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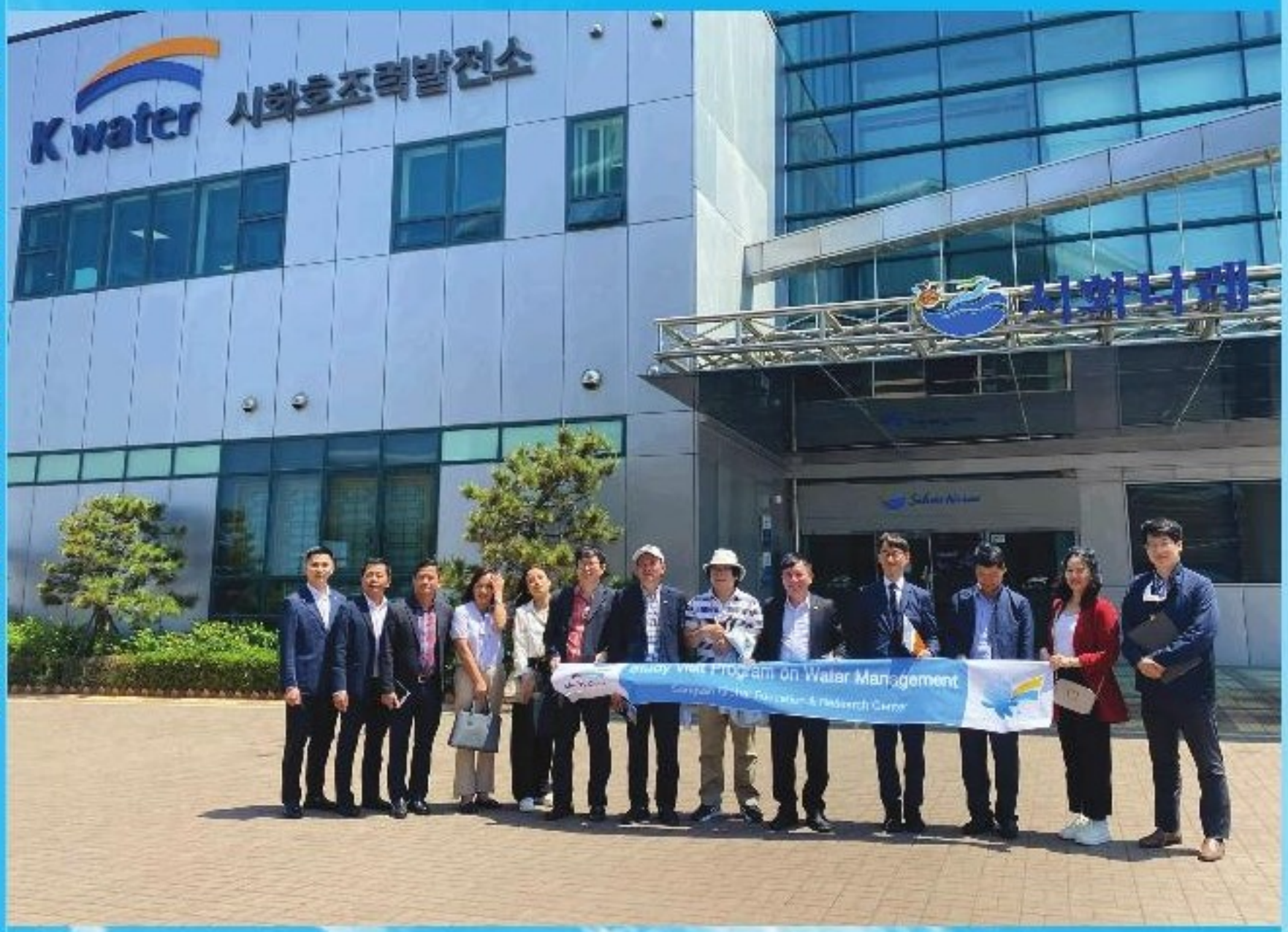

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STUDYING INTO SOLUTIONS FOR FLOOD AND INUNDATION CONTROL IN BUI BASIN AND ITS VICINITY

Le Viet Son, Nguyen Van Tuan, Bui Tuan Hai, Nguyen Duy Quang, Bui The Van
Institute of Water Resources Planning

Abstract: *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.

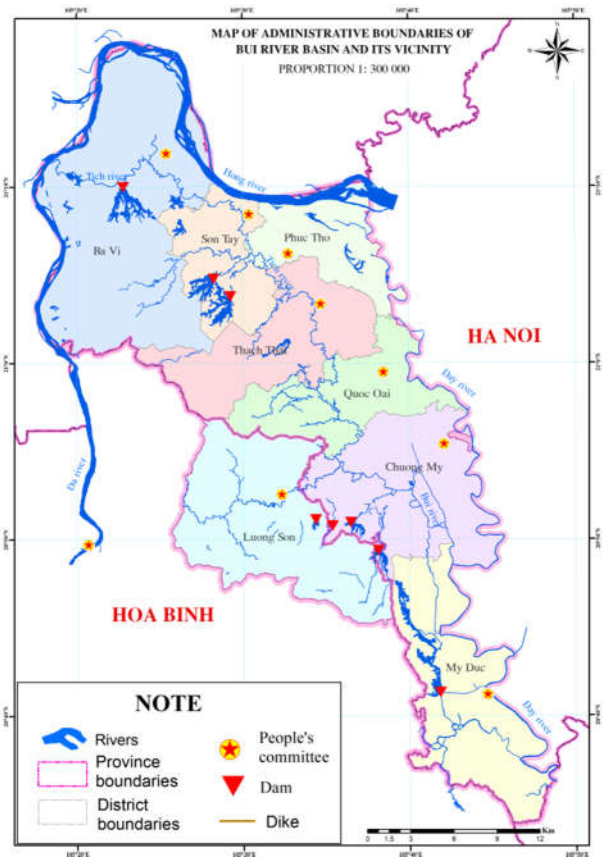

Figure 1: Map of the Bui river basin and its vicinity

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:

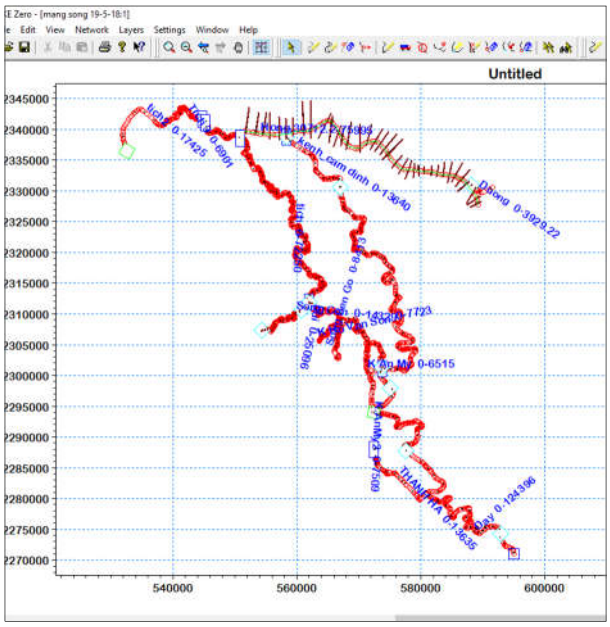

Figure 2: Computational river network

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.

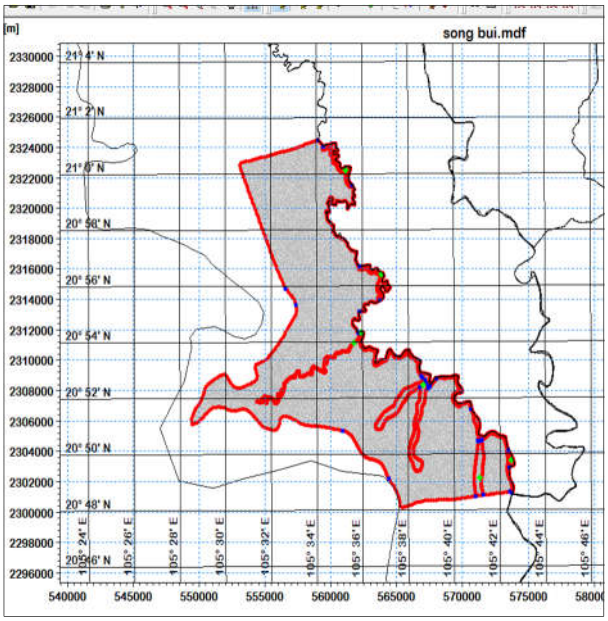

Figure 3: Calculation grids

- 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).

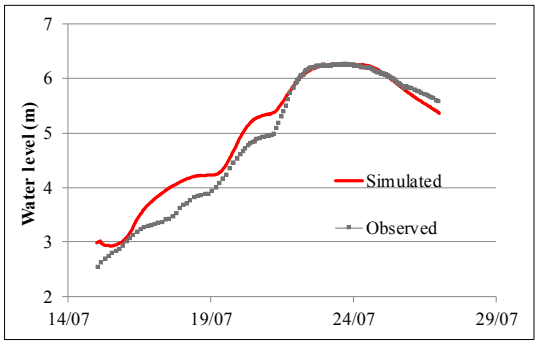

Figure 4: Simulated and observed water level at Ba Tha station, calibrated for year 2018

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).

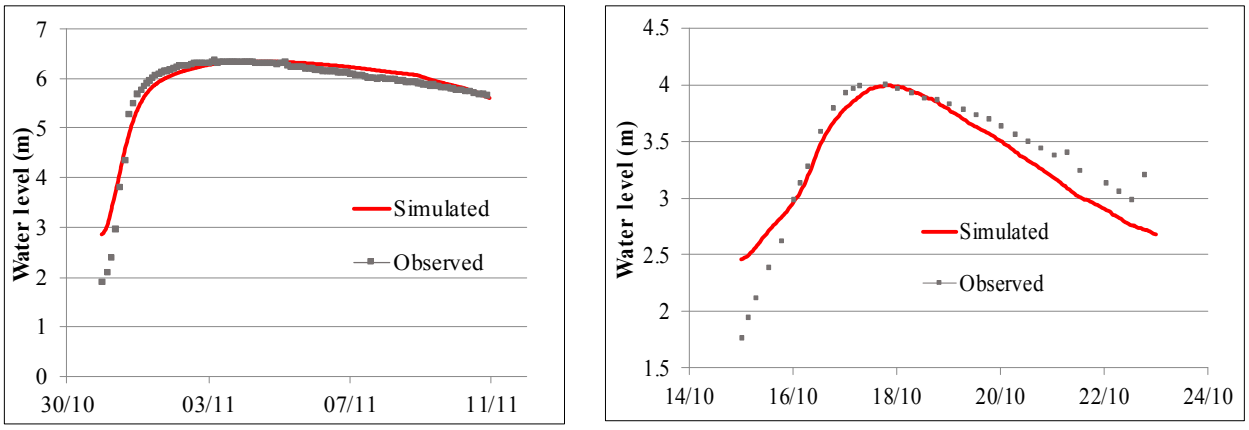

Figure 5: Simulated and observed water level at Ba Tha station, validated: (a) 2008; (b) 2020

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 m^3 (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

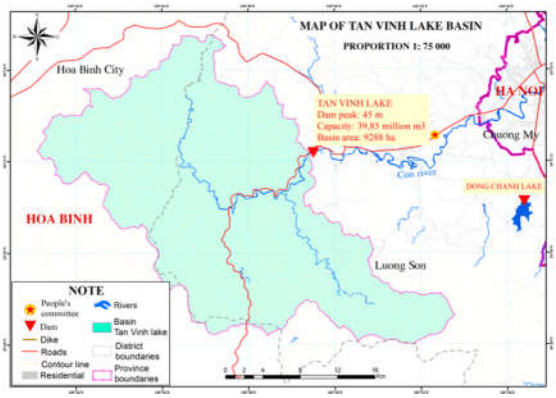

Figure 6: Map of the Tan Vinh reservoir catchment area (proposed to be built)

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.

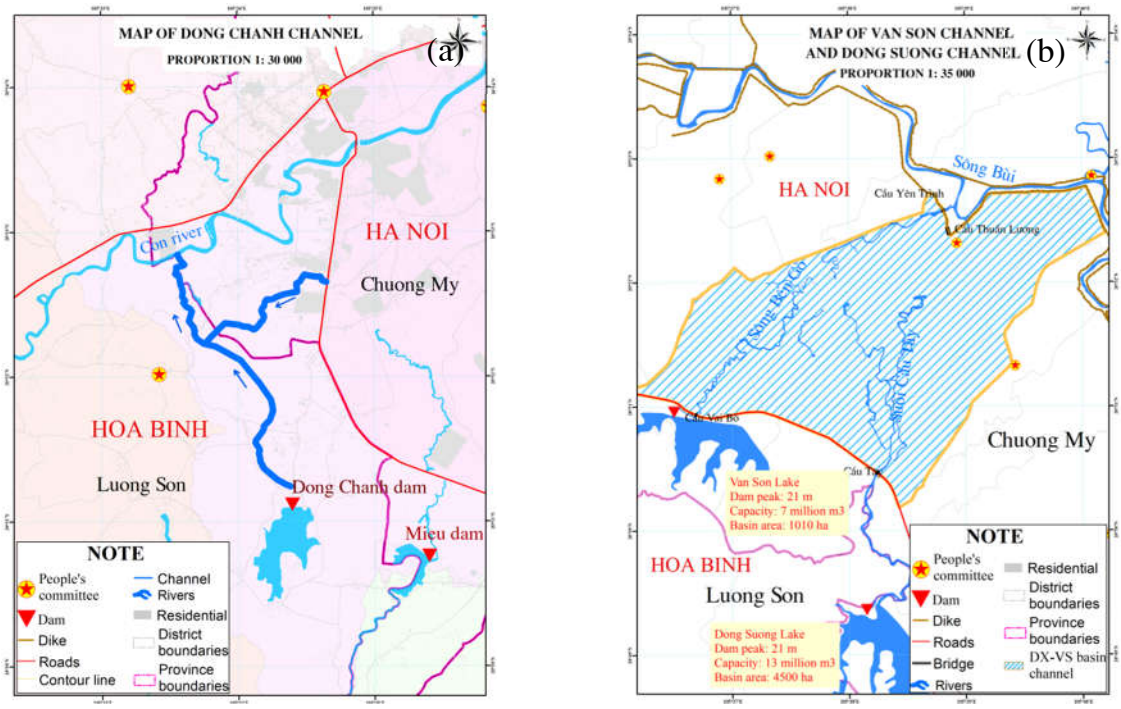

Figure 7: Map of channel routes to isolate mountain floods in the sub-basin (a) Dong Chanh, Mieu; (b) Dong Suong, Van Son

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

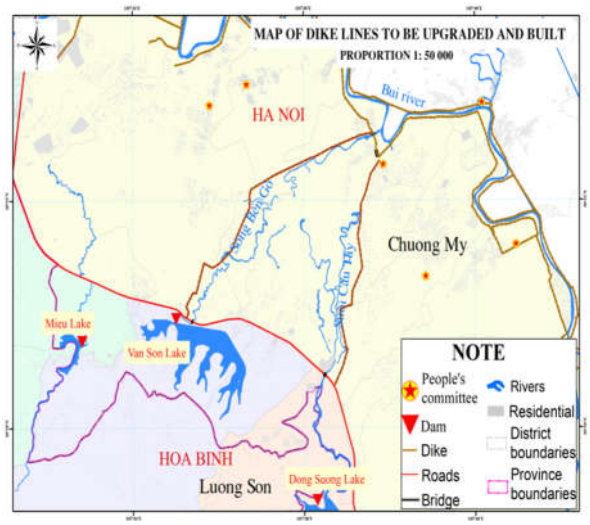

Figure 8: Dike routes to be built: Cau Tay dike

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.

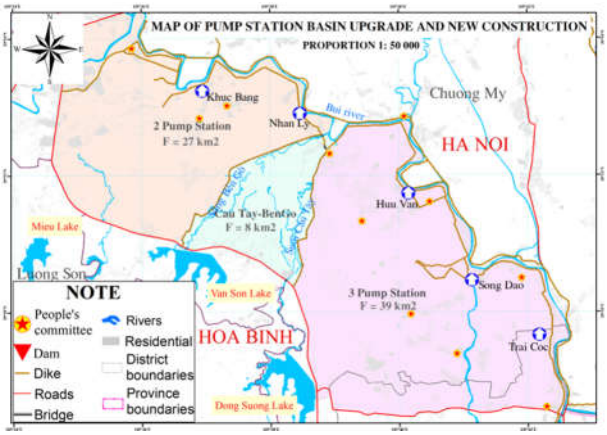

Figure 9: Location, scale and service area of the proposed pumping stations and detention basins

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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