# The Impact of Natural and Socio-Economic Conditions on the Stability of Groundwater Resources in Cao Bang Province, Vietnam

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## Abstract

*Cao Bang Province, Vietnam, is facing a water shortage that affects daily life and the economic development of the locality, especially in mountainous areas. The study of the impact of natural, and socio-economic conditions on the stability of groundwater in some highland regions where water is scarce in Cao Bang province is the basis for developing a suitable water exploitation management plan, ensuring the lives of local people. By collecting documents, conducting field surveys, consulting with the community, and analyzing samples in the laboratory, the study found that the total population in 10 highland areas in 7 districts was 12,398 people who were lacking domestic water and predicted that the water demand by 2030 would be 1,823 $m^3$/day. In addition, the study results showed that the exploitable underground water reserve was 14,748 $m^3$/day, meeting the current and future water supply needs of the locality. In addition, the findings show that natural conditions have a strong impact on the stability of water resources because the area is located in a mountainous area, which creates complex water formation conditions, and irregular rainfall, flood and flow regimes. In addition, socio-economic conditions only have a low and medium impact on the stability of water resources because there has not been much investment in economic development in these areas, the population is sparse, the demand for water is low and the number of water exploitation works is not high. Therefore, the study has proposed a number of suitable water exploitation solutions to serve the domestic water supply for local people, ensuring economic development and limiting the current water scarcity.*

**Keywords:** *socio-economic conditions, stability of groundwater resources, Cao Bang province*

## 1. Introduction

Groundwater is the most significant freshwater reservoir for industrial, agricultural, and residential water supplies [1]. In a developing world, it is necessary to recognize the various factors that affect groundwater sustainability and security [2] determined by its amount and quality that are impacted by a variety of parameters such as climate change, geology, overexploitation, changing land use, economics, pollution, socioeconomic conditions, agro-food systems, and governance [3]. The impact of each of these factors on groundwater sustainability has been mentioned by many studies. While [4] assessed the influence of climate change on the sustainability of groundwater resources, [5] evaluated the impact of land use change, [6] analyze the implications of pollution, [7] dealt with the effects of overexploitation on groundwater stability. However, there have not been many studies considering the importance of socio-economic factors, so this study focuses on assessing the impact of this criterion on groundwater sustainability.

Currently, there are some publications studied on the influence of natural and socio-economic conditions on groundwater resources with different aspects such as groundwater use [8], pollution [9], protection [10], comsumption [11], recharge [12], etc. While [13] conducted a comparative evaluation of various irrigation systems to analyze the socioeconomic impact of depleted groundwater resources in Punjab, [14] provided an analysis of polluted groundwater caused by nature-ecosystem and socio-economic impacts, [15] assessed the variations in the hazards of groundwater pollution in an agricultural watershed under various socioeconomic and environmental circumstances. In addition, the influence of socio-economic criteria on groundwater sustainability is also mentioned in some research. [16] proposed a straightforward dynamic indicator-based method to assess the impact of natural and social factors on groundwater stability. Similarly, [17] introduces a new approach to evaluate groundwater sustainability in Iran by utilizing integrated different social, and economic indicators. The findings demonstrated that many environmental and socioeconomic indicators can give a useful summary of groundwater sustainability conditions for future planning and water management decision-making.

This study was conducted to confirm the influence of socio-economic conditions on groundwater sustainability in Cao Bang province. The authors studied and assessed the impact of natural conditions (geographical location, topographical features, geology, meteorology, hydrology) and socio-economic activities (increased water demand, mineral exploitation, aquaculture, population distribution, water use habits, etc.) on the stability of groundwater resources. This is the basis for proposing solutions to protect water resources. In addition, the research results are also reference documents for managers to plan the exploitation and use of water resources in accordance with the economic restructuring in the period of promoting industrialization and modernization of the country, especially in high mountain areas with water scarcity.

## 2. Study area

Located in the Northern mountainous region (Northeast region), Cao Bang province has geographical coordinates

Tab. 1. Methods for determining water demand for different purposes [2]

Tab 1. Metody określania zapotrzebowania na wodę do różnych celów [2]

| Purpose of water use | Method for determining water demand and water supply coefficient |
|---|---|
| Domestic use | = Total water demand for domestic use ($m^3$/day) = Water supply coefficient (liter/person.day) x population (1,000 people). |
| Industry | = (30 $m^3$/ha x industrial park area) + (30 $m^3$/ha x 50% of dispersed production facility area) |
| Water demand for livestock | = Water demand for livestock ($m^3$/day) = Water coefficient for livestock (liters/day-head) of each type of poultry and livestock x number of poultry and livestock (1,000 heads)<br>Coefficient: buffalo/cow is 140 liters/day-head, pig: 60 liters/day-head, chicken: 10 liters/day-head. |
| Water demand in the medical sector | Total water demand for the medical sector ($m^3$/day) = Σ(Medical water demand coefficient (liters/bed.day) x Number of beds x $10^{-3}$<br>Coefficient: General and specialized hospitals: 500 liters/bed.day; District and county hospitals: 350 liters/bed.day; Clinics and medical stations: 300 liters/bed.day. |
| Total water demand for all purposes = Water demand for all purposes (Domestic + Industrial + Livestock + Medical) | |

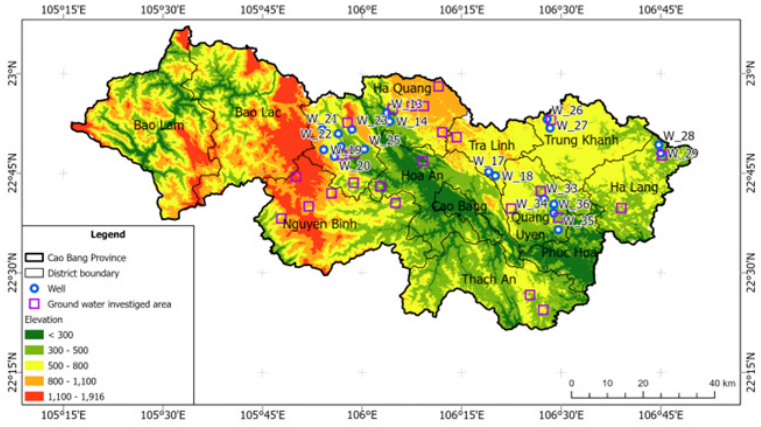


Fig. 1. Map of survey areas and well locations of the study area

Rys 1. Mapa obszarów badawczych i lokalizacji studni na obszarze badań

from 22°21'21" to 23°07'12" North latitude and 105°16'15" to 106°50'25" East longitude. This province has an area of 6,690.72 km², with an average altitude of over 200 m, the border area has an altitude of 600 ÷ 1,300 m above sea level. With the characteristics of mountainous terrain, high, steep, and with many limestone mountains, it is not favorable for the socio-economic development of the province, especially water supply for agricultural production and domestic use [18]. Currently, Cao Bang province is also facing water scarcity, especially in mountainous areas. In addition, with the increase in population, investment in economic development, and the impact of climate change, erratic rains and floods have also directly affected the province's groundwater resources, causing changes in water reserves and quality. The stability of water resources is used to assess the ability to meet the needs for water use purposes in the study area without reducing the reserves and quality of groundwater resources [19]. According to [20], the change in groundwater reserves depends greatly on the natural conditions of the region such as geographical location, topographic features, climatic/meteorological conditions and hydrogeological characteristics of aquifers, the influence of seepage, and the quality of groundwater.

In addition, the socio-economic conditions of each region with population distribution, water use needs for various purposes, people's water use habits and practices, and activities that pollute water sources have an impact on the reserves and quality of groundwater. The assessment results show that the flow is mainly concentrated in the flood season months. In which, the flood season usually starts from June and lasts until the end of September, the rest are the dry season months. In the transition months (May and November), there may still be large floods or later floods depending on the period. The total flow of the 4 flood months accounts for about 60% to 75% of the total annual flow. Thus, it can be observed that during the dry season months, although it takes up a longer period, the flow rate is limited. Meanwhile, the demand for water for domestic use and production activities remains relatively stable throughout the year. This affects the stability of water resources due to the high use demand while the limited supply capacity [18].

## 3. Methodology

To assess the impact of natural and socio-economic conditions on the groundwater resources of Cao Bang province, the author conducted the following research methods:

Collecting documents: To conduct the research, the authors collected materials on natural conditions, geological and hydrogeological characteristics, as well as socio-economic activities in 10 highland areas in 7 districts of Cao Bang province, including Ngoc Dong, Luong Thong, Da Thong (Thong Nong district); Van Dinh – Xuan Hoa (Ha Quang district); Quoc Toan (Tra Linh district); Ngoc Chung (Trung Khanh district); Minh Long (Ha Lang district); Hong Quang, Chi Thao (Quang Uyen district); and Yen Lac (Nguyen Binh district) [21]. The documents were obtained from the Department of Natural Resources and Environment of Cao Bang Province, the National Center for Water Resource Planning and Investigation, and the Vietnam Academy for Water Resources. The collected data were used to assess the current state of natural distribution and socio-economic activities in the study area and utilized as a basis for analyzing and evaluating impacts on the stability of the region's water resources.

Tab. 2. The basis for determining the impact level of natural and socio-economic conditions on the stability of water sources
Tab 2. Podstawa do określenia poziomu wpływu warunków naturalnych i społeczno-gospodarczych na stabilność źródeł wody

| No. | Criteria | Level | Basis for evaluation |
|---|---|---|---|
| **I** | **Factors of natural conditions** | | |
| 1 | Geographical location | 1 | Upper reaches of major rivers |
| | | 2 | Middle reaches of large rivers or upper reaches of medium-sized rivers |
| | | 3 | Middle reaches of medium-sized rivers or upper reaches of small rivers and streams |
| | | 4 | Middle areas of small rivers and streams |
| | | 5 | Downstream areas of rivers, small streams or coastal areas |
| 2 | Topographic features [22] | 1 | Plains with elevation < 60 m |
| | | 2 | Midlands and hills have an altitude of 60 to less than 300 m. |
| | | 3 | Plateau has an altitude of 300 to less than 500 m |
| | | 4 | Mountains have an altitude of 500 to less than 1,000 m |
| | | 5 | Mountains > 1,000 m high or coastal sand dunes |
| 3 | Meteorological and climatic conditions (aridity index Kt) [23] | 1 | $K_t$ < 0.5 |
| | | 2 | $K_t$ = 0.5 to < 1.0 |
| | | 3 | $K_t$ = 1.0 to < 2.0 |
| | | 4 | $K_t$ = 2.0 to < 4.0 |
| | | 5 | $K_t$ > 4.0 |
| 4 | Hydrological characteristics | 1 | There are only small rivers and streams in the province. |
| | | 2 | There is 1 medium-sized river and 2 or more small rivers located in the province. |
| | | 3 | There is 1 large river and 2 or more medium-sized rivers located in the province. |
| | | 4 | There are 2 large rivers and 3 or more medium-sized rivers located in the province. |
| | | 5 | There are 3 or more large rivers (length > 10 km) located in the province. |
| 5 | Hydrogeological characteristics | 1 | There are 4 or greater freshwater aquifers that have the potential for centralized exploitation. |
| | | 2 | There are 3 or greater freshwater aquifers that have the potential for centralized exploitation. |
| | | 3 | There are 2 or greater freshwater aquifers that have the potential for centralized exploitation. |
| | | 4 | There are 1 or greater freshwater aquifers that have the potential for centralized exploitation. |
| | | 5 | There is no freshwater aquifer or only freshwater aquifers capable of household-scale exploitation. |
| **II** | **Socio-economic factors** | | |
| 1 | Population [24] | 1 | Under 100,000 people |
| | | 2 | From 100,000 to less than 200,000 people |
| | | 3 | From 200,000 to less than 500,000 people |
| | | 4 | From 500,000 to less than 1 million people |
| | | 5 | Over 1 million people |
| 2 | Population distribution [24] | 1 | Population density under 1,000 people/km$^2$ |
| | | 2 | Population density from 1,000 people/km$^2$ to less than 1,400 people/km$^2$ |
| | | 3 | Population density from 1,400 people/km$^2$ to less than 2,000 people/km$^2$ |
| | | 4 | Population density from 2,000 people/km$^2$ to less than 3,000 people/km$^2$ |
| | | 5 | Population density from 3,000 people/km$^2$ or more |
| 3 | Water demand [25] | 1 | Under 40 l/person/day |
| | | 2 | From 40 to under 150 l/person/day |
| | | 3 | From 150 to under 200 l/person/day |
| | | 4 | From 200 to under 300 l/person/day |
| | | 5 | From 300 l/person/day or more |
| 4 | Water usage habits | 1 | Use water efficiently, ensure hygienic toilets, and have a centralized wastewater treatment system that meets standards. |
| | | 2 | Water usage is relatively economical, there is a 2-compartment toilet and a wastewater treatment system but it does not meet standards. |
| | | 3 | Use water sparingly; there is a toilet but no wastewater treatment system yet |
| | | 4 | Water use is relatively economical but there are no toilets or wastewater treatment systems. |
| | | 5 | Wasteful use of water, no toilets, no wastewater treatment system |
| 5 | Activities that pollute water sources | 1 | There are only scattered residential areas, livestock grazing activities |
| | | 2 | There are concentrated residential areas, livestock grazing activities, and small-scale use of plant protection chemicals. |
| | | 3 | There are residential areas, industrial production facilities that generate wastewater or waste disposal sites, small-scale livestock farms, and the use of plant protection chemicals. |
| | | 4 | There are industrial clusters/craft villages, urban areas, waste disposal sites, and medium-scale livestock farms, using plant protection chemicals. |
| | | 5 | There are industrial zones/export processing zones, urban areas, waste disposal sites, large-scale livestock farms, and the use of plant protection chemicals. |

Statistics and synthesis: Based on the data collected and surveyed in the field, the study conducted statistics, synthesis, analysis, and assessment of the impact of natural conditions, socio-economic activities (increased water demand, mineral exploitation, aquaculture, population distribution, water usage habit, etc.) on the stability of water resources in the study area. In particular, the research also performs calculations to forecast water usage needs for the study areas based on water supply coefficients (detailed in Table 1).

Field survey: The study conducted surveys in high mountainous areas, assessed population distribution, and socio-economic activities in the region, and implemented community consultations to evaluate water usage needs for various sectors in the province. They also examined the current state of water exploitation, habits and customs related to water use, activities that pose risks of water pollution, and the water demand of different industries in the study area. Figure 1 shows the survey locations in the field. Additionally, the authors also took samples to assess the quality characteristics of aquifers in the study area. A total of 300 samples were selected for analysis and evaluation of water reserves and the quality of water sources in the survey area, taken from 19 groundwater extraction wells during both the rainy and dry seasons.

Additionally, based on the extent of the impact of various factors, the research team used a scoring method with 5 levels to assess the influence of natural and socio-economic conditions on the stability of groundwater sources in the Cao Bang region. The research team established 5 groups of factors related to natural conditions and 5 groups of criteria related to socio-economic conditions, with a basis for determining the impact level of these parameters on the stability of water sources in the study area. The 5 levels of influence are detailed in Table 2 where:

Level 1: Does not affect the stability of water sources; Level 2: Low impact on water source stability; Level 3: Moderate

Tab. 3. Groundwater characteristics in the study areas of Cao Bang province [10]
Tab 3. Charakterystyka wód podziemnych na obszarach badawczych prowincji Cao Bang [10]

| No. | Location | Well | TCN | Thickness (m) | Average water level (m) | $Q_{ttl}$ ($m^3$/day) |
|---|---|---|---|---|---|---|
| 1 | Ngoc Dong | W_19 | Bac Son Formation (c-p) | 95.6 | 14.11 | 2,556 |
| | | W_20 | | | 7.47 | |
| 2 | Quoc Toan | W_17 | Bac Son Formation (c-p) | 73.8 | 2.67 | 257 |
| | | W_18 | Na Quan Formation ($d_{1-2}$) | 76.4 | 2.60 | 1,069 |
| 3 | Van Dinh – Xuan Hoa | W_13 | Song Hien Formation ($t_1$) | 50 | 5.91 | 65 |
| | | W_14 | Dong Dang Formation ($p_2$) | 55.3 | 2.14 | 1,393 |
| 4 | Luong Thong | W_21 | Song Hien Formation ($t_1$) | 35 | 8.82 | 1,685 |
| | | W_22 | Dong Dang Formation ($p_2$) | 40.7 | 1.92 | 142 |
| | | W_23 | Bac Son Formation (c-p) | 37.6 | 9.59 | 493 |
| 5 | Da Thong | W_24 | Dong Dang Formation ($t_1$) | 35 | 5.71 | 472 |
| | | W_25 | Hệ tầng Đồng Đăng ($p_2$) | 79.5 | 6.95 | 517 |
| | | W_23 | Bac Son Formation (c-p) | 79.7 | 7.2 | 319 |
| 6 | Ngoc Chung | W_26 | Na Quan Formation ($d_{1-2}$) | 95.4 | 5.02 | 2,751 |
| | | W_27 | | | 2.97 | |
| 7 | Minh Long | W_28 | Na Quan Formation ($d_{1-2}$) | 73.8 | 1.95 | 1,479 |
| | | W_29 | | | 6.06 | |
| 8 | Hong Quang | W_35 | Bac Son Formation (c-p) | 96.4 | 3.20 | 2,005 |
| | | W_36 | | | 4.02 | |
| 9 | Chi Thao | W_33 | Bac Son Formation (c-p) | 97.1 | 0.60 | 1,203 |
| | | W_34 | Na Quan Formation ($d_{1-2}$) | 81.55 | 1.70 | 946 |

Tab. 4. Assessment of the level of influence of natural conditions on the stability of groundwater resources in Cao Bang province
Tab. 4. Ocena poziomu wpływu warunków naturalnych na stabilność zasobów wód podziemnych w prowincji Cao Bang

| No. | Criteria | Level | No. | Criteria | Level |
|---|---|---|---|---|---|
| 1 | Geographical location | 3 | 4 | Hydrological characteristics | 5 |
| 2 | Topographical features | 4 | 5 | Hydrogeological characteristics | 5 |
| 3 | Meteorological conditions, climate | 3 | 6 | Summary of impact assessment levels | 4.0 |

impact on water source stability; Level 4: Strong impact on water source stability; Level 5: Very strong impact on water source stability.

## 3. Results and discussion

### *3.1. Characteristics of groundwater resources in Cao Bang Province*

Cao Bang is a province characterized by a high, steep mountainous terrain with many limestone ranges, resulting in diverse groundwater formations [18]. The collection of data and field surveys conducted in 10 highland areas in 7 districts indicates that Cao Bang has the following aquifers:

- The fractured and fractured-karst aquifer in the carbonate sediments of the Na Quan Formation ($d_{1-2}$) is an unconfined aquifer with a lithological composition consisting of limestone and limestone containing silicic content with thin to medium layers. The main source of supply for the aquifer is rainwater and irrigation water.
- The fractured aquifer, fracture-karst in the carbonate sediments of the Bac Son Formation (c-p) is an unconfined aquifer with a primary supply source of rainfall, water from lakes, rivers, and streams that infiltrates, as well as from the aquifers above that seep down. The aquifer is evenly distributed over the entire study area, with lithological components including limestone, limestone containing silicon content, with thin to medium layering.
- The fissured, fissured-karst aquifer in the carbonate sediments of the Dong Dang Formation (p2) consists of terrigenous sediments with a lithological composition including limestone containing silica content, which is thin to medium layered. This is an unconfined aquifer with the source of water supply to the aquifer being rainwater and irrigation water that seeps down.
- The fissured aquifer in the terrigenous and terrigenous-eruptive sediments of the Song Hien formation ($t_1$) is an unconfined aquifer with the main sources of water supply being rainwater, water from lakes, rivers, streams, and water seeping down from the upper aquifers. However, this aquifer cannot be exploited centrally and is only suitable for exploitation by dug wells and drilled wells on a household scale.

The details of the distribution and characteristics of aquifer layers in the groundwater investigation and survey areas of Cao Bang Province are listed and summarized in Table 3. The locations of the wells are shown in Figure 1.

In the Yen Lac region, the characteristics of the aquifer based on a synthesis of data from field investigations, surveys, and materials collected from the National Center for Water Resources Planning and Investigation indicate that the groundwater in the study area primarily belongs to the terrigenous, terrigenous-eruptive sediments of the Song Hien formation ($t_1$), and fractured aquifers within carbonate sediments of the Dong Dang formation (p2).

The research results show that groundwater sources exploited in the Cao Bang province are mainly unconfined water, closely linked hydraulically with rainwater, surface water, and irrigation water. Therefore, groundwater has seasonal variations and is closely related to meteorological factors. In the dry season, the water level in the wells is lower, but in the rainy season, the water level of all wells rises quickly after rain. This also leads to the situation that in the dry season, dug wells of residents almost run out of water, and natural springs flow minimally or sometimes not at all, resulting in a shortage of clean water for daily living and local economic development. Additionally, the quality of groundwater is also affected, especially in the rainy and flood seasons, the suspended solid content in the water is high, the water is turbid and contains a lot of waste making it difficult for the water treatment process for domestic use and production activities [26]. Due to the high mountainous terrain, there are currently no centralized water supply facilities with a capacity greater than 1 $m^3$/day-night in the surveyed areas. Groundwater is

Tab. 5. Population of surveyed communes in Cao Bang province [10]
Tab. 5. Populacja badanych gmin w prowincji Cao Bang [10]

| No. | Research area | Geographical location | Population (people) | Number of people lacking water (people) | Water demand by 2030 ($m^3$/day) |
|---|---|---|---|---|---|
| 1 | Ngoc Dong | Ngoc Dong Commune - Thong Nong District | 1,165 | 1,165 | 169 |
| 2 | Quoc Toan | Quoc Toan Commune - Tra Linh District | 1,428 | 1,039 | 159 |
| 3 | Van Danh - Xuan Hoa | Van Dinh Commune, Xuan Hoa - Ha Quang District | 1,570 | 1,570 | 228 |
| 4 | Luong Thong | Luong Thong Commune - Thong Nong District | 1,932 | 1,932 | 280 |
| 5 | Da Thong | Da Thong Commune - Thong Nong District | 1,325 | 1,325 | 192 |
| 6 | Ngoc Chung | Ngoc Chung Commune - Trung Khanh District | 974 | 974 | 141 |
| 7 | Minh Long | Minh Long commune - Ha Lang district | 1,314 | 928 | 142 |
| 8 | Hong Quang | Hong Quang Commune - Quang Uyen District | 940 | 940 | 136 |
| 9 | Chi Thao | Chi Thao Commune - Quang Uyen District | 1,909 | 1,451 | 220 |
| 10 | Yen Lac | Yen Lac Commune - Nguyen Binh District | 1,074 | 1,074 | 156 |
| | **Sum** | | **13,631** | **12,398** | **1,823** |

Tab. 6. Assessment of the level of socio-economic impact on the stability of groundwater resources in Cao Bang
Tab. 6. Ocena poziomu wpływu społeczno-gospodarczego na stabilność zasobów wód podziemnych w prowincji Cao Bang

| No. | Criteria | Level | No. | Criteria | Level |
|---|---|---|---|---|---|
| 1 | Population | 2 | 4 | Water usage habits | 3 |
| 2 | Population distribution | 1 | 5 | Water pollution activities | 3 |
| 3 | Water usage demand | 3 | 6 | Summary of impact assessment levels | 2.4 |

mainly extracted through drilled and dug wells on a household scale, with the exploitation flow is about 5.3 to 6.2 l/s, the water level is lowered from 7.8 to 9.8 meters, which is below the calculated allowable water level.

### *3.2 Assessment of the impact of natural conditions on the stability of water resources*

The criteria for evaluating the impact of natural conditions on the stability of water resources indicate that the study area is primarily located in high mountainous regions with steep terrain and numerous limestone formations. These conditions are not favorable for the development of the province's economic sectors and water extraction for agricultural production and domestic use. Mountains with an average height of 500 to less than 1,000 m are concentrated in the midstream areas of medium-sized rivers or the upstream areas of small rivers and streams. The study area has a dense network of rivers and streams with large rivers such as the Bang River, Gam River, Quay Son River, and many intra-provincial river and stream systems... Among these, the major river systems primarily flow through districts such as Thong Nong, Ha Quang, Hoa An districts, Phuc Hoa, Trung Khanh, and Cao Bang Town. With a subtropical climate, the climate of Cao Bang province exhibits characteristics of a high-altitude continental tropical monsoon climate, distinct from other mountainous areas in the Northeast region. The aridity index (Kt), estimated based on the ratio of evaporation over a calculated time to rainfall, is approximately 1.6. The annual flow modulus in the whole region varies significantly. In areas with low rainfall, the average annual flow modulus is the smallest, ranging from only about 10 to 15 liters per second per square kilometer (l/s/$km^2$). Meanwhile, in areas with heavy rainfall, the highest average annual flow modulus can reach up to 70 l/s/$km^2$. In addition, the hydrogeological characteristics of the study area show that groundwater is primarily extracted from unconfined aquifers on a household scale, providing fresh water to meet local needs [26]. Based on the evaluation data according to the criteria, it can be seen that the natural conditions in the study area have a strong influence on the stability of groundwater resources. Therefore, it is necessary to be taken into account in controlling and managing exploitation to ensure the stability and sustainability of groundwater (Table 4).

### *3.3 Assessment of the impact of socio-economic conditions on the stability of water resources*

Changes in groundwater reserves and quality depend largely on socio-economic conditions such as population, population distribution, water demand for various purposes, people's water usage habits, and activities that pose a risk of polluting water sources. It can be seen that the flow is mainly concentrated in the flood season months, and the dry season months, although occupying a longer period of time, the flow is limited. Meanwhile, the demand for water for daily life as well as agricultural production activities (cultivation, livestock breeding), and aquaculture is relatively stable between times of the year. This will affect the stability of the flow of surface water and groundwater due to the high demand while the water flow is limited. It can be observed that the flow volume is mainly concentrated during the flood season, while the dry season, despite lasting longer, has limited flow volume. Meanwhile, the demand for water for domestic use, agricultural production activities (cultivation, livestock), and aquaculture remain relatively stable throughout the year. This will impact the stability of surface water and groundwater due to high usage demand while water flow volume is limited. According to collected data, statistics show that the population of the highland communes with scarce water resources in the study area is 13,631 people. The population is scattered with a low density, in which nearly 12,400 people face water shortages (Table 5). Based on the data on planning orientation and economic development of the province, the research has estimated the water usage demand for the study region by 2030 [27].

Rural residents live scattered in villages, with many areas having only a few households living on high mountains, such as the Hmong people. Some villages only consist of several dozen households, like the Dao ethnic group, or 50–100

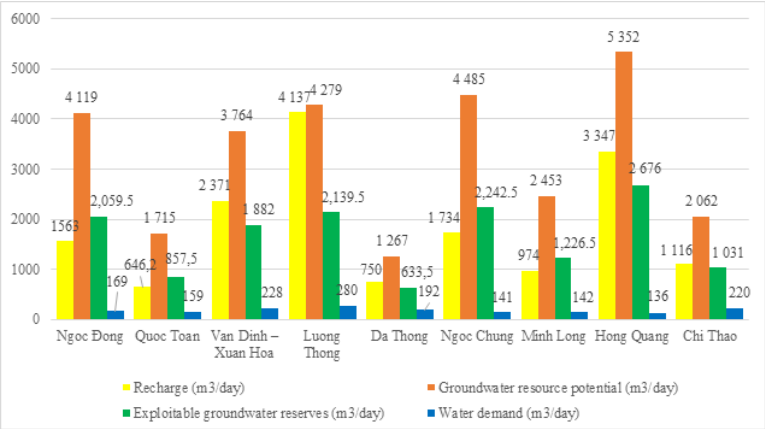


Fig. 2. Exploitable underground water reserves to ensure water stability in the study areas

Rys. 2. Eksploatacyjne rezerwy wód podziemnych zapewniające stabilność zasobów wodnych na obszarach badawczych

households, such as the Tay, Nung, and San Chay ethnic groups. Households are often located quite far apart, especially among the Hmong ethnic group, where villages are separated by tens of kilometers, which makes it very difficult to provide water to the people. According to statistics from Cao Bang Province in 2023, the total population of the province is 547,879 people, of which 25.5% live in urban areas (139,540 people) and 74.5% reside in rural areas (408,339 people) [27]. The population density is 82 people/km². Survey results show that the main water sources for drinking and daily activities of residents in the mountainous areas of the province are mountain stream water and rainwater; surface water (rivers, streams); open stream water; drilled and dug wells collecting underground karst water; and open karst water [28]. However, wastewater from factories, enterprises, hospitals, slaughterhouses, and domestic wastewater from residential areas are currently almost all directly discharged into rivers and streams, leading to a worsening of surface water quality and warning of serious pollution. The use of pesticides is also one of the many causes of surface water pollution and poses a risk of impacting and polluting groundwater sources. Furthermore, because the locality is located in a mountainous area, waste management is still not thorough, and many spontaneous landfills of households arise, causing environmental pollution in general and affecting the quality of underground water in particular. However, for water extraction projects at great depths and on a small scale, the level of impact on water quality is low. Moreover, the number of groundwater extraction wells within the studied communes of Cao Bang province is low, only 1 to 2 wells, so it does not cause a decrease in flow, lower water level, change the water quality of other groundwater exploitation works located in the affected areas, as well as does not impact surrounding surface water sources. Based on the survey results, along with the criteria developed to assess the level of socio-economic impact on the stability of water resources, the study has provided the impact level in Table 6.

The research results show that the socio-economic conditions in the research area affect the stability of water resources at low and medium levels. This is because the local population is scattered and socio-economic development activities are not high while underground water exploitation activities still ensure the exploitation capacity to meet the water usage needs of local people.

### *3.4 Proposal for Solutions to Protect Groundwater Resources*

With the goal of achieving over 95% of urban residents using clean water and over 90% of rural residents using hygienic water for daily life, combined with the results of assessing the impacts of natural and socio-economic conditions on the stability of water resources and calculated data on water demand in highland, water-scarce areas of Cao Bang province, the study has synthesized and calculated the exploitable underground water reserves to ensure water supply meets usage needs and still maintain the stability of water resources in the area. Figure 2 shows recharge volume, groundwater resource potential, exploitable groundwater reserves, and water demand of each survey area of the study area. Currently, the water demand is much lower than the exploitable water reserves. However, in the future, when water demand increases, it will be possible to enhance the extraction flow from these wells to ensure water supply. In addition, to increase the groundwater reserves with sufficient quality to ensure the water supply for domestic use and economic, production, and business activities in the region, it is necessary to plan large-scale exploitation and construct centralized water supply facilities in the study areas. Depending on the characteristics of each research area and the water usage needs to build centralized water supply works with appropriate exploitation reserves.

In addition, to ensure the stability and sustainability of groundwater resources in the highland, water-scarce areas of Cao Bang province, it is also necessary to pay attention to protecting water quality. In addition, to ensure the stability and sustainability of groundwater resources in the mountainous and water-scarce areas of Cao Bang province, attention must also be given to protecting water quality. In particular, for groundwater extraction facilities supplying domestic water with a scale of over 10 m³/day and night up to less than 3,000 m³/day and night, the sanitary protection range of the domestic water intake area is not less than 20 m from the wellhead. Furthermore, in this area, there must be no livestock barns, toilets, waste dumps, warehouses, chemical storage sites, or other sources of pollution [29]. At the same time, it is necessary to strictly control the discharge of waste (wastewater, solid waste...) into river systems, lakes, and water sources to ensure a safe water supply for people. Investigation and assessment of groundwater resources are carried out at a scale of 1:50,000 to 1:25,000, covering an area of 1,006/6,700 km²

of the province's natural area [30]. In addition, it is necessary to focus on generating a database on wastewater sources and building a suitable domestic wastewater treatment system before discharging. At the same time, the locality also needs to invest in building and operating a monitoring system to monitor groundwater exploitation activities to ensure stable control of groundwater quality and reserves [31]. On the other hand, regularly promote and encourage the public to participate in protecting water sources, managing, and safeguarding the components of local water supply facilities; practice the economical and efficient use of domestic water.

**4. Conclusion**

The study investigated the impact of natural and socio-economic conditions on the stability of groundwater in some highland, water-scarce areas of Cao Bang province by using data collection, field surveys, community consultations, and laboratory sample analysis. The research results indicate that Cao Bang province is facing a shortage of water for domestic use and local economic development, particularly in high mountainous areas. Specifically, the population suffering from water scarcity in the mountainous communes in the surveyed area is 12,400 people, of which the total number of people lacking water in the whole region is nearly 13,631 people. The study has forecasted that the water demand by 2030 will be 1,823 $m^3$/day, and the exploitable groundwater reserves would be14,748 $m^3$/day. This forecast is sufficient to meet the current and future water supply needs of the locality. The study also reveals that the groundwater extracted in Cao Bang province mainly consists of unconfined water, which has a close hydraulic relationship with rainwater, surface water, and irrigation water. During the dry season, residents' dug wells almost run dry, and exposed sources flow weakly or sometimes stop flowing altogether, leading to a shortage of clean water for daily use and local economic development. Due to the mountainous terrain, the surveyed areas currently do not have any centralized water supply systems with a capacity greater than 1 $m^3$/ day and night. Groundwater is mainly exploited by drilled wells and dug wells on a household scale. Their exploitation flow is from 5.3 to 6.2 l/s, the water level is lowered from 7.8 ÷ 9.8 m, lower than the calculated allowable water level.

The findings show that the number of groundwater extraction wells in mountainous areas is low, typically only 1 to 2 wells, so they do not cause significant impacts on flow reduction, water level decline, or changes in water quality of other groundwater extraction facilities located in the area of influence of the project. Furthermore, the obtained results indicated that while natural conditions have a strong impact on the stability of water resources, socio-economic conditions have a low and medium impact. Therefore, the study proposed several solutions for water exploitation to provide domestic water for local people, ensuring stability and sustainability of water resources and socio-economic development of the locality.

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## *Wpływ warunków naturalnych i społeczno-gospodarczych na stabilność zasobów wód podziemnych w prowincji Cao Bang (Wietnam)*

*Prowincja Cao Bang (Wietnam) boryka się z niedoborem wody do codziennego życia i rozwoju gospodarczego regionu, zwłaszcza na obszarach górskich. Badanie wpływu warunków naturalnych i społeczno-gospodarczych na stabilność wód podziemnych w niektórych regionach górskich, gdzie woda jest deficytowa w prowincji Cao Bang, stanowi podstawę do opracowania odpowiedniego planu zarządzania eksploatacją wody, zapewniającego życie mieszkańców. Poprzez zbieranie dokumentów, przeprowadzanie badań terenowych, konsultacje ze społecznością i analizę próbek w laboratorium, badanie wykazało, że całkowita populacja w 10 obszarach górskich w 7 dystryktach wynosiła 12 398 osób, które brakowały wody do użytku domowego, a zapotrzebowanie na wodę do 2030 roku przewidywano na 1 823 m³/dzień. Ponadto wyniki badań wykazały, że rezerwa wód podziemnych możliwa do eksploatacji wynosiła 14 748 m³/dzień, co zaspokaja bieżące i przyszłe potrzeby zaopatrzenia w wodę regionu. Dodatkowo wyniki pokazują, że warunki naturalne mają silny wpływ na stabilność zasobów wodnych, ponieważ obszar ten znajduje się na terenie górskim, co tworzy złożone warunki formowania się wód, nieregularne opady, powodzie i reżimy przepływu. Warunki społeczno-gospodarcze mają natomiast niski i średni wpływ na stabilność zasobów wodnych, ponieważ w tych obszarach nie było dużych inwestycji w rozwój gospodarczy, populacja jest rzadka, zapotrzebowanie na wodę jest niskie, a liczba prac eksploatacyjnych jest niewielka. Dlatego badanie zaproponowało szereg odpowiednich rozwiązań dotyczących eksploatacji wody, aby zapewnić zaopatrzenie w wodę dla mieszkańców, zapewniając rozwój gospodarczy i ograniczając obecny niedobór wody.*

**Słowa kluczowe:** *warunki społeczno-gospodarcze, stabilność zasobów wód podziemnych, prowincja Cao Bang*