GREEN EME 2023

GREEN EME 2023

ORGANIZATIONS

ISBN: 978-604-67-2826-9

DO NOT SALE

VIET NAM NATIONAL UNIVERSITY HO CHI MINH CITY
VIET NAM METEOROLOGICAL AND HYDROLOGICAL ADMINISTRATION

Proceedings of the Sixth International Scientific Conference
EARTH AND ENVIRONMENTAL SCIENCES, MINING FOR DIGITAL TRANSFORMATION, GREEN DEVELOPMENT AND RESPONSE TO GLOBAL CHANGE

SCIENCE AND TECHNICS PUBLISHING HOUSE

VIET NAM NATIONAL UNIVERSITY HO CHI MINH CITY

THE STATE COUNCIL FOR PROFESSORSHIP
THE INTERDISCIPLINARY EARTH - MINING SCIENCES COUNCIL FOR PROFESSORSHIP

VIET NAM METEOROLOGICAL AND HYDROLOGICAL ADMINISTRATION

東京大学 THE UNIVERSITY OF TOKYO

Proceedings of the Sixth International Scientific Conference

EARTH AND ENVIRONMENTAL SCIENCES, MINING FOR DIGITAL TRANSFORMATION, GREEN DEVELOPMENT AND RESPONSE TO GLOBAL CHANGE

GREEN EME 2023

SCIENCE AND TECHNICS PUBLISHING HOUSE

GREEN EME 2023

VIET NAM NATIONAL UNIVERSITY HO CHI MINH CITY

THE STATE COUNCIL FOR PROFESSORSHIP
THE INTERDISCIPLINARY EARTH - MINING SCIENCES COUNCIL FOR PROFESSORSHIP

VIET NAM METEOROLOGICAL AND HYDROLOGICAL ADMINISTRATION

Proceedings of the Sixth International Scientific Conference

EARTH AND ENVIRONMENTAL SCIENCES, MINING FOR DIGITAL TRANSFORMATION, GREEN DEVELOPMENT AND RESPONSE TO GLOBAL CHANGE

SCIENCE AND TECHNICS PUBLISHING HOUSE

FOREWORD

The fields of Earth, Mines, and Environmental sciences (EME) have emerged and evolved alongside with the evolution of human society, and have created a profound impact on all aspects of life and socio-economic development through utilizing natural resources, impacting the environment, and driving global change. The robust development of these areas serves as the foundation for various other fundamental and applied sciences, and concurrently act as a catalyst for technological advancements worldwide, contributing to the common prosperity and safety of humankind as well as the conservation of the blue Earth.

Global change, rapid development of science and technology, and the fourth industrial revolution (Industry 4.0) create many opportunities and challenges for sustainable development. Vietnam, being one of the most vulnerable countries to climate change and natural disasters, is devoting great efforts to achieve sustainable development goals and achieve net zero emissions by 2050 as well as to improve productivity and national competitiveness. In this context, innovation, digital transformation in training, basic and applied research on EME become more urgent than ever for green, circular development and response to global change, sustainable development, prosperity, and safety of the country, the region and the world.

Against such considerations, Viet Nam National University Ho Chi Minh City, in collaboration with Viet Nam Meteorological and Hydrological Administration, the Interdisciplinary Council for Professorship of Earth - Mining Sciences, as well as various research institutes and local and international higher education institutions, jointly co-organizes the International Conference "Earth Science, Mining, Environment for Digital Transformation, Green Development, Circular Growth, and Response to Global Change" (GREEN EME 2023).

The GREEN EME 2023 is a forum for scientists, administrators, and businesses, who are passionate about Earth Science and Environment, Mining (EME) to meet, present and share their research findings, to engage in discussions, and to exchange solutions for a wide range of overall academic issues in these fields. The specific objectives include:

- Publishing outstanding research results and sharing, replicating achievements and experiences in innovation and digital transformation in fundamental and applied research and technology development in Earth Science, Mining, Environment, and related fields in

order to advance economic efficiency, national competitiveness, sustainable development, national, regional and international safety.

- Proposing solutions to promote innovation in the fields of Earth Science, Mining, and Environment (institutions, policies, promoting educational science and technology, training of high-quality human resource, digital transformation, engagement, and enhancing collaboration with stakeholders, etc.) to meet the requirements of green, circular growth, and response to global changes.

During the preparation for GREEN EME 2023, the Organizing Committee has received 86 scientific manuscripts. After a rigorous reviewing process, 30 highly valued articles were selected for publication in the conference proceedings and other 22 articles will be published in the "IOP Conference Series: Earth and Environmental Science". The Organizing Committee highly appreciates the efforts of the Editorial Board, domestic and international scientists and experts in either submitting their manuscripts or contributing valuable time to review and editing the articles. We would also like to thank the Secretariat for their efforts in preparing and organizing the conference as well as the sponsors for their important contribution. We believe that the GREEN EME 2023 will be successful and all the participants will have opportunities to meet, exchange ideas, and collaborate to propose sustainable development goals for the development of EME sectors.

GREEN EME 2023 CONFERENCE ORGANIZING COMMITTEE

Table of Contents

SUSTAINABLE AND GREEN ENERGY TRANSITION CIRCULAR ECONOMY IN RESOURCE-MINERAL MANAGEMENT AND SUSTAINABLE DEVELOPMENT

(Wind power, solar power, gas power, geothermal, garbage power, hydrogen, etc.; low carbon emission technologies; resource-mineral management and sustainable development)

CLIMATE CHANGE AND DISASTER MITIGATIONINNOVATION MEASURES FOR EARTH, MINING AND ENVIRONMENTAL SCIENCES (innovative measures for earth, mining and environment sciences to meet sustainable development goals)

THE STATUS OF KARST SPRINGS DEGRADATION IN THE WATER-SCARCE HIGH MOUNTAIN AREAS OF NORTHERN VIETNAM AND SOLUTIONS TO MANAGEMENT FOR SUSTAINABLE DEVELOPMENT

Dao Duc Bang[1,*], Tran Thi Thanh Thuy[2], Nguyen Van Trai[3], Nguyen Minh Viet[3], Vu Thu Hien[1] and Duong Thi Thanh Thuy[1]

[1] Faculty of Geosciences and Geoengineering, Hanoi University of Mining and Geology, Hanoi, Vietnam

[2] Faculty of Environment, Hanoi University of Mining and Geology, Hanoi, Vietnam

[3] Vietnam Academy for Water resources, Hanoi, VietNam

E-mail: daoducbang@humg.edu.vn

Abstract: Alongside the rapid economic development, the quality of life of people in high mountain and border areas has received increasing attention in various aspects, with household water supply being one of the top priorities. Since the 2000s, the government and non-governmental organizations from abroad have invested in numerous domestic water supply projects. Due to both human activities and natural factors, climate change has been reducing the efficiency of these projects over time. This decline results from both the deterioration of the infrastructure and the water sources themselves. Research findings from a study of 408 karst springs in the water-scarce high mountain areas of the Northern Vietnam indicate signs of depletion in the quantity and quality of these water sources. Through field investigations and interviews with residents, flow measurements and water sampling in the study area, the karstic springs have been categorized into nine groups based on varying levels of decline in water reserves and quality. Group I is the lowest level of degradation, which accounts for 6.6% of the total, followed by groups IIa and IIb, IIIa and IIIb, and IVa, IVb, and IVc. Group V represents the highest level, at 9.6%. These results serve as a foundation for managers to formulate digital transformation, green development, circular economy, and climate change adaptation solutions aimed at enhancing the efficiency of domestic water supply models for the region.

1. INTRODUCTION

The Northern mountainous region of Vietnam has the basic characteristic of an arc facing away from the sea, with quite strong cleavage and eroded karst terrain erosion in the Northeast and Northwest regions, featuring high mountain ranges extending towards the Northwest - Southeast, strongly dissected, creating the largest and most dangerous terrain difference in our country (Nguyen Kim Ngoc et al., 2003). Alongside this topographic condition, the geological and hydrogeological structure is quite complex with 3 porous aquifers, 25 fracture aquifers and 05 fracture - karst aquifers, making water supply difficult (Nguyen Van Lam et al., 2018). This complexity poses significant challenges to the provision of domestic water supply in the region, especially in water-scarce high mountain and border areas.

Water-scarce high mountain areas, characterized by an area of 4,451.94 square kilometers, exhibit challenging terrain with steep slopes ranging from 7.4% to 52.0%. Inhabitants are predominantly ethnic minorities, facing economic constraints and relying heavily on nature. Livelihoods are sustained through small-scale, self-sufficient livestock farming, with water primarily utilized for dietary and household purposes. According to surveys, the daily water consumption for domestic use in the region ranges from 50-60 liters per person, resulting in a total demand of 16,392 cubic meters per day for the entire area (Do Ngoc Anh et al., 2019).

Government and non-governmental organizations have implemented various water supply projects, primarily sourcing from springs, caves, or surface water flows, catering to several dozen to a few hundred households. Some recent projects have incorporated effective water treatment systems; however, a significant portion of water remains untreated or undergoes only preliminary filtration. Regular quality checks and evaluations are limited. These water supply projects have partly fulfilled the demand for domestic water needs of the population. However, after several years of operation, the effectiveness of these projects has still not reached the expected level. In high mountainous communes, the sustainability of the water supply model is not high, with many degraded and damaged constructions (Do Ngoc Anh et al., 2019). This unsustainability is due to many different reasons, notably the deterioration of water reserves and quality. Therefore, conducting an assessment of water resource degradation is necessary to find out the appropriate solutions to help improve the effectiveness of water supply models for highly mountainous, water-scarce areas in the Northern region, ensuring water supply to serve residents.

2. METHODS

The degradation of water resources includes both reserve (quantity) and quality degradation. In the case of springs, the degradation of water reserves is assessed through a reduction in flow rates. The degradation of water quality is approached from two distinct perspectives. The first perspective argues that water resources are degraded when the quality exceeds a specific threshold in predefined standards. The second viewpoint posits that water resources are degraded when they surpass their natural background values (Nguyen Van Lam et al., 2020). The study area spans 15 northern mountainous provinces, focusing on high mountainous areas with water scarcity. There are currently no monitoring projects or documentation within the research area that carry out multi-year monitoring to evaluate flow changes in terms of time series. Therefore, to evaluate the possibility of water resource degradation and depletion, the research team implemented the following specific methods:

- Conducted monitoring and measurement of water flow in 408 springs in communes in 15 provinces to evaluate water reserves capable of supplying local people and changes in water flow in the study area. Assessing flow degradation requires measurements and observations over a long time series, however, within the scope of the study, we only measured flow in 2 periods that is two dry seasons in 2022 and 2023. The flow rate is determined using methods such as volumetric tanks, floatboards, or by measuring the cross-sectional area and flow velocity, depending on the actual conditions of each watercourse.

- Carry out quickly measuring total dissolved solids (TDS) parameters in the field at karst springs sources to evaluate the water quality using the Hanna HI 9034 meter.

Because the number of springs sources in the study area is very large and the rapid measurements in the field will help to assess the overall water quality of the study area. Rapid measurement of TDS was also carried out in 2 survey periods with a total number of measurement points of 408 points distributed on springs in communes in 15 provinces.

- Sampling to analyze water quality in karst springs sources in communes of 15 provinces with signs and potential quality deterioration. The total samples are 84 samples in the dry season in 2022 and 84 samples in the dry season in 2023. Analytical criteria of water quality assessment include Turbidity, Ammonium, Arsenic, Iron, Manganese, E.coli, and Coliforms. The result analysis was performed at the High-Tech Analysis Center, Hanoi University of Mining and Geology.

- Investigation, field surveys, consultation community, and information collection from local authorities and residents who use karst springs sources about changes in the water quality and reserves over time, interviewing 10-15 people in each surveyed area.

This information can be used to assess the possibility of water resource degradation. Besides, conduct surveys in water recharge areas to assess waste sources that have the potential to affect the quality of karst springs sources such as waste discharge from daily life, industrial and agricultural production, tourism, and trade in services,…

- Synthesize and build criteria to evaluate the water quality degradation, including:

+ *Assessing the degradation of reserve water (quantity):* The degradation in quantity water for karst springs is the decline in flow. Here, the degradation is understood as a decrease in quantity water value and it is determined when the observed flow of monitoring period 2 is smaller than monitoring period 1. During the monitoring process, some margin of error is inevitable, the flow measurements in the first and second phases always show differences. According to the circular No. 17/2021/TT-BTNMT on monitoring the exploitation and use of water resources issued by the Ministry of Natural Resources and Environment, effective from November 30, 2021, 'the relative error shall not exceed 5% compared to the measured value for flow parameters". Therefore, using the result comparing the quantity in the first and second phases as a basis for assessing degradation, if the quantity in the second period is less than 95% of the quantity in the first period, the water source is considered to have a degraded flow according to this criterion.

Based on the two criteria mentioned above, we classify the water quantity degradation into three levels: (1) Not experiencing quantity degradation, (2) Quantity degradation, but signs not clear and (3) Clear signs of quantity degradation (see table 1)

Table 1. Criteria for evaluating the water quantity degradation.

The quantity degradation level	The basis for assessing the level of quantity degradation	
	The reduction quantity of water according to the interviews and information collected from residents	Expression of quantity degradation according to the measurement results of period 1 (Q_1) and period 2 (Q_2)
Not experiencing quantity degradation	Not degradation	Not Degradation
Quantity degradation, but signs not clear	Not degradation	Degradation
	Degradation	Not degradation
Clear signs of quantity degradation	Degradation	Degradation

Note: Signs of quantity degradation, based on the flow rate results of period 1 (Q_1) and period 2 (Q_2), are determined as "Degradation" when 95% of $Q_1 > Q_2$, and vice versa.

+ *Assessing the degradation of quanlity water:* The quality degradation is assessed based on the results of the analysis from period 1 and period 2, which are determined as "Degradation" when at least 4 out of 7 water quality indicators from period 1 are lower than those from period 2 (for water sources with water sample analysis results) and the result of TDS in period 1 is lower than TDS in period 2 (for water sources without water sample analysis results), and vice versa. In addition, water sources show signs of quality deterioration when the regional level has activities that have the potential to adversely affect water quality. Based on the two criteria mentioned above, we classify water quality degradation into three levels: (1) Not experiencing quality degradation, (2) Quality degradation, but signs not clear, and (3) Clear signs of quality degradation (see table 2).

Table 2. Criteria for evaluating the water quality degradation.

The quality degradation level	The basis for assessing the level of quanlity degradation	
	Activities that have the potential to adversely affect water quality	Signs of water quality degradation according to the analysis results of period 1 and period 2
Not experiencing quality degradation	Not degradation	Not degradation
Quality degradation, but signs not clear	Degradation	Not degradation
	Not degradation	Degradation
Clear signs of quality degradation	Degradation	Degradation

3. RESULTS AND DISCUSSION

Based on the criteria for assessing water resource degradation in terms of both flow rate and quality, we have categorized water resource degradation into 9 groups. Specifically, group I consists of karst springs sources that have not experienced degradation in terms of both quantity and quality, while group V includes conduits with the most significant degradation in both flow and quality. Groups IIb and IVc are primarily associated with flow degradation, while froups IIIb and IVb are primarily related to quality degradation. The remaining groups exhibit unclear signs of degradation in both flow and quality (see table 3).

Table 3. Grouping degradation of karst springs sources according to quantity and quality.

Group	The quantity degradation level			The quality degradation level		
	Not experiencing quantity degradation	Quantity degradation, but signs not clear	Clear signs of quantity degradation	Not experiencing quality degradation	Quality degradation, but signs not clear	Clear signs of quality degradation
I	x			x		
IIa		x		x		
IIb			x	x		
IIIa	x				x	
IIIb	x					x
IVa		x			x	

Group	The quantity degradation level			The quality degradation level		
	Not experiencing quantity degradation	Quantity degradation, but signs not clear	Clear signs of quantity degradation	Not experiencing quality degradation	Quality degradation, but signs not clear	Clear signs of quality degradation
IVb		x				x
IVc			x		x	
V			x			x

Given the interview results and information collected from water users in the study area, it was found that out of 408 surveyed water sources, 181 (44.4%) experienced a decrease in flow rates in recent years. Flow rate measurements during two periods in two dry seasons showed that the first period's flow rate ranged from 0.03 to 75.2 L/s, with an average of 1.16 L/s. The second period's flow rate ranged from 0.02 to 64.7 L/s, with an average of 1.08 L/s. Among the 408 water sources, 216 (52.9%) exhibited reduced flow rates (see table 5).

Surveying in the water source replenishment region revealed that out of 408 water sources, 200 (49%) were at risk of being affected by human activities. Analysis of 84 water samples during the second period, using seven parameters, indicated that some samples exceeded the water quality standards for domestic use set by the Ministry of Health (QCVN 01-1:2018/BYT). Parameters such as turbidity (29 samples), ammonium (37 samples), iron (10 samples), and manganese (9 samples) were found to exceed the standards. Turbidity ranged from 0 to 5 NTU, iron concentrations ranged from 0.02 to 2.38 mg/L (average 0.221 mg/L), ammonium ranged from 0.03 to 0.62 mg/L (average 0.252 mg/L), and Coliforms ranged from 0 to 3 CFU/100mL. Comparing these results with the data from the first period, 22 out of 408 sources experienced an increase in turbidity, 28 saw an increase in ammonium, and 50 exhibited an elevated iron concentration, while E.coli levels showed almost no variation (refer to table 4). The rapid TDS measurements during the second period at the field indicated variations in levels ranging from 6.2 to 347.7 mg/L, with an average of 101.7 mg/L. The combined analysis of water sample results and on-site TDS measurements revealed that 238 out of 408 water sources showed signs of deterioration in water quality (58.3% of total sources), (see table 5).

Table 4. The number of water sources exceeding standards and showing signs of declining quality.

Water quality indicators	Unit	Min	Max	Average	Water quality standards	Number of samples exceeds the standard	Number of samples has a higher concentration than period 1
Turbidity	NTU	0	5	-	2	29	22
Ammonium	mg/L	0.02	0.62	0.252	0.3	37	28
Arsenic	mg/L	0	0.075	0.0055	0.01	4	11
Iron	mg/L	0.02	2.38	0.221	0.3	10	50
Manganese	mg/L	0.01	0.64	0.066	0.1	9	9
E.colie	CFU/100mL	0	0	0	<1	0	0

Water quality indicators	Unit	Min	Max	Average	Water quality standards	Number of samples exceeds the standard	Number of samples has a higher concentration than period 1
Coliforms	CFU/100mL	0	3	-	<3	0	21

Table 5. The number of water sources experiencing a decrease in flow rate and quality

Province	Number of karst springs	The reduction quantity of water according to the interviews and information collected from residents	Expression of quantity degradation according to the measurement results of period 1 (Q_1) and period 2 (Q_2)	Activities that have the potential to adversely affect water quality	Signs of water quality degradation according to the analysis results of period 1 and period 2
Son La	20	12	12	10	11
Dien Bien	11	6	5	7	6
Lai Chau	34	15	17	17	21
Yen Bai	48	20	21	26	28
Ha Giang	34	13	17	16	19
Bac Can	35	16	18	21	24
Cao Bang	91	42	51	41	53
Hoa Binh	19	7	10	8	11
Phu Tho	3	2	3	1	1
Lao Cai	9	5	6	5	5
Tuyen Quang	5	1	2	1	3
Thai Nguyen	4	1	2	1	2
Lang Son	82	35	45	40	47
Bac Giang	8	3	4	3	6
Quang Ninh	5	3	3	3	1
Total	408	181	216	200	238

Based on the results of field surveys at the karst springs sources in the study area and according to the basis for constructing groupings in Table 3, synthesize and group the degraded karst springs sources according to both quantity and quality. Detailed grouping degradation of karst springs is in Table 6. The research results show that the largest number of karst springs sources are exploited and used in Cao Bang province with 91 sources, Lang Son province with 82 sources and Yen Bai province with 48 sources. The number of exploited and used underground Karst water sources is the lowest in Phu Tho province with

03 sources. In particular, the greatest level of degradation and depletion of karst springs sources is in Lang Son province with 24 sources belonging to group IVc - V, accounting for about 29.3% of the karst springs sources in this province, followed by Cao Bang province with 24 sources, accounting for about 26.4% of the province's total springs sources. Particularly in Son La province, although springs sources are low with only 20 sources, the proportion of water sources belonging to groups IVc - V is high, accounting for 40% of the total spring sources of the province. This shows that karst water spring sources are currently facing the risk of degradation and depletion and need to be protected.

Table 6. Results of grouping degradation of karst springs in the water-scarce high mountain areas of Northern Vietnam

Province	Number of karst springs	Number of karst springs according to the degradation level groups								
		Group I	Group IIa	Group IIb	Group IIIa	Group IIIb	Group IVa	Group IVb	Group IVc	Group V
Son La	20	1	2	1	3	1	3	1	5	3
Dien Bien	11	1	0	1	1	2	2	1	2	1
Lai Chau	34	1	4	2	6	4	6	4	4	3
Yen Bai	48	4	2	3	8	9	9	2	7	4
Ha Giang	34	3	2	2	7	5	6	0	6	3
Bac Can	35	2	2	1	4	6	7	3	4	6
Cao Bang	91	6	5	9	17	8	16	6	15	9
Hoa Binh	19	2	1	1	4	2	3	1	4	1
Phu Tho	3	0	0	1	0	0	1	0	1	0
Lao Cai	9	0	1	1	1	1	1	1	2	1
Tuyen Quang	5	1	0	0	2	0	1	0	1	0
Thai Nguyen	4	1	0	0	1	0	1	0	1	0
Lang Son	82	4	5	6	17	11	13	2	17	7
Bac Giang	8	0	1	1	2	1	1	1	0	1
Quang Ninh	5	1	0	0	1	0	0	0	3	0
Total	**408**	**27**	**25**	**29**	**74**	**50**	**70**	**22**	**72**	**39**

The research result shows that the number of karst springs sources in group IIIa is the highest in the karst water sources found in 15 provinces in the water-scarce high mountain areas of Northern Vietnam with 74 sources, accounting for 18%, proving that these water sources have not degraded in reserve but have shown signs of deterioration in water quality. The number of springs sources that are degradated in both quality and quantity is high with 142 sources belonging to groups IVa and IVc, accounting for nearly 35% of the total karst water sources in the study area (see table 6).

The classification results indicate that, across the entire research area, out of a total of 408 karst springs sources, a small proportion remains unaffected by degradation which is 6.6%, while a larger proportion experiences both quantity and quality degradation is 9.6%.

Karst springs with degradation in either flow rate or water quality, or both, represent a higher percentage, over 17% which is groups IIIa, IVa, and IVc (see figure 1).

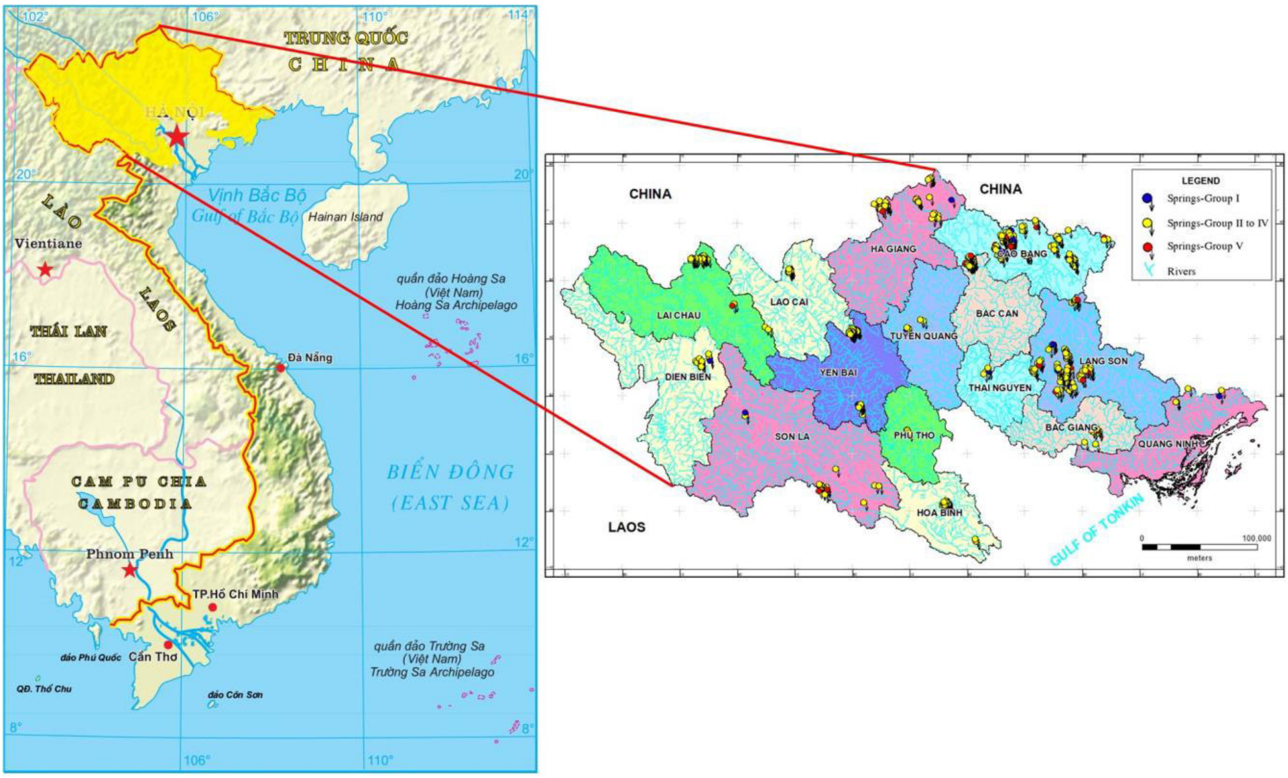

***Figure 1**. Map of karst springs degradation groups in the study area.*

The degradation of water sources is caused by various factors. For the reduction in water flow, there are three main reasons: (i) climate change, (ii) deforestation at the headwaters reducing water supply, and (iii) forest conversion and changes in crop structure. Climate change leads to a significant decrease in rainfall, especially during the dry season, resulting in a reduction in water supply. According to surveys, most water channels experience decreased flow during the dry season, with many channels showing a reduction of over 60% (such as in Tua Thang, Ho Mit, Quoc Toan commune, etc.). Deforestation at the source region prevents rainwater from being retained, diminishing the underground water supply. In the research area, the headwaters are largely unprotected or poorly protected (61%) (Do Ngoc Anh et al., 2019). Deforestation often occurs on a small scale, driven by the needs of local residents. Some areas have converted natural forest into flower cultivation, fruit-bearing crops such as maize and acacia (Ha Giang, Dien Bien, Tuyen Quang, Quang Ninh, etc.), tea plant (Thai Nguyen, Son La), litchi tree (Bac Giang), leading to a decrease in forest cover and water retention capacity.

Concerning the decline in water quality, factors include: (i) agricultural activities, livestock farming, and residential construction in the upper region, (ii) mineral exploitation, (iii) inadequate construction and protection of surrounding areas. In many regions, due to economic difficulties and insufficient awareness, people use pesticides, herbicides, and chemical fertilizers when cultivating crops (maize, tea, oranges, litchi), affecting water quality. In some areas, ethnic minorities in water replenishment regions dispose of livestock and household waste, posing a risk of water pollution. Waste mud from mineral exploitation is often untreated, or poorly placed, posing a potential threat to water sources. During field studies in some locations, locals reported issues, such as in Pung Ho Cave, Vu Nong commune, Nguyen Binh district, Cao Bang province, where the discharge of mining mud turned the water yellow and turbid, making it unsuitable for local households and the elementary school. In Coc Phat 1 stream, Pac Vo hamlet, Quoc Toan commune, Quang Hoa district, Cao Bang province, concerns were raised about the ore processing plant upstream potentially affecting the water source. However, visible signs were not evident, requiring more detailed studies in this area for accurate conclusions. Moreover, the awareness of water source protection among the local residents is limited, and lax management practices in localities contribute to the decline in both water quantity and quality.

Based on the assessment of the current situation and grouping of water resource degradation according to both quantity and quality, the authors propose the solutions to manage, protect, and rationally exploit water resources belonging to the groups that ensure sustainable development as follows:

(1) For areas without any signs of water resource degradation (Group I): To ensure sustainable exploitation in the future, it is essential to protect the source buffer zones by clearly defining these areas, setting up protective boundaries, and limiting or prohibiting activities such as deforestation, livestock grazing, the use of fertilizers, pesticides, herbicides, and construction. Additionally, afforestation in areas with low vegetation coverage can enhance water resources.

(2) For areas with degradation primarily in quantity rate (Groups IIb, IVc): Combining solutions like digging retention ponds, small infiltration tanks, and creating parallel ditches at the contour to temporarily reduce flow velocity, retain water, and supplement water during the dry season. Expanding forest cover to increase the vegetation areas and government mechanisms policy to relocate the land of residents in the buffer zone to maintain their livelihoods while preserving water resources are also recommended.

(3) For areas with degradation primarily in quality water (Groups IIIb, IVb): need to cease mining operations immediately with the areas affected by mineral mining activities, environmental treatment and penalties for waste discharge activities. For areas where residents use pesticides, raising awareness among residents to avoid or use environmentally friendly pesticides to prevent water quality deterioration is crucial. Local authorities should have policies to convert the land of residents and crops to suitable locations to ensure their livelihoods while returning the source buffer area for recovery and protection.

(4) For areas with degradation in both quantity and quality water (remaining groups): A comprehensive approach combining solutions from groups (2) and (3) is necessary. Furthermore, raising awareness and knowledge among residents about the importance of water resources and related issues is essential, ensuring that every resident takes responsibility for protecting and developing water resources for sustainable exploitation in the future.

In addition, in the coming time, as the economic conditions of the region improve, it is necessary to research and apply digital technology solutions for monitoring and data collection on flow rate and water quality to implement timely measures and ensure the sustainable development of karst springs sources.

The research area comprises high mountain villages with scarce water resources, lacking long-term quantity and quality water monitoring projects. In the current conditions, the authors have conducted surveys and measurements in two periods (corresponding to two dry seasons) to establish initial groupings of water resource degradation. These are preliminary results providing an overview of the entire research area. Therefore, long-term monitoring of quantity and quality water over several years, during different seasons is necessary to refine the classifications.

4. CONCLUSION

The water-scarce high mountain areas of Northern Vietnam face significant challenges in terms of domestic water supply. However, signs of water resource degradation are becoming evident in the karst spring sources in this area. Based on the field surveys, consultation community, flow rate measurements, sampling and water sample analysis, the research team has evaluated the degradation of water resources and classified karst springs sources into nine groups. The study of 408 karst springs sources has revealed signs of both quantity and quality degradation in the water sources. The degradation levels are as follows: Group I has the lowest degradation rate (6.6%), followed by Groups IIa, IIb, IIIa, IIIb, and then Groups IVa, IVb, and IVc, with the highest degradation in Group V (9.6%). The classification results serve as a foundation for proposing measures to restore and protect water resources, ultimately improving the efficiency of the domestic water supply model in the region. However, the survey data from this study were collected during only two dry seasons. Therefore, the classification is preliminary and needs more comprehensive data collected over years, spanning various seasons to establish more specific groups.

REFERENCES

[1] Do Ngoc Anh et al., 2019 Research and propose models and technological solutions to exploit and protect sustainable development of Karst water sources to serve domestic water supply in water-scarce high mountain areas of Northern Vietnam. Final Report Project, Hanoi.

[2] Nguyen Van Lam et al, 2018 Groundwater potential in water-scarce high mountain areas of Northern *Journal of Mining and Earth Sciences and Technology* vol 59, Issue 3, pp 1-9.

[3] Nguyen Van Lam et al, 2018 Evaluating and selecting models and technological solutions for sustainable exploitation and use of karst water resources in high mountainous and water-scarce areas in the Northern region *Journal of Mining and Earth Sciences and Technology* Water Resources Science and Technology Journal vol 43, ISSN: 1859-4255/04-2018, pp 30-39, Hanoi.

[4] Nguyen Van Lam et al, 2020 Hydrogeological contamination *Transport Publishing House*, pp 8-10, Hanoi.

[5] Nguyen Kim Ngoc et al, 2003 Hydrogeology and groundwater resources of Vietnam territory *Transport Publishing House*, pp 44-51, Hanoi.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to the Hanoi University of Mining and Geology and the project DTDL-CN.66/21 which was led by the Vietnam Academy for Water resources, as well as the local authorities and the residents of the water-scarce high mountain areas of Northern Vietnam. Your support and cooperation have been invaluable in providing the conditions and assistance needed for the authors to complete this research.