope is the main cause of landslides [9], in many studies, the slope is considered as a major factor causing landslides [10] [11] [12]. Depending on the characteristics of each area (in terms of geological structure, lithology, landcover etc.), there is a different hazard level of landslide.

There are some minor adjustments in the slope used in this study compared to the slope of the grid cells. We assume that a grid cell located on a steep shoulder also has a very high risk of landslide while the slope of that grid cell is very low. Therefore, we considered the slope of a grid cell in this landslide assessment as the average slope of the three grid cells in the direction flow which originates from that grid cell. The newly formed slope map is a combination of the slope map and the flow direction map.

We were developed new tool in python to generate the new slope map (called slope down).

Plan curvature

Plan curvature is the curvature of a contour line at a given point on the topographic surface and it is generated from a digital elevation model (DEM). This factor has an unlimited range that can take either positive or negative value. A positive value of the index indicates flow divergence while a negative plan curvature value indicates flow convergence [13]. We calculated the plan curvature by SAGA tool in QGIS.

Distance from the river and road

In the study area, most of the landslide sites are located near roads and rivers. We used the Proximity tool in the GDAL library to calculate the distances of each pixel to rivers and roads.

Normalized Difference Vegetation Index (NDVI)

Although in many landslide studies, land use land cover (LULC) maps are used, in this study, the NDVI is considered as the preferred index. Because landslides are collected over a 20-year period, it is not possible to determine the LULC corresponding to each period. Some studies have shown that the higher the NDVI is, the lower the probability of hazard of landslides. However, in the process of data collection and analysis, we were found that even in areas with high vegetation index, many landslides appeared.

We use the Google Earth Engine to collect, process and calculate the NDVI for the entire study area.

Elevation

Topographic elevation is considered as an impact on the distribution of rainfall and humidity in the area. DEM data is obtained from MONRE at the scale of 1/10,000

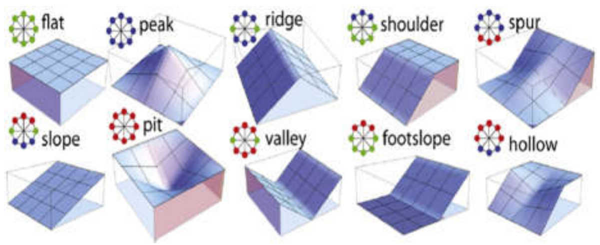
Soil

Different soil types have different cohesive characteristics, which have direct effects on landslides. We use the land map collected from DONRE to build a soil map for the study area.

Geomorphons

Geomorphons is a factor that is rarely considered in landslide studies. However, we found that hilly areas have a greater hazard of landslides than other areas, so this index is considered to assess the impact on landslide hazard.

Geomorphons were described by Jasiewicz as a calculation method in 2013 [14] to indicate 10 common types of landforms including: Flat; Peak; Ridge; Shoulder; Hollow; Slope; Spur; Footslope; Valley; and Pit.



We were used the r.geomorphons tool in GRASS library to build this map.

Density of streams

High density of streams increases soil saturation and reduces cohesion, which are indirect cause of the landslide process. We calculated the density of neighboring cells to determine the density of rivers and streams based on a self-developed algorithm in python language.

Precipitation

The characteristics of the largest accumulated rain by days at 8 rainfall stations are shown as follows:

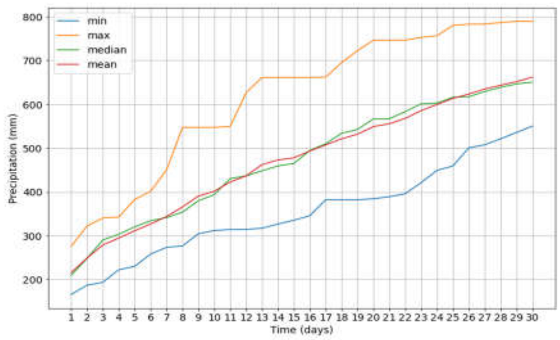


Figure 2: Characteristics of accumulated rainfall

There have been a number of studies that have attempted to determine a correlation between the time of precipitation accumulation and the landslide event, but have failed to show a specific way [15]. At each different time of accumulation of preciptation, landslide events also have different responses.

We found that, during the period of 9÷11 days, the total maximum and minimum rainfall accumulation was almost unchanged. In this study, we use 10-day cumulative rainfall as the rainfall to calculate landslide hazard.

Since it is not possible to determine the time of landslide occurrence for each collected landslide site (2000 ÷ 2020 period), we assumed that there was a rain event over a 20-year period as the landslide-induced precipitation threshold for the collected landslide sites. Based on this assumption, precipitation with a return period of 20 years for 10-day cumulative precipitation is calculated.

2.3. Modeling

1. Logistic Regression (LR)

The LR model has become one of the most popular methods in machine learning althorigms. This is a multivariate statistical method that is generally used to deal with binary classification issues. An outstanding feature of LR is that it calculates the weights for each conditioning factor.

2. Random Forest

Random forest is an ensemble learning method, first proposed by Breiman [16] and Cutler [17] that builds multiple decision trees through different subsets of data and votes the results of many decisions tree to get the results of the random forest.

The construction of random forest mainly includes the following steps [18].

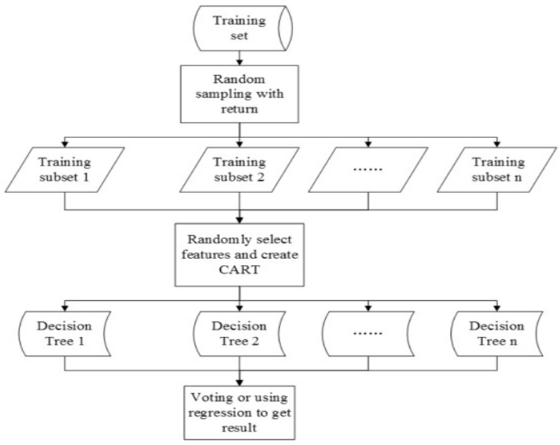


Figure 3: The process of RF model

A large number of available studies have shown that random forests have a significant tolerance to extraneous factors and noise, unlikely to over-fit, and of high prediction accuracy and stability [19].

3. Gradient Boosting Classification

Similar to RF, gradient boosting classification (GBC) is another technique useed to perform supervised machine learning. GBC has generated a predictive model in the form of an ensemble of weak prediction models as decision trees [20].

3. Extreme Gradient Boosting (XGBoost)

Extreme Gradient Boosting (XGBoost) is a kind of efficient and optimized gradient tree boosting algorithm and has recently gained wide popularity, especially due to its exceptional performance in Kaggle competitions.

The core achievement behind the XGBoost algorithm is its scalability in all scenarios and fast processing execution by providing bagging-bootstrap aggregation and randomization, XGBoost both prevents overfitting problems while taking into account the variance trade-off. Due to such special advantages, XGBoost has recently become one of the most popular ML algorithms in landslide susceptibility mapping studies [21] [22]

3. RESULT AND DISCUSSION

3.1. Data distributions

The distribution of data greatly affects the results of machine learning models. Big data bias causes inaccurate results. Therefore, we have renormalized the input data in the vicinity of 0 and shown in the following table:

Table 2: Data and data normalization

No.	Factor	Range of values	Data normalization
1	Slope	0 ÷ 77.2 °	Divide by 100
2	Plan Curvature	-124.98 ÷ 51.77	0 ÷ 1
3	Distance from road	0 ÷ 7,955	0 ÷ 1
4	Distance from streams	0 ÷ 1,627	0 ÷ 1
5	NDVI	-1 ÷ 1	-1 ÷ 1
6	Elevation	5.96 ÷ 1914.84 m	0 ÷ 1
7	Soil	Separate value	Frequency Ratio → 0 ÷ 1
8	Geomorphons	Separate value	Frequency Ratio → 0 ÷ 1
9	Density of streams	0 ÷ 1	0 ÷ 1
10	10 days accumulated rainfall	281.34 ÷ 433.45 mm	Divide by 1000

Table 3: Frequency Ratio for Soil and Geomorphons

No.	Class	Area (km^2)	Area percentage (%)	Number of landslides	Percentage of landslides (%)	FR	LSI
Geomorphons							
1	Peak	182.53	2.50%	6	0.70%	0.3	-1.2
2	Ridge	953	12.90%	150	18.60%	1.44	0.366
3	Hollow	1,082.91	14.60%	155	19.20%	1.31	0.271
4	Slope	1,663.56	22.50%	197	24.40%	1.09	0.082
5	Spur	1,128.88	15.20%	139	17.20%	1.13	0.121
6	Valley	1,666.93	22.50%	112	13.90%	0.62	-0.485
7	Pit	727.44	9.80%	49	6.10%	0.62	-0.482
Total		7,405.25	100.00%	808	100.00%		
Soil							
1	Rocky mountain	648.8	8.80%	31	3.80%	0.44	-0.826
2	Rhodic Ferrasols	187.25	2.50%	28	3.50%	1.37	0.315
3	Xanthic Ferrasols	300.34	4.10%	26	3.20%	0.79	-0.231
4	Ferralic Acrisols	6,041.62	81.60%	712	88.10%	1.08	0.077
5	Humic Acrisols	228.07	3.10%	11	1.40%	0.44	-0.816
Total		7,406.08	100.00%	808	100.00%		

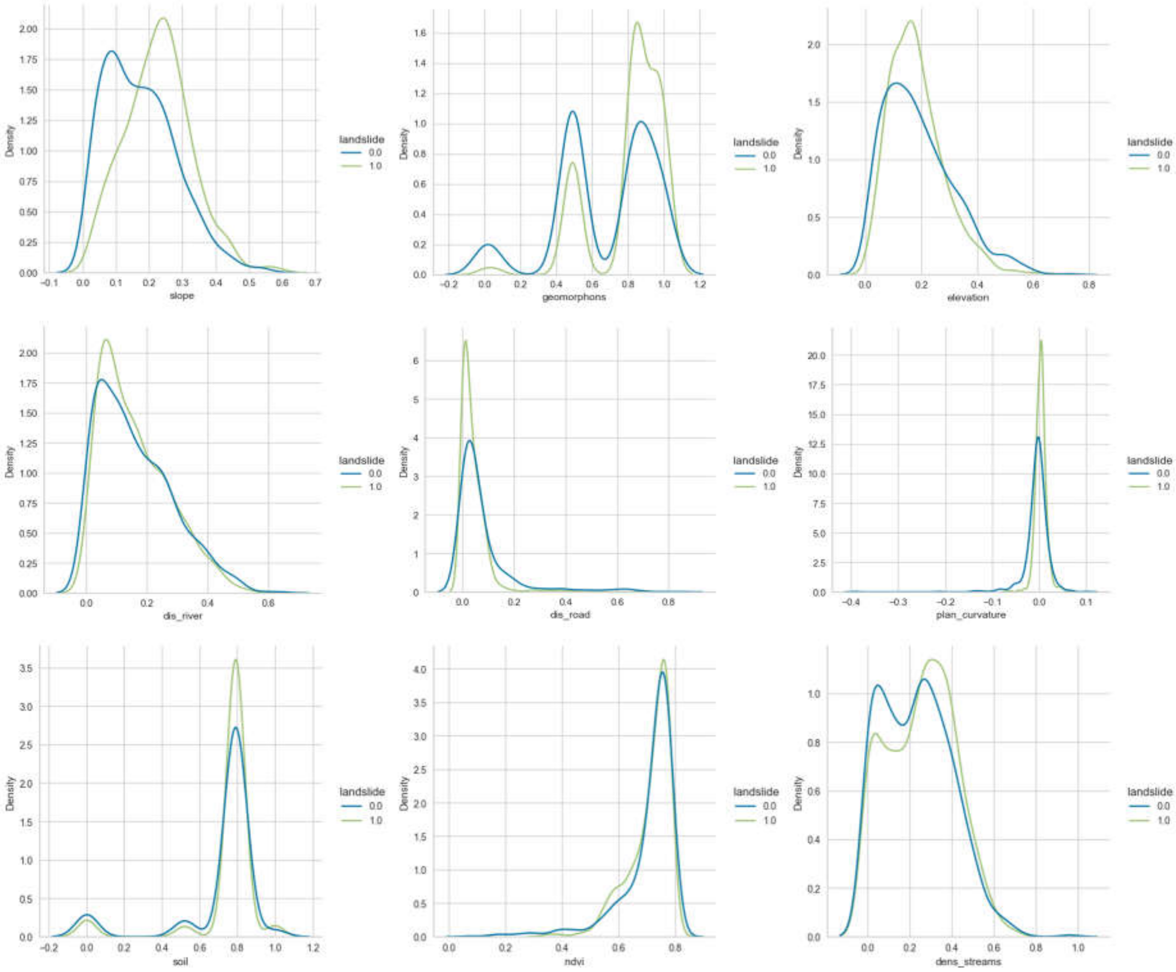
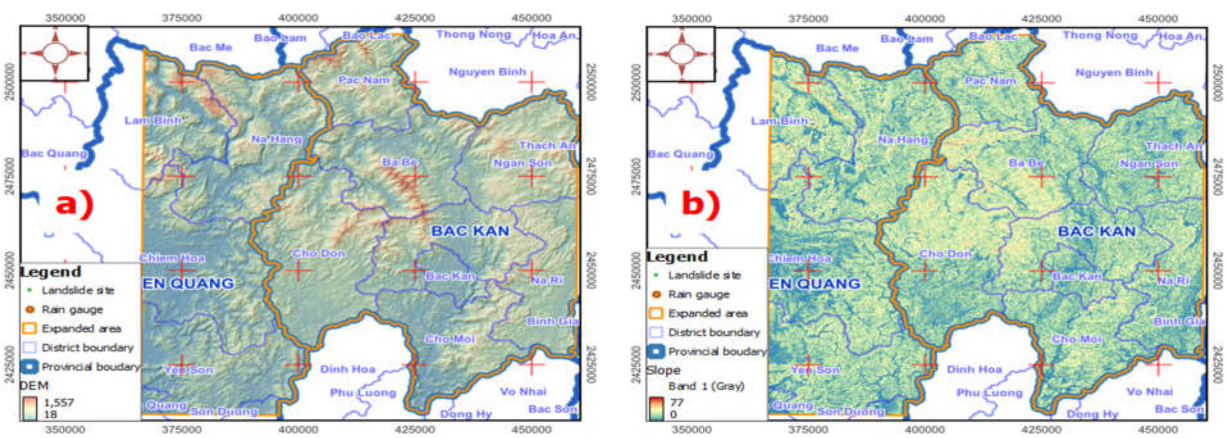


Figure 4: Graphs of distributions of the variables

The distribution of data shows that the landslide sites have a higher slope than the non-slide sites. Meanwhile, areas with hollow, spur and slope landform tend to have more landslides than others.

At the elevation from 100÷500m, there are the most number of landslide points (615/808 points), especially from 250÷500m, there are 398 landslide points (accounting for nearly 50% of the total number of landslides).



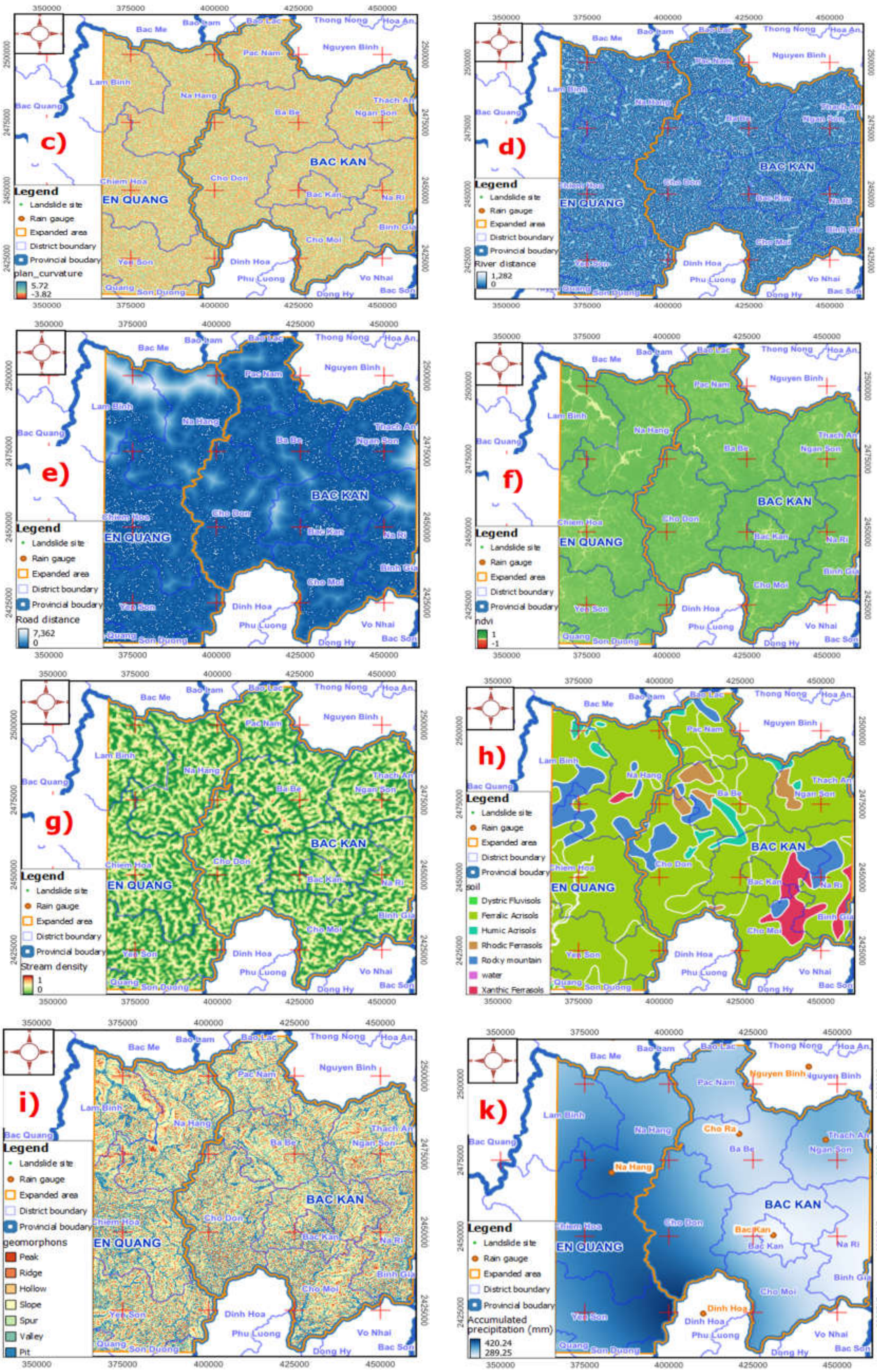


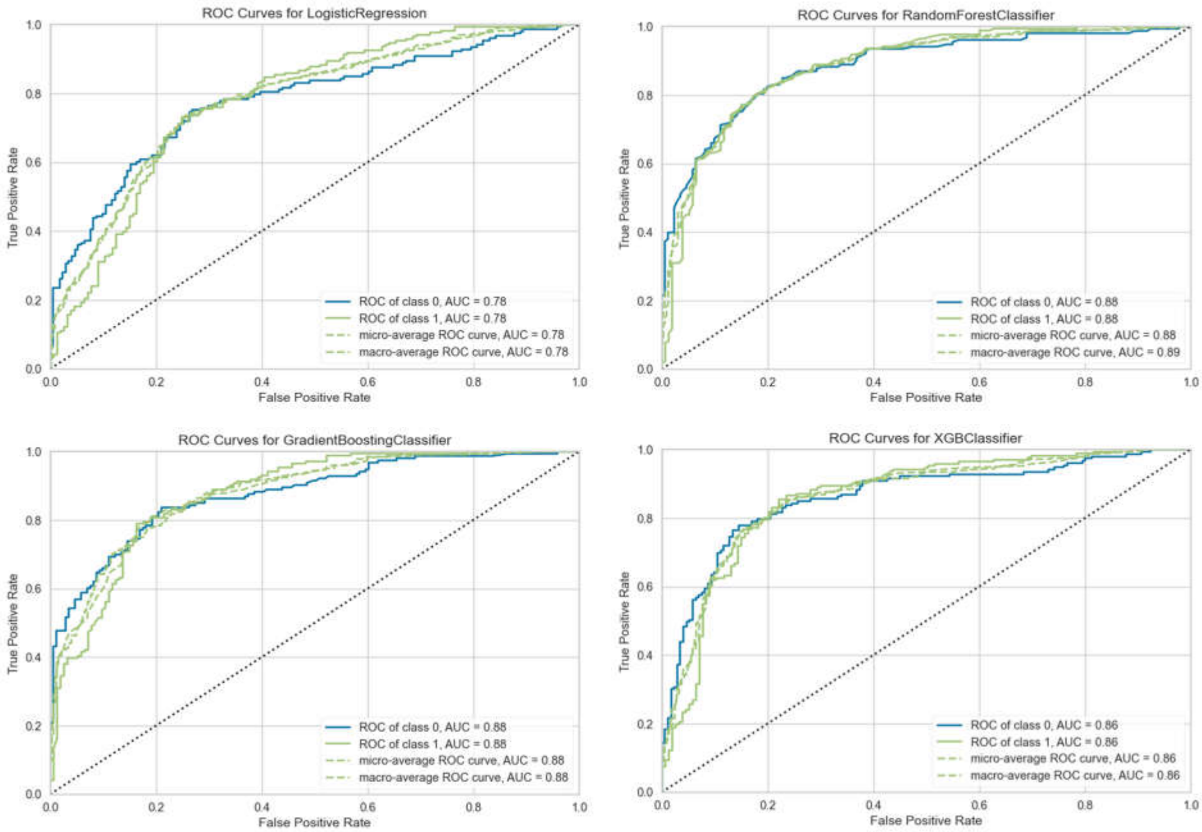
Figure 5: a) Digital Elevation Model; b) Slope; c) Plan Curvature; d) Distance from river; e) Distance from road; f) Normalized Difference Vegetation Index; g) Stream density; h) Soil; i) Geomorphons; k) Precipitation (20 year-return period in 10 day-induced rainfall)

Sites near streams and roads are more prone to landslides than distant points, while spots with slight or no curvature tend to be more prone to landslides than areas with extreme curvature.

Rhodic Ferrasols are soils susceptible to landslides, followed by Ferralic Acrisols, in addition, the density of rivers and streams at about 10÷40% more susceptible than other areas.

3.2. Models

1. ROC and AUC



Simulation results show that the RF model gives the best simulation ability (AUC ≈ 0.88) and has the highest accuracy (accuracy = 0.81), followed by two models, GBC and XGB, give as equivalent. The LR model gives the lowest results with AUC = 0.78 and accuracy = 0.73.

2. Factor importance analysis

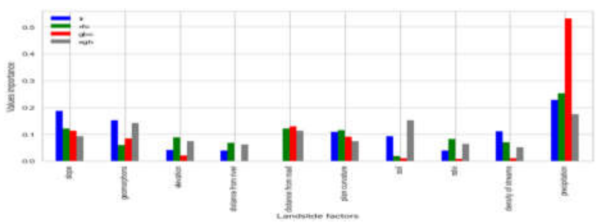


Figure 6: The importance value of each factor by machine learning model

Each machine learning model has a different assessment of the importance of each factor. However, coefficient of precipitation in all models is highest, followed by slope. The GBC model has a bias in the precipitation coefficient, while the XGB model assumes that the precipitation coefficient, soil type and geomorphons factor are also quite important in landslide hazard assessment.

The RF model assesses rainfall, slope, distance to roads and plan curvature as important factors in landslide hazard assessment. Meanwhile, the LR model suggests that in addition to rainfall, slope, geomorphology and plan curvature have a great influence.

Although there are different views on the importance of each factor, the models give very good evaluation results, which enriches the views in the assessment of landslide hazard. In the final result, we use the average combination of all models.

3.3. Result of Landslide hazard maps

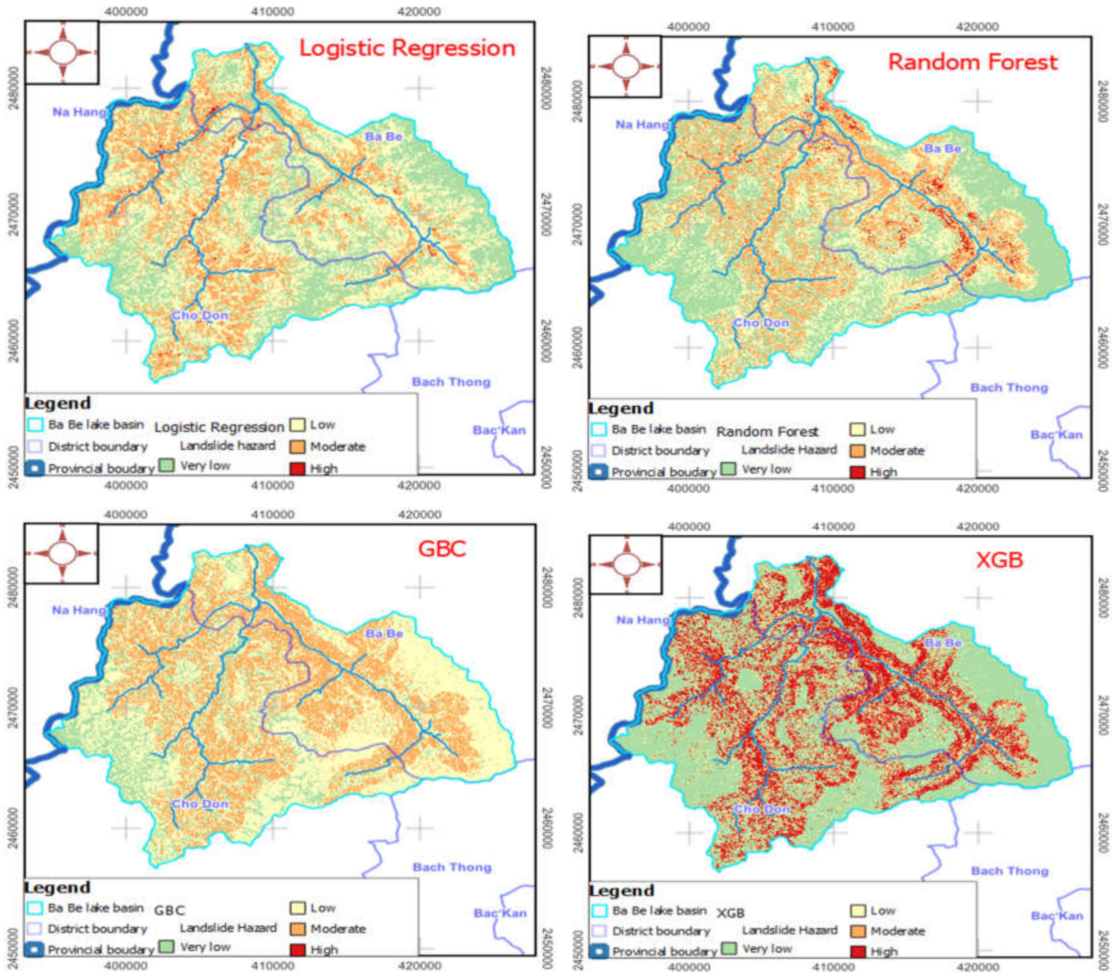


Figure 7: Landslide hazard mapping for each machine learning model

Different views on the importance of these factors have resulted in different landslide hazard maps. LR and RF models suggest that sites with high precipitation and slope are the main causes of landslides, these sites are distributed in the mountainous slopes. In addition, the points considered to be high hazard for XGB and GBC models are distributed near the traffic roads where there is steep slope too.

Although all have good accuracy, 2 models LR and RF show a better suitable in landslide hazard distribution than the other 2 models. Although the majority of landslide sites are located next to roads, this factor should still be only a small factor in the formation of landslide hazard. The bias in road distance in the collected data has caused the unbiased recognition of these two models. An average combined map of 4 machine learning models is the final product that we propose and is presented below.

The points with high hazard of landslides account for a very small part of the scattered distribution at the foot of the mountain, where there is a steep slope. This combination is similar to the principle of the RF model, which is a decision based on the votes of each model.

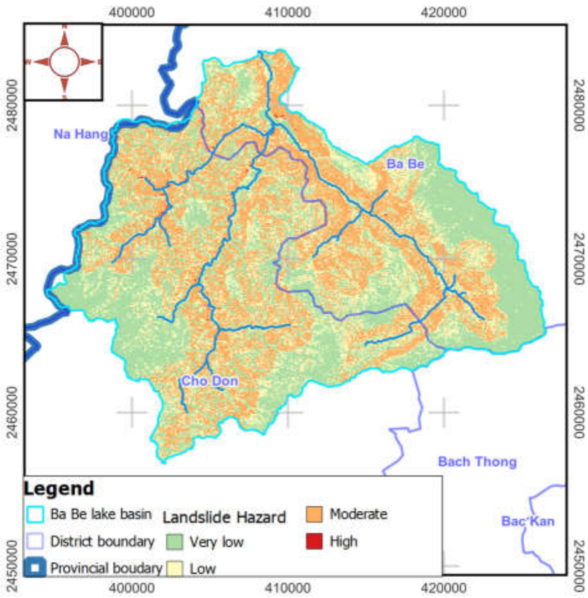


Figure 8: Landslide hazard mapping in Ba Be Lake basin

4. CONCLUSION

To build a landslide hazard map for Ba Be Lake basin, we used 10 factors combining 4 machine learning models. The simulation results show that precipitation and slope are two decisive factors in the process of landslide hazard formation.

Each machine learning model has a different view of the importance of the factors, which creates different landslide hazard map products. Although the models all have good evaluation indicators, the LR and RF models are our two favorite models due to their agreement with the evaluation of many previous scientists.

We hope this is a useful product for managers and scientists, contributing to the richness of the perception of landslide hazard on a large scale. The landslide hazard maps could be useful to planners in land use planning and management.

5. DECLARATIONS

This is the original product of an independent national project: "Research on solutions to some major natural disasters causing natural instability in Ba Be Lake area to serve the socio-economic development of the locality". We would like to thank the Ministry of Science and Technology as well as Bac Kan province for funding this research.

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CLIMATE CHANGE AND IMPACTS ON SUSTAINABLE SOCIO-ECONOMIC DEVELOPMENT IN THE COASTAL AREA OF CA MAU PROVINCE

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Summary: *The Mekong River Delta has 7 coastal provinces including Tien Giang, Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, Ca Mau and Kien Giang. Typically, Ca Mau province which exposes to both the East and West sea with a coastline of 254m (6 coastal districts: Dam Doi, Nam Can, Ngoc Hien, Phu Tan, Tran Van Thoi, U Minh) in the recent years, has been severely influenced by climate change. The Ca Mau province has lost nearly 10,000 ha of land and coastal forests; infrastructure and properties of local people along rivers have been eroded and seriously damaged; production activities are vulnerable to sea level rise and other hydro-meteorological hazards.*

The life of coastal people mainly depends on agricultural production. The main income is agricultural production, forestry, aquaculture and fishing.

This paper aims to provide a situational analysis on how climate change and natural disasters affect the livelihoods of coastal communities in Ca Mau Province and a case study results is conducted for Phu Tan District, in order to propose urgent measures for sustainable socio-economic development of the coastal area of Ca Mau province, adapting to climate change in the immediate and long-term period.

Keyword: *Risk, climate change, livelihood, coastal community, Ca Mau province*

1. THE APPROACH

Ca Mau province is one of 13 provinces in the Mekong River Delta region which is the southernmost province of the country. Ca Mau province has a geographically located from 8°30’ to 9°10’ North latitude and from 04°80’ to 105°5’ East latitude. Ca Mau is also the only province which has 03 (three) sides bordering the sea (the East is bordered by the East Sea, the West and the South borders the Gulf of Thailand – West Sea), the North borders 02 provinces including Bac Lieu and Kien Giang, the total length of the coastline of Ca Mau province is 254 km (East Sea: 100 km and West Sea: 154 km). With the above special geographical location, Ca Mau province is also affected by 02 (two) different tidal regimes (diurnal tides in the West Sea and irregular semi-diurnal tides in the East Sea) and is the most vulnerable province by extreme weather events in recent years and the trend to increase in the coming time. Ca Mau province is facing many challenges: climate change – sea level rise (CC- SLR), subsidence and erosion of river banks and coasts. Challenges will change the hydrometeorology, flow, mud, landslides and directly affects the lives of people in the region.

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Climate change – Sea level rise (CC-SLR) has caused a strong impact on the socio-economic life of coastal areas, on the mangrove ecosystem of Vietnam, including the coastal area of Ca Mau province. Especially, during the highest tides of the year (October to December), the sea level rise was highest in stormy days combined with high tides that cause great damage to properties of coastal communities and make eroded coastlines including areas with protective mangroves. According to the documents of the Vietnam Mekong River Commission (1993), when the speed of wind was 5m/s, then the sea water level increased to 10cm and when the speed of wind is 10m/s, then the sea water level increased to 20 cm; and there was no wind, the sea water level only increased to 4cm. Besides weather factors, livelihood activities also increase the vulnerability to climate change and sea level rise in coastal areas of Ca Mau province. The destruction of mangroves, the widespread embankment of shrimp ponds in the intertidal zone has prevented the movement of tides, thereby, greatly affecting the growth and development of mangroves specie, losing the nutritional place of seafood and animals in the intertidal zone, changing the flow, reducing the dispersion of water in the tidal flats and coastal area. The use of groundwater to regulate the salinity in large shrimp farming ponds as well as the wasteful use of water for domestic purposes has led to a serious decline in groundwater resources needed for mangroves plants and the organisms living in the mud and simultaneously affecting the geological structure of the coastal zone [1].

2. CLIMATE CHANGE CONTEXT AND POSED ISSUES FOR THE COASTAL AREA OF CA MAU PROVINCE

Climate change and sea level rise are a great threat and challenge to natural resources, environment and social development of the Mekong River Delta, of which Ca Mau province is the most dangerous area because it is a place with low terrain compared to sea level. Under the impact of climate change, the coastal area of Ca Mau province is affected by natural disasters with increasing frequency, intensity and scope (especially storms, floods, droughts,…) has changed the mode of production and business activities as well as human habitation activities.

According to experts from the Vietnam Academy of Water Resources, there is an indirect link between climate change and mangrove ecosystems through changes in sea level [2]. Sea level rise along with monsoons, storms, high tides have eroded the coast. In the East of Ca Mau, the Northeast monsoon (gusty winds) along with high tides have eroded many kilometers from Ganh Hao to Dat Mui village, each year there is a loss of 20-30m in width, such as Bo De estuary, Rach Goc, Khai Long area… spilling mangrove trees, including many perennial Avicennia marinas. Sea level rise also prevents the accretion of tidal flats, preventing the natural regeneration of pioneer mangrove species such as Avicennia marinas, Sonneratia caseolaris, etc. Sea level rise has created conditions for some mangroves species to encroach deep into inland soils, agricultural production lands. Wherever the saltwater, brackish water go into, then bring the mangroves along with the water inland to go there. Some freshwater flora and fauna species have been lost and replaced by brackish water species, thereby affecting food production and biodiversity.

According to monitoring data, sea level survey in recent years conducted by the Department of Agriculture and Rural Development of Ca Mau province, shows that the high tides in the following year are higher than the previous year, and along with that, the damage also increases. Especially as the following table:

Table 1: The extent of damage to Ca Mau province due to high tide

Year	Peak tide (m)	Damaged area (ha)	Notes
2007	+1.5	4,886	
2008	+1.6	10,632	
2009	+1.8	14,795	
2010	+1.85	15,832	
2011	+2.1	19,653	Monitoring at Ganh Hao

(Source: the Department of Agriculture and Rural Development of Ca Mau province)

In 2012: damage of 2,833.8 hectares; in 2013: damage of 59.15 hectares and in 2014 due to the influence of high tide (water rise) combined with cold air intensifying to the south, making the already higher tide peak, overflowing on a large area (total length of spillway 194,769 m, of which: spilled 194,598.5m, broken bank 170,5m), affected area 6,028.8 hectares; locally flooded about 2,360 residential houses [3]. In the first months of 2019, due to the strong influence of the southwest monsoon, many areas in the province appeared heavy rain accompanied by thunderstorms, lightning, tornadoes combined with high tides, causing about 51 billion VND, damage of people, property and production in the province. If the water level continues to rise as it is now, in the coming time, it will directly affect over 26,000 coastal households and 90,000ha of agricultural land at risk of flooding, especially the coastal areas of Phu Tan, Tran Van Thoi, Nam Can and Ngoc Hien districts.

According to Ministry of Agriculture and Rural Development (MARD) statistics, annual landslides are taking place strongly both on rivers and in the coastal areas of the Mekong River Delta, the area of land loss because of landslides is about 500 hectares. In the coastal area of Ca Mau province, landslides have taken place seriously in many places such as the West Sea and the East Se, causing great damage to property and destabilizing people's production. In the climate change condition, the possibility of storms increases in both intensity and frequency; sea level rise; excessive groundwater extraction; Intensive aquaculture hinders the sedimentation in the field plots to compensate for subsidence leading to an increased risk of flooding and landslides. Many mangrove areas have gradually lost their protective function; erosion is increasingly encroaching inland at a rate of 30-50 m/year [4]. The weather is becoming more and more unfavorable and unpredictable, especially in the rainy and stormy season, the sea area of Ca Mau province often rise, combining rain, thunderstorms and waves with strong intensity, most likely protective forests to protect the coast will be destroyed; Sea waves directly affect the body of the dike, there is a very high risk of breaking the West Sea dike, greatly affecting production, daily life, houses and people's lives, with a length of 57 km in U Minh, Tran Van Thoi and Phu Tan districts.

The western sea dike route in Ca Mau province starts from Tieu Dua to Kenh Nam canal with a length of 93 km, of which the section from Tieu Dua to Cai Dai Vam is about 76 km long the dike route is about 150÷2,000 meters from the sea, which has been built since Typhoon Linda in 1997, up to now, it is being upgraded with the scale of: the top of the dike +3m, the dike surface is 7.5 m wide (particularly the 5.5 m wide structural road to meet the requirements of grade V plain roads) to ensure the task of preventing salinity, preventing natural disasters to protect about 26,160 households and about 80,000 hectares of arable land in districts: Phu Tan, Tran Van Thoi and U Minh [5].

In addition, the negative impact of the current climate change on Ca Mau province is one of the reasons why the production of people in both coastal and inland areas faces many difficulties and occurs almost in the seasons of the year. Inland areas are often affected by natural disasters in the dry season. Due to being divided by a system of rivers and canals with a total length of over 10,000 km, there are 87 estuaries to the sea. In the dry season, prolonged drought, no additional fresh water sources. Lower water level in the field causes saltwater intrusion inland and salinization of groundwater, adversely affecting agricultural production and freshwater resources, increasing the risk of forest fires. For coastal areas, both the dry season and the rainy season are affected. In the rainy season, the storm surges with increasing intensity causing great damage to production, property and life of the coastal areas. people, and at the same time caused severe destruction of coastal protection forests. In the dry season, due to the lack of additional fresh water sources from the inside of the field, there are many "freshwater" areas deposited sediment, limiting the ability to exchange water sources for production, leading to the phenomenon of subsidence, river bank and coastal erosion.

Groundwater extraction is one of the main causes of subsidence in the Mekong River Delta, the average subsidence rate in the Mekong River Delta is about 1.6 cm/year and with sea level rise, then the resonant effect of two factors, the topography of the Mekong River Delta may be lower than the present from 0.42m to 1.54m by 2050 [4]. If we do not have timely solutions, the challenges of high tides, floods, landslides and saltwater intrusion will be very serious for the Mekong River Delta.

The risks from climate change – sea level rise, the people's livelihood activities in the areas also make coastal erosion and sedimentation on canals increasingly complicated. In the past (from 2000 and earlier), the west coast of the province has always been deposited by silt, but in recent years, especially since 2008, most of the west coast has not been deposited as before, but landslides have frequently occurred inland. Erosion occurs both along the East and West coasts (average erosion in the West Sea is from 20÷25 m/year, in particular places up to 50 m/year; in the East Sea, the average landslide is from 45÷50 m/year, especially in places where landslide are 60 m/year). In recent years, erosion occurs with severity and regularity, there are some fairly strong landslides, landslides close to the foot of the West sea dike route. According to statistics since 2008, 80% of the coastline has been eroded, with an area of about 450 ha/year of vital coastal protection forest lost. Adverse impacts of climate change and sea level rise have the risk of breaking the West Sea dike, greatly affecting the lives and properties of people as well as public works with a length of 57km on the West sea dike route and about 20km east coast. To solve this problem, the province has to spend hundreds of billions of VND annually to reinforce, protect the coast and invest in dredging the canal system [6].

In order to minimize landslides and the risk of subsidence, it is necessary to have appropriate technical infrastructure, combined with good management of mangroves, water resources and flexible livelihoods that will bring economic efficiency and stabilize people's lives, contribute to coastal protection (anti-erosion), increase water efficiency. Limiting subsidence by generating livelihoods from silt (eco-shrimp extensive aquaculture), limiting the use of groundwater will both promote regional advantages and reduce risks in the future.

The western coast of Ca Mau province is an ecologically diverse region, which plays a great role in the economic development of the province. However, the economic potential of the region has not been adequately exploited, unstable development, potential risks due to natural disasters,… are obstacles to socio-economic development in the region. To exploit natural resources to serve sustainable socio-economic development, protect the ecological environment, especially to limit and mitigate natural disasters caused by climate change-sea level rise; to ensure national defense and security for the West Coast region, besides investing in the West sea dyke in combination with solutions for sustainable livelihood development in the current period, it is a very urgent and important issue.

In the West sea area of Ca Mau province, Phu Tan and Tran Van Thoi districts, the terrain is low, only less than 1m above sea level. According to climate change-sea level rise scenario in 2016 [7] of Ministry of Natural Resources and Environment (MONRE), if there is no sea dyke route and constructions to protect and restore protection forest, then the risk of the entire area of this area being completely submerged may occur in the near future.

Table 2: Risk of flooding due to sea level rise by climate change

Location	Area (ha)	Flood rate corresponding to sea level rise (% of area)					
		50cm	60cm	70cm	80cm	90cm	100cm
Ca Mau	528,870	8.47	13.7	21.9	30.3	40.9	57.7
Entire area of Mekong River Delta	3,969,550	4.48	8.58	14.7	21.0	28.2	38.9

(Source: Climate change-sea level rise scenario in 2016 – MONRE)

The results of flood map analysis when integrating both subsidence and sea level rise factors in the current situation (without sea dykes), then the flood level due to sea level rise is very large, with the sea level rise scenario up to 50 cm in 2025, up to 95.84% of the natural area of Ca Mau province will be flooded.

Figure 1: Image of landslide in My Binh estuary, Phu Tan commune, Phu Tan district, 2017

Figure 2: Current image of shoreline erosion at Sao Luoi estuary, Nguyen Viet Khai commune, Phu Tan district, June 2018

Figure 3: Current image of coastal erosion at Go Cong estuary, Nguyen Viet Khai commune, Phu Tan district, June 2018

Regarding investment for constructions to prevent waves and reduce high tides, in recent years Ca Mau province has invested in coastal landslide prevention and control embankments, mainly applying underground embankment solutions to reduce waves to cause land reclamation of protective forests in front of dikes with many supporting funds from the central and local governments. However, with a large dyke length, there are still many sea dike sections that need to have structural solutions to protect against impacts from the sea, including key sections from Doc to Bay Hap estuary such as: Doc, My Binh, Cong Nghiep, Sao Luoi, Go Cong estuary,… which is now under direct threat due to protected forests and increasingly eroded coastlines. In order to overcome the west coast landslides in the weak sections mentioned above, create conditions for the restoration of protective forests, protect sea dikes, production, population, and infrastructure inside the dikes, it is necessary to have solutions to build underground embankments to reduce waves to create beaches. The construction of anti-erosion embankments, restoration and development of protection forests is an effective, fundamental and sustainable solution to the problem of landslide prevention and safety for the West Sea dyke, which has been verified in recent years in Ca Mau province.

Regarding production development conditions, people's livelihoods in the western sea of Ca Mau province are mainly fisheries, forestry, agriculture and aquaculture; people's lives are still difficult, the per capita income is only 35÷40 million VND/year, most of them are poor and near-poor households [8]. Sea dikes play a particularly important role to protect production, property and people's lives. The dyke route along with the protective forest is also a shield for natural disaster prevention, creating a coastal traffic route thereby contributing to socio-economic development, creating residential areas, building new rural areas, creating jobs, increasing incomes for a large part of the rural population, contributing to poverty alleviation and ensuring national defense and security. Applying both structural and non-structural solutions to perform the tasks of natural disaster prevention, anti-erosion, mangrove restoration and development, coastal protection... are very urgent issues at present of the province. The implementation of these tasks contributes to responding to climate change, protecting and improving people's lives, and creating a sustainable development environment for the locality.

3. RESEARCH RESULTS OF SOME BIOLOGICAL MODELS IN THE COASTAL AREA OF PHU TAN DISTRICT AND EFFECTIVE APPLY SOLUTIONS FOR CA MAU PROVINCE

3.1 Research approaches and methods

Research of some livelihood models in the coastal area and effective apply solutions for Ca Mau province are within the framework of the West Sea dyke construction project from Cai Doi Vam to Kenh Nam and embankments to prevent coastal erosion in key sections from the estuary of Ong Doc to Bay Hap, Ca Mau province (CNV Project 1245**)** to improve the incomes for communities, reduce poverty, integrate gender development plan in the context of climate change adaptation and sea level rise with the expected results: (i) Identify suitable livelihood models to climate change and available local livelihood resources on the basis of assessment of livelihood resources, specific conditions, consideration of impacts of Climate change – salinity intrusion on the current status of agricultural production and local people's livelihood; ii) Propose and build sustainable livelihood models that integrate gender development, improve living standards for the community, contribute to socio-economic development, security and defense stability and social safety, prevent and reduce the natural disaster risks in the coastal area of Phu Tan district , Ca Mau province; and (iii) Propose the solutions to improve, support community livelihoods, improve adaptability to climate change – salinization for sustainable development in accordance with local conditions such as improving farming skills for people; creating opportunities for transformation and development of new livelihoods; diversify income sources and improve living standards for the community.

In the approach to climate, sea level rise, salinization risk adaptation, in order to propose a suitable and sustainable livelihood model to adapt to climate change, the team used sociological research methods, transdisciplinary approaches in developing survey tools and organizing field research activities. Through social survey methods such as interviews and fieldwork to clarify the model's characteristics and the factors that promote the model's development, the climate change adaptation conditions. Through consultation activities, promoting the community uses "indigenous knowledge" [9] to improve adaptability. Indigenous knowledge includes: 1) Knowledge of natural and environment (including the universe); 2) Knowledge of human (physiology, nutrition and disease treatment); 3) Knowledge of production, exploitation and rational use of natural resources; 4) Knowledge of social behavior and community management; 5) Knowledge of artistic creation [9].

3.2 Assessment results of livelihood activities of communities that are highly adaptive to climate change

3.2.1 Results of gender analysis

The assessment of gender characteristics in the area of Phu Tan district, Ca Mau province aims to consider and evaluate: Human resources and employment such as: Labor force (labour and income by gender), education and training (vocationally trained women), decision-making roles, ownership and control of assets, income and poverty. Gender status in production, livelihood development and access to resources, women in forestry, agriculture and fisheries livelihood activities.

Table 3: The division of labor by gender of household

Activity	Percentage of households that answered (%)		
	More male	More female	Equally male and female
Forestry (planting and exploiting forests)	29.2		4.2
Fisheries	73.7	5.3	15.8
Aquaculture	36.7	10.2	20.4

Activity	Percentage of households that answered (%)		
	More male	More female	Equally male and female
Raising livestock and poultry	9.1	39.4	18.2
Growing vegetables and fruit trees	12.5	25	18.8
Participate in community meeting in villages and communes	34.6	19.8	43.2
Production investment decision	66.7	11.5	11.5
Contributing to family income	68.7	9.6	21.7

(Source: Results of the field assessment of the research team, March 2020)

According to Table 3, the proportion of women participating in production activities such as forestry, fishing and aquaculture is still very limited, while men are still the main labor force such as fishing (73.7%), aquaculture (36.7%), while women mainly participate in livestock and poultry raising activities at home (39.4%), mainly chickens and ducks to serve the food needs of the family rather than the main income generating activity.

Regarding community activities, the percentage of women participating is quite high, the percentage of both men and women participating in meetings in villages and communes is (43.2%), this is partly explained due to the specific activity of the fisheries sector, men have to be away from home often or spend little time at home, so women take on the role of representing the family in meetings invited by local authorities.

3.2.2. Assessment of livelihood activities

Research and propose non-structural solutions to adapt to climate change that incorporate gender issues. Analysis, evaluation, groups of models are being carried out locally, based on resources of land, coastal forests, farming practices, production levels... including:

- Model of association of production/business, management, planting and protection of coastal forests: forest for management and care by cooperative groups, cooperatives, cooperative groups for shrimp farming and fishing seafood products and processing;
- Ecological model of aquaculture: extensive shrimp farming, brackish water fish farming, crab farming, oyster farming...
- The household-scale livestock model takes advantage of local food sources and the actual needs of the market: raising goats, cows, cattle, poultry...
- The model of fisheries services combining forest protection and rescue at sea;
- Model of women's small business and production cooperative groups, using local female laborers;
- The model of supporting the collection and storage of domestic water in the dry season in combination with shelter in the rainy season for households with difficulty conditions;
- Model of safe latrines.

The results of consultation with organizations, individuals and households show that livelihood activities are still unsustainable and small at household scale (including aquaculture, fisheries, cultivation and farming). The lack of means of production such as land, capital, machinery and technology affects the productivity and production efficiency, especially vulnerable households such as poor households, migrant households, women. The results are summarized in the following table.

Table 4: Main source of family income

Index	Average percentage (%)
Cultivation (rice, vegetables, fruit trees...)	2.4
Forestry (planting and exploiting forests)	8.4
Fisheries (fishing, aquaculture)	63.9
Industry, construction	1.2
Trading, transportation, other services	15.7
Employed in another commune, province	26.5
Local employment	18.1
Other sources of income	2.4

(Source: Results of the field assessment of the research team, March, 2020)

Aquaculture: Phu Tan is a coastal district with a natural area of 44,819.3 hectares, of which the aquaculture area is 39,072 hectares (accounting for 87.2% of the natural area), arranged according to the production structure such as: industrial shrimp, improved extensive shrimp intercropping and wild shrimp (ecological shrimp farming). Sustainable shrimp farming continues to be effective with 19,516 hectares of improved extensive shrimp farming, with 14,580 farming households, accounting for nearly 50% of the total production area. The average yield per crop is 550 kg/ha. This is a type of farming that is being encouraged by the profession to be replicated by people in the area, many farmers focus on doing it because of its low production cost, ensuring sustainability and efficiency, and can be combined with other aquatic species to increase economic efficiency, raise and diversify the income sources.

Cultivation: In Phu Tan district, there are about 2500 ha (2018 is 1,611 ha) of vegetables and fruit trees, of which: vegetables, cabbage of all kinds is 676 ha; gourd, squash, melon, herbs, onions, chives is 341 ha, fruit tree planting area is 1,300 ha (850ha of coconut and other fruit trees: red flesh dragon fruit, mango, guava, jackfruit...) The cultivation industry is not the strength of the district, but the development of cropping models to meet the local food needs, especially for households who do not have or lack land for aquaculture, creating favorable conditions for economic development, increasing income, and expanding employment.

Forest management and agro-forestry production under forest canopy: Phu Tan district has 4,348 ha of concentrated forest area, the percentage of forest cover and scattered trees increased from 13% in 2018 to 15% in 2019 and continues to have new planting in 2020. The problem of protection forest development is affected by climate change and climate conditions, high tides in the last months; water environment is increasingly polluted; Poor quality afforestation varieties, relatively low selling prices for forest products, and limited investment capital for forest development. The pilot implementation of a livelihood model in combination with forest protection, although it has created jobs and incomes for people, especially households without productive land, has also revealed many limitations and inadequacies in the management and use of forest resources.

Cooperative economy: The collective economy has contributed an important part to the overall economic growth of Phu Tan district, reducing production costs and creating more jobs. Currently, there are 17 active cooperatives with 233 members and 124 cooperative groups with 1,355 members operating in the field of improved extensive shrimp farming; industrial shrimp farming; blood cockle production, raising cattle and poultry; knitting nets, sewing, repairing boats…

3.2.3. Research results on some livelihood models in Phu Tan district

The results of the study on livelihood models in Phu Tan district are as follows:

3.2.3.1. Link model of knitting nets – patching nets

The profession of knitting nets - patching nets is one of the models that helps people in the coastal area make a living in recent years, mainly female workers - without jobs in the locality, no capital for business or production capital involved. The average income is from 150,000 VND to 200,000 VND/day/person, the participation period is from 6÷9 months/year. This activity has helped female workers create jobs, contribute to household income, contribute to poverty reduction in the locality, especially keep women in the locality and participate more in activities of the women's union. The cooperative groups shared capital to buy raw materials, orders, and assign production stages to make production activities more efficient.

3.2.3.2. Model of drying all kinds (Dried fish of all kinds, dried shrimp, making fish sauce)

Nguyen Viet Khai commune is a poor commune, people mainly live by fishing and aquaculture, seasonal workers... Especially female workers do not have stable jobs, and have to leave their hometown to work as hired laborers in other areas, from that fact, the Women's Union has established a model of drying all kinds (dried shrimp, dried fish, fish sauce...) to solve on-the-spot jobs for local women as well as self-consumption of locally produce materials, contributing to increasing women's income, helping economic development, hunger eradication and poverty alleviation. The model is attracting from 30 to 40 households to participate in, the average income is from 3,500,000 VND to 8,000,000 VND/person/month. On average, a year works for about 8 months (except for rainy months), so the average total income is 28,000,000 VND to 64,000,000 VND/person/year.

3.2.3.3. Model of hygienic latrines to ensure the safety of ecological aquaculture environment

Pollution of water sources in aquaculture-fishery leading to diseases for humans and animals, which is a locals and residentials interested today. Sanitary problems, water pollution clearly affect women, with a high rate of gynecological diseases, affecting medical costs and family happiness. However, the cost of installing and building one toilet is much higher than the average income of households, especially poor households, near-poor households, and difficulty households in the locality (installation cost is about 12 million VND/toilet). Supporting these models will help improve the quality of community life, protect the environment, maintain the ecosystem to develop ecological aquaculture models.

3.2.3.4. Model to support water tanks to collect rainwater for use in the dry season

Facing the context of climate change, sea level rise, changes in upstream flows lead to saline intrusion, lack of fresh water and domestic water in the dry season. The well water source is often contaminated with brown rust, cloudy water color, salty taste, changed color overnight ... which only used for bathing, water for livestock, and not for daily consumption. For many years, people in the area have experienced in storing rainwater for living and eating. However, due to limited resources, unsecured storage equipment, the risk of infection from water sources is still high. The model of renovating the thatched roof to collect rainwater for food and drink at a cost of about 15 million VND/model (Figure 4) has greatly improved the quality of life for many households in the area, which can be replicated through the following projects: credit support packages such as preferential loans, non-refundable grants for poor households…

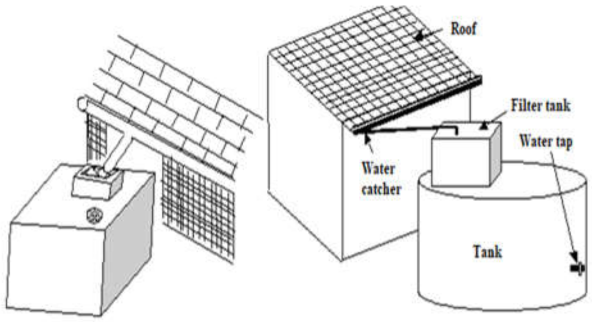

Figure 4: Rainwater collection tank, filter and rainwater collection tank from the roof

The results of consultations at all levels of the Women's Union, production and business models with the main participation of women show that: Local needs in supporting the development of models for the goal of hunger eradication, poverty alleviation and development. Promoting the role of women to adapt to climate change is necessary through awareness raising activities, gender capacity building, introduction and transfer of science and technology, propaganda and guidance for women to establish especially in aquaculture production models that combine planting and protecting mangrove forests, in the context of climate change adaptation and sea level rise.

3.2.4. Assessment of favorable and difficult conditions for community livelihood development

3.2.4.1. Favorable

- Favorable geographical position, suitable climate for diversified economic development;

- Large land resources, abundant saline water;

- The dike system and infrastructure have been gradually invested in accordance with the general planning of the region as well as the inter-regional of Ca Mau peninsula. The system of canals is quite thick, which is a favorable condition to serve agricultural production. In the industry, in recent years, irrigation work has also been interested in dredging investment, so it can have enough water for production and navigation;

- People in the region have had a lot of experience in developing livelihood models related to forest production, ecological shrimp farming (shrimp-forest, shrimp-garden) and shrimp farming adapted to natural conditions (extensive shrimp farming);

- The situation of agricultural production, in which aquatic products (especially shrimp farming) are interested in development by functional sectors and local authorities because this type of model have high economic efficiency. The scale of the farming area has been expanded, and local training has been maintained and enhanced to aim at improving the quality of shrimp farming towards sustainability and high economic value;

- Other production models such as cultivation (vegetables, fruit trees) are encouraged, supported to develop and replicate in order to meet local food needs as well as for the commodity market.

3.2.4.2. Difficulties

- The rate of soil contaminated with alum is high;

- The weather situation is increasingly abnormal and complicated, the water environment is increasingly polluted from untreated industrial shrimp farming activities, affecting the water environment for aquaculture and domestic use;

- Rainwater is abundant but unevenly distributed: in the dry season, there is a shortage of fresh water for production, while in the rainy season, most of the area is flooded;

- The salt water source is abundant, but the use is still difficult, not proactive in supplying salt for shrimp farming or limiting the water level to penetrate into the field;

- The coastal bank is continuously eroded due to loss of protection forest;

- The system of sea dikes, river dikes and irrigation works has not yet ensured the function of controlling tides against inundation, controlling salinity, keeping fresh water, alum drainage… flexibly in both spacial and timely manner;

- The situation of drought occurs frequently due to inadequate and asynchronous irrigation system, lack of water source control works (rainwater discharge through canals to the sea);

- Lack of measures to protect, manage, upgrade and renovate infrastructure to ensure harmonious development between economy, society and environment;

- Production activities are still unsustainable, small at household scale (including farming, fishing, raising livestock, and cultivation activities). The lack of means of production such as land, capital, machinery and technology also affects productivity and production efficiency, especially for vulnerable households such as poor households, resettled households, women…

3.2.5. Proposing prioritize activities for the community in adapting to climate change and natural disasters in Phu Tan district

To comprehensively exploit natural resources for sustainable socio-economic development and ecological environment protection; supporting livelihood development for coastal communities in order to increase income for the community, hunger eridication and reduce poverty, mainstream gender development in the context of climate change adaptation and sea level rise; ensuring national security for the West Coast, besides investing in sea dikes, which is a very urgent and important issue, non-structural solutions will contribute to stabilizing the life of the community, promote the ability to care and protect mangrove forests. The study has suggested specific activities for the short term as follows:

3.2.5.1. Measures to mitigate gender vulnerability in coastal areas of Ca Mau province

Diversifying income sources for women as a solution to reduce risks in terms of income, livelihoods in the context of climate change, and limited access to land and credit resources: Livestock and crop production are livelihood activities that suitable for women to improve their economic ability, especially when households do not have a lot of land for aquaculture, it is difficult to access large capital sources for the development of production models, and complicated situation of climate change affecting seafood production (high risk).

Non-agricultural economic activities: include small trading activities, providing fishery services, doing traditional side jobs (knitting, drying, fish cake, sewing, patching nets...) to create jobs for female workers who not have productive land, take advantage of labor to directly serve local market needs in terms of business, trading, transportation, and pre-processing of ready-made products that locally available.

Participating in models of fisheries exploitation combined with sustainable forest management: this is a definite advantage in communes with coastal protection forests that can combine aquaculture under the forest canopy (snail, crabs...) both aim to create jobs, livelihoods and protect sustainable protection forests.

3.2.5.2. Raise awareness about gender equality, disaster prevention and climate change prevention

By means of mass media, education and training programs aim to change the social perception of gender equality, thereby promoting the role of women in production activities and economic development. Raise awareness of climate change and climate risks, support the establishment of commune-level climate change response teams. Improve adaptive capacity for vulnerable groups, especially women through training activities, appropriate science and technology transfer training, knowledge and skills in household economic management, supporting small-scale credit to support diversification of income sources, ensuring life stability and reducing vulnerability to production shocks, natural disasters, and climate change. Further promote the mainstreaming of gender equality and climate change into local socio-economic development plans at all levels, especially at the commune level. Include gender equality targets in socio-economic development plans, socio-economic development programs and projects such as the target program on building new rural areas... Strengthen the organization of capacity building activities for managers, full-time officials at all levels of government and associations in coastal areas through short-term training courses.

3.2.5.3. Proposing non-structural solutions for livelihood transformation/development associated with gender development to reduce poverty and adapt to climate change

Vocational training and technical transfer training activities: Training and guidance on risk reduction in aquaculture and fishing in coastal areas; Apply integrated management methods for coastal areas; Training to support the development of models/ career orientation, diversifying income sources; Developing models of job creation on the spot that attracting the participation of female workers, poor households, and difficulty households in the locality; Training on food safety, carefully guiding the safe processing of seafood; Product marketing training, market access and connection.

Developing models of job creation on the spot that attracting the participation of female workers, poor households, and difficulty households in the locality: developing models of purchasing and processing seafood; developing models of knitting and patching nets to serve fishermen at the sea; developing sewing models, processing clothes, sewing foot mats. Market connection activities, credit fund building, seminars.

Developing production models in the direction of sustainable and environmentally friendly ecology: developing an improved extensive shrimp farming model (02 phases); develop a mixed aquaculture model suitable to mangrove ecological conditions in order to adapt to climate change; develop a household-scale livestock model using local food sources.

Support the development of livelihood resources and facilities to adapt to climate change: support the model of building hygienic latrines; support the model of rainwater collection for daily life in the dry season to adapt to climate change; supporting the construction of centralized water treatment and supply stations using solar energy.

4. RECOMMENDATIONS FOR SUSTAINABLE ECONOMIC - SOCIAL DEVELOPMENT IN COASTAL AREA OF CA MAU PROVINCE

In the western coastal area of Ca Mau province, livelihood activities are relatively diverse, however, the main source of income is from aquaculture and fishing activities, in which shrimp farming is the production activity accounting for a large proportion of the total income. In the field of shrimp farming, in the area, there are many models and methods of farming at different levels from natural farming, farming in combination with forests, semi-intensive farming, and super-intensive farming. Depending on the conditions of the land, and the ability to invest, the level of development with different types of farming is suitable. Currently, there is a trend of increasing the types of farming with the participation of science and technology such as semi-intensive, super-intensive, and improved extensive. However, only households with productive resources such as land and capital can develop these models. For households that do not have capital to invest in upgrading the model, it is necessary to have outside support to develop and expand.

Other occupations such as farming, raising cattle and poultry, although contributing to raising incomes and diversifying livelihood sources, are not the advantages of communes in the area. Difficulties in capital, high input costs, limited disease management and competitiveness, and access to output markets for products hinder the development and expansion of the cultivation and livestock sectors.

The activities of fishing, seafood processing, fishing logistics services... are also advantages of the region such as natural conditions, taking advantage of vacant labor, taking advantage of aquaculture products. generated by the locality for preliminary processing and packaging into goods for the market. These activities also contribute to helping households without productive land have jobs, improve living standards, reduce hunger and reduce poverty.

Several livelihood models that have been implemented by investment sources from international organizations, the state budget, through mass organizations such as farmers, women... also been promoting their effectiveness. However, the results are still on a small scale, unable to attract a large number of households to participate due to difficulties in capital sources and investment conditions... Some models are experimental and ineffective because they are not suitable for the natural resources conditions of the region such as freshwater fish farming and large-scale safe vegetable cultivation. In addition, some models combined with forest protection have limitations due to the lack of strict regulations and management mechanisms, balancing the interests of the parties involved.

The coastal districts of Ca Mau province are heavily affected by the increasingly complex climate change and affect production and economic development. Therefore, it is necessary to have models of economic development and production that adapt to this climate change condition. In addition, the upgrading and construction of infrastructure such as sea dikes, breakwaters, culverts to prevent salinity, development of protection forests and production forests to ensures the safety of people and properties, and at the same time protects people and property, and support the production activities of coastal localities.

Limitations in access to land resources, family assets, fresh water, clean water, position and roles, lead to affect the status, voice, participation and health conditions of women. Although initially effective livelihood models for women have been implemented, the difficulties in capital, management capacity, skills, science and technology in production and access to the market is a barrier for women to participate in the development of local production models. These are issues that need to be solved and supported so that women can participate more, express their roles, contribute their own as well as contribute to creating jobs, generating income, and improving the lives of women in particular and the community in general.

Proposing a number of prioritize activities in the immediate period for sustainable socio-economic development in the coastal area of Ca Mau province in the context of climate risk adaptation:

- Support for livelihood transformation for coastal communities in order to diversify livelihood activities and increase income for the community; reduce dependence on fishing activities in coastal areas; contribute to the protection and restoration of coastal mangrove ecosystems, protection and restoration of aquatic resources, environmental protection, towards the development of coastal fisheries in a sustainable manner under climate change and sea level rise conditions.

- Support gender equality through supporting women to access livelihood activities, to diversify income sources; support women's groups to strengthen capacity, raise awareness of climate change, appropriate aquaculture production techniques, access to small credit funds... to enhance women's participation in economic development of farmers.

- Technical support: Developing a sustainable integrated coastal zone management strategy (ICZM) in the coastal area of Ca Mau province and implementing the plan to respond to climate change.

- Supporting the local implementation of Project 1002 "Raising community awareness and community-based disaster risk management", through activities of Organize content dissemination to raise public awareness and management community-based disaster risk in natural disaster prevention and control for officials, public employees and individuals (belonging to subject 4 and subjects being typical individuals, reputable people in the community) participating in annual defense and security knowledge training (including members of the Commune Disaster Prevention Committee and community groups located in vulnerable areas of the coastal area).

Develop and implement a number of technical assistance activities of national, regional and long-term:

- Research on sustainable solutions for coastal protection in the context of climate change adaptation and sea level rise;

- Research and propose a model of sustainable management of mangroves with the participation of the community;

- Clarifying the causes of forest loss: assessing the effectiveness and impacts of wave reduction structural solutions; study the lack of silt that kills the forest; the subsidence of the beach makes the waves bigger, making the trees unable to withstand big waves, deepening the forest clearing;

- Assess the impact of sea dikes on the existence and development of mangrove forests and vice versa, the protective effects of forests on dikes and coastal infrastructures;

- Assess mangrove forest management, propose solutions for sustainable livelihood transformation for local communities in order to diversify livelihood activities in combination with forest protection and income enhancement; reduce dependence on fishing activities in coastal areas, towards sustainable offshore fishing.

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RESEARCHING AND PROPOSING THE MODEL OF AFORESTATION COMBINING MEDICINAL PLANTS SUITABLE TO THE NATURAL AND SOCIAL CONDITIONS OF BA BE DISTRICT, BAC KAN PROVINCE

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Summary: *The agro-forestry system is a farming model that brings many social and economic benefits and has been implemented effectively in many forested localities of Vietnam. Bac Kan province (including Ba Be district) has a lot of potential for developing this farming system because of having largest forest area in Vietnam and favorable natural conditions for cultivating of many types of precious medicinal plant. The results of the investigation about models of afforestation/growing medicinal plants in Bac Kan as well as in Ba Be district showed that many forestry lands have not been exploited effectively. The models of growing medicinal herbs were still small, not commensurate with the development potential of local and have not yet brought the maximum benefits of the agro-forestry system. On the basis of the fact investigation, we proposed a model of growing medicinal plant combination with afforestation in Ba Be district, also proposed forest trees (including Tram tree and De van tree) and medicinal plants (Camellia chrysantha). These plants have been suitable to the farming practice of indigenous people, the natural conditions of the local and these plants are also bring a lot of economic and social value for the forest growers.*

1. INTRODUCTION

In recent years, "agroforestry farming system" has played an important role in the economic and social development of many countries around the world as well as Vietnam. This is a method of enriching the forest with agricultural trees, medicinal plants, specialty trees, shade-tolerant or shade-loving fruit trees that can be planted under the forest canopy [1].

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The agroforestry system has been proven to bring many benefits such as: providing regular and annual income from intercropping trees under the forest canopy; protecting natural forests and planted forests with large and precious timber species; rational and efficient use of abundant light energy sources in the tropics; increasing water permeability and water retention, increasing the ability to prevent soil erosion of forests, especially planted forests, minimizing flood's impact in the rainy season and have water for domestic use and agricultural production in the dry season [2].

The model of afforestation combining medicinal plants is a subsystem in agroforestry farming system, bringing dual benefits to forest growers, has been implemented in many localities of Vietnam and is considered as a biological availability of people, especially people in ethnic minority areas. The fact has proven that this model brings both immediate and long-term economic benefits to forest growers, especially in the early stages when the trees have not yet closed their canopy [3], [4], [5] .

The forest cover of Vietnam reaches 42%, higher than the world average (29%) [6]. Vietnam is also a country with great potential for the development of medicinal herbs because it has many precious, rare and high-value medicinal herbs. Meanwhile, Bac Kan is a mountainous province with a large area of forest land with the highest forest coverage rate in the country (73.4%). Bac Kan province also has a lot of potential for the development of medicinal plants, but due to rampant exploitation, the area of naturally growing medicinal plants has gradually shrunk, and some precious medicinal herbs are almost eradicated. Therefore, the conservation and development of medicinal plants is a matter of concern today. Bac Kan province identifies the main strength of the province as forestry, especially the development of timber and medicinal products under the forest canopy of more than 300,000 hectares of forest land. However, the province has not been able to exploit this strength to increase people's income [7].

Ba Be district (Bac Kan province) has more than 80% of forest land, located in the tropical monsoon climate area, the annual average temperature is from 21^{0}C – 23^{0}C, the fertile soil is very suitable for the development of many plant species, especially medicinal plants. For example, Ba Be National Park has a system of primeval forests on limestone mountains, which preserves a rich forest habitat system, in which there are many rare indigenous medicinal species. The climate, soil and large forest area of Ba Be are very favorable for the development of medicinal plants mixed with forest trees or medicinal plants under the forest canopy. However, at present, only a few types of forest gardens with very small scale exist in some communes in the district.

Development of forest and medicinal plant is considered an important socio-economic development orientation of Ba Be district as well as of Bac Kan province. Therefore, how to build models of afforestation combining medicinal plants for bringing overall benefits and improve production value per unit of forest land area is a very necessary and effective direction with high realism. To do this, it is necessary to have data to investigate and evaluate the existing models of afforestation with medicinal herbs or planting medicinal herbs in some localities of Bac Kan province. However, but so far, there is no adequately assessing data about this issue.

In this paper, the data on surveying and evaluating models of afforestation combining medicinal herbs/ models of planting medicinal herbs in Bac Kan province was provided. These surveying and evaluating results were the basis for proposing development of a model of afforestation with medicinal herbs efficiently (both of developing multi-product forest economy and protecting the environment, responding to climate change), in line with the agro-forestry development orientation of Bac Kan province.

2. CONTENT AND METHOD

2.1. Research content

- Investigate and evaluate some models of growing medicinal plant models in Bac Kan province.

- Proposing a model of afforestation combined with medicinal plants suitable to natural and social conditions in Ba Be district, Bac Kan province.

2.2. Research method

- Inheritance method: inheriting scientific documents and related research results

- Methods of survey, field investigation of relevant models

- Method of making questionnaires with contents suitable for local residents and businesses/Cooperatives, satisfying enough information to serve the evaluation and analysis of models.

- Expert method: consult relevant experts on silviculture, herbal medicine, ... at research institutes and pharmaceutical establishments

- Analytical and synthesis methods

3. RESEARCH RESULTS AND DISCUSSION

3.1. Assessting medicinal herbs growing models in Bac Kan province

According to the survey results, in Bac Kan province, although there are policies to promote the development of the model of afforestation combining with medicinal plants, this model has not been widely deployed. The main models are still growing indigenous medicinal plants or imported medicinal plants according to individual household scale, cooperative scale or household association scale, scale within the framework of a project/ topic.

3.1.1. Model of growing medicinal herbs with household scale

The model of growing medicinal herbs at household scale is scatteredly developed in some localities of Bac Kan province. These patterns appeared because many people realized the practical role of certain types of medicinal herbs in the health care of their family members, or because there is a need to buy medicinal herbs from some people and healer. This has created supply and demand. However, this supply and demand is not really sustainable. Besides, many localities of Bac Kan have sources of indigenous medicinal herbs that grow naturally in people's gardens. Knowing the benefits of medicinal herbs that have both health care value and improved family economy, many households have zoned and taked care of those natural medicinal gardens for using and commerce.

Table 1: Some models of growing medicinal herbs according to household scale

Model	Combining with other plants	Item/ distribution	Project	Productivity (dry tons/year)
Celastrus hindsii (Xạ Đen- Vietnamese name)	Fruit trees	Dried branches/ Free	3PAD*	0,5
Gynostemma pentaphyllum (Giảo Cổ Lam - Vietnamese name)	Mixed trees	Dried branches/ free	None	0,5
Illicium verum (Hồi - Vietnamese name)	None	Fresh flower/ Free	PAM5327**	6,7
Camellia chrysantha (Trà Hoa Vàng – Vietnamese name)	Mixed trees	Fresh flower/free	None	unharvested

** Partnership project for the poor in agroforestry development in Bac Kan province (3PAD project) is funded by the International Fund for Agricultural Development (IFAD).*

*** Planting forests with funding from the World Food Program (PAM)*

Through investigating the model of growing some medicinal species according to individual households, these households all realized the role and economic value of medicinal plants higher than traditional plants such as rice. However, the scale of planting was also located in the garden of the households, not in combination with intercropping with forest trees on forestry land. The difficulty for these households was output stage for products, leading to limitations in investment to expand the farming scale. Although some models of growing medicinal herbs of individual households had been originated from a certain project, but after the end of the project, to continue planting and tending, people had to find the output for products by themselves. There had not been a link between one household and another in expanding production and consumption, and hd not been linked with cooperative models and businesses, so input and output productivity was unstable. People are mainly self-collecting, self-sufficient, self-sufficient, small-scale consumption at fairs by selling fresh or preliminary processing by drying. Tthere is no orientation to invest in processing system, develop into licensed products on the market. Therefore, the effectiveness of these medicinal plants had not really been promoted.

3.1.2. Model of growing medicinal herbs with cooperative scale

The cooperative model of growing medicinal herbs is quite popular and is being replicated in localities of Bac Kan province. With the strategy of one commune – one product, Bac Kan province has contributed many OCOP-standard medicinal products such as Giao Co Lam (*Gynostemma pentaphyllum*), Tra Hoa Vang (*Camellia chrysantha*), Ca Gai Leo (*Solanum hainanense*), etc.

Table 2: Some models of growing medicinal herbs with cooperative scale

Cooperative/ location	Area/herbal type	Products	Origin of participating projects	Mode of Operation
Hoang Huynh/ Khang Ninh commune, Ba Be district	1 ha/ *Gynostemma pentaphyllum*	*Gynostemma pentaphyllum* OCOP3*	New rural program	Planting, caring, harvesting, purchasing, processing, developing products into commodities and consuming
Hoa Thinh/ Nghia Ta commune, Cho Don district	3.5ha/ *Camellia chrysantha*	*Camellia chrysantha* OCOP3*	None	Seed supply, technical support, purchasing, processing, product development and consumption
Thien An/ Vi Huong commune, Bach Thong district	10ha/ *Cinnamomum cassia, Illicium verum, Gleditsia australis*	Products for bathing from traditional medicinal herbs of the Dao people/OCOP3*	The joint project of growing and processing medicinal herbs and the project of deep processing of local medicinal products	Cultivation medicinal herbs; Support for seed and fertilizer for associating households, purchasing, processing, developing into commodity products and consumption
Bao Chau/ Lạng San commune, Na Ri district	20ha/ *Morinda offcinalis Fallopia multiflora, Solanum procumbens, Gynostemma pentaphyllum, Ampelopsis cantoniensis, Ardisia silvestris, Lonicera japonica*	Herbal extract, tea bag filter, *Solanum procumbens* extract /OCOP 3*	-The project is coordinated by TRAFFIC and the Provincial Forest Protection Department on strengthening management and fair benefit sharing for natural medicinal product chains in Vietnam. -The standard FairWild 2.0 project for harvesting wild plants	Growing and processing products for the market; medical examination and treatment according to traditional medicine methods

Cooperative/ location	Area/herbal type	Products	Origin of participating projects	Mode of Operation
Van Lang HT/ Van Lang commune, Na Ri district	12ha/ *Morinda offcinalis, Milletia speciora, Solanum procumbens, Celastrus hindsii, Ardisia silvestris*	*Solanum procumbens*	Joint project for the production and consumption of products from medicinal plants (*Solanum procumbens, Celastrus hindsii*)	Seed supply, planting, haversting and supplying raw materials to pharmaceutical product manufacturers, product development
Thang Lợi/Binh Van commune, Cho Moi district	2.2 ha/ *Morinda officinalis* 2.03 ha/ *Fallopia multiflora*	None	The project for researching and development medicinal plants in Bac Kan province	Growing and processing medicinal herbs; Mining of stone, sand, gravel for construction, petroleum
Đong Nam Duoc/Ha Vi commune, Bach Thong district	0.5 ha/ *Hypericum sampsonii*	*Hypericum sampsonii*	None	Planting, harvesting and consuming, using for traditional medicine clinic of cooperative

Table 2 presents some models of cooperatives operating in the field of planting, processing and consuming medicinal herbs in some localities of Bac Kan province. In general, these models are derived from different projects and programs for the development of medicinal herbs. Most of the activities are involved in the chain of planting, tending, harvesting, processing and developing commodity products. Cooperatives have received the attention and support of local government and bringing positive effects for the economy - society. However, most of the models have difficulties of budget for expanding the farming area into material zone and purchasing equipment for processing and preserving products. Thus, the products are still not diversified, mainly still processed in raw form. These models have not been implemented on local large forest land.

3.1.3 Model of growing medicinal herbs according to other projects

Along with the province's policies on the development of forests and medicinal plants, Bac Kan province has implemented scientific projects to develop medicinal herbs. Table 3 presents some information on some projects for developing medicinal herbs in Bac Kan province.

Table 3: Some projects to develop medicinal herbs in Bac Kan province

Project	Funding source	Executed in
Researching, evaluating, plant breeding and cultivation techniques *Zingiber purpureum* Roscoe in Bac Kan	Department of Science and Technology of Bac Kan province	Liem Thuy commune, Na Ri district
Researching on biological characteristics and technology for planting *Anoectochilus setaceus*	Department of Science and Technology of Bac Kan province	Bach Thong district, Cho Don district
Management and fair benefit sharing for natural medicinal product chains in Vietnam	Traffic International Organization in Việt Nam	Cho Don, Ba Be, Ngan Son, Na Ri
Building a model of growing medicinal plants associated with product consumption in some northern provinces of Vietnam	National Agricultural Extension Center	Huong Ne commune, Ngan Son commune Phuong Vien, commune Yen Thinh, Cho Don district
Model of growing medicinal plants and support growing	Project 3PAD	Khang Ninh commune, Ba Be district Duong Son commune, Na Ri district

Project	Funding source	Executed in
Model of growing medicinal plants	UN-REDD program of the Norweigen government	My Phuong commune, Ba Be district Quang Phong commune, Na Ri district
Research on planting and processing *Gynostemma pentaphyllum*	Department of Science and Technology of Bac Kan province	Nam Mau commune, Ba Be district
The model of growing *Solanum procumbens*	Youth Union of Ha Hieu Commune and Youth Union of Bac Kan province	Ha Hieu commune, Ba Be district
Model planting of *Polyscias fruticosa*	The Department of Agriculture cooperates with Center for Application of Science and Technology Advancement of Bac Kan province	Ha Hieu and Cao Tri communes, Ba Be district

All models of growing medicinal herbs according to the programs and projects achieved the targets of the projects. However, the effectiveness of the projects should be assessed not only when the project finished but also the maintenance and development of the post-project models. In fact, many medicinal models without the project's seedfunding could not be maintained. The cause may be subjective and objective: Many households only participated in the projects in moderation, according to their commitments, but do not intend to develop for long-term; Many households wanted to develop but cannot afford to invest in developing the model. The models that could be maintained and developed mostly cooperative models due to related to the interests of the cooperative members. This showed that when the project finnished, still need supportting about capital, techniques for cultivation, harvesting, processing, and output for medicinal products by local authorities, related departments and agencies and the project leader.

3.2. Proposing an appropriate model of afforestation combining medicinal herbs in Ba Be district

Although with the largest forest area in the country, with the terrain, soil and climate are very suitable for the growth and development of many species of indigenous medicinal plants as well as medicinal plants imported from the other localities. However, the model of growing medicinal herbs in combination with forests in Bac Kan province in general and Ba Be district in particular has not been expanded. According to the survey, Ba Be district has quite large area of primary and plantation forest, but it has still large forestry land area that has not been effectively exploited or has a lot of areas with only naturally regenerated trees. This showed that Ba Be district has still many potentials and advantages to develop the forestry economy. Based on the level of forest cover, forestry land that has not been effectively exploited and the advantages of climatic and soil conditions, the model of planting medicinal herbs under the available forestry canopy or planting forests with medicinal herbs is a solution bringing many benefits: both preserving and developing forests, preserving and developing medicinal herbs in accordance with the orientation of Ba Be district as well as of Bac Kan province.

3.2.1 Proposing forestry and medicinal plants in the model of afforestation combining medicinal plants in Ba Be district

Forestry is identified as one of the key orientation, playing an important role in the socio-economic development of Bac Kan province. For that reason, the project on restructuring the agricultural sector in Bac Kan province towards increasing value and sustainable development in the period of 2020-2025, with a vision to 2035, is affirmed: it is necessary to research and select forest trees that have high economic value, focusing on indigenous forest tree and valuable multi-purpose trees on the market, research and innovate planting methods, business cycles according to production of goods [8].

To response to that target, in the past few years, people have invested themselves in planting *Castanea mollissima* (Dẻ Ván – Vietnamese name) and *Canarium tramdenum* or *Canarium album* (Trám - Vietnamese name, including Trám Đen and Trám Trắng) to harvest chestnuts, and sell Tram fruit to the market, bringing high income for people. However, the cultivation *Castanea mollissima* is still mainly spontaneous and tends to increase, using seed sources that are self-seeded, planting and care techniques have not been guided by profesional agencies. Therefore, there may be many risks such as poor seed quality, resulting in after many years of planting the tree has low yield, poor quality.

In fact, when planting Dẻ Ván and Trám, that were made by grafted technique, can be harvested after 2-3 years of planting, the rate of trees for harvesting seeds is high. For the grafted Trám Đen tree can be harvested after 3-4 years of planting. Therefore, the expansion of the area of these trees will come with alot of profit for economy and society. Based on the, policies and orientations of local government for the development of multi-purpose forest economy, based on the benefits and the actual situation of the planting of Dẻ Ván and Trám Đen in Bac Kan, the model of mixed forest plantation, multi-purpose forest was proposed on inefficient forestry land in Ba Be district, includes grafted Trám Đen and Dẻ Ván. Both species are multi-valued trees: timber, seeds or resin harvesting. The height and dispersion of these two types of trees are different. Trám Đen is higher and larger canopy than Dẻ Ván, so it can be planted simultaneously in the same forestry land. These two types of trees are also in line with the province's policy on restructuring crops, promoting forestry economic development by planting forest trees with high economic value, focusing on indigenous forest trees, multi-purpose trees with value on the market [9]. For medicinal plants, *Camellia chrysantha* (Trà Hoa Vàng in Vietnamese), that is used to make special tea, are proposed in this model. Trà Hoa Vàng is a small tree, shade-tolerant, likes scattered light, not suitable for direct light, very suitable for cool climates, grows under forest canopy. Therefore, they can be planted as a lower plant layer for protective forest belts to nourish water sources and prevent erosion. They have many leaves, have the effect of retaining water and improving soil [10], [11]. Trà Hoa Vàng are grown naturally in some localities in Bac Kan province such as Cho Don, Ba Be,... Comparing with other crops, Trà Hoa Vàng bring high incomes to people, contribute positively to economic growth. Therefore, Trà Hoa Vàng is increasingly focused on developing in many districts and communes in the province. This is also a key medicinal plant in development projects linked to the value chain, associated with the consumption of medicinal herbs [2].

3.2.2 Proposing a model of afforestation combining with medicinal herbs

According to the survey results, some villages around Ba Be Lake have still many areas of unexploited forest land, where only regenerated mixed wood species exist. Therefore, in these areas, if the mentioned model is applied, (mixed afforestation between Dẻ Ván, Trám Đen and Trà Hoa Vàng), it will be very suitable, increasing the production value per unit area of forest land, taking advantage of the forestry land that is being abandoned or inefficiently exploited. The diagram of mixed afforestation including Trám Đen - Dẻ Ván - Trà Hoa Vàng is proposed as follows:

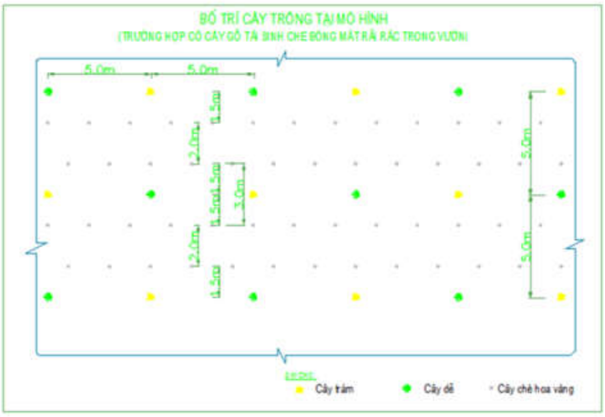

Figure 1: Diagram of mixed forest planting with medicinal plants (In case there is shading by regenerated trees)

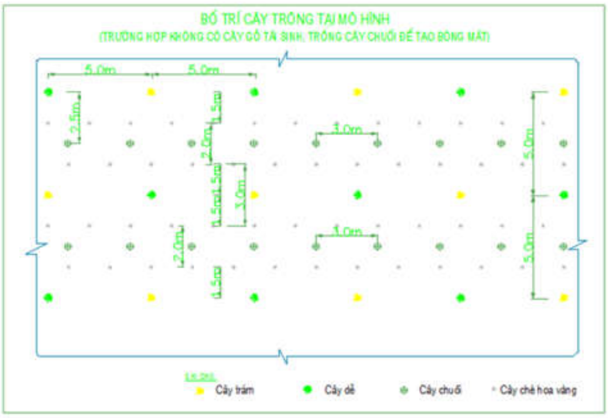

Figure 2: Diagram of mixed forest planting with medicinal plants (In case there is no shading of regenerated trees)

Figure 1 showed the forest land areas with regenerated timber trees that can create shade for growing of Trà Hoa Vàng, especially in the early stages when the timber trees are not yet mature. However, there are also some areas where there are no regenerative trees, so if the above plantations are applied, it will be difficult to create shade for Trà Hoa Vàng in the early stages, so in these areas, the banana trees can be intercropped. Because banana has fast growth rate, the large and spreading foliage will create shade and keep moisture for Trà Hoa Vàng growing with a high survival rate. Besides, the bananas also bring good income for growers (Figure 2).

4. CONCLUSION

Bac Kan province currently exists most of the models of growing medicinal herbs according to household scale, cooperative scale. Through the investigation and survey of medicinal plant cultivation models as well as the actual situation of forestry land exploitation in Bac Kan province, including Ba Be district, it showed the potential for the development of medicinal plants on local forestry land still very large. In order to promote the effectiveness of the agro-forestry system in Ba Be district, the model of growing medicinal herbs in combination with afforestation with plant species including Trám Đen – Dẻ Ván and Trà Hoa Vàng has been proposed on the basis of the actual situation: the forestry land has not been effectively exploited and suitable to local natural conditions.

ACKNOWLEDGEMENT

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SAFE WATER SUPPLY FOR PEPPER COMMUNITY IN DAK NONG PROVINCE IN THE CONTEXT OF CLIMATE CHANGE

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Summary: *Dak Nong is one of the provinces with a large pepper growing area of the Central Highlands of Viet Nam where pepper is considered as the major crop. Similar to other provinces in the Central Highlands, the sources of rural water supply are mainly from groundwater taking from drilled and dug wells, and partly from surface water taking from ponds, lakes, rivers and streams. However, rural water supply is potential unsustainable factors due to water resources degraded and scarcity, and water pollution appearing in some places and inefficient operation of piped water supply systems. The increased exploitation of water sources for agriculture production and domestic use and climate change impacts have significantly affected to rural water supply in the Central Highlands. Drought and water shortage occur more frequently and increasing recently affected local people, most affected the poor, women and children. This paper introduces research results on safe water supply for pepper producing communities in the context of climate change in Dak Nong province including gender role in water supply in order to make recommendations to relevant agencies to ensure safe water supply in Dak Nong in particular and the Central Highlands in general, contributing to the achievement of the sustainable development goals (SDG) in Vietnam.*

Keywords: *Rural water supply, safe water supply, climate change, gender, pepper.*

1. INTRODUCTION

Clean water and sanitation are basic human necessities that represent each family's and country's quality of life. The Sustainable Development Goal (SDG6.1*)* targeted, *"By 2030, achieve universal and equitable access to safe and affordable drinking water for all.”.* On November 24, 2021, the Prime Minister approved the National Strategy in Rural Water Supply and Sanitation by 2030 and vision to 2045, in order to fulfill Vietnam's commitment to achieving sustainable development goals. The objective of the Strategy by 2045 *"Strive for 100% of people in rural areas to have access to safe and sustainable clean water and sanitation".*

Dak Nong is located in the southern Central Highlands of Vietnam, and it shares a 130-kilometer border with Đăk Lăk, Lâm Đồng, Bình Phước provinces, and Mondulkiri Province of Cambodia. The natural area of Dak Nong is 651,927 hectares and a population of 625,822 inhabitants in 2019. The area is home to 40 ethnic groups, accounting for 33 % of the province's overall population. Dak Nong is one of the largest pepper-growing provinces in the Central Highlands, and pepper is also one of the province's major crops.

Rural Water Supply in Dak Nong: By the end of 2018, 83% of rural residents have access to safe drinking water, which is lower than the Central Highlands average of 87.6%. However, in terms of clean water[1] access, with 48% of rural residents have access to clean

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[1] Clean water is understanded as water quality that meets National Technical Regulation, QCVN: 02/2009/BYT

water is higher than the Central Highlands average of 35%, but lower than the country's average of 51.9%. Furthermore, Dak Nong has also the highest percentage of households using clean water in the Central Highlands. As other provinces in the Central Highlands, the sources of rural water supply are mainly from groundwater taking from drilled and dug wells, and partly from surface water taking from ponds, lakes, rivers, streams. However, rural water supply is potential unsustainable factors due to water resources degraded and scarcity, and water pollution appearing in some places and inefficient operation of piped water supply systems. The increased exploitation of water sources for agriculture production and domestic use and climate change impacts have significantly affected to rural water supply in the Central Highlands. Drought and water shortage occur more frequently and increasing recently affected local people, most affected the poor, women and children.

Because of the topographic characteristics and population distribution in Dak Nong, the pepper farming community frequently uses water directly from the groundwater without treatment. Consequently, on-the-spot safe water supply cannot be guaranteed. Besides, the habit of local pepole in pepper cultivation is mostly based on experience. It uses a lot of water, and is spontaneous development at present. Therefore, the risk of water scarcity and unsafety is growing and more exacerbation in the context of climate change.

The paper introduces the results of the research on "Safe water supply and resilience for pepper community in Dak Nong province in the context of climate change" which was carried out in Thuan Hanh and Nam N'Jang Communes, Dak Song District, Dak Nong Province, sponsored by McCormic and conducted in collaboration between CARE International in Vietnam and the Institute for Water and Environment (IWE). The research is expected to provides practical recommendations for (i) improving practices and/or filter technology and equipment to ensure safe water for local people, particularly for women and children (ii) recommendation for improving local water governance towards water resilience taking into accounts climate change factor.

2. RESEARCH AREA AND METHODOLOGY

2.1. Research area

The research is conducted in Thuan Hanh and Nam N'Jang Communes, Dak Song District, Dak Nong Province.

Thuan Hanh is a border commune of Dak Song district with a natural area of 73.43 sqkm. There are 11 villages and four of which have Cambodian borderlines. The population is 2,732 households with 9,699 inhabitants, and a poverty rate of 3.52%. The commune's principal crops are coffee and pepper. According to the CPC's reports of the three years from 2017 to 2019, coffee producing area has been increasing while pepper growing area has been decreasing. In 2019, the pepper and coffee area were 2,278ha, accounting for 30% and 1,899ha, accounting for 25% of the agricultural production area, respectively.

Domestic water supply: There is an operating piped water supply system using groundwater supplying for 168 households. And the rest use water from drilled and dug wells, with a total of 108 drilled and 1,647 dug wells. The proportion of households used hygienic water is 74%, and 20% of which used clean water.

Nam N'Jang Commune is located in the south of Dak Song District with a natural area of 165.46 sqkm. There are 9 villages with 2,756 households and 10,934 inhabitants. A poverty rate is 3.54%. According to the CPC's report, as Thuan Hanh commune, the coffee producing area has been increasing while the pepper area has been decreasing throughout the three years from 2017 to 2019. In 2019, the pepper and coffee area were 2,840 ha, accounting for 34.3% and 2,721 ha, accounting for 32.8 % of the agricultural production area, respectively.

Domestic water supply: It's has not been any constructed piped water supply system in Nam N'Jang commune. Drilled and dug wells are used for domestic water supply with 183 drilled wells and 1,658 dug wells. The proportion of households used hygienic water is 72.8%. Of which 35% of poor households used hygienic water.

Table 1: General information on the communes of Thuan Hanh and Nam N'Jang

Commune	Number of households	Number of people	Poverty rate (%)	Natural area (ha)	Agricultural production area (ha)	Pepper growing area (ha)	Coffee growing area (ha)
Thuan Hanh Commune	2,732	9,669	3.52	7,343	6,555	2,278	1,899
Nam N'Jang Commune	3,132	11,797	3.54	16,546	8,285	2,840	2,721

2.2. Methodology

The following methods were applied during the research:

a) Inheritance method

Relevant research/studies were gathered and synthesized to evaluate and find out in the area regarding water resources, water usage, and climate change.

b) Modeling method

The models such as MIKE and HYPE were used to analyze water availability in correspondence with climate change scenarios in the region launched by the Ministry of Natural Resources and Environment.

c) Field study method

The research team conducted a study in Dak Nong province. The meetings were conducted with local departments and agencies of Dak Nong Province and Dak Song District, and Thuan Hanh and Nam N'Jang Communes. The interviews with local residents in Thuan Hanh and Nam N'Jang Communes were also carried out. In total, 313 households were interviewed and 47 households were placed in group discussions in the two communes. In which, the number of households interviewed are 161 and 152 in Thuan Hanh and Nam N'Jang, respectively. The number of participated households in group discussions are 21 in Thuan Hanh and 26 in Nam N'Jang.

d) Data management and quality control

- A rigorous, methodical and logical data entry process was developed.
- Use of the cross-checking and comparing data approach.
- Develop a plan for staffs in checking data.
- Use STATA software in analyzing and processing information and data through data tables, charts, graphs, and formulas.

e) Data analysis and processing

- Excel or SPSS are used to collect data and information. Based on the criteria and assumptions defined from the project design, key parameters must be identified to measure existing circumstances of the study area such as the rate of clean water consumption, human behaviors on clean water, and so on.
- Among the given numerals, the appropriate data sources for the primary investigation report should be selected.

o Secondary data: collected from relevant reports and field surveys through data tables and questionnaire.

o Primary data: local economy and income, demography, health care, water sources, livelihoods, and education, etc.

o Cross-checked: Mix methods and sources.

f) Group discussion

Group discussions were held throughout the research process from planning to field work, data analysis, etc. The discussions between research team's members were conducted frequently during the research.

A specific task is assigned for every team's member corresponding with the positions they are in charge of. The assigned contents must be prepared before the group discussions led by the team leader.

Discussion tools are used for group discussion including papers, markers, projectors, screens, and other materials.

3. RESULTS AND DISCUSSION

3.1. Water resources and climate change in Dak Song

3.1.1. Water resources in Dak Song

Dak Song district is located in the north of Dak Nong Province and is known for having good water resource conditions in the province [26]. The water available in the Dak Song is evaluated using modeling method. The MIKE-NAM rainfall-runoff model was applied to assess present surface water resources as well as climate change impacts on surface water resources. Furthermore, the CROPWAT model is utilized to determine current water usages for agriculture cultivation. The hydrometeorology data set used in the report is monitoring data at Dak Nong station between 1978 and 2014.

According to the calculation results, total annual rainfall and rainfall in the rainy and dry seasons have all decreased over the years 1995 to 2014. It's also been noted that surface runoff is on the decline. The average annual flow is 386.26 MCM[2], and the flood and dry season flow are 304 and 82.36 MCM, respectively.

Table 2: Characteristics of average flow from 1995 to 2014

Station	F (km^2)	Q_o (m^3/s)	M_o ($l/s.km^2$)	Total flow in flood season (MCM)	Total flow in dry season (MCM)	Total annual flow (MCM)
Đak Nông	280	12.18	43.50	303.99	82.26	386.26

Figure 1 shows the imbalance of flow distribution in months of the year when most of the flow discharge allocates in July, August, September, October, and November with the total volume of flood season flow accounting for 79% of the annual flow total volume. The total volume of flow in the dry season accounts for only 21% of the annual flow total volume.

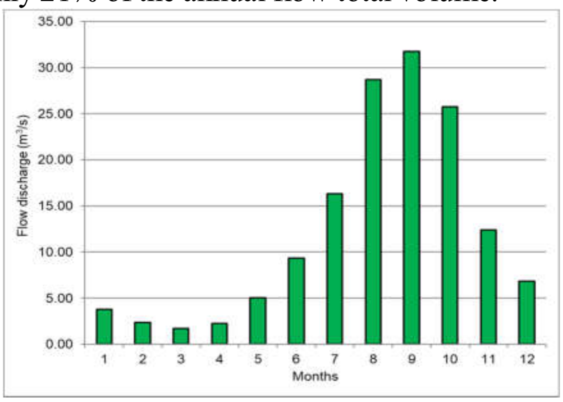


Figure 1: Monthly average flow distribution over years from 1994 to 2014

[2] MCM – Million Cubic Meters

3.1.2. Climate change impacts on water resources

3.1.2.1. Water demand estimation

The study calculated the current water demand for the major sectors such as cultivation, domestic uses, livestock, industry, and fisheries in Dak Song district. Table 3 displays the results.

Tables 2 and 3 show that the overall water demand is 152 MCM per year, whereas the surface water available is 386.26 MCM per year. Thus, if considering the period of 1 year, the amount of surface water available in the Dak Song can completely meet the water demand of all sectors. However, during the dry season, the water demand for cultivation is 126.5 MCM, while the water available is 82.26 MCM. Thus, the water shortage is 44.24 MCM, or approximately 35%.

Table 3: Current water demand in Dak Song District *Unit: MCM*

Cultivation			Livestock	Domestic water	Industry	Fisheries	Livestock	Total
Flood season	Dry season	Year						
13.5	126.5	140.0	0.2	1.7	3.8	6.3	0.2	152

3.1.2.2. Climate change impacts on water resources

The climate change scenarios RCP 4.5[1] and RCP 8.5[2] are applied to calculate the climate change impacts on water resources in Dak Song District.

a. Rainwater resources

According to the calculation results, in the future periods in the both scenarios RCP 4.5 and RCP 8.5, rainwater resources tend to increase in annual rainfall and rainy season rainfall while decreasing in dry season rainfall. Annual rainfall and rainy season rainfall increase to a maximum in the period 2080 - 2099 are 1.2% and 2.4% respectively under the RCP 4.5 and 1.6 % and 3.6 % under the RCP 8.5. In addition, rainfall in the dry season decreases to a minimum during the period 2080 - 2099 are 13.2% and 22.4% under the RCP 4.5 and RCP 8.5 respectively.

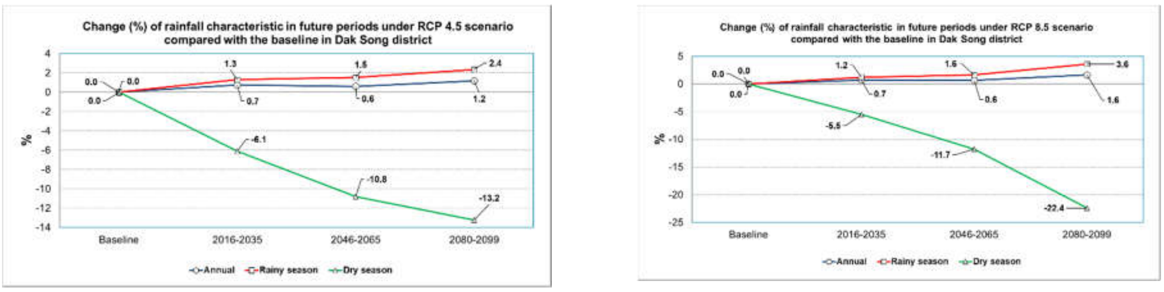


Figure 2: Variation (%) of annual rainfall, rainy season rainfall and dry season rainfall of future periods compared with the baseline in Dak Song district under the RCP 4.5 and RCP 8.5 scenarios

b. Surface water resources

According to the RCP 4.5 and RCP 8.5 scenarios, in the future periods, surface water resources have a tendency to increase in annual flow and flood season flow while decreasing in dry season flow. In the period 2016 - 2035, annual flow increased to the peak flow at 0.5 % and 0.6 %, respectively. The flood season flow increase to the peak at 1.5 and 2.0 % in the period 2080-2099. The dry season flow drops dramatically in the period 2046 - 2065, reaching 4.7% and 7.4%, respectively.

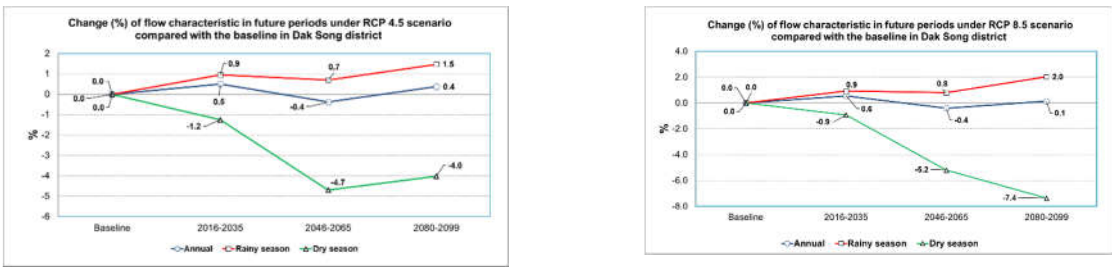


Figure 3: Variation (%) of annual flow, flood and dry season flow of future periods compared with the baseline period in Dak Song district under RCP 4.5 and RCP 8.5 scenarios

[1] RCP 4.5 - the medium emissions scenario
[2] RCP 8.5 - the high emission scenario

c. Climate change impact on water demand for cultivation

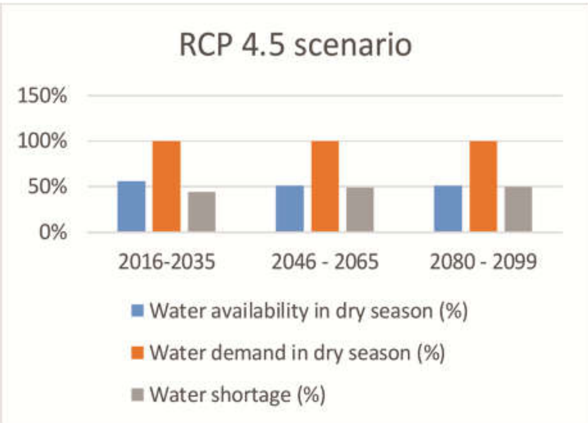
Among the water-using sectors, cultivation is the most affected by climate change. CROPWAT model is applied to calculate and analyze the water demand for cultivation. The inputs for the model are meteorological data corresponding to the RCP 4.5 and RCP 8.5 scenarios. The results show that, the future potential evaporation cause an increase in the water demand for cultivation in both RCP 4.5 and RCP 8.5 scenarios. According to the above computation, surface water resources in the dry season are expected to decrease in the future, while water demand for crops tends to increase leading to water shortage in the dry season.

Table 4: Impacts of climate change on surface water resources, water demand and water shortage corresponding to the RCP 4.5 and RCp 8.5

	The amount of dry season water available (MCM)			Water demand in dry season (MCM)			Water shortage in the dry season (MCM)		
Period	2016 – 2035	2046 - 2065	2080 - 2099	2016 – 2035	2046 - 2065	2080 - 2099	2016 – 2035	2046 - 2065	2080 - 2099
RCP 4.5	75.53	72.91	73.43	135.08	141.30	145.35	59.55	68.38	71.92
RCP 8.5	75.77	72.53	70.90	134.04	142.55	158.30	58.26	70.02	87.39

The climate change impacts are becoming increasingly in the area. It show in precipitation tend to increase in the rainy season and decrease in the dry season causing unusual floods and droughts.

The results of the modeling under the scenarios RCP 4.5 and RCP 8.5 demonstrate that water shortage due to climate change impacts in the dry season ranges from 43% to 55%, respectively (Figure 4). Hence, water resource planning and allocation should be devloped appropriately, and the priority should be considerred for cultivation. It is one of the most water consumption sector.



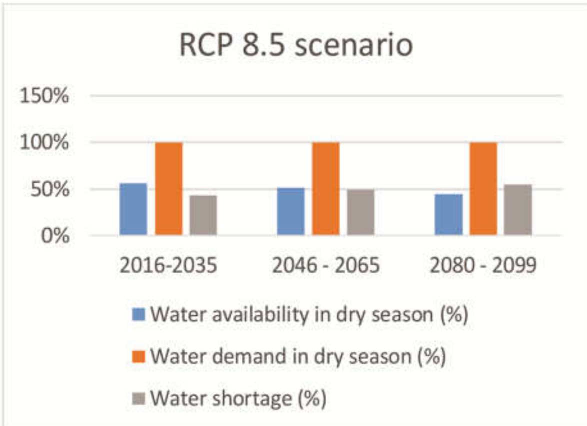


Figure 4: Water shortage due to climate change impacts under the scenarios

3.2. Current situations in rural water supply in Dak Nong Province

3.2.1. Groundwater is major sources used for rural domestic water supply, accounting for more than 98 % in the most localities in Dak Nong Province in general and the research region in particular, as well as irrigation. It is putting pressure on groundwater sources, which have been warned in decreasing in recent years.

By the end of 2018, 83% and 83.45% of rural residents in Dak Nong Province and Dak Song

District, respectively, used hygiene water. And the proportion of people used clean water meeting the National Technical Regulation QCVN 02: 2009/BYT is 48%, which is higher than the Central Highlands average of 35% but lower than the country's average of 51.9%. In which, the percentage of poor households used clean water is 67% and 54.7% in Dak Nong province and Dak Song district, respectively.

Ground water from drilled and dug wells is primarily source for domestic water supply, accounting for more than 90%. The rest uses water from the piped water supply systems, which mostly also use groundwater as the supply sources and a very few uses rainwater and surface water. Furthermore, this rate is also compatible with the surveyed data in Thuan Hanh and Nam N'Jang communes. 100% of the surveyed households used groundwater, with 90% use drilled and dug wells. Several households in Thuan Hanh Commune use the piped water supply system, and only a small proportion of them use rainwater and surface water drawn from ponds, lakes, rivers, and streams (Figure 5).

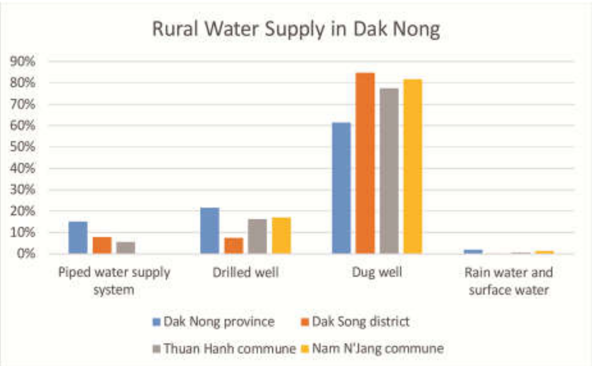


Figure 5: Water supply sources in Dak Nong Province, Dak Song District, and the two communes

3.2.2. Water quantity is decreasing, and the risks of water shortage during the dry season is becoming more apparent

The depletion of groundwater and surface water in the region have been noticed by the Ministry of Natural Resources and Environment. This warning has been also confirmed by the above modeling calculations as well as actual surveys, with 100% of interviewees agreed that water quantity has been declining recently.

The deficient groundwater source is the cause of lowered water level or exhausted dug wells during dry season. Water shortage has occurred in households during the dry season, from January to May. This is more prevalent in Nam N'Jang Commune, where 44.7% of affected households and only 13% of affected households in Thuan Hanh commune (Figure 6). The measures have been made by some households to supplement the shortage water, such as deeper dug wells and made horizontal drills, built water-storage tanks to store rainwater or surface water from lakes, rivers, and streams or asked the neighbors for water supply.

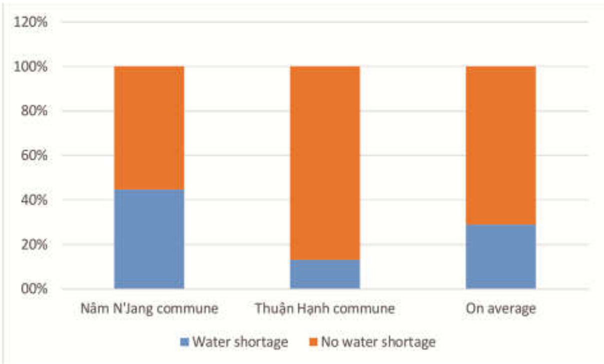


Figure 6: Water shortage situation in dry season in Thuan Hanh and Nam N'Jang Communes

3.2.3. The types of water supply systems are piped and household water supply systems, included drilled and dug wells

Piped water supply system: There are 246 piped water supply systems in Dak Nong Province. Only three of which use surface water and the rest use groundwater. In which, 24 piped water supply systems using groundwater sources were built in Dak Song District. The rate of systems with treatment technology is low, accounting for 9.7% in Dak Nong Province and 12.5% in Dak Song District.

Table 4: Current situations of centralized rural water supply systems in Dak Nong Province and Dak Song District

Management department	Number of systems	Water sources		Treatment technology available	Number of households use	Meet the water quality	Active status			
		Ground water	Surface water				Sustainable	Medium	Less effective	Inactive
Dak Nong Province	246	243	3	24	27.008	66	31	35	10	170
Dak Song District	24	24		3	2076	7	2	4		18

Source: Department of Agriculture and Rural Development of Dak Nong Province

The high rate of piped water supply systems is no longer operation, more than 69 % in Dak Nong Province, and 75% in Dak Song District. In two research communes, only two piped water supply systems were constructed taking groundwater in Thuan Hanh commune. Due to lack of investigation on water sources situation during construction process, the water shortage appeared in one drilling well leading one inoperative system. Another is operating to supply water for 168 households.

Small water supply system: Drilled and dug wells extract water from both the shallow and deep aquifers. According to the survey results of 313 households in Thuan Hanh and Nam N'Jang, they mostly use groundwater from dug wells, accounting for 80% and drilled wells, accounting for 17%. Some use water from piped water supply system in Thuan Hanh. The rest use rainwater and surface water taking from ponds, lakes, rivers, and streams, but this is a very small. Drilled and dug wells have been constructed at household-scale and uncontrolled. This is potential pollution and depletion of groundwater.

3.2.4. Water quality is deteriorating, and potentially being polluted by the domestic and agriculture production activities

To assess water quality, water samples were taken in Thuan Hanh and Nam N'Jang and analyzed. Ten water samples were taken from dug wells, drilled wells, water purifiers, and rainwater. The analysis results show that, physical parameters, such as color, taste and turbidity, are under National Technical Regulation, and water has a sensation of turbidity and color. Chemical parameters such as pH, residual chlorine, and fluoride are under the National Technical Regulation QCVN 02:2009/BYT, Column II. PH value of between 6.9 and 7.1 indicates that no signal of acid and basic contaminated water.

Ammonium parameter: Ammonium value of 10 samples is within the allowed thresholds of the National Technical Regulation of QCVN 02:2009/BYT, Column II. However, high ammonium concentration found in 2 over 10 samples named GĐ-T11, Village 11 Nam N'Jang (1.29 mg/l) and NN-TT, Thuan Thanh village, Thuan Hanh (1.34 mg/l). The reason is that these wells are located next to the animal breeding and cultivation areas. Therefore, there are potential risks of ammonium pollution, especially during rains as rainwater carries pollutants seeping into the groundwater.

Metal parameter: As value is within the allowed thresholds of the National Standard of QCVN 02:2009/BYT; The excess of iron (Fe) concentration 1.04 time in 1 over 10 samples compared to national standards showed the aluminum water contamination. Additionally, observation at some households was also found the phenomenon of scum and yellowing stick storage water facilities.

Metal parameter such as arsenic are within the allowed National Technical Regulation limits. Iron concentration was within the allowed National Technical Regulation limit in 9 out of 10 the samples. Particularly, the water sample named GĐ-T4 from village 4 in Nam N'Jang Commune has symptoms of iron contamination of 1.04 times greater than the regulation. Furthermore, field observation conducted at this location found scum and yellowing of the living equipment. This indicates the possible water contaminated with alum.

Microbiological parameter: The excess of coliform concentration was found in 8 over 10 samples of from 2.2 times to 66.67 times compared to National Technical Regulation of QCVN 02:2009/BYT column II show the microbiological water contamination. The highest coliform concentration was found in the two samples name GĐ-A.Ngu and NN-TT (10,000 MPN/100ml). The reasons explained for high coliform concentration are: (i) it might be affected by livestock waste; (ii) it may be polluted from surface runoff pollutants into shallow groundwater (dug wells); (iii) improper operation and maintenance of water storage and delivery facilities. On the other hand, the water purifier system has not been maintained or replaced for a long time, resulting in reduced filtration efficiency and microbiological contamination in the filtered water (78 MPN/100ml).

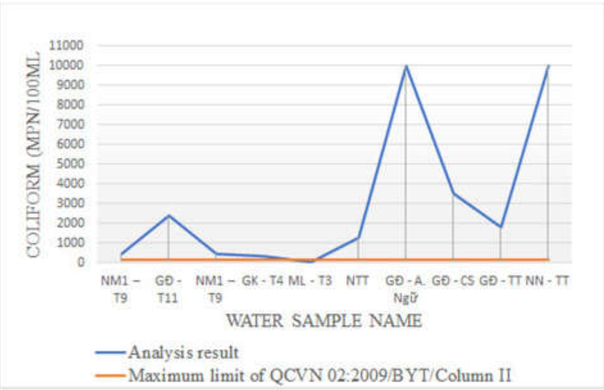


Figure 7: Coliform analysis results compared to Vietnamese National Technical Regulation QCVN 02:2009/BYT – column II

3.2.5. Use two much water for domestic supply

Use two much water for domestic supply will aggravate the water scarcity in the region. As observation during field survey, local residents consume more water than in other rural areas because of their habits and characteristics of farming on red basaltic soils. The average daily water used is 250 liters per person, which is 2.5 times the rural water supply standard in Dak Song in 2020 (100 liters per person per day) and 4.2 times the Vietnam rural water supply standard TCXDVN 33:2006.

3.2.6. Local water governance

There is a lack of coordination between local sectors in water resources management. The usage and exploitation of water, particularly groundwater, has not been adequately managed. The Department of Natural Resources and Environment (DONRE) is responsible agency for water resources management. However, due to limited qualified staffs together with inadequate water resource management regulations and local authorities at the district and commune levels have not paid attention enough to water resources management, these led to the poor water resource management.

- Unlicensed exploitation of water is very common. River and stream plans for water protection and exploitation have not been developed, resulting the overlap hydraulic works constructed and ongoing conflicts that cause mutual harm.

- It is a common occurrence of unmanaged and in violation of water protection regulations in groundwater exploitation for domestic use and agriculture production causing the rapidly declined groundwater sources.

- Piped water supply system management: After the construction completed, the new piped water supply system is transferred to the Commune People's Committee (CPC). The CPC assign to the village's self-governing boards or operation groups elected by the local people for management. However, no technical training on maintenance and management is provided. On the other hand, monitoring and inspection have not yet conducted regularly by the local authorities. There is also no technical staff on rural water supply working in profession agencies at district and commune levels.

3.2.7. Household water treatment

Most households use untreated water pumped directly from drilled and dug wells. Around 35% of households use R.O water purifiers for drinking, other daily activities such as cleaning and washing use unfiltered water. Water purifiers used are very diverse and from many manufactures. The price is also quite variety, ranging from 3 million to 15 million VND each. Local people often purchases water purifiers based on their feelings and advertising of product sellers. It has not been verified the purifier's quality and efficiency by any local responsible agency.

The period to change the filters varies as well. Instead of following the manufacturer's instructions, most households merely change them when they become dirty. The filter replacement intervals are ranging from 2 months, 3 months, 6 months to 12 months.

Water quality test: Generally, water quality monitoring has been carried out annually by the Department of Natural Resources and Environment. However, monitoring locations (1–2 spots per commune) and frequency (2–4 times per year) are limited, and such do not fully reflect the water quality situation in the areas. At household level, no water quality tests have been conducted and the farmers are unaware where to do so. However, some of them understood that water for their uses had been tested as well. Nevertheless, those tests are simply a quick check of some fundamental parameters offered by water purifier marketers for selling water purifiers.

3.2.8. Local people awareness in clean water use

Local people awareness in clean water use has been seen during the field survey. Results showed that they are aware of the need of using clean water for domestic supply and current water quality in the area. Hence, some used water purifiers for drinking.

- 100% of interviewees were aware of hygiene and clean water. When it comes to the concept of clean water, many of them have never heard of QCVN 02:2009/BYT - National Technical Regulation on household water quality. And their understanding of clean water is simply clear water without pathogens or dangerous substances.
- 11.8% of interviewees have heard the information on water sources protection and management in upstream reservoirs or rivers through the loudspeaker system and commune officials.
- 100% of interviewees aware that unhygienic water use causes diseases affecting human health and living equipment.
- Most of the ideas state that they will warning or remind if waste or appliances are thrown into water resources by someone.

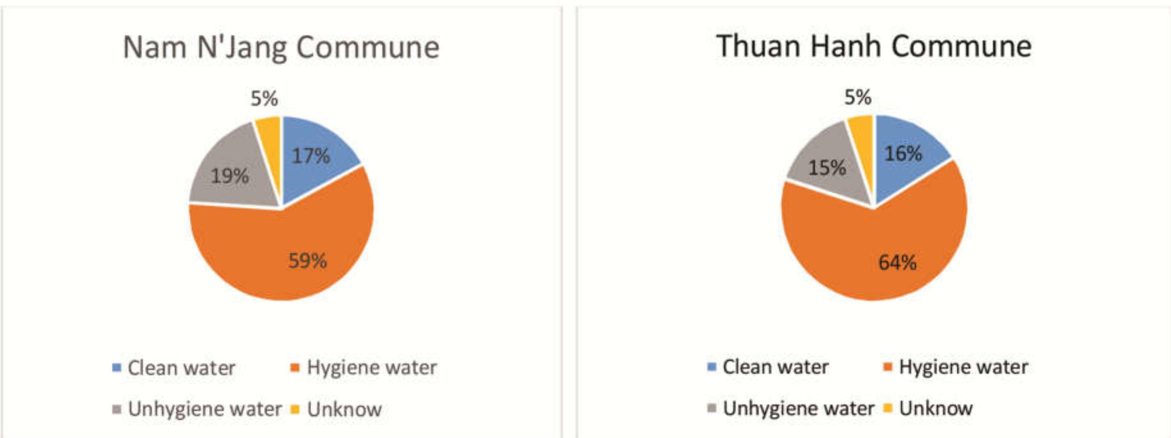


Figure 8: The water quality assessment by the local residents in Thuan Hanh and Nam N'Jang Communes

3.2.9. Gender and role of family members in domestic water supply

Gender and division of labor in the family

Division of labor in the family and gender difference was one of the core topics discussed in group discussions organized in Thuan Hanh and Nam N'Jang Communes. Each commune formed two groups, one male and one female, who discussed separately in addition to household interview. Most people believe that because of the different physical characteristics, women are more likely to undertake activities requiring less physical strength like cooking, washing, looking after children, cleaning, and so on, whereas males are more likely to do heavy works like production, construction, well digging, maintenance, tank cleaning, and so on. Some say that men occasionally support women do household work such as cleaning and childcare.

Both wife and husband participate in pepper production tasks such as weeding, fertilizing, watering, spraying, and harvesting. While the husband is mainly in charge of making decisions and performing activities such as pumping water, spraying, carrying and grinding, the wife is in charge of stripping pipes, pulling the string, holding watering hoses, picking, and drying. According to findings from both current and previous study conducted by CARE, women are primarily responsible for taking care of their families and children, and other unpaid works. However, these works spent more their times compared to men's.

Role of gender and family members in domestic water supply

Residents said they spent an extra 15 to 30 minutes to collect water during the dry season. Men oversee irrigation water, while women are in charge of domestic water. This increases the burden on them, particularly women, who use the most domestic water. Men dominate decision-making, even though women and children suffer the most impacts in using unsanitary water. Regarding to investing in domestic water supply, 71.9% said that all family members were involved in the discussion, but the husband/father made the final decisions. Women are thought to be lacking in technological knowledge and skills, as well as misunderstanding on equipment used for domestic water supply and irrigation. Therefore, men are mostly responsible for making decisions. In addition, the husband is primarily responsible for household water supply system operations, such as water pumping, tank cleaning, and filter replacement. Women, on the other hand, share the same investment obligation as men in domestic water supply systems (Figure 9). Indeed, men make the major decisions while women bear a fair portion of the investment expenses in the household.

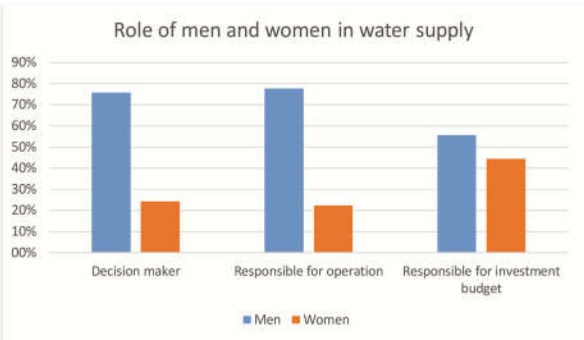


Figure 9: Role of family members in domestic water supply in Thuan Hanh and Nam N'Jang Communes

3.2.10. Agriculture practices and living activities affecting water resources

Local agricultural production activities currently pose a significant threat to water resources. As the cultivation technics and the habits of utilizing chemical fertilizers and pesticides at present, a considerable amount of chemical fertilizers and crop protection chemicals are left in the soil, and the process of infiltration and leaching will pollute soil, surface water, and groundwater. Water pollution is also caused by fertilizer and pesticide packaging. According to the environmental report in Dak Song District from 2016 to 2020 [16], around 1,500 tons of chemical fertilizers and crop protection chemicals had been used annually for 1 hectare of agricultural cultivation. Meanwhile, the Department of Crop Production of the Ministry of Agriculture and Rural Development encouraged the fertilizer use for pepper cultivation during the business period, including: manure and compost (15–20 tons per ha per year), and chemical fertilizers (maximum 350 kg N + 200 kg P + 250 kg K per ha per year, which is equivalent to 800 kg per year). Thus, the actual use of fertilizers and pesticides are double as the guidance.

The survey data on the use of fertilizers and pesticides in coffee and pepper cultivation in the Thuan Hanh and Nam N'Jang show that, the farmer habits of using fertilizer and pesticide base on personal experience are very common. Of which they use a lot of chemical fertilizers and pesticides with chemical origin. Furthermore, fertilizer application during the rainy season has the potential impact to water sources since the unabsorbed fertilizer when raining will be flowing into rivers and streams.

+ Fertilizer uses: Residents claimed that they used less fertilizer than in prior years due to a fall in pepper prices at the time of investigation. According to survey data, manure and organic fertilizer are used less frequently, ranging from 0.1 to 9.3 tons per ha, whereas chemical fertilizer is used more frequently. In Nam N'Jang Commune and Thuan Hanh Commune, respectively, 37 % and 32 % of the households utilized chemical fertilizer as directed. More than 60% of the households surveyed said they used more than in the instructions, and 20% said they used 2.5 times more than in the instructions (Figure 10).

+ Crop protection chemical uses: Crop protection chemicals are still widely used in the area, with over 60% of households use. Furthermore, containing bags or packaging have not been properly collected and treated. The treatment measures applied here are burning and burying and some bags with green markings are collected and sold as junk.

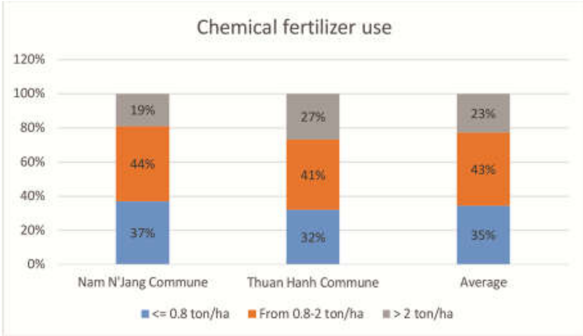


Figure 10: Chemical fertilizer use for pepper in Thuan Hanh and Nam N'Jang Communes

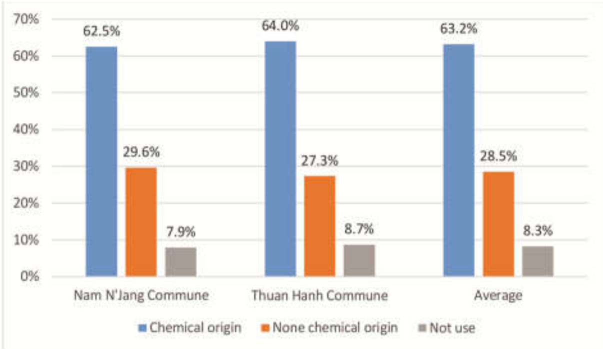


Figure 11: Crop protection chemicals use in Thuan Hanh and Nam N'Jang Communes

People's daily activities generate garbage and waste water, which have potential to pollute water sources. In addition, more modern equipment used as a result of rapid population growth and improved quality of life, consequencing of increasing solid waste and domestic waste water. This will pollute water if improperly collected and treated measures applied.

- Domestic solid waste: The survey data show that, solid waste has been collected in some villages in two communes, but it's not much waste collected. The proportion is 33.5% and 54.6% in Thuan Hanh and Nam N'Jang respectively. The rest of the households gathered and dumped into the garden, where they were buried or burned. This is potential pollution of surrounding water sources.

- Domestic waste water: The amount of domestic waste water generated is equal to the amount of water used per person per day. Thus, estimation of wastewater discharged into the environment in the two communes is

5,366.5 m^3 per day. In which, toilet wastewater contains the highest concentration of contaminants. However, approximately 90% of households use septic toilets or squat toilets. Therefore, the large amount of wastewater is not discharged directly into rivers and streams, but rather through septic tanks. It's pretreated here, and then discharged into absorbing wells and out into the garden or canals around the house, before being discharged into rivers and streams. Furthermore, the current population density is less likely to have an impact on water resources.

3.2.11. Safe drinking water assess of local people

Residents have not yet used safe water for domestic purposes. Water born diseases have appeared such as diarrhea, pinkeye, and dental caries, etc. Even though they are aware of the importance of using clean and hygiene water, they lack understanding of how to collect, store, and treat to get clean and hygiene water. Additionally, it has not yet supported from the local authorities in clean water supply and use.

Women and children are the most vulnerable to unclean water use. However, water supply operations and investment for the both domestic and irrigation are decided by men.

Households' ability to invest in water supply: Local people are aware of the importance of using safe water and are capable in contributing a portion of the cost of water supply and treatment systems. However, poor and near-poor households find it difficult to invest in those systems due to the recent drop in coffee and pepper prices in the past 2 years, which has made life tough for them.

4. CONCLUSION AND RECOMMENDATIONS

Rural water supply in Dak Nong Province contains potentially unsustainable factors in both water quantity and quality: (i) Water quantity and quality are decreasing noticeably; (ii) Unsafe domestic and production activities cause water pollution; (iii) Weak coordination between the local responsible agencies in water management. And Water resources has not yet exploited and managed properly, particularly groundwater resources; and (iv) climate change impacts are potentially exacerbating the safe water supply in Dak Nong province.

Integrated water resource management is appropriate approach in addressing issues and challenges in current rural water supply as well as water resources. Recommendations are made to ensure the safe water supply areas as following:

- A complete water supply policy framework such as investment policy, operation and management policy, water price policy, and so on, should be developed, and appropriate resources for rural water supply investment should be allocated.

- Training and awareness raising on safe water supply and treatment should be enhanced. Warning about water quality situation and guiding on how to protect water resources and using water safely should be provided for local people.

- Communication on saving water use and water sources and environmental protection should be conducted regularly.

- Mobilizing support from international organizations such as McCormick, CARE, UNDP, and others to develop the community based sustainable integrated management models such as ecological pepper production models. Certificates for sample models must also be provided to expand models to new areas. The scale and scope of models are determined depending on the cost; an integrated measures for clean water supply and sustainable pepper models should be provided in order to respond to climate change as well as gender equality challenges oriented to disadvantaged groups benefited.

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SOME RESEARCH RESULTS USING THE CEMENT, FLY ASH, GROUND BLAST FURNACE SLAG AND MAGNESIUM OXIDE TO IMPROVE THE MECHANICAL CHARACTERISTICS OF THE DREDGING MUD IN CA MAU PROVINCE

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Summary: *The article present studies of dredged mud hardened in brackish water in Ca Mau province using a mixture of cement binder, finely crushed blast furnace slag, fly ash and magnesium oxide to improve the mechanical and physical properties of the dredged mud material. The dredged mud is used to replace sand leveling materials, embankment structures surrounding irrigation works. The results also show that using magnesium oxide in different proportions in the mixture of cement, finely crushed blast furnace slag and fly ash significantly improves the mechanical and mechanical properties of the hardened sludge, especially the compressive strength. This is a useful solution to reuse the dredged sludge in addition to other solutions being used.*

Keywords: *Cement; Ground Blast Furnance Slag; Fly ash; Magnesium oxide; Hardened mud soil.*

1. INTRODUCTION

The Mekong Delta is the lower delta of the Mekong River, a large river flowing through six countries, namely China, Myanmar, Laos, Cambodia, Thailand and Vietnam, located adjacent to the Mekong Delta. Southeast region, bordering Cambodia to the North, the South-West is the Gulf of Thailand and the Southeast-South is the East Sea. With 13 administrative units including: One city directly under the government (Can Tho City) and 12 provinces (Long An, Dong Thap, An Giang, Tien Giang, Ben Tre, Vinh Long, Tra Vinh, Hau Giang, Kien Giang, Soc Trang, Bac Lieu and Ca Mau) account for about 12% of the country's area and 20% of the country's population

- Demand for dredging to clear large creeks and canals. Every year, with the assurance of waterway traffic and the demand for water drainage, the whole Mekong Delta has to spend hundreds of billions of VND on dredging to clear the flow. With the volume of mud to be dredged tens of millions of m3, the inevitable filling of storage yards has put pressure on local authorities.

In recent years, the scarcity of construction sand has occurred nationwide, especially in the first months of 2017 due to the sudden increase in sand prices. In order to contribute to ensuring the supply and demand for construction sand and stabilizing sand prices, the Ministry of Construction has proposed and recommended to the Prime Minister a number of solutions, including:

Therefore, the solution to harden the dredged

Ngày nhận bài: 12/8/2022
Ngày thông qua phản biện: 30/9/2022
Ngày duyệt đăng: 06/10/2022

mud to replace the leveling and filling sand of the Mekong Delta is a positive solution. This solution is evaluated as superior because the Mekong River Delta has: (1) A large system of waterways and irrigation canals that must be dredged annually to ensure safety; (2) The reserve of leveling sand in the Mekong Delta is increasingly depleted. If the exploitation continues, it will lead to the erosion of riverbanks and coasts of the whole region. The implementation of research on hardening of dredged mud is not only of scientific value but also of great political significance. It contributes significantly to the prevention of erosion in the Mekong Delta

2. MUD HARDENING SOLUTIONS

Mud is soil, humus, silt or clay mixed with water. It is usually formed after rain or near a water source. Ancient mud deposits hardened over geologic time to form sedimentary rocks such as shale or mudstone (commonly known as luthite). When geological deposits of mud are formed in estuaries, the resulting layers are known as mud

2.1. Mud hardening by heating solution

The sludge is pressed into blocks, then heated at different temperatures to create products such as construction materials such as bricks, artificial gravel, lightweight aggregates [1], [2]. This technique has been exploited for nearly 20 years in Germany and the Netherlands.

2.2. Sludge hardening by mixing binder materials (Chemical method)

Using inorganic and polymer material in order to improve machenical properties of soil

Use organic binders

Organic or polymeric binders have also been applied in many where of the world for soil stabilization.

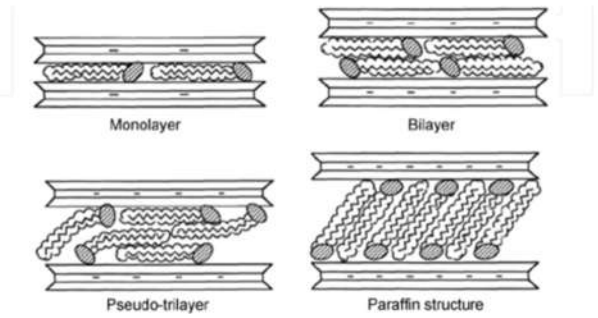

Figure 1: Structure rearrangement of soil particles under the influence of polymers [6]

Polymers stabilization soil through interactions with soil particles, here also called structural rearrangement of soil particles which tend to become tighter as polymer molecules (such as alkyl ammonium cations) are adsorbed between the soil layers in response to the intensity of charge density on the clay surface [3].

Use inorganic binders

Inorganic compounds capable of reinforcing soil and mud include cement, hydrated lime, fly ash, blast furnace slag, etc. [4], [5], [6], [7], [8], [9]. The main components of inorganic binders include SiO_2, Al_2O_3 and CaO in crystalline and amorphous form. Depending on the specific content of the above components, the positions of these binders expressed on triangular coordinates (with three sides being CaO, SiO_2 and Al_2O_3) will be different. Accordingly, the hydration activity of inorganic binders increased in the following order: Kaolin (metakaolin), Silica fume (silica fume), Organic matter ashes, natural Puzolan (volcanic rocks), Fly ash, Blast furnace slag, Portland cement. In general, the active inorganic additives mentioned above all contain amorphous SiO_2, Al_2O_3, so they can react with lime at normal temperature to become a solid mixed binder in water. In general, the active inorganic additives mentioned above all contain amorphous oxide SiO_2, Al_2O_3, so they can react with lime at normal temperature to become a solid mixed binder in water.

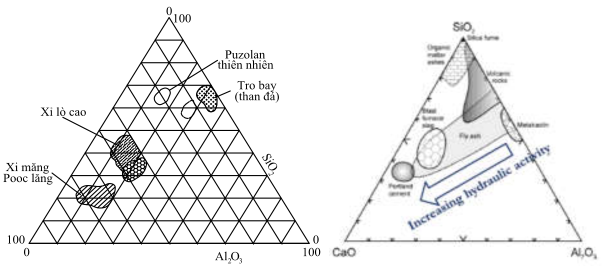

Figure 2: Representation of the composition of inorganic binders on equilateral triangle coordinates a) [10], b) [11]

In general, the use of lime, cement, fly ash, blast furnace slag and rice husk ash to reinforce soil for road construction has been widely applied in the world, in which lime, cement and fly ash are used. most commonly used.

2.3. Theoretical basis of reinforcing dredged mud soil by chemical method

In order to reinforce the mud, a variety of binders can be used such as Portland cement, lime, combined with additives such as fly ash, blast furnace slag, natural or artificial puzzolans. However, cement is still the most widely used and widely used binder. The mechanism of soil hardening, and reclamation is flocculation via cation exchange reactions and generation of C-S-H colloids through puzzolanic reactions in the mud soil medium:

$$nCaO + SiO_2^{vdh} + yH_2O \rightarrow C\text{-}S\text{-}H$$

After mixing with water, the mixed binders (such as lime - fly ash, lime - Puzolan...) will produce the following reaction:

$$xCa(OH)_2 + SiO_2^{vdh} + yH_2O \rightarrow xCaO.SiO_2.(y+1)H_2O$$

Thus, amorphous SiO_2 reacts with Ca $(OH)_2$ to form hydrated silicates. This substance, after a long time will turn into crystalline hydrated silicate. With lime-clay binder, when mixed with water, the following two reactions will produce stable hydration components:

$$Al_2O_3.2SiO_2 + CaO + yH_2O \rightarrow CaO.\ Al_2O_3.\ 2SiO_2.\ yH_2O$$

$$SiO_2 + CaO + yH_2O \rightarrow SiO_2.\ CaO.\ yH_2O$$

These stable hydration components will, after a while, become crystalline hydrate components.

Magnesium oxide (MgO): Magnesium oxide binder is usually in the form of a fine powder consisting mainly of magnesium oxide (MgO), produced by heating magnesium oxide $MgCO_3$ or Dolomite rock ($CaCO_3.MgCO_3$) at the temperature of 750 - 850 ^{0}C.

$$MgCO_3 \xrightarrow{750-850℃} MgO + CO_2$$

When mix a magnesium binder with water, hardening occurs very slowly, but if mixing with a solution of magnesium chloride or other magnesium salts, hardening occurs more rapidly and increases the strength considerably of the binder, because the hydration product in addition to $Mg(OH)_2$ also contains a hydrated double salt $3MgO.MgCl_2.6H_2O$. The bearing strength of the magnesium binder is relatively high, depending on its mineral composition, the compressive strength at the age of 28 days can reach 100 ÷ 600 kG/cm^2.

3. MATERIAL USED IN THE STUDY

3.1. Mud soil: The dredged mud used for the study is brackish water mud typical of the Mekong Delta. Mud samples were taken at

Ong Doc River, near Khanh An bridge, in Ca Mau province. The physical and chemical parameters of the mud soil are summarized in Tables 1 and 2.

Table 1: Chemical proportion of brackish water dredged mud

Sample type	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Na_2O	Fe_2O_3
	%	%	%	%	%	%	%	%	%	%	%
Brackish water mud	0.679	12.683	52.048	0.978	0.760	5.054	1.343	1.804	0.394	0.143	21.290

Bảng 2: Physical properties of brackish water mud

Sample mark	Organic content	pH	Moisture content	Natural density	Specific gravity	Atterberg limit			Force parameter	
						Liquid limit	Plastic limit	Consistency	Friction angle	Cohesive strength
			W	g_w	D	W_l	W_p	I_s	J_u	C_u
	%		%	g/cm^3	g/cm^3	%	%		độ	kPa
Brackish water mud	1.70	6.76	82.2	1.47	2.53	72.0	41.8	1.38	2^{0}39’	14.0

3.2. Cement: The study uses Ha Tien PCB40 cement to design, test results of some physical properties of cement as presented in Table 3. Cement meets technical requirements according to TCVN 6260:2009 [12]

Table 3: Physical properties of Ha Tien PCB40 cement

No.	Test items	Unit	Test results
1	Specific gravity	g/cm^3	3.10
2	Fineness (remaining on 0,09 mm sieve)	%	3.65
3	Mixing water requirement	%	27.5
4	Time of setting (start)	minute	119
	Time of finished setting	minute	185
5	Soundness	mm	3.0
6	Compressive strength 3 days	N/mm^2	23
	Compressive strength 28 days	N/mm^2	44

3.3. Fly ash

The fly ash mineral admixture of Duyen Hai 1 thermal power plant was used in the study. The test results of some physical and chemical properties of fly ash met the requirements according to TCVN1032:2014 [[13].

Table 4: Physical properties and chemical composition of fly ash Duyen Hai 1

No.	Test items	Unit	Test results
1	Moisture content	%	0.28
2	Natural unit weight	kg/m^3	944
3	Specific gravity	g/cm^3	2.24
4	Loss on ignition	%	6.48

No.	Test items	Unit	Test results
5	SiO_2 content	%	56.02
6	Hàm lượng Fe_2O_3 content	%	6.61
7	Hàm lượng Al_2O_3 content	%	22.47
8	Hàm lượng SO_3 content	%	0.22
9	Strength activity index at the age of 28 days	%	82.0

3.4. Blast furnace slag

In the study using Hoa Phat finely ground activated blast furnace slag with the density of 2.90 g/cm3, specific surface area of 5020 cm^2/g, strength activity index at the age of 28 days reached 96%. The basic chemical composition is presented in Table 5 below. Activated blast furnace slag has mechanical and physical criteria satisfying TCVN 11586:2016[14] and BS EN 15167-1:2006 standard [15].

Table 5: Chemical composition of Hoa Phat blast furnace slag

Compostion	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	K_2O	Na_2O	MKN
% by mass	35.18	16.26	0.25	0.15	39.95	5.95	0.31	0.18	0.01

3.5. Magnesium oxide: The magnesium oxide (MgO) used in the study has the mechanical and physical parameters as presented in Table 6.

Table 6: Physical properties of MgO

No.	Technical parameter	Unit	Test result	TCXDVN 383:2007
1	MgO content	%	85,26	≥80
2	Color		White podwer	
3	Particle size passing through 0.5 mm sieve	%	100	100
4	Particle size passing through 0.075 mm sieve	%	62	≥50

4. TEST RESULLTS

Trial mix designs: The cement content selected to carry out experiments with fly ash, blast furnace slag and magnesium oxide was 6% by weight of 1 m^3 natural mud with density of 1.42 g/cm^3. The blast furnace slag content changes were 2%, 4% and 6% and the fly ash content was 6%, 4% and 2% respectively. MgO is 0.5%, 1.0% and 2.0%, respectively. The material composition of the mixes and the test results of the physico-mechanical properties of the mixture of mud, cement, fly ash, blast furnace slag and MgO are presented in Table 7.

Table 7: Test result of mud, cement, fly ash, blast furnace slag and MgO mixture

Sample mark	Cement	Blast furnace slag	Fly ash	MgO	Moisture content	Liquid limit	Plastic limit	Consistency	Friction angle	Cohesive strength	Compressive strength
					W	W_L	W_P	Is	Ju	Cu	Qu
	%/kg	*%/kg*	*%/kg*	*%/kg*	*%*	*%*	*%*		*độ*	*kPa*	*kPa*
L_X6X2TB6Mg0.5	6/85.2	2/28.4	6	0.5	71.48	78.75	66.28	0.42	14.40	31.66	328.53

Sample mark	Cement	Blast furnace slag	Fly ash	MgO	Moisture content	Liquid limit	Plastic limit	Consistency	Friction angle	Cohesive strength	Compressive strength
					W	W_L	W_P	Is	Ju	Cu	Qu
	%/kg	*%/kg*	*%/kg*	*%/kg*	*%*	*%*	*%*		*độ*	*kPa*	*kPa*
L_X6X4TB4Mg0.5	6/85.2	4/56.8	4	0.5	70.30	75.88	66.87	0.38	14.51	33.61	348.66
L_X6X6TB2Mg0.5	6/85.2	6/85.2	2	0.5	69.80	77.17	65.30	0.38	17.39	37.60	373.68
L_X6X2TB6Mg1.0	6/85.2	2/28.4	6	1.0	64.80	81.22	58.48	0.28	17.15	37.99	383.29
L_X6X4TB4Mg1.0	6/85.2	4/56.8	4	1.0	64.10	73.83	60.79	0.25	16.49	42.02	406.77
L_X6X6TB2Mg1.0	6/85.2	6/85.2	2	1.0	66.00	93.01	55.97	0.27	18.90	45.12	423.51
L_X6X2TB6Mg2.0	6/85.2	2/28.4	6	2.0	51.80	54.87	51.30	0.14	19.48	47.48	447.17
L_X6X4TB4Mg2.0	6/85.2	4/56.8	4	2.0	53.48	70.65	50.66	0.14	17.18	50.42	474.56
L_X6X6TB2Mg2.0	6/85.2	6/85.2	2	2.0	52.46	66.86	50.20	0.14	22.50	56.39	479.98

Table 8: Permeability coefficient and Density of hardening mud mixture have best strength

Sample mark	**Permeability coefficient**	**Density**
	$K \times 10^{-8}$ m/s	g_W (g/cm^3)
L_X6X6TB2Mg2.0	3.20	**1.49**/1.42

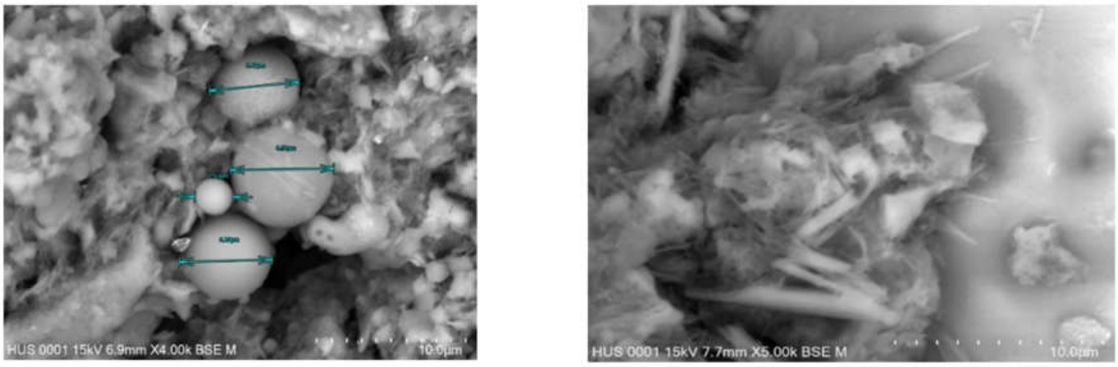

Figure 3: Scanning electron microscope (SEM) image of hardened mud sample at 28 days (Mud + XM + fly ash + XLC + MgO)

The research results show that the use of MgO has a clear effect in improving some mechanical and physical properties of the hardened mud, the physical and mechanical parameters of the hardened mud satisfy the design requirements, especially hardened mud soil with small permeability, suitable for replacing natural sand for embankment work in the Mekong Delta.

From figure 3, it can be seen that C-S-H, C-A-H and MgOH crystals appear on the surface and voids.

The results of XRD analysis (X-ray diffraction) of hardened samples (mud+ cement +fly ash+blast urnace slag+MgO) are presented in Figure 4.

The XRD analysis results showed the presence of Bavenite compounds which is a calcium beryllium aluminosilicate and Clintonite compounds which are calcium, magnesium, aluminum, iron and silicon minerals.

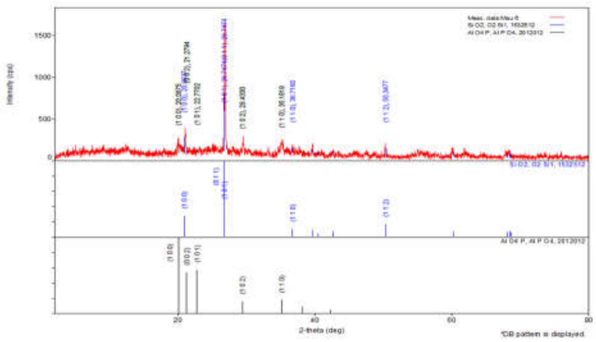

Figure 4: XRD differential thermal analysis results of hardened mud samples (Mud + Cement + fly ash + Blast furnace slag + MgO)

5. CONCLUSION

The test results of mixtures of brackish water mud with cement, fly ash, blast furnace slag combined with MgO showed that the physico-mechanical parameters of the sludge were significantly improved compared to untreated sludge samples. The test results of hardened mud samples showed that:

+ When hardening dredged mud with 6% cement content, combined with blast furnace slag, fly ash and MgO, the viscosity, internal friction angle, adhesion force, and strength of the mud mixture are improved. Specifically, the higher the MgO content, the lower the viscosity, the larger the friction angle, the greater the adhesive force, the strength of the hardened mud increases proportionally to the MgO content.

+ The use of MgO in combination with the traditional binder of cement and active mineral additives showed a marked improvement in the physico-mechanical parameters of the mud, especially the strength of the mud after hardening increased. This is one of the solutions that can be considered to harden the soil in general and harden the mud in particular. Therefore, this is a solution that should be studied and applied widely to all types of mud soil not only in Ca Mau province but should be applied to other provinces in the Mekong Delta.

Gratefulness

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[12] TCVN 6260: 2009 Portland blended cement – Specifications

[13] TCVN1032:2014 Activity admixture – Fly ash for concrete, mortar and cement

[14] TCVN 11586:2016 Ground granulated blast furnace slag for cement and mortar

[15] BS EN 15167-1:2006 Ground granulated blast furnace slag for use in concrete, mortar and grout Definitions, specifications and conformity criteria

PREDICTION OF PILE CAPACITY USING ARTIFICIAL NEURAL NETWORK WITH TWO HIDDEN

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Summary: *The bearing capacity of the pile is an important factor in the design of the pile foundation. Determining the bearing capacity of piles through in situ load testing is costly and time consuming. The purpose of this study is to show the applicability of artificial neural network (ANN) to predict the axial load capacity of piles. The data set used to build and verify the ANN simulation tool includes 100 data of test results of pile load testing in Dong Van industrial zone - Ha Nam. After conducting trial and error, the structure of the selected ANN includes 10 input parameters, two hidden layers with the number of neurons in the two layers of 12 and 10 neurons, respectively. Programmed and run in the Matlab platform, the authors use the ANN tool to predict the output parameters of the axial load capacity of the pile. The results show that ANN has good potential to be used as a pile bearing capacity prediction tool to help design engineers predict pile load capacity based on pile parameters, minimizing the time experimental and expensive.*

Keywords: *Artificial Intelligence (AI), Artificial Neural Network (ANN), pile bearing capacity; pile foundation.*

1. INTRODUCTION

The bearing capacity of the pile is one of the most important parameters in the design process of the pile foundation [1]. To determine the current load capacity of piles, we often use the following method [1], [2]: static analysis, dynamic analysis, dynamic testing, pile load test and in-situ testing [2]. In those methods, the pile load test method is the most reliable method to determine the bearing capacity of piles, but this method is time consuming, expensive and often applicable to large-scale projects. In addition, according to the traditional method, we can also determine based on the results of field tests such as standard penetration test (CPT) and static penetration test (SPT). In study by Jesswei et al [3] the calculation of the bearing capacity of piles according to SPT is not completely reliable and inaccurate because the determination formula is still assumed, although it is easy to implement and low cost. This calculation method is considered impractical, as it is based on too many assumptions and simplifications [4]. In addition, Farsakh and Titi [5] argue that the method of pile empirical analysis or static analysis is high cost and low accuracy due to the choice of many safety factors. Other way, for the static pile compression method, although it has high reliability, it is time consuming, expensive and the equipment is often cumbersome [6]. The dynamic analysis method relies heavily on the characteristics of the pile, the compressive load and the position of the pile to predict the bearing capacity of the pile without considering the influence of the soil [7], [8]. Finally an equally important method is finite element based, it is basically an approximation method and the result depends heavily on the modeling process [9], [10]. In specific conditions, the above methods

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all have advantages, but besides that, there are still disadvantages, so we need to consider when applying them to specific.

In recent years, many scientists have used new approaches to the problems related to the foundation of building [4]. That method is called artificial intelligence (AI) [11]. Based on the development of computer science, AI has gradually proven its outstanding effectiveness in many different fields such as construction, transportation, medical, security [12]. The essence of AI algorithms is a combination of mathematics, algorithms and creativity. AI allows solving complex problems and many unknowns, so it is very suitable for nonlinear problems in geoengineering [4]. Likewise, to determine the load capacity of piles, a large number of studies have used AI as a reliable method [4], [7], [13]. Scientists have used many different AI algorithms to solve the pile load prediction problem, which can be named as artificial neural network (ANN), fuzzy inference system (FIS), and genetic programming (GP), random forest (RF). All of the above studies give good predictive efficiency and are expected to become a highly generalized tool in predicting the bearing capacity of piles. The main objective of this study is to use the hidden 2-layer artificial neural network model to determine the axial load capacity of piles on the basis of a dataset of 100 experimental results that have been published in peer-reviewed journals reputation. Based on that, the results of this study provide construction engineers with a reference to quickly and accurately determine the pile load capacity.

2. DATABASE AND MODELING

2.1. Data used

In this study, data were collected from the results of static compression tests of 4720 reinforced concrete piles published by Pham Tuan Anh et al [14]. The input parameters to determine the load capacity of the pile include: (i) Diameter of pile (D), (ii) Length of first pile (Z1), (iii) Length of second pile (Z2), (iv) Pile tip length (Z3), (v) Natural ground elevation (Zp), (vi) pile top elevation (Zg), (vii) Guide pile stopping elevation (Zt) , (viii) Pile tip height (Zm), (ix) average SPT value over pile length (Nsh), (x) average pile tip SPT value (Nt). The output parameter is the bearing capacity of the pile (Pu). The data of the model (*Table 1*). For illustrative purposes, *Fig 1* shows the graph of the correlation between input and output parameters of the parameters in this study

Table 1: Statistical analysis of databases

	D	Z1	Z2	Z3	Zp	Zg	Zt	Zm	Nsh	Nt	Pu
count	472	472	472	472	472	472	472	472	472	472	472
mean	363.77	3.83	6.58	0.33	2.80	3.50	2.92	13.54	10.74	7.06	0.98
std	48.12	0.48	1.64	0.46	0.62	0.08	0.60	1.80	2.26	0.66	0.35
min	300.00	3.40	1.50	0.00	0.68	3.04	1.03	8.30	5.60	4.38	0.41
25%	0.75	3.40	5.25	0.00	2.05	3.45	2.15	12.05	8.65	6.75	0.61
50%	1.00	3.45	7.31	0.00	2.95	3.48	3.28	14.11	10.80	7.18	1.07
75%	1.00	4.35	8.00	0.94	3.40	3.54	3.42	15.34	13.25	7.60	1.32
max	400.00	5.72	8.00	1.69	3.40	4.12	4.35	16.09	15.41	7.75	1.55

In this study, the data used is divided into two data used: training and testing. The first data (including 70% data) is used to train the ANN network model; The second dataset (30% remaining data) is used to test the model. With the above division, the dataset consists of 472 data with 330 samples for the training dataset and 142 samples used to estimate the predictive performance of the ANN. The data set in this study, including input parameters and output parameters, is normalized in the range [0-1]. This method is mainly used in artificial intelligence problems to minimize the error generated by the simulation.

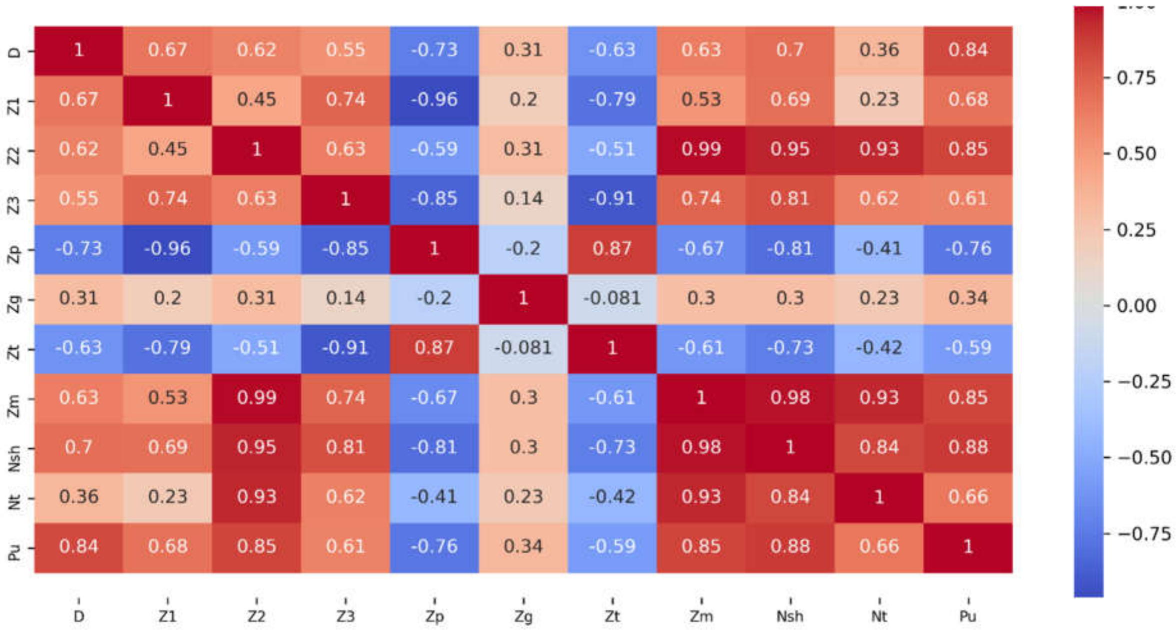

Fig 1: The chart of input and output parameters

2.2. Artificial neural network

Artificial Neural Network (ANN) is a powerful machine learning-based data analysis algorithm that is a model of biological neural networks. They provide a wide range of mathematical calculations used to model biological mechanisms of the human brain, such as knowledge and memory [15], [16]. Compared with conventional computational methods, ANN algorithms are especially useful in solving problems of high complexity. So far, the use of artificial neural networks has been widely applied in many fields [17]–[19]. ANN model, information inputs are provided to an artificial neuron; each input is associated with a weight and an offset. The backpropagation (BP) algorithm is a popular tool used to adjust the weight and bias of each neuron in the network. A set of inputs is fed into some presumptive system to derive an output value, which is then compared with the actual value. If there is no difference, then no testing is needed, otherwise the weights will be changed during the back-propagation in the neural network to reduce the difference. Mạng lan truyền ngược thường có một hoặc nhiều lớp ẩn với các nơron dạng sigmoid và lớp ra là các nơron với hàm truyền tuyến tính. A backpropagation network usually has one or more hidden layers with sigmoid neurons and an output layer of neurons with a linear transfer function. Multilayer networks using back-propagation learning are the most widely used in the field of neurons. However, the underlying BP algorithm is still too slow for applications. The study of faster algorithms has been proposed to speed up the convergence for the ANN training phase. In this study, the BFGS Quasi-Newton (BFG) back-propagation algorithm is used to optimize the ANN training that predicts the 28 days compressive strength of concrete.

The BFGS method is a network training algorithm that updates the weights and bias values according to the Quasi-Newton method. The BFGS algorithm is one of the algorithms used to solve the nonlinear optimization problem without any constraints:

$$\min f(x), \quad x \in R^n \qquad (1)$$

The algorithm proposed by Broyden [20], Fletcher [21], Goldfarb [22] và Shanno [23] is implemented including the following steps:

Step 1: Let $x_1 \in R^n; B_1 \in R^{n\times n}$ be positively defined. Calculate $g_1 = \nabla f(x_1)$. If $g_1 = 0$ then stop, if not set k = 1.

Step 2: Set $d_k = -B_k^{-1} g_k$

Step 3: Do a search along d_k; receive

$\alpha_k > 0$, $x_{k+1} = x_k + \alpha_k d_k$ and $g_{k+1} = \nabla f(x_{k+1})$;

Step 4: Set

$$B_{k+1} = B_k - \frac{B_k s_k s_k^T B_k}{s_k^T B_k s_k} + \frac{y_k y_k^T}{s_k^T y_k} \qquad (2)$$

With $s_k = \alpha_k d_k$, $y_k = g_{k+1} - g_k$

Step 5: k = k+1, go back to step 2

2.3. Performance Evaluation

To evaluate the accuracy of the ANN model between the predicted results and the actual results, the authors used three indexes: Root mean square error (RMSE), the coefficient of determination (R^2) and namely the mean absolute error (MAE). The R^2 value allows to determine the statistical relationship between the predicted values and the experimental results. R^2 having values in the range of [-∞ ÷ 1], the model will be said to be more accurate as R^2 to 1. Conversely, the lower the values of RMSE and MAE, the more accurate the calculation results. The values of R^2, RMSE, MAE are calculated using the following formulas:

$$RMSE = \sqrt{\frac{1}{k}\sum_{i=1}^{k}\left(y_i - \overline{y}_i\right)^2} \qquad (1)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{k}\left(y_i - \overline{y}_i\right)^2}{\sum_{i=1}^{k}\left(y_i - \overline{y}\right)^2} \qquad (2)$$

$$MAE = \frac{1}{k}\sum_{i=1}^{k}\left(y_i - \overline{y}_i\right) \qquad (3)$$

Where k: number of samples; y_i và $\overline{y}_i$ are the actual and predicted outputs, respectively; $\overline{y}$: is the mean value of y_i .

3. RESULTS AND DISCUSSION

In this part, the authors use the ANN artificial neural network model with 2 evaluation hidden layers with the number of error correction iterations of 100. Using two root mean square error (RMSE) and namely the mean absolute error (MAE) selected for the optimization problem. The evaluation of 2 error functions during the optimization process for the training and testing datasets is presented in *Fig 2*. The results show that there is no sudden change in the optimization process for the training data set. training and testing data set with 100 iterations. Therefore, the number of iterations for the optimal process with a training set of 100 has good results for successfully predicting the bearing capacity of pile.

The optimal ANN defined in the above section allows to predict the pile load capacity for the training and testing. Fig3 shows the value of the pile bearing capacity as predicted by the ANN model for the training and testing datasets. These values are compared with the experimental data. The results show that the proposed algorithm is capable of predicting quite accurately about the value of the bearing capacity of piles with experimental data. The error of the model for the training and testing data is small compared to the test data. Fig 4 shows the error value frequency of the training and testing data. The error value of the training and testing data is small, with only a few errors in the range [-0.2; 1.0] (kN). These small error values show that the predictive ability of the ANN model is very good.

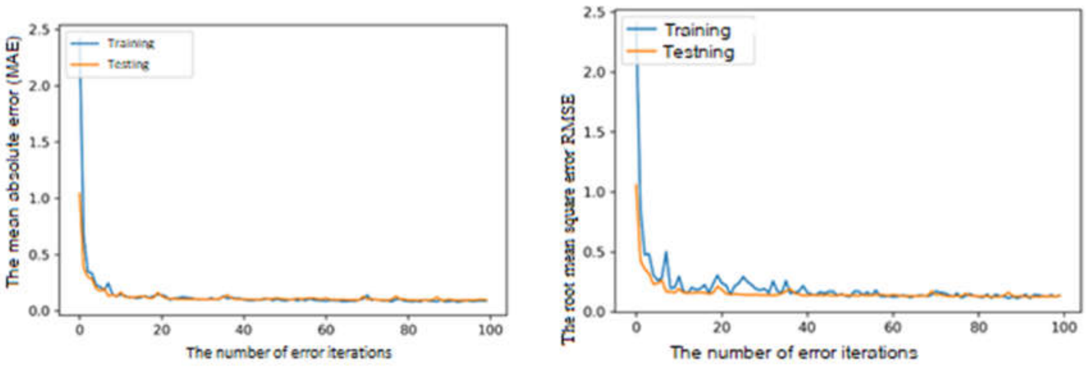

Fig 2: Evaluation of MAE and RMSE functions during optimization

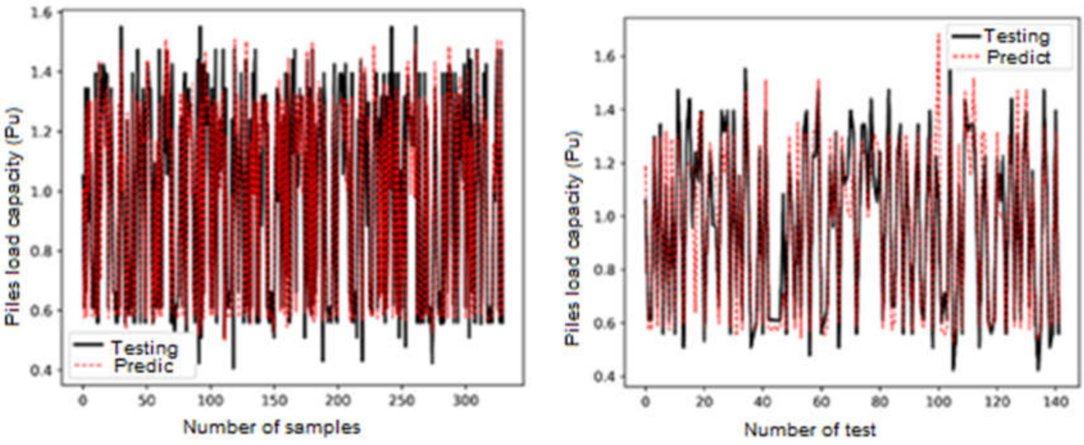

Fig 3: Value of bearing capacity of pile according to experimental data and ANN

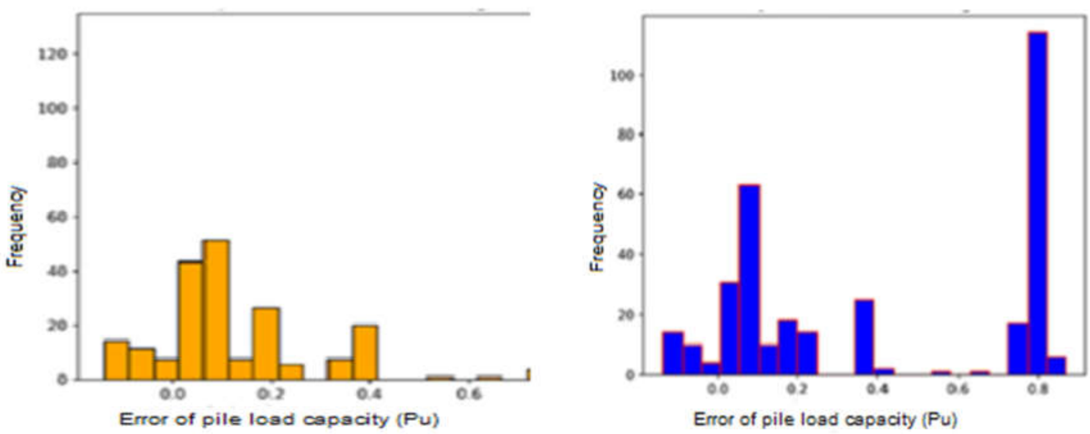

Fig 4: Error on the bearing capacity of piles of the ANN

Fig 5 shows the correlation of the pile load capacity between the simulated and experimental values using the ANN. The results are listed in *Table 2*. The values of the model show that the difference between training and testing is not large, which shows that the application of the hidden 2 layers ANN to predict the load capacity of piles is highly effective and feasible.

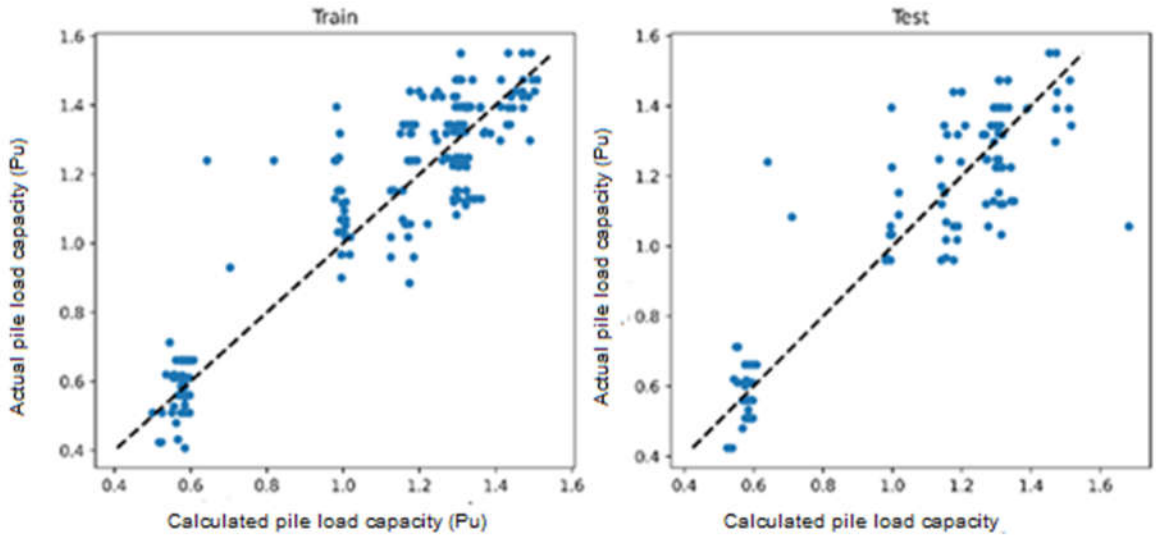

Fig 5: The results between simulation value and experimental value

Table 2: Statistics for the model with training and testing sets

Model rating index	R^2	RMSE	MAE
Training	0,903	0,11	0,081
Tesning	0,873	0,13	0,087

4. CONCLUSIONS

In this study, the ANN artificial neural network model with 2 hidden layers is used to predict the bearing capacity of piles. A data set of 472 field pile static compression test samples was used to build, develop and verify the model.

The results showed that the ANN model with 2 hidden layers with training and verification datasets showed nearly identical values (training: R^2 = 0,903, RMSE = 0,11 kN, MAE = 0,081 kN; testing R^2 = 0,873, RMSE = 0,13kN, MAE = 0,087 kN).

The hidden 2 layers ANN model has advantages over the conventional method, when there is training model data we can quickly and accurately determine the load capacity of the pile.

Correlation analyses between the dataset and training showed the parameters of pile length, pile height. (Z_1, Z_2, Z_m), the average SPT value along the Nsh pile length has the most significant effect on the prediction of pile load capacity.

The results of this study indicate that the ANN hidden 2-layer model allows us to predict the load capacity of piles more accurately than traditional methods.

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A MODEL FOR SIMULATION OF ACID WATER IN CANALS AND LINKAGE TO ACID SULPHATE SOIL MODEL

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Summary: *It is given in this paper an attempt to consider the problem of canal acid water in linkage to the ground acid water with the presence of the alunite and jurbanite in the soil. 1D model is applied for canals while 2D depth-average model is used to simulate the processes occurred in the soil. Data of 1995 collected at Tan Thanh farm, in the Plain of Reeds of the Mekong Delta in Vietnam, are used as a case study.*
Keywords: *Acid water in soil and canal, modeling, spreading of acid water*

1. INTRODUCTION

It is mentioned in [11] that for the Mekong Delta, acidity in the surface water is a particular problem at the beginning of the rainy season. Much effort has been made to mathematically simulate the processes occurred in both canals and soils [1,10,11,14,18].

It is given here an attempt to numerically simulate the physical and chemical dominant processes in the canals and in the soil and their interaction with the assumption that the canal water is governed by jurbanite equlibrium and the alunite and jurbanite are present in the soils.

2. ACID WATER MODEL FOR CANALS

In canals, the dominant process is longitudinal so one-dimensional model is practically useful for consideration and the governing equations in this case can be obtained by direct integration of the three-dimensional equations over cross-section normal to the axis of the canal. In [11] three-dimensional mass balance law is written for aluminum, sulphate and hydrogen in which the precipitation /redissolution and sedimentation processes have been taken into account. After integration over canal cross-section the following governing equations for one-dimensional case with jurbanite equilibrium are obtained

$$\frac{\partial C_i}{\partial t} + U(1+\varepsilon)\frac{\partial C_i}{\partial x} = E\frac{\partial^2 C_i}{\partial x^2} - \phi_i . C_i + \varphi_i \quad (1)$$

i=1,2,3 corresponding to Aluminum, Sulphate and Hydrogen concentrations averaged over canal cross-section. $\phi_i > 0$ and φ_i are given parameters ; ε is considered as an adjusted parameter during calibration; U is average flow velocity over crossection; E is dispersion coefficient .

3. MODELS FOR SOILS

The physical and chemical mechanism of acidity in the soils has been discussed in many studies [14, 19, 20]. Some simple mathematical models have been also found in [4,5,10, 15-17]. The basic governing equation of these models is :

$$\frac{\partial C}{\partial t} + \frac{\rho}{\theta}\frac{\partial S}{\partial t} + U\frac{\partial C}{\partial z} = D\frac{\partial^2 C}{\partial z^2} + \frac{-R.C + Q^*}{\theta} \quad (2)$$

where C and S are concentrations of any constituent in the solution and adsorption phases, respectively; ρ : soil bulk density ; θ : volumetric moisture; *D*: dispersion coefficient; U is flow rate (Velocity); R : water taken by roots ; and Q^* : source/ sink term.

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The difference between these models can be found in the relationship between C and S. For instantaneous linear model the relationship is

$$S = K.C \quad (3)$$

K is called the distribution coefficient and is the slope of the isotherm curve. The Langmuir equation is one kind of (3).

There are some even more complicated models. In general, all the models try to reflect the structure of the physical phenomenon to be modeled. But the more detailed the model is, the more coefficients need to be determined and sometimes this makes the model unrealistic.

It can be seen that (3) is the simplest in terms of model development and only one coefficient K needs to be determined by experiment. Moreover, the number of equations like (2) to be included in the model is equal to the number of constituents in the simulation. E.g. If jurbanite equilibrium in canal water is used in simulation then only sulphate, aluminum and hydrogen in the soil are necessary in the simulation. So it is suggested to use (2) and (3) for simulation of solute transport in a soil column and to generalize these equations for the large-scale area of the Plain of Reeds (or even for the Long Xuyen Quadrangle) in the Mekong Delta,Vietnam.

In order to simulate acid water in canals and solute transport in soil in Tan Thanh farm, a master model may consist of two submodels : one for processes in the canal and another for processes in the soil.

3.1. Submodel for canal

To simulate processes taking place in the canal, it is customary to use an one-dimensional model and the movement of water is described by the Saint-Venant system of equation.

For solute transport it is assumed that in the Plain of Reeds canal water is governed by jurbanite equilibrium [13] , so the pH can be calculated by (see [11])

$$pH = -d + pAl + pSu \quad (4)$$

where: H, Al and Su are Hydrogene, Aluminium and Sulphate concentrations, respectively; $pH = -log_{10}(H)$; $pAl = -log_{10}(Al)$; $pSu = -log_{10}(SO_4)$; d is a constant. Concentrations of aluminum and sulphate satisfy the following transport-dispersion equation

$$\frac{\partial C_i}{\partial t} + U\frac{\partial C_i}{\partial x} = E\frac{\partial^2 C_i}{\partial x^2} + \frac{Q_{is} - q.C_i}{A} \quad (5)$$

where C_i (i=1,2) are aluminum and sulphate concentrations, respectively.; E : dispersion coefficient; U : flow velocity ; Q_{is} : source/sink term coming from plains, underground water-table, pumping, rainfall, settling and interaction between the components; q : lateral flow ; A : cross-sectional area ; E : dispersion coefficient.

Eq. (5) with suitable boundary and initial conditions is numerically solved for aluminum and sulphate and then (4) is used for the calculation of the pH. Data of flow are provided from solving flow equations. The linking terms Q_{is} will be dealt with in the next paragraph.

3.2. Submodel for soil

For a soil column it is suggested to use (2) and (3) for each constituent concerned. For a large area some extensions should be made so that the model can simulate the change of flow in different directions. In the groundwater table the flow is essentially horizontal and thus the groundwater motion is described by the equation

$$\mu\frac{\partial H}{\partial t} = \frac{\partial}{\partial x}\left(T\frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(T\frac{\partial H}{\partial y}\right) + \omega \quad (6)$$

where μ denotes the storage coefficient ; $H(x,y,t)$: groundwater head ; ω : (source or sink term) exchange flow between the canal and water-table or interchange with the unsaturated zone; t : time; x, y : the horizontal coordinates of the water-table; T is the transmissivity and practically can be defined by

$$T = Ks(\eta - \eta_0) \quad \text{if} \quad Z \geq \eta$$
$$T = Ks(Z - \eta_0) \quad \text{if} \quad \eta_0 < Z < \eta \qquad (7)$$
$$T = 0 \quad \text{if} \quad Z \leq \eta_0$$

where Ks : horizontal hydraulic conductivity; η_0 : impermeable bottom level ; η : ground surface level.

Eq. (6) is numerically solved by combining a Galerkin triangular finite element technique for the spatial variables with a finite difference technique for the temporal variable. Flow in the soil is calculated by Darcy's law:

$$U = -\frac{K_S}{\vartheta}\frac{\partial H}{\partial x} \quad ; \quad V = -\frac{K_S}{\vartheta}\frac{\partial H}{\partial y} \qquad (8)$$

where ϑ is effective porosity.

To estimate the exchange flow between a canal and underground water-table, it should be noted that, in general, H is higher than the canal bottom level, so, exchange flow q can be calculated by the formula

$$q = \frac{K_S}{\psi}(H - Z) \qquad (9)$$

where ψ is thickness of the groundwater table, Z is canal water level. If H > Z flow from the groundwater table goes into the canal and inversely if Z > H.

As suggested, eqs. (2) and (3) can be extended to a large-scale, so in that case, for each constituent with concentration Ci, eq. (2) can be rewritten as :

$$\frac{\partial C_i}{\partial t} + \frac{\rho}{\theta}\frac{\partial S_i}{\partial t} + U\frac{\partial C_i}{\partial x} + V\frac{\partial C_i}{\partial y} = \frac{\partial}{\partial x}\left(T\frac{\partial C_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(T\frac{\partial C_i}{\partial y}\right) + \frac{-R.C_i + Q_i^C}{\psi\theta} \qquad (10)$$

where Ci and Si : concentrations of any constituent in the solution and adsorption phases, respectively; ρ : soil bulk density ; θ : volumetric moisture ; ψ : thickness of the water table; U, V : flow rate in x and y directions; R : water taken by roots ; $Q^C{}_i$: source/sink term (e.g. solute exchange flow between groundwater table and canals).

The relationship between Ci and Si for the instantaneous linear model now reads

$$Si = Ki.Ci \qquad (11)$$

Ki is also called the distribution coefficient and is the slope of the isotherm curve. If (11) is used, eq. (10) becomes

$$R_{ei}\frac{\partial C_i}{\partial t} + U\frac{\partial C_i}{\partial x} + V\frac{\partial C_i}{\partial y} = \frac{\partial}{\partial x}\left(T\frac{\partial C_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(T\frac{\partial C_i}{\partial y}\right) + \frac{-R.C_i + Q_i^C}{\psi\theta} \qquad (12)$$

in which $R_{ei} = 1 + \frac{Ki.\rho}{\theta}$ is called the retardation factor.

In order to couple with the problem in canals, only aluminum, hydrogen and sulphate are considered. Two relationships between pH, Aluminum and Sulphate can be used in the model:

+) If jurbanite equilibrium is assumed to be dominant in the soil then the following relationship is used :

$$pH = -d + pAl + pSu$$

+) According to [1,18] the presence of alunite and jurbanite in the soil in the Plain of Reeds has led to a constant value of the acid potential, so the pH can be calculated from the expression

$$pH = 2.3 - \frac{1}{3} Log\left(Al / 3000\right) \quad (13)$$

The distribution coefficient, Ks, for sulphate can be estimated from the Langmuir equation after carrying linearization :

$$K_S = \frac{A_m.b}{\left(1+b.Su\right)^2} \quad (14)$$

where A_m, b are experimental coefficients (Langmuir isotherm constants); Al and Su are aluminum and sulphate concentrations, respectively. Thus it remains to determine only one distribution coefficient Ka for aluminum, of which the magnitude is about 0.001 to 0.1 [10]. If additional constituents need to be considered (e.g., Nitrogene N, phosphorous P,...), some more distribution coefficients must be determined and additional equations of type (12) must be included in the model.

4. NUMERICAL SCHEME

The numerical procedure for flow and mass transport in canals has already mentioned in many studies , e.g. see [11, 21].

4.1. Numerical computation of water movement in the soil

At this stage, equation (12) is numerically solved to give hydraulic head and flow rate at every point in considered area. For good representation of the complexity of the boundary and the bathymetry of the region, the FEM (Finite Element Method) with triangular elements is used in this model. According to FEM [12] a system of coordinate or basis functions N_k (k=1,2,..., M with M is number of grid points) is chosen. Any function f(x,y,t) defined in the considered region can be approximated by :

$$f\left(x,y,t\right) \approx \sum_{j}^{M} f_j\left(t\right).N_j\left(x,y\right) \quad (15)$$

Where f_j (t) is the value of f at node j and at time t. Eq. (15) is substituted into (12) and resulting equations are made orthogonal to Nj according to Galerkin's procedure. The equations that result are

$$\sum_{j}^{M}\iint_{A}\left\{\mu\frac{dH_j}{dt}N_jN_i-\left[\frac{\partial}{\partial x}\left(T\frac{\partial H_j}{\partial x}\right)+\frac{\partial}{\partial y}\left(T\frac{\partial H_j}{\partial y}\right)\right]N_i-\omega N_i\right\}dxdy = J1-J2-J3=0$$

i = 1, 2,....M (16)

where A is a triangular element with three vertices (i, j, k). Upon application of Green's theorem the integral J2 for an element becomes

$$J2 = \iint_{A}\left[\frac{\partial}{\partial x}\left(TN_i\frac{\partial H_j}{\partial x}\right)+\frac{\partial}{\partial y}\left(TN_i\frac{\partial H_j}{\partial y}\right)\right]dxdy - \oint N_i\Re_n d\Gamma \quad ; i = 1, 2,...M \quad (17)$$

$$= J21 - J22$$

where $\Re_n = \left(T\frac{\partial H_j}{\partial x}, T\frac{\partial H_j}{\partial y}\right)_n$

The integral $J22$ is taken along three sides of each element and is the contribution (or extraction) from the boundary or from canals inside region to the soil. The integrals in (16) are calculated and assembled in the following matrix form:

$$\boldsymbol{M}\frac{d\boldsymbol{H}}{dt} + \boldsymbol{D.H} = \boldsymbol{P} \quad (18)$$

where $\boldsymbol{M, D, P}$ are sparse coefficient matrices; $\boldsymbol{H}$ is column matrix with components H_1,

$H_2,\ldots,\ H_M$; matrix $\boldsymbol{P}$ characterizes for exchange flow with outside domain (canals, air,..). If the Preissmann scheme for time derivative is applied eq. (18) becomes:

$$\left(\frac{\boldsymbol{M}}{\Delta t} + \theta \boldsymbol{D}\right)\boldsymbol{H} = \left(\frac{\boldsymbol{M}}{\Delta t} + \theta \boldsymbol{D}\right)\boldsymbol{H^0} - \boldsymbol{D}\boldsymbol{H^0} + \boldsymbol{P} \qquad (19)$$

where $\boldsymbol{H^0}$ is values of $\boldsymbol{H}$ at time $n\Delta t$.

The coefficient matrices in (19) are sparse, so the *SOR* method (**S**uccessive **O**ver**R**elaxation) can be applied to (19). In fact SOR is iterative method applied to sparse matrix and its size is not expandable during elimination.

4.2. Numerical computation of solute transport in the soil

If Darcy's law (8) is used we can rewrite (12) in the form

$$R_{ei}\frac{\partial C_i}{\partial t} - \frac{K_S}{\vartheta}\left(\frac{\partial H}{\partial x}\frac{\partial C_i}{\partial x} + \frac{\partial H}{\partial y}\frac{\partial C_i}{\partial y}\right) = \frac{\partial}{\partial x}\left(T\frac{\partial C_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(T\frac{\partial C_i}{\partial y}\right) + \omega C_i^b - \omega C_i \qquad (20)$$

where C_i^b is concentrations in the source/sink flow.

The same FEM procedure as mentioned above is also applied to (20). It is interesting to note that by the application of FEM and the direct coupling of Darcy's law in one equation (10) we can use directly hydraulic head values at grid point but not its gradient so can avoid numerical error coming from differencing calculation of velocity field.

For each triangular element, Galerkin's procedure is applied to (20) and Preissmann is also used for time derivative we can obtain the following matrix equation:

$$\left\{\frac{\boldsymbol{M1}}{\Delta t} + \theta(\boldsymbol{D} - \mathrm{Kp}\,\mathbf{H})\right\}\boldsymbol{C_i} = \boldsymbol{P_i} + \left\{\frac{\boldsymbol{M1}}{\Delta t} + (\theta - 1)(\boldsymbol{D} - \mathrm{Kp}\,\mathbf{H})\right\}\boldsymbol{C^0_i} \qquad (21)$$

where $\boldsymbol{M1, D, P_i}$ are coefficient matrices ; **H** is also a given matrix coming from hydraulic head calculation; $\boldsymbol{C_i^0}$ are concentrations at previous time step and $\boldsymbol{P_i}$ is mass flux of exchange flow (e.g. from canal or to canal); Kp is average over element value concerning hydraulic conductivity; θ is weighting coefficient.

Eq. (21) is put together over all elements and the resulting equation is also solved by SOR method.

5. OUTLINES OF APPLICATION OF THE DEVELOPED MODEL TO THE AREA OF TAN THANH FARM

To illustrate the use of the developed model and to evaluate the validity of the model's conceptual basis, the model is applied to Tan Thanh area with data set collected in March 1995. During five days, from 17 to 22 March, a measurement campaign was carried out in Tan Thanh and covered about 250 ha (the schematization of the master model for Tan Thanh farm consists of two submodels, one-dimensional for canals and two-dimensional for the soil. The two-dimensional region is divided into 42 triangular elements with 32 nodes. The one-dimensional schematization contains 10 canal branches and 36 grid points). The collected data consist of four types:

+ physical data in three surrounding canals and in two ditches inside the area.

+ chemical data collected in canals.

+ ground water level (physical data) collected in the soil.

+ and chemical data collected at some nests in the soil.

From data analysis it is suggested to use the following values for parameters in the test runs of the model : storage : μ = 0.002 & 0.014 ; moisture θ: from 0.60 to 0.75 ; effective porosity: 0.75 ; thickness of ground table: 1.2m . The Langmuir isotherm average constants: A_m = 12.38; b = 1.28E-2; horizontal conductivity hydraulic varies from 1m/day to 5m/day.

It is also noted that it is difficult to correctly create a relation between pH, Aluminum and Sulphate in the soil. Look into the below table we can see one value of pH can correspond to some values of Aluminum and Sulphate . For example, from the first two rows and (pH = 4.02) and the rows 5 and 6 (pH= 3.52 and 3.53) it seems pH does not depend on Aluminum concentrations.

Date	Time	Nest	pH	Al^{+3} (mg/l)	$SO4^{-2}$ (mg/l)
03/17	19	F1	4.02	20.30	429
03/17	23	F1	4.02	10.07	429
03/18	3	F1	4.01	5.94	446
03/19	1	F1	3.53	16.36	534
03/19	3	F1	3.52	12.02	515
03/19	17	F1	3.53	9.56	515
03/18	15	F8	3.52	14.19	784
03/20	1	F8	3.53	12.86	679
03/21	1	F8	3.52	11.68	693
03/17	21	F10	3.52	4.79	342
03/18	1	F14	3.51	5.85	335
03/18	9	F11	3.50	10.01	869

So we can conclude that the relation pH= 2.3 - Log(Al/3000)/3 mentioned in [1] is not suitable for simulation of pH in the soil of Tan Thanh area. So data of March 1995 have been used only for the test runs.

6. REMARK AND CONCLUSION

Some first test runs mentioned above show that physically the developed model can be used for real-life simulations of large-scale problems. The chemical equilibrium formulated by previous studies, mainly for soil column, seems to be suitable for a limited range of simulations. In order to correctly reproduce chemical processes in the soils or in canals and their interactions further more studies must be carried out.

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CALCULATION OF FLOOD DISCHARGE AND STORAGE CAPACITY BY CLIMATE CHANGE SCENARIOS IN RACH BAU HA, TUY HOA CITY USING THE MIKE MODEL

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Summary: *The world climate change is increasingly severe with the most obvious manifestation is of global warming. Extreme weather phenomena such as ice melting, sea level rise, hurrican, flood, tsunami, earthquake, drought, etc. have led to urban flooding, especially in coastal urban areas, causing damage to human life and property. The climate and topography characteristics of Tuy Hoa city are quite complicated and being affected by most types of natural disasters, in which storms and floods frequently occur in the downstream of rivers. Huge amount of water from upstream in combination with heavy rain have caused numerous flash flooding. Racâu, the main flood-discharge area for part of the city, is a low-lying area and often being submerged during soakers. The article aims to research the MIKE model application in forecasting the flood discharge and storage capacity of Rach Bau Ha, Tuy Hoa city, Phu Yen province according to climate change scenarios and proposing appropriate alternative for the purpose of minimizing flood in the research area. Collected hydro-meteorological, topographical and geological data, previous research results, synthesis, analysis and calculation of designed hydro-meteorological characteristics will be used as input of MIKE model, with aiming to simulating the flood discharge and storage of the research area and along Rach Bau Ha; thereby proposing suitable plan to eliminate the flood effects. The results show that the cross-sectional area and lake area of Rach Bau Ha according to the PA3 scenario (lake surface area F = 12.50 ha) completely ensure the flood discharge and storage of Rach Bau Ha, without much increase of the maximum water level and inundation duration, ensure that the water levels of the canal shall not affect inhabitants and infrastructure of the vicinity.*
Keywords: *Mathematical model, flood discharge, climate change.*

1. INTRODUCTION

Tuy Hoa city, Phu Yen province is becoming a dynamic economic center and an attractive destination of the region. The city is prioritizing the construction of comprehensive and sustainable infrastructure, of which the planning and construction of urban areas will significantly contribute to the development demand of the city. The climate and topography characteristics of Phu Yen province in general and Tuy Hoa city in particular are quite complex and being affected by most types of natural disasters with a frequent occurence of storms and floods in the

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downstream of rivers. Huge amount of water from upstream in combination with heavy rain have caused numerous flash flooding. There have been a number of historic floods causing extensive damage in 1993, 1999, 2007 and 2009. According to storm partition results, risk identification of storm and storm-surge of coastal areas, Tuy Hoa city is located in zone IV with rain-storm concentrated in November and December. The storm level was recorded at level 13, maximum daily rainfall was up to 470mm, sea level rose by 1.5-2.0m, in case of flood tide combining with storm-surge, the water level could reach 3.2-3.4m. Climate change has also contributed to an increase in extreme weather that affects inundation. Rach Bau Ha, the main flood-discharge area for part of the city, is a low-lying area and often being submerged during soakers. Therefore, it is necessary to apply MIKE model to calculate and forecast flood discharge and storage of Rach Bau Ha for the purpose of formulating drainage planning and evaluating impacts of construction works on drainage capacity of Tuy Hoa city.

2. THEORETICAL BASIS AND CALCULATION METHODS

2.1. Basis for selection of calculation methods

In order to choose a reasonable calculation and anticipation method, factors affecting the capability of flood discharge and storage of Rach Bau Ha should be evaluated:

+ Width of fortified embankment canals along Rach Bau Ha.

+ System of bridges, road culverts and tide-lock in the downstream area of Rach Bau Ha before discharging into the sea.

+ Due to low terrain, the influence of tidal level at the estuary of Rach Bau Ha during the process of flood discharge and storage is quite significant.

+ Landscape construction and improvement of the canal area that affects the flood storage volume of Rach Bau Ha.

+ The accretion and dumping in the channel, damage of tide-lock and regulators greatly affect the ability of flood discharge and storage of the canal.

The problem of hydraulics and canals is quite complicated, requiring a large amount of data; research tools and methods must simulate the actual flow on the canal as closely as possible. On the basis of the problem requirements and collected survey data, the authors have chosen a mathematical modeling method to simulate the flood discharge and storage of Rach Bau Ha.

The mathematical modeling method is based on the system of mathematical equations describing the flow and sediment rule of the researched river section, determining reasonable boundary and initial conditions in order to find out analytic and algebraic solutions to research problems. In mathematical models of two-dimensional (2D) and three-dimensional (3D) flow simulations, river-bed development simulation, the MIKE model is preeminent and most reliable to calculate and forecast flood discharge of the research area.

The MIKE model, developed by DHI Water & Environment, is a software package used to simulate flow (flow discharge), water quality and sediment transport at estuaries, rivers, irrigation canals and other water bodies. The MIKE software consists of many application modules for different problems. Considering the calculation requirements of the research area, the authors have used hydraulic and sediment transport modules of MIKE11 and MIKE21. Hydrodynamic (HD) modeling module, the central part of the MIKE 11 modeling system, is the basis for most of the modules including: flood forecast, diffusion loads, water quality and sediment transport modules. The hydraulic module of MIKE 11 solves synthetic equations by flow direction to ensure the consecutiveness and conservation of momentum (Saint Venant system of equations).

2.2. Application of hydraulic calculation model for flood discharge and storage of Rach Bau Ha

2.2.1. Scope of hydraulic calculation research

The scope of the study is the flood discharge basin of Rach Bau Ha as shown in Figure 1:

Figure 1: Research area for flood discharge and storage of Rach Bau Ha (zone B).

2.2.2. Hydraulic calculation diagram

Hydraulic calculation on flood discharge and storage of Rach Bau Ha is closely related to the tidal level of Da Rang estuary. Therefore, the hydraulic calculation diagram is set up for the canal section from the upstream of Rach Bau Ha to the tributary of Da Rang river with a simulation length of about 6.3km.

Figure 2: Diagram of river network and hydrological stations of research area

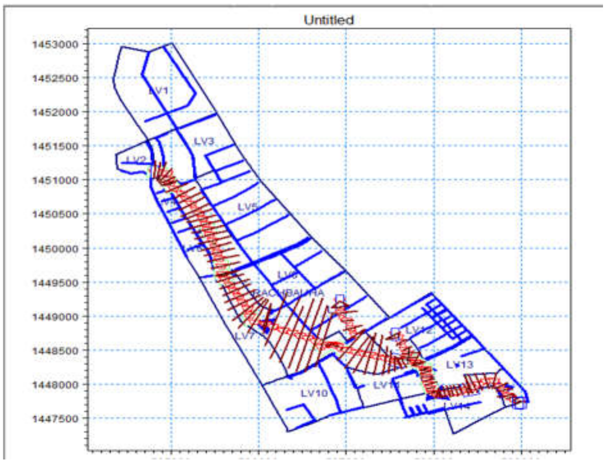

Figure 3: Diagram of simulated river network by hydraulic model

2.2.3. Set up MIKE 11 hydraulic model

Input data:

- Terrain data is the topographic cross-sections of construction projects along Rach Bau Ha. The cross-sections of remaining areas are based on the topographic map of Tuy Hoa city with the scale of 1:2000.
- Hydrological data is calculated based on actual measured data from the upstream of Rach Bau Ha to the Da Rang estuary with a total length of 6.3km. The upper boundary is the design rainfall graph of drainage areas, upstream of Rach Bau Ha; the lower boundary is the water level corresponding to the design frequencies; Middle tributary boundary is the design rainfall graph of the urban drainage areas to Rach Bau Ha.
- System of works on canal: Simulated canal system consists of works affecting the flow regime of research area such as traffic roads, bridges, culverts, channels, regulators...
- Model revision and calibration: The rainfall and inundation model selected to be verified and calibrated is the rainfall model in December 2016, which is the recent soaker causing severe flood in Rach Bau Ha.

Calculation scenarios

+ Hydrological calculation scenario: includes the design rainwater drainage scenario with a 5-year repetition cycle (Tuy Hoa is grade II urban area. Open canals and ditches will be calculated according to design rainfall with a 5-year repetition cycle).

+ Tidal level scenario: The tidal level is determined at Da Rang estuary with a 5-year repetition cycle.

+ Tide-lock operation scenario: The tide-lock is calculated for 2 cases: tide-lock completely closed at high tide; tide-lock operated when the sluice's water level is higher than the tidal level.

+ Climate change - sea level rise scenario: For coastal urban areas affected by tidal, climate change - sea level rise is an important factor in terms of water drainage. Scenarios include:

- Scenario for design rainwater drainage increased by 3%

- Scenario for tidal level rose by 30cm.

Climate change scenarios are calculated for the proposed lake surface area that does not consist of extreme variables within the same scenario. Each scenario calculates one extreme factor due to climate change: increased design rainfall or sea level rise.

+ *Scenarios of using lake surface area as detention basin:*

- PA0: *The urban area has not yet been built (current status scenario).*

- PA1: *The lake surface area has been used as stipulated in the Decision approving the plan of previous period with the scale of 1:5000, F lake = 7.45ha.*

- PA2: *The proposed lake surface area has been used in this period: corresponding to 10.00 ha.*

- PA3: *The lake surface area: corresponding to 12.50 ha*

Calculation results:

- The calculation results of design rainwater drainage by actual rainfall model of Tuy Hoa meteorological station show that the water level is higher than in the rainwater drainage model as stipulated in TCVN 7957 (2008).

- The maximum water level according to the design rainwater drainage with a 5-year repetition cycle is of +2.22m without tide-lock, corresponding to the lake surface area of PA1 (7.45 ha as approved in previous period) and +1.72m with operated tide-lock.

Among all the calculation scenarios, PA1 has the maximum water level, with a rise of 0.06 - 0.20 m. PA3 (F lake = 12.50 ha) has an increase of water level of 0.04 -0.16 m. The lake surface area varies from 7.45 ha to 12.50 ha, showing that the water level in research area remains stable, with the maximum variation of 0.06m.

- The inundation duration of Rach Bau Ha depends much on the estuary's water level as well as the opening and closing mode of flap valves. In case the flap valves operate when the tidal level is lower than the water level in the canal, the effect is negligible with an increase of about 30 minutes compared to current situation. In case flap valves are completely closed, the inundation time will last longer, but this scenario is less likely to happen.

The time to maintain the water level higher than +1.6m in case of having rainfall with a 5-year repetition cycle is of 6 hours 20 minutes. The scenario is calculated for actual flood model and the downstream flap valves are operated.

Table 1: Calculation results of water level along Rach Bau Ha, taking into account climate change and sea level rise scenarios

No.	Section	Distance (m)	Maximum water level (m)				Notes
			Design rainwater drainage by TCVN 7957		Design rainwater drainage by actual typical rainfall		
			Tidal level increases of 30 cm	Rainfall increases of 3%	Tidal level increases of 30 cm	Rainfall increases of 3%	
1	MC01	0	1.61	1.62	1.82	1.80	Upstream Rach Bau Ha
2	MC06	302	1.58	1.59	1.82	1.80	Mau Than road culvert
3	MC22	1803	1.58	1.59	1.81	1.79	Nguyen Huu Tho road
4	MC26	2187	1.58	1.59	1.77	1.75	Planned area
5	MC31	2725	1.58	1.59	1.77	1.75	Mau Than road
6	MC34	3067	1.58	1.59	1.77	1.75	Planned area
7	MC39	3542	1.58	1.59	1.77	1.75	Tran Phu road culvert
8	MC48	3799	1.58	1.59	1.74	1.72	Culvert to Son lake
9	MC56	4416	1.58	1.58	1.72	1.70	Mau Than culvert
10	MC57	4465	1.58	1.58	1.71	1.69	Youth park
11	MC59	4655	1.58	1.58	1.69	1.67	Dien Bien Phu road culvert
12	MC60	4750	1.58	1.58	1.68	1.67	Nguyen Hue road culvert
13	MC66	5119	1.58	1.58	1.67	1.65	Le Loi road culvert
14	MC68	5238	1.58	1.58	1.66	1.64	Hung Vuong road culvert
15	MC75	5594	1.58	1.58	1.62	1.60	Truong Chinh road culvert
16	MC79	5909	1.58	1.58	1.62	1.59	Van Kiep park
17	MC80	6010	1.58	1.58	1.62	1.59	Tide-lock
18	MC81	6092	1.73	1.42	1.55	1.25	Tran Hung Dao road culvert
19	MC85	6330	1.57	1.27	1.55	1.25	Tide-lock (Da Rang river)

Table 2: Peak water level duration of Rach Bau Ha-Calculation results of actual rainfall for the 5-year repetition cycle

Flap valves close completely.			
No.	Scenarios	Peak duration (hour)	Notes
1	PA0.2	55	Current status scenario
2	PA1.2	42	F lake =7.45 ha
3	PA2.2	42.3	F lake =10.00 ha
4	PA3.2	42.5	F lake =12.50 ha
Flap valves operate.			
No.	Scenarios	Peak duration (hour)	Notes

Flap valves close completely.			
No.	Scenarios	Peak duration (hour)	Notes
1	PA0.3	44.2	Current status scenario
2	PA1.3	43.5	F lake =7.45 ha
3	PA2.3	43.6	F lake =10.00 ha
4	PA3.3	43.7	F lake =12.50 ha

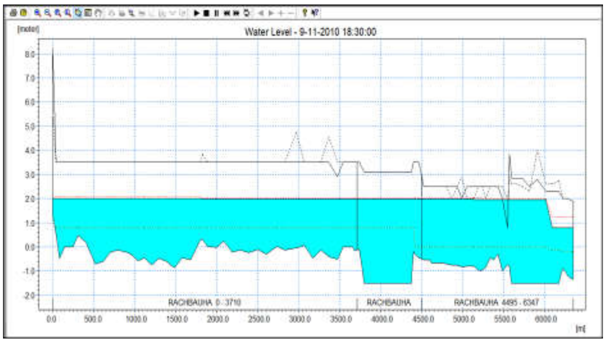

Figure 4: Water level along Rach Bau Ha – Current status scenario – Rainwater drainage model by actual rainfall model – Flap valves close completely.

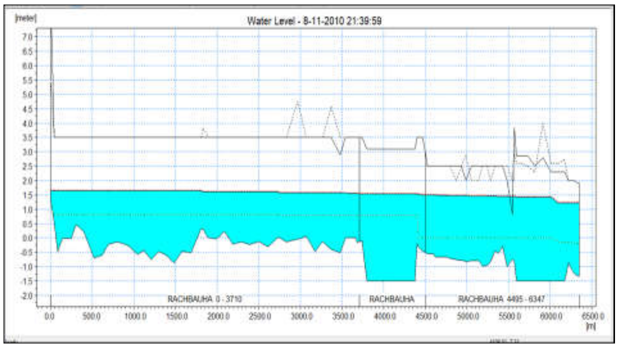

Figure 5: Water level along Rach Bau Ha – Current status scenario – Rainwater drainage model by actual rainfall model – Flap valves operate

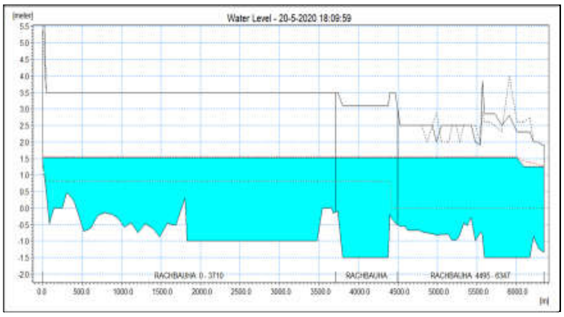

Figure 6: Water level along Rach Bau Ha – Lake surface area by PA3 scenario –Rainwater drainage model by TCVN 7957 (2008)

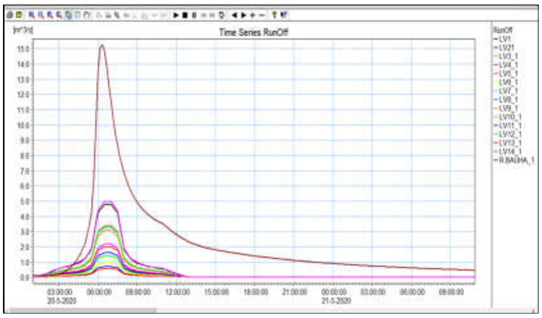

Figure 7: Discharge flow into Rach Bau Ha of all water concentration basins – Rainwater drainage model by TCVN 7957 (2008)

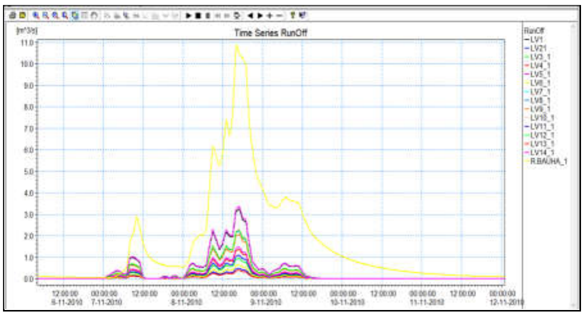

Figure 8: Discharge flow into Rach Bau Ha of all water concentration basins – Rainfall model scenario by actual rainfall model

3. CONCLUSIONS

From the above results, it could be seen that the cross-sectional area and lake area of Rach Bau Ha according to the PA3 scenario completely ensure the flood discharge and storage of Rach Bau Ha, without much increase of the maximum water level and inundation duration. The water levels of the canal do not affect inhabitants and infrastructure of the vicinity.

It is suggested to exploit and use lake surface of urban area in the North of Tran Phu street according to the PA3 scenario, with a total surface area of 12.50 ha. Thus, the maximum water level corresponding to rainwater drainage of the 5-year repetition cycle is of 2.18 m, an increase of 0.04 -0.16cm compared to the current status of works on the basin.

4. ACKNOWLEDGMENTS

The authors would like to express sincere thanks to the University of Mining and Geology for assistance and facilitation on the completion of this research.

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STUDYING INTO SOLUTIONS FOR FLOOD AND INUNDATION CONTROL IN BUI BASIN AND ITS VICINITY

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Summary: *Bui River is a tributary of the Day River that flows in the territory of Hanoi city and Hoa Binh province. The downstream part of the Bui River, located in the districts of Chuong My and Quoc Oai of Hanoi, is where heavy rains often occur, causing serious impacts on people, especially the floods in 2008, 2017, and 2018 notably. The study used the MIKE hydraulic model, ArcGIS software, and Google Earth to build inundation maps and evaluate effectiveness of the solutions. The research results have shown solutions to prevent and control flooding and inundation for the Bui River basin and its vicinity, including Restoration of the Tich, Bui and Day rivers; Upgrading and building new reservoirs; Building channels to isolate mountain floods; Upgrading and building new dikes; Upgrading and building new drainage pumping stations, detention basins, and relocation in vulnerable areas. In addition, the study also estimated the number of households to be relocated and the required costs to implement the solutions.*

Keywords: *Bui basin and its vicinity, Flood prevention solutions, MIKE, ArcGIS*

1. INTRODUCTION

Bui River has a length of about 40km. Its upstream flow starts from Luong Son district, Hoa Binh province to Tan Truong bridge in the West – East direction on a 20 km length. before merging into Tich River then flowing in the Northwest – Southeast direction and finally meets the Day River at Ba Tha [1].

The lower part of Bui River basin, which is located in Chuong My and Quoc Oai districts of Hanoi capital, has a dense population. In the past 10 years, this area has been seriously flooded three times, seriously affecting the property, daily life and living environment of people [2-3]. For instance, in 2018, the flooding duration was more than 20 days. Given the current rapid socio-economic development in peri-urban areas, the damage will be more serious without effective solutions to prevent and adapt to flood and inundation situation in the basin.

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In Vietnam, research on flood and inundation has received much attention in recent years, especially those using new technologies such as remote sensing, satellite rainfall data [4–5] and studies on flood mapping [6-8]. So far, there have been several topics and projects that studied flood control planning for the Bui river basin and its vicinity. They are comprehensive studies assessing the impact and damage caused by floods and storms on socio-economic life [1–3]. However, most of the solutions implemented are still of local significance and have not completely solved the flooding and inundation problem in the Bui river basin.

Flooding in the Bui river basin is a complex problem that has caused by floods on large rivers overflowing into the fields and mountain floods (horizontal forest floods) flowing through the basin, accompanying the transfer of flood from the Red River to the Day River. Therefore, flood control solutions for the Bui river basin need to be approached in an integrated way.

This article cites a number of solutions for flood control in the Bui river basin and its vicinity, along with assessing the impacts of these solutions and finally proposing suggestions.

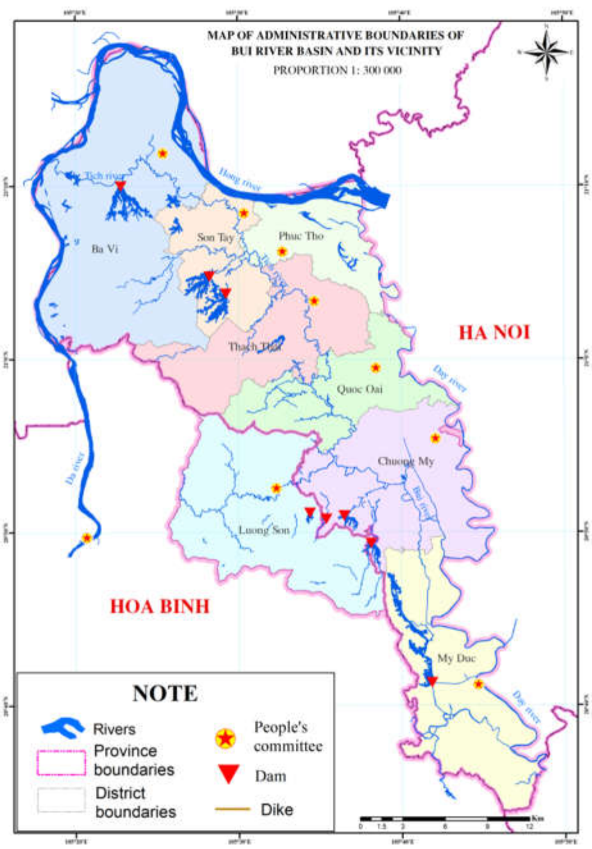

Figure 1: Map of the Bui river basin and its vicinity

2. MATERIALS AND METHODS

This research synthesizes information and uses results of baseline investigations to collect data on the state of infrastructure for flood prevention, water drainage, and flooding in the study area.

Qualitatively, the research provides an overall assessment of the causes of inundation and locations where infrastructure and natural conditions affect flood drainage and vulnerable areas. In addition, the study inherits the solutions mentioned in previous irrigation and disaster prevention plans, which were related to the study area but have not yet been implemented, besides consultation with experts and opinions of the study team to come up with solutions to prevent floods and inundation for the Bui river basin.

Quantitatively, the authors used the MIKE hydraulic model suit developed by the Danish Hydraulic Institute (DHI), including the one-dimensional hydraulic model (MIKE11), the two-dimensional hydraulic model (MIKE21) and the flood hydraulic model (MIKE FLOOD) to calculate hydraulics for the scenarios [9-12]. The modelling results were then used to build inundation maps using ArcGIS software. Furthermore, Google Earth software and population data were also used to calculate the number of affected households that need to be relocated. From there, scenarios were compared and evaluated in terms of the effectiveness of the proposed solutions.

- MIKE 11 model:

A one-dimensional hydraulic model MIKE 11 for the study basin was built with the river network diagram as follows:

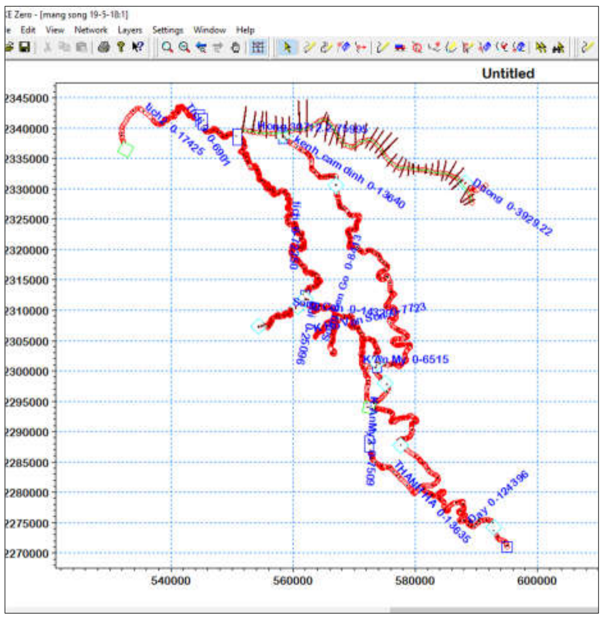

Figure 2: Computational river network

River network: The river network included in the calculation is shown in Figure 2.

+ Red River: from Son Tay hydrological station to Hanoi hydrological station: 45.283 km long.

+ Duong River: from the Red-Duong junction to the Thuong Cat hydrological station: 3.625 km long.

+ Cam Dinh–Hiep Thuan canal: from Cam Dinh culvert to Day dam: 13.64 km long

+ Entire Day river: from downstream of Day dam confluence to Phu Ly hydrological station: 124.396 km long.

+ Tich River: from Luong Phu (located adjacent to Da River) to the outlet to the Bui River at Tan Truong bridge: 96.576 km long.

+ Bui river: from Tan Truong bridge to the outlet to the Day River at Ba Tha: 25.096 km long.

+ Con River: from Dong Chui bridge (Luong Son town) to merge into the Bui river at Xuan Mai: 14.329 km long.

+ Thanh Ha River: from Quan Son to the outlet to the Day River at Hoi Xa bridge: 13.635 km long.

In addition, there are branches of canals: Ben Go river, Cau Tay stream, and An My canal.

- MIKE21 model:

The two-dimensional hydrodynamic domain is defined as an area that is most likely to be affected by floods or heavy raina. In the study area, this calculation domain is determined based on the results of analysis of post flood surveys, topographic maps at scale 1:5,000, 1:10,000. Upon analysis, the flood calculation area is limited to the right side of Tich and Bui rivers. The entire calculation domain, after being preliminarily defined through the SRTM global elevation numerical model, is further divided into smaller regions of about 28,406 hectares (Figure 3). In this study, the setting of the parameters of the grid is divided into categories, with the density decreasing from the river side into the field.

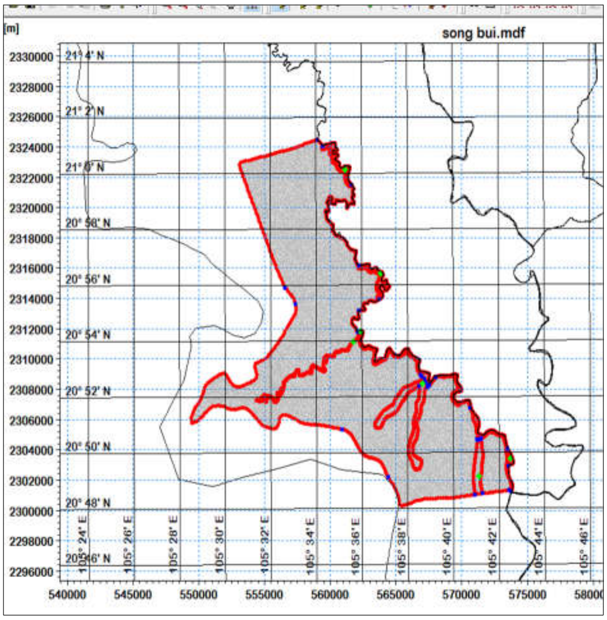

Figure 3: Calculation grids

- Linking the one- and two-dimensional hydraulic models

Although the MIKE 11 and MIKE 21 models have outstanding advantages in simulating 1-D flow in complex river networks and can simulate 2-D of overflow on the field surface, they have individually some limitations in flood simulation. Therefore, it is necessary to link the MIKE 11 and MIKE 21 models to form a MIKE FLOOD model. One or more MIKE 21 cells can be connected to the end of a MIKE 11 tributary and can be connected to the beginning of another branch to the downstream of the river network. MIKE FLOOD is created by connecting a detailed MIKE 21 mesh into a large MIKE 11 network.

3. RESEARCH RESULTS AND DISCUSSION

3.1. Simulation, calibration and validation of the hydraulic models

After linking the MIKE 11 model with the

MIKE 21, simulations will be run. The results obtained from the first runs are compared with the measured data at Ba Tha station to determine the accuracy of the results. In the studies where the required documents are available and of high and accuracy, the model calibration only needs to be done by adjusting the Manning coefficient. The flood simulation period is from 15/7/ 2018 to 27/8/ 2018 (Figure 4).

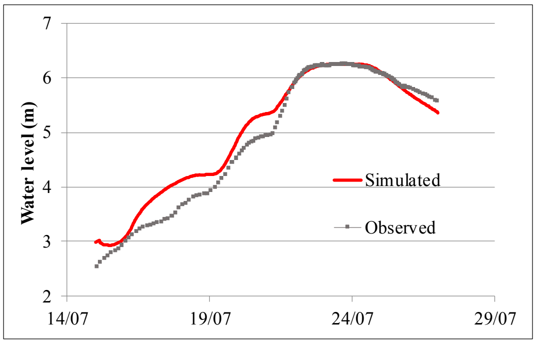

Figure 4: Simulated and observed water level at Ba Tha station, calibrated for year 2018

Table 1: Calculation results of flood water levels in July–August 2018

No	Location	River	Hmax observed (m)	Hmax simulated (m)	Error
1	Ba Tha	Day	6.250	6.251	0.001

On the basis of the set of parameters determined during the simulation of the occurred flood in July–August 2018, the research team conducted the validation against the actual flood occurred in November 2008 and October 2020.

Table 2: Observed and simulated maximum water level of the November 2008 flood

No	Location	River	Hmax observed (m)	Hmax simulated (m)	Error
1	Ba Tha	Day	6.341	6.340	0.001

Table 3: Observed and simulated maximum water level of the October 2020 flood

No	Location	River	Hmax observed (m)	Hmax simulated (m)	Error
1	Dong Chui bridge	Con	13.389	13.368	-0.021
2	Ba Tha	Day	4.000	4.001	0.001

The simulation results of the November 2008 and October 2020 floods show that the difference between simulation and observation is –0.021÷0.001 m. On the other hand, the shape of the water level and discharge curves at each location is very similar (Figure 5).

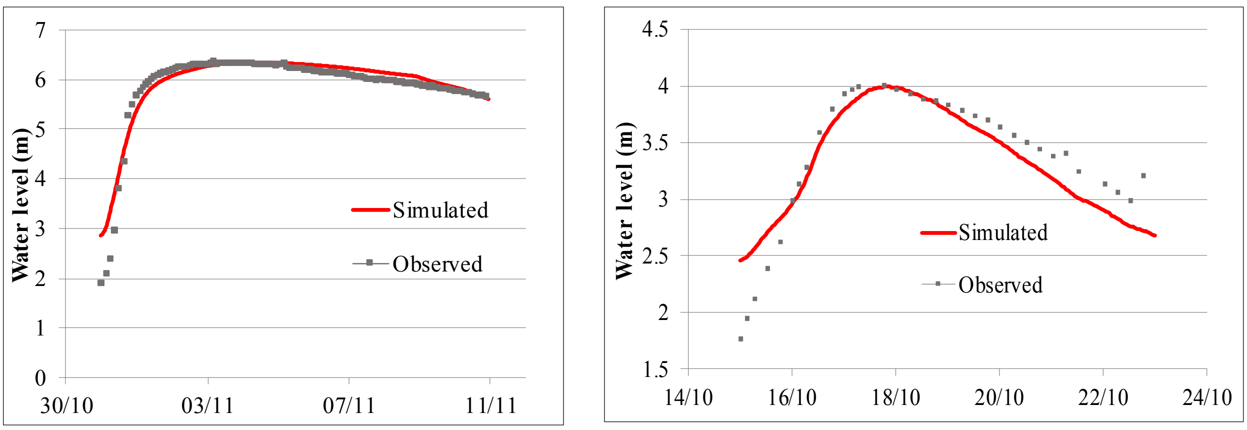

Figure 5: Simulated and observed water level at Ba Tha station, validated: (a) 2008; (b) 2020

3.2. Analysis of the results of the calculation scenarios

a. Scenarios for flood prevention

- Scenario 1 (KB1): Restoration of Tich, Bui, and Day rivers. The rehabilitation scale is inherited from the Day River Flood Prevention and Control Plan, and the Tich River Rehabilitation Project from Luong Phu.

- Scenario 2 (KB2): New construction of Tan Vinh reservoir and rehabilitation of Tich, Bui, and Day rivers. The dimension of Tan Vinh reservoir is calculated for many cases of different flood storage capacities, the selected scale is presented in the following section.

- Scenario 3 (KB3): Construction of mountain flood isolation chanels, renovation and upgrading of dikes, construction of pumping stations, and restoration of Tich, Bui, and Day rivers. The length of the mountain flood isolation channels, the dike lines, and the size of the drainage pumping stations are selected following the topographical conditions and drainage requirements, the specific sizes are shown in the following section.

- Scenario 4 (KB4): Combining the solutions mentioned in KB1, KB2, and KB3.

b. Inundation level corresponding to the scenarios

Based on the calculation results of the link between the 1-dimensional hydraulic model MIKE11 and the 2-dimensional hydraulic model MIKE21 in MIKE FLOOD, the largest flooded area is determined for each scenario and flood maps are built correspondingly using ArcGIS software [13].

Table 4: Comparison of the scenarios

No	Parameter	Unit	Status quo	KB1	KB2	KB3	KB4
1	Hmax in Ba Tha	m	6.34	6.08	6.04	6.20	6.13
2	Hmax in Tan Truong	m	7.96	7.75	7.57	7.78	7.60
3	Qmean	m^3/s	298.5	369.0	362.1	370.1	361.9
4	Duration of water level >5m in Ba Tha	day	12.2	7.0	6.8	7.7	7.6
5	Area with flooded depth > 20cm	ha	6538	3965	3006	2944	2647

- KB1: Given the very poor flood drainage capacity of the Bui and Day rivers, the restoration of the Tich, Bui, and Day rivers according to KB1 (clearing the narrowed sections, widening riverbeds, dredging beds river to ensure flood drainage elevation) is an urgent requirement. The rehabilitation of the riverbeds of Tich, Bui, and Day rivers as proposed above can help improving the flood drainage capacity in the basin significantly. In addition, the flood water level is also lowered and so the flooded area is reduced consequently. It can be affirmed that the rehabilitation, dredging, and expansion of the Tich, Bui, and Day rivers are mandatory requirements for flood prevention.

- KB2: Additional construction of Tan Vinh reservoir with a flood storage capacity of about 17.6 million m3 (accounting for about 5% of the total inflow) combined with the restoration of rivers can lower the water level at Tan Truong and Ba Tha by 18cm and 4cm, respectively (compared to KB1). Also compared to KB1 (improvement of the riverbeds of Tich, Bui, and Day rivers), part of the flood flow is retained in the proposed reservoir, so the flooded area is reduced by 959ha. Inundation duration and conveyance capacity of Bui and Day rivers do not change significantly. Thus, the construction of Tan Vinh reservoir can effectively reduce flood water levels, and the flooded area for Chuong My district.

- KB3: By upgrading the dike and building mountain flood isolation channels, building drainage pumping stations combined with river improvement (without building Tan Vinh reservoir), flood water level is not reduced compared to KB1, but flood water level at Tan Truong increases by 3cm on contrary. The most obvious effect of KB3 compared to KB1 is to reduce the flooded area for Chuong My district (an additional 1021ha reduction compared to KB1). The dike lines are closed, so flood water can't overflow into low-lying areas, then almost the entire right side of the Bui river in Chuong My district is protected, except for some areas in the polder and the area intercalated between the Cau Tay and Ben Go streams. The effectiveness of reducing flooded area in KB3 and KB2 is similar (with a reduction of d 1000ha approximately compared to KB1).

- KB4: If all solutions are implemented (rehabilitation of the rivers; construction of Tan Vinh reservoir; upgrading of dikes and construction of mountain flood isolation channels), the flood water level will be reduced by 18cm at Tan Truong compared to KB3. However, the flooded area of KB4 compared to KB2 or KB3 do not change significantly. Thus, only KB2 or KB3 should be selected considering the effectiveness of reducing the flooded area among the scenarios, while ignoring KB4 as its investment cost is higher but the effect of reducing the flooded area is not significant).

3.3. Solutions to prevent inundation for the Bui river basin

Based on the calculation results on the effectiveness of flood and inundation control for each scenario, the study proposes the solutions to prevent flooding and inundation for the Bui river basin as follows:

a. Solutions to rehabilitate Tich, Bui and Day rivers

Tich, Bui, and Day rivers are the main flood drainage channels for the basin. Currently, the riverbeds are narrowed, deposited, and encroached that seriously affect flood drainage capacity. Therefore, it is necessary to implement a solution to restore the riverbeds of the Tich, Bui, and Day rivers, and this is also the core solution, which has been proposed in a few previous studies and is currently in the process of implementation.

b. Solutions to upgrade and build new reservoirs

It is topographically and hydrologically feasible to build a reservoir in Tan Vinh. However, the construction of a flood control reservoir on the mainstream of the Bui River at Tan Vinh will cause major flooding to the residences, infrastructure, and tourist and service areas in the Luong Son district.

Based on the technical parameters of the reservoir, the reservoir's water level is expected to be 45m, corresponding to a total capacity of 39.8 million m^3, and a flood storage capacity of 17.6 million m^3.

Table 5: Effects of a possible Tan Vinh reservoir

No	Elevation	Capacity (million m^3)	Flood storage capacity (million m^3)	Water surface area (ha)	Number of relocated households	Flooded roads (km)
1	30	5,03	3,32	88	101	2,06
2	35	11,0	5,9	155	194	4,36
3	40	22,2	11,2	283	306	9,20
4	45	39,8	17,6	421	508	13,34

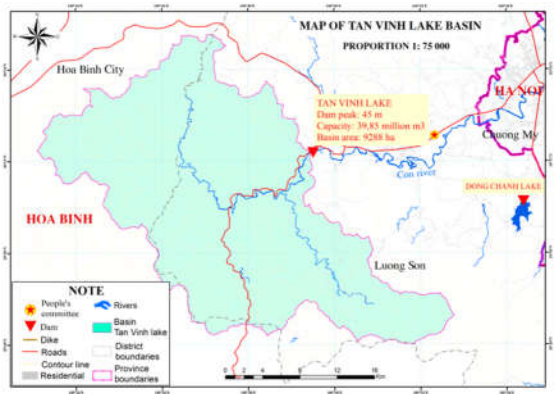

Figure 6: Map of the Tan Vinh reservoir catchment area (proposed to be built)

c. Solutions to build isolation channels for mountain floods

- Dong Chanh and Mieu sub-basins

It is necessary to restore the Dong Chanh stream divert water directly from the Dong Chanh sub-basin to the Bui River without pouring into the Bui River polder. The proposed isolation channel originates from downstream of Dong Chanh lake in Tan Tien commune (Chuong My district), collects water from the Dong Chanh sub-basin, runs along the low-lying areas and connects to Dong Chanh stream, then pours out into Bui river at Nhuan Trach commune (Luong Son district). The length of the isolation channel is approximately 3.5km and the width is about 10m. The channel passes through field areas without affecting residential areas.

- Dong Suong and Van Son reservoir catchment areas

The flood storage area of Cau Tay and Ben Go streams is about 400ha. This research suggests rehabilitating the streambeds of Cau Tay and Ben Go to increase flood drainage: the stream cross-section is proposed to be maintained as the current cross-section with some widening at the congested and narrowedsections. It is also to raise and improve the quality of the Bui 2 dike; build and upgrade the embankments of the villages to protect residential areas against the designed flood and protecting the flood storage space located between the Bui 2 dike and the embankments without building works or houses in the flood storage area.

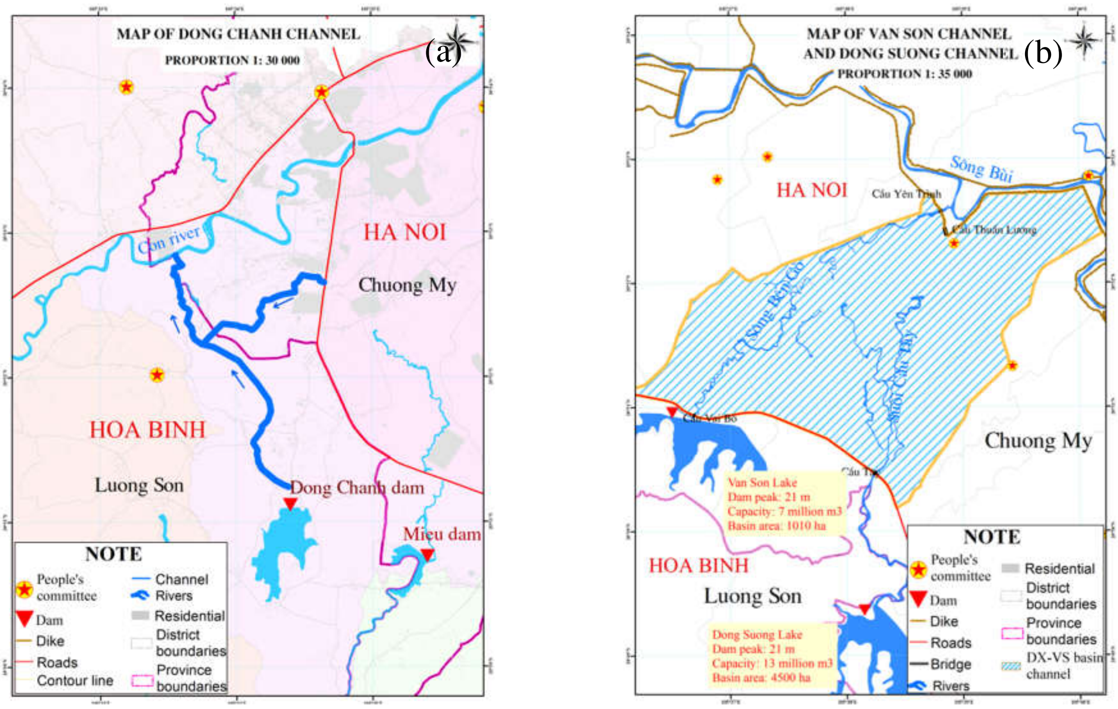

Figure 7: Map of channel routes to isolate mountain floods in the sub-basin (a) Dong Chanh, Mieu; (b) Dong Suong, Van Son

d. Solutions to upgrade and build new dikes

To prevent flood overflowing into economic and residential areas in the basin, it is necessary to study upgrading and building new dikes. In inheriting the previously studies, this research suggests upgrading and building new dikes including the left of Tich river dike, the left Bui river dike, the right Bui river dike; the Bui 2 river dike, and the Cau Tay dike.

Figure 8 shows the proposed dikes for upgrading and new construction

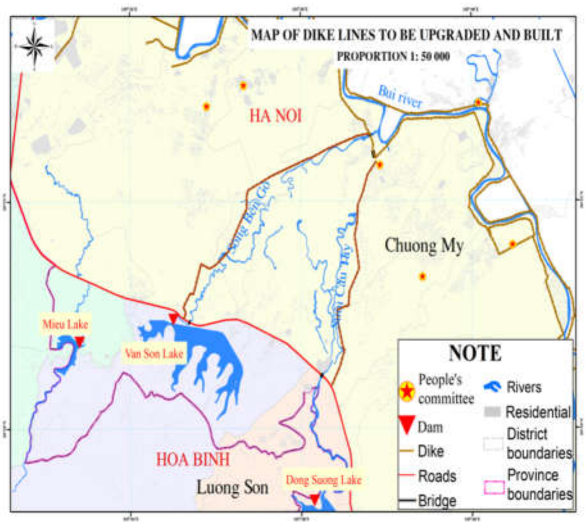

Figure 8: Dike routes to be built: Cau Tay dike

e. Solutions to upgrade and build new drainage pumping stations and detention basins

Once the proposed channels and Bui river dikes are built to present floods from mountains and the rivers, it is additionally necessary to build more drainage pumping stations and detention basins to drain water caused by local rain in the Bui river delta.

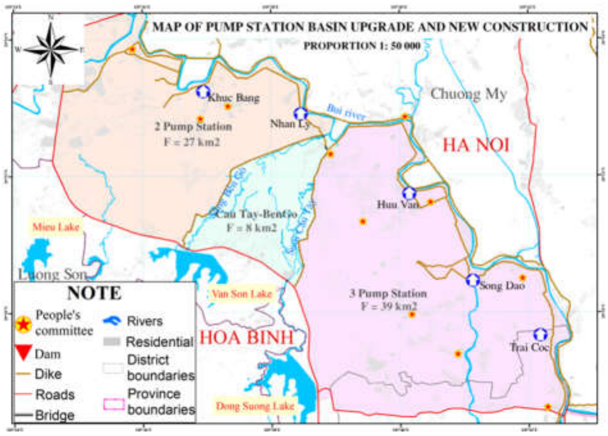

Figure 9: Location, scale and service area of the proposed pumping stations and detention basins

g. Relocation solutions in vulnerable areas

People living on the polders not only face the risk of flooding, but also hinder the flood drainage capacity of the Bui River, and the Day River, and affect the safety of the dikes and other structures along the rivers. The research has determined the minimum riverbed width of Bui river as is 70m at Tan Truong area, 100m at Ba Tha; and of Day River is 150m to ensure flood drainage space and the population living within that minimum range must be relocated.

Table 6: Number of residents to be relocated in each commune within Hanoi territory

No	Commune	District	To be relocated households	No	Commune	District	To be relocated households
1	Tot Dong	Chuong My	107	20	Dai Hung	My Duc	5
2	Thanh Binh	Chuong My	15	21	Van Kim	My Duc	23
3	Huu Van	Chuong My	25	22	Doc Tin	My Duc	23
4	Quang Bi	Chuong My	138	23	Huong Son	My Duc	88
5	Thuy Xuan Tien	Chuong My	21	24	Phuc Lam	My Duc	68

No	Commune	District	To be relocated households	No	Commune	District	To be relocated households
6	Tan Tien	Chuong My	109	25	Phung Xa	My Duc	90
7	Nam Phuong Tien	Chuong My	45	26	Van Dinh	Ung Hoa	65
8	Hoang Van Thu	Chuong My	38	27	Vien An	Ung Hoa	90
9	My Luong	Chuong My	60	28	Vien Noi	Ung Hoa	3
10	Hong Phong	Chuong My	81	29	Cao Thanh	Ung Hoa	35
11	Dong Phu	Chuong My	155	30	Son Cong	Ung Hoa	52
12	Hoa Chinh	Chuong My	115	31	Dong Tien	Ung Hoa	28
13	Phu Luu Te	My Duc	89	32	Van Thai	Ung Hoa	5
14	Dai Nghia	My Duc	13	33	Hoa Xa	Ung Hoa	43
15	My Thanh	My Duc	10	34	Hoa Phu	Ung Hoa	50
16	Bot Xuyen	My Duc	28	35	Lu Hoang	Ung Hoa	56
17	An My	My Duc	53	36	Phu Lưu	Ung Hoa	25
18	Le Thanh	My Duc	98	37	Hoa Nam	Ung Hoa	48
19	Xuy Xa	My Duc	63	38	Hong Quang	Ung Hoa	95
Total			2155				

4. CONCLUSION

This study summarized the status of flood control infrastructure in the Bui river basin, identified the critical areas, and then proposed the solutions. The study proposed six main groups of solutions, including: a) Restoration of the Tich, Bui and Day rivers; b) Upgrade and building of a new reservoir; c) Construction of channels to isolate mountain floods; d) Upgrade and building of new dikes; e) Upgrade and building of new drainage pumping stations and detention basins, and e) Relocation of people in vulnerable areas. The study applied MIKE hydraulic models, ArcGIS mapping software, Google Earth to calculate and evaluate 4 scenarios with the different solutions to prevent flooding and inundation. Preliminary cost estimates were also made for the implementation of the solutions. This serves as basis for the responsible authorities to make decision, based on the technical and economic assessment along with the social benefits that the solutions can generate.

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