Radon-Radium Thermal Mineral Water in Vo Am Ecotourism Project Area, Ngoc Luong Commune, Yen Thuy District, Hoa Binh Province, Vietnam

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Abstract

Ngoc Luong thermal mineral water at Vo Am ecotoursim, Ngoc Luong commnune, Yen Thuy district, Hoa Binh province, northern Vietnam. The thermal mineral water source is at karstic-fractured limstones of Dong Giao Formation aged Anisi. Methods used in this study conists of basic field survey of hydrogeology, resistivity, borehole drilling, pumping tests, and thermal mineral water sample analysis. The thermal mineral water is classified as radon-radium, low mineralised thermal mineral water. The water source is originally related to the deep Moc Chau-Tam Diep Fault directing northwest-southeastward. Its exploration reserve is estimated at 1,497 m³/d with good quality, sastifying all national criterals for the use of domestic supply, bathing, and medical treatment. This is one of ten rare thermal-mineral water sources in Vietnam, containing radon and radium. It is thefore necessary to have good management to ensure the thermal-mineral water to be effectively exploited, used, and protected.

Keywords: *thermal mineral water, Ngoc Luong, Hoa Binh, Vietnam*

1. Introduction

Ngoc Luong thermal mineral water source is located in Vo Am eco-tourism area in Ngoc Luong commune, south of Yen Thuy district (Hoa Binh province), having a boundary with Nho Quan district, Ninh Binh province, about 15km away from Hang Tram town (Figure 1). For a long time, local people have used Ngoc Luong thermal mineral water to bathe effectively for bone and joint diseases (To Xuan Ban, 2021). The Ngoc Luong thermal mineral water has yet listed in the 1996 Vietnam atlas of mineral water and not in a list of the list of 400 national thermal mineral water sources reported by Ho Minh Tho (2019).

Located 10–15km away to the east and southeast of Ngoc Luong source are some thermal mineral water spots such as Kenh Ga, Cuc Phuong, and Thuong Sung in Ninh Binh province (Ho Minh Tho, 2019; Vo Cong Nghiep, 2000). Further to the northwest about 30 to 45 km, in Kim Boi district (Hoa Binh province), there are natural resources of Kim Boi, Sao Bay, Xom Denh (Vo Cong Nghiep, 2000). These thermal mineral water sources have been exploited for bathing and health care. Raw materials from Thuong Sung and Kim Boi are exploited and bottled. The distinctive feature of Ngoc Luong in comparation with other surrounding thermal mineral water is rich in Radon (Rn) and Radium (Ra) contents (To Xuan Ban, 2021), which is effective in treatment of born-relating disses and improving joint function when bathing.

2. Methods

Methods used in this work include basic field investitagtion of hydrogeology, geophysics (resistivity), pumping tests and sample analysis for thermal mineral water. The field investigation is to study the geology and hydrogeology of the site for the potential of thermal mineral water. Resistivity works involves to alocate anorm relating to thermal mineral water in the area. The pumping test was carried out at three discharge rates of 43.0 m³/h, 30.5 m³/h, and 25.0 m³/h at two boreholes at which then were pumped for experimental exploitation at discharge of 25 m³/h for period of 6 months. The two boreholes were then monitored for water levels and temperatural for 12 months. There were 9 groups of water samples at the area to analyze with about 130 thermal water parameters.

3. Results and discussion

3.1. Hydrogeological setting

As with other thermal mineral water sources of Thuong Sung, Kenh Ga, Kim Boi, Sao Bay Xom Denh, etc., Ngoc Luong thermal mineral water resource distributes in the Anisi limestones of the Dong Giao Formation (T2adg). There is an exploration well named as NL2/1 for assessing water reserve and a monitoring borhole QT1 (NL1) penetrating the limestone of Dong Giao limestone Formation (T2adg) overlain by Quaternary sediments of Thai Binh Formation which has a thickness of 2 to 3m (Figure 1 and Figure 2).

Hydrogeological stratigraphic column of NL2/1 well shows 2 layers: the above thin layer of Quaternary sediments directly overlying the below the fracture-karstic aquifer of up to 60m below ground surface. The fracture-karstic aquifer constists of cracked and irregularly karstified massive blueish grey limestones. The karstification of limestones is irregular with short unconected kartsic caves with cave heigh of 0.5 to 1.2m. Backfilling caves are also different with two emplty caves above and one below filling with clay materials. Aquifer thickness at NL2/1 well is 25m. The aquiclude consists of blueish grey limestones and dolomitestones which are mas-

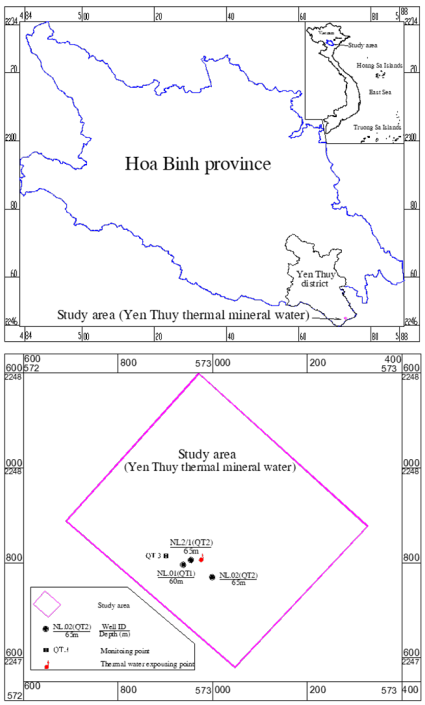

Fig. 1. A sketch map showing location of Ngoc Luong thermal mineral water

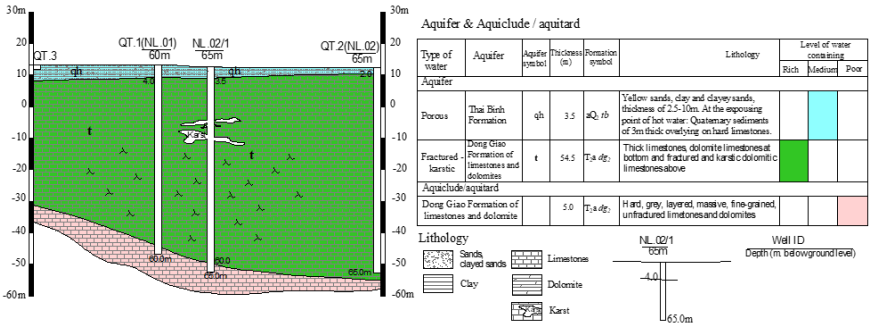

Fig. 2. Hydrogeological cross-section at Ngoc Luong thermal mineral source

sive, unfractured or weekly fractured locating at depth greater than 60 bewlow surface (Figure 3).

Field investigation and pumpinng tests at Well NL2/1 and 2 monioting wells QT1 abd QT2 indicates that thermal water at Well NL2/1 is confined (To Xuan Ban, 2021). Thermal mineral water source from deep below, extruding to the surface via cracks and fractures and exposing on the surface in the form of extrusion and effervescent circuits. The water pumping test of 15 days long (45 shifts) and trial exploitation of 6 months long with an abtraction rate of 600 m^3/day at Well NL2/1 along with monitoring time of 12 months at the monitoring Well QT1 and QT2) were carried. The results are shown in Table 1, Table 2 and Table 3.

3.2. Quality of thermal mineral water

To evaluate the quality of the Ngoc Luong thermal mineral water source, 9 sets of samples were analyzed, each set was analyzed with 130 parameters. Of 9 sample sets, 3 sets were taken at pumping tests (3 times water abstraction), another 3 sets of samples were taken in 6 months of trial exploting pumping and the last 3 sets of samples taken in 12 months of monitoring. The results were summazed, compared with the standards of water quality.

The basic chemical composition of water

The basic chemical composition of the thermal mineral water includes 17 parameters: color, turbidity, taste, pH, total dissolved solids (TDS); cations (Na^+, K^+, Ca^{+2}, Mg^{+2}, Fe^{+3}); anions (Cl^-, HCO_3^-, SO_4^{-2}), free CO_2, total hardness. Figure 3 indicates that the chemical composition of the samples was taken under different conditions and time, but the distribution was concentrated and stable in the calcium magnesium bicarbonate field. That shows that the water source is not mixed and does not fluctuate over time.

Classification of the Ngoc Luong thermal mineral water

According to Circular No.52/2014/TT-BTNMT of Vietnam Ministry of Natural Resources and Environment (2014), Ngoc Luong thermal mineral water is classified as a natural thermal mineral water with low mineralization, radon, radium (Table 4). The nominal values have very stable values, being unchanged with season and to the experimental pumping tests.

The thermal mineral water for drinking botter

Assessment according to QCVN 6-1: 2010/BYT of Ministry of Health Portal of Vietnam (2010), including 25 criteria Sb, As, Ba, B, Cu, CN, F, Pb, Mn, Hg, Ni, NO_3, NO_2, Se, sur-

Tab. 1. Summary of 15-day-pumping tests at NL2/1 well and monitoring at QT1 and QT3

Times	Pumping well				Monitoring wells			
	NL2/1				NL1 (QT1)		Surface water (QT3)	
	Discharge rate Q (m^3/h)	Drawdown S (m)	Specific discharge q (l/s.m)	Temperature (°C)	Drawdown S (m)	Temperature (°C)	Variation in temperature (degree Celcis)	Variation in water level* (m)
1st	43.0	5.17	2.30	41.0	2.60	40.5	14-23	0.5-0.8
2nd	30.5	4.38	2.12	41.0	1.75	41.0	15-24	0.9-1.1
3rd	25.0	2.88	2.41	41.0	1.66	41.0	15-23	0.8-1.3

Tab. 2. Summary of a 6-month-long pumping test

	Pumping Well NL2/1				Monitoring Well QT1 (NL1)			Monitoring QT3 (Surface water at the trend)*		
	Elevation of water level (m)	Water level (m)	Discharge rate (m^3/h)	Temperature (^{0}C)	Elevation of water level (m)	Water level (m)	Temperature (^{0}C)	Elevation of water level (m)	Water level (m)	Temperature (^{0}C)
Average	8.63	3.98	25	40.05	8.60	4.63	40.19	13.09	0.25	28.34
Maximum	8.70	4.05	25	40.64	8.65	4.7	40.64	13.34	0.57	35.83
Minimum	8.58	3.91	25	39.06	8.54	4.58	39.54	12.77	0.00	20.74

Tab. 3. Summary of 12-month-long monitoring record at QT1, QT2, and QT3

	Well NL2/1		Well QT1		NL2 QT2		Surface water QT3	
	Elevation of water level (m)	Temperature (^{0}C)	Elevation of water level (m)	Temperature (^{0}C)	Elevation of water level (m)	Temperature (^{0}C)	Elevation of water level (m)	Air temperature (^{0}C)
Min	11.25	39.0	10.05	39.00	12.61	28.00	12.54	17.00
Max	11.67	41.0	10.50	40.00	13.02	29.00	13.31	38.00
TB	11.52	40.3	10.37	39.92	12.91	28.85	13.08	26.45

factants, pesticide residues and PCBs, mineral oils, polycyclic aromatic hydrocarbons, E. Coli or heat-resistant coliform, Total Coliform, Streptococi feacal, Pseudomonas aeruginosa, Spores of sulfite-reducing anaerobic bacteria.

The thermal mineral water for drinking water

Assessment according to QCVN 01-1:2018/BYT of Ministry of Health Portal of Vietnam (2018), including 99 indicators belonging to the groups of microbiological parameters, inorganic organoleptic parameters, parameters of disinfectant chemicals and by-products, and level of radiation contamination.

Combining QCVN 6-1:2010/BYT (2010) and QCVN 01-1:2018/BYT (2018) of Ministry of Health Portal of Vietnam indicates that Ngoc Luong hot mineral water source in borehole NL2/1 is qualified for drinking and bottling.

Ngoc Luong thermal mineral water for bathing

In comparation with the table of criteria and standards of therapeutic mineral water (total mineralization, free CO2, total (H_2S+HS^-), H_2SiO_3, (Fe^{+2}+Fe^{+3}), F^-, As, Br, I, Rn, Ra and temperature), Ngoc Luong mineral water source meets three criteria. That is the temperature and radon and radium content. Specifically: the temperature is higher than the specified value to 100 C; average radon (Rn) content of 2.52 nCi/l, more than 2 times higher than the regulation; radium (Ra) content averaged 5.45.10–11 g/l, 5 times higher than prescribed. With the above characteristics, Rn and Ra Ngoc Luong hot mineral water sources are very rare in the Northern region and in the territory of Vietnam.

3.3. Reserves of Ngoc Luong thermal mineral water

Ngoc Luong thermal mineral water source is distributed in the fractured zone, karstic systems of limestones, dolomitic limstones (To Xuan Ban, 2021). To Xuan Ban (2021) reported total reserves and resources in Well NL2/1 is 1497 m^3/day (combination grade B and C1; with grade B of 600 m^3/day and grade C1 of 897 m^3/day). Compared with neighboring non-renewable sources, Ngoc Luong thermal mineral water resource is in the group of large reserves.

3.4. Origin of Ngoc Luong thermal mineral water

Origin models of thermal mineral water

Natural thermal mineral water is a special type of water of geological origin, overflowing on the ground or located at a small depth, which can be exploited and used for very different purposes depending on the characteristics of the source. Thermal mineral sources are natural underground water formed by a geological process, with temperature, mineral composition and chemical, physical, microbiological properties, purity, meeting standards and regulations. Technical standards can be exploited for use in drinking, bottling, bathing, and medical treatment. Thermal mineral water often contains a small amount of dissolved chemical compounds in the form of cations and anions. The pH of thermal mineral water ranges from very acidic to alkaline, silicon-saturated alkaline chloride, calcium bicarbonate. Some sources contain iron cations and other metals. The temperature, chemical composition change from one source to another and over time, seasonally, affected by neighboring groundwater sources.

Thermal mineral water is derived from groundwater and rain water (meteorological water). These water move deep down. At the great depths of the Earth's crust, water is heated by heat sources and moves back to the upper part and extrudes to the surface. The most favorable path of moving downwards and extruding back to the surface is tectonic faults, especially deep faults, strongly deformed and fractured soil and rock (Figure 4).

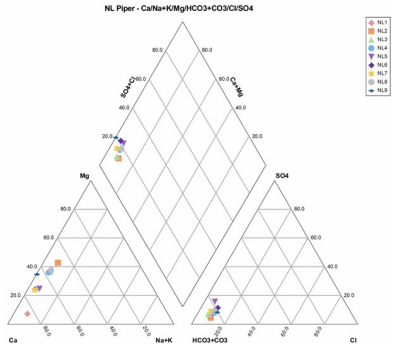

Fig. 3. A piper diagram showing sample analysis of Ngoc Luong thermal mineral water

Tab. 4. Classification of Ngoc Luong thermal mineral water according to the Circular No.52/2014/TT-BTNMT [* Standard according to TT 52/2014 of Vietnam Ministry of Natural Resources and Environments. ND: Not ditected]

#	Parameters	Unit	TT52/2014 /BTNMT*	Name of mineral water	Results of Well NL2/1	Assessment
1	TDS	mg/l	≥ 50 – 500	Low mineral water	297	Acceptable
2	CO_2 (free gas)	mg/l	≥ 500	Carbonic mineral water	30.57	
3	Total ($H_2S + HS^-$)	mg/l	≥ 1	Sulphuric mineral water	ND	
4	$H_2SiO_3^+$	mg/l	≥ 50	Silic minerl water	ND	
5	Iron ($Fe^{2+} + Fe^{3+}$)	mg/l	≥ 10	Ironic mineral water	ND	
6	Flourite (F^-)	mg/l	≥ 1.5	Flourite mineral water	ND	
7	Asenic (As^-)	mg/l	≥ 0.7	Asenic mineral water	ND	
8	Brom (Br^-)	mg/l	≥ 5	Bromic mineral water	ND	
9	Iod (I)	mg/l	≥ 1	Iodic mineral water	ND	
10	Radon (Rn)	nCi/l	> 1 nCi/l	Radonic mineral water	2.52 nCi/l	Acceptable
11	Radi (Ra)	g/l	> 10^{-11} g/l	Radii mineral water	5.45*10^{-11}g/l	Acceptable
12	Temperature	° C	≥ 30	Thermal mineral water	40° C	Acceptable

The analysis results of oxygen isotope δ18O and hydrogen δ2 H from hot mineral water sources around the world show that most of the thermal mineral water is formed by the mixing of meteorological water and thermal water from magma sources at different ratios. The heat sources that create hot water mineral include residual heat source of magma blocks, geothermal gradient source, heat source due to radioactive decay reactions.

Chemical compounds are present in thermal mineral water sources due to many reasons: provided by gases or hydrothermal solutions of magma during crystallization, during metamorphism. On the way to move upwards, hot water sources with high temperatures, containing gases cause chemical reactions with surrounding minerals and rocks, and are supplied with additional chemical components. The dissolution process is very favorable when the hot water source moves through the limestone strata, ore bodies containing sulfur minerals. Many hot water springs are surface manifestations of underground "thermothermal" mineral deposits. For example, when the source of hot water moves in limestone layers will have a following reaction:

$$CaCO_3 + H_2O + CO_2 \leftrightarrow Ca^{+2} + 2HCO_3^-$$

The source will receive more calcium bicarbonate. When the hot water source moves through the sulphur ore bodies, it is possible to receive more sulphate according to following reaction:

$$2FeS_2 + 7O_2 + 2H_2O \leftrightarrow 2Fe^{2+} + 4SO_4^{-2} + 4H^+$$

As a result of the processes of dissolving, mixing, acquiring more components due to chemical reactions, from an initial meteorite water source, it has developed into many sources of thermal mineral water with different chemical compositions. In fact, in Hoa Binh province, the source of Sao Bay (Kim Boi district, Hoa Binh province) Aqueous Minerals is located near pyrite ore bodies, so the sulphate content is higher, higher than that of Ngoc Luong, Bo, Kim Boi, Dinh hamlets (Cao The Dung, 2013, 2015; Tran Ngoc Minh, 1997).

In areas where thermal mineral water is developed, large-scale heat sources in the depths may appear. The temperature in the depths can be up to several hundred degrees, exploited for different needs such as electricity generation, heating and many other applications. For example, the geothermal energy of the Malawi rift, Mozambique in South Africa (Estefanny Davalos-Elizondo, Eliot A. Atekwana, et al.D. A. L. Davila, 2021) is very large (Figure 5). Thermal mineral water points with temperature from 35 to 80°C, the type of hot mineral water is sodium sulfate (bicarbonate), sodium bicarbonate (sulphate) and sodium chloride (sulphate). Depending on the location, at a depth of up to 1000m, the temperature rises to 100°C, the depth of 2500m, the temperature rises to 150°C. Figure 5 indicates cold meteoric rainwater moves down deep along faults heated by heat sources; parent water continues to be heated further as it approaches the heat source, and mixing water after being heated, goes up and mixes with the aquifer farming and adding CO_2 (Emmanuel A. Njinju et al., 2019; Estefanny Davalos-Elizondo, Eliot A. Atekwana, Estella A. Atekwana, et al., 2021).

Radon-radium thermal mineral water in the Moc Chau-Tam Diep deep fault zone

The Moc Chau-Tam Diep deep fault has been known in many geological documents in Vietnam, extending for more than 100 km from Mai Chau (Son La province) through Ngoc Luong (Yen Thuy, Hoa Binh province) to Tam Diep area (Ninh Binh province) in northwest southeast direction (Cao Dinh Trieu & Pham Huy Long, 2002). The fault of large scale coincides with the topographic elevation levels and indicates with

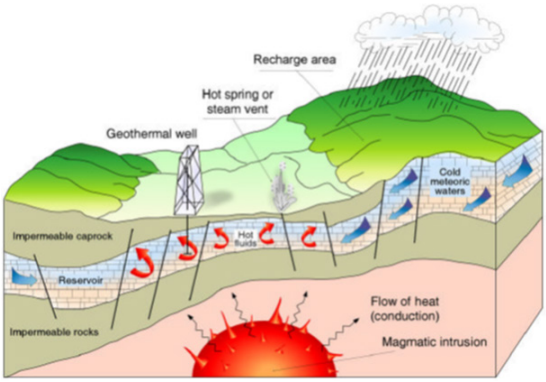

Fig. 4. A simple model explaining the form of a source of thermal mineral water and geothermal system (Mary H.Dicson & Mario Fanelli, 2004)

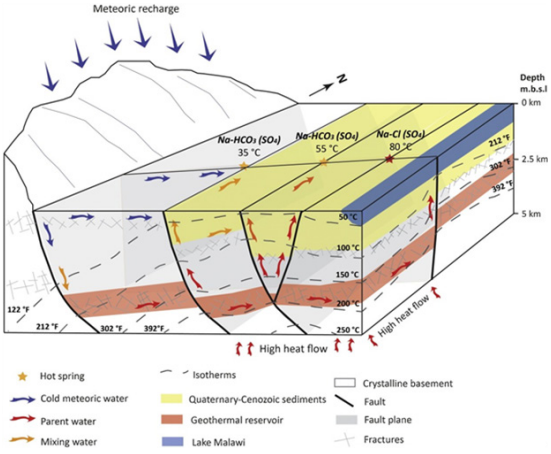

Fig. 5. A schematic geothermal conceptual model of the Malawi Rift Zone, explaining the form of thermal mineral water and heat sources (Dávalos-Elizondo et al., 2021)

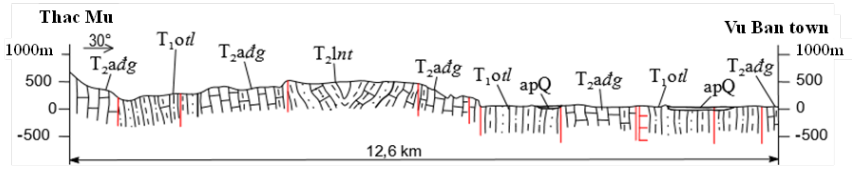

Fig. 6. Geological cross-section showing the allocation of Thac Mu-Vu Ban within the Moc Chau – Tam Diep tectonic zone. Note: T1tl: Tan Lac Formation (Brownish red sandstones, siltstones, claystones); T2ađg: Dong Giao Formation (limstones, dolomitic limestones, dolomite); T2lnt: Nam Tham Formation (clayed limestones, siltstones, schist), aqQ: alluvium-prolovium sediments (gravels, sands, silts, clays)

Vu Ban - Hang Tram (Hoa Binh province) - Tam Diep (Ninh Binh province) negative topographic valley line, filled with Quaternary sediments. According to the section from Vu Ban town (Hoa Binh province) through Con River, to Thac Mu (Lac Son, Hoa Binh province), the deformation zone is over 12 km wide (Le Tien Dung & To Xuan Ban, 2021), conisisting of limestones and shale bands of milonitization, slab slope angle 85–900 interspersed with dolomitic cataclasite limestone beds and tectonic gritstones (Figure 6 and Figure 7).

According to Cao Dinh Trieu and Pham Huy Long (2002), the Moc Chau-Tam Diep fault, plugged to the northeast, 100km long and 20km wide, includes a series of faults of the same nature. The slope is right, plugging to the northeast, forming a zone of step structure, the foundation surface crystallizes within 2–3km. Conrad face (12–14 km) and Moho face (26–30 km) (Nguyen Van Hoanh, 2005). The influent depth of the fault is 35–40km. The zone coincides with the band-positive structure, the Bouguer gravity anomaly varies in the range of -50 to +10 mGal, the relative positive structure of the magnetic field has a variable value in the range of from -200 to +40. The fault bodies of the zone coincide with the gravity anomalous horizontal gradient with an average value of 1.0–2.5 mGal/km and the horizontal anomalous gradient from the air with an average intensity of 8.0–12 nT/kilometer. Along the fault, earthquakes of magnitude Ms approximately 4.0–4.9 magnitude are observed and hot mineral water sources.

3.5. Therapeutic effects of radon-radium thermal mineral water at Ngoc Luong

Ho Minh Tho (2019) reported that among 400 sources of thermal mineral water in Vietnam, there are only 8 sources having radii and 8 sources featured with radon in water. The Ngoc Luong thermal mineral water sources is istingushed to have both radon and radii. The nearsest sources to Ngoc Luong are La Phu flouride-radon thermal mineral water located in Thanh Thuy district, Phu Tho province, and Tan Vien radii thermal mineral water located at Tan Linh moutain, Ba Vi district, Hanoi.

Accoring to the medical studies of La Phu source, the fouride-radon thermal mineral water featured with present of

Fig. 7. Deformed limestone (right) and claystone steep dipping in Moc Chau-Tam Diep milonite fractured zone

Fig. 8. Local people taking bath with thermal water abstracted from the Welll NL02 at Ngoc Luong thermal mineral water sources

radi element have more use and effect (www.tnmtphutho.gov.vn). Bathing: when soaking or submerging whole or part of man body in the mineral water, radon can penetrate through skin to the bloodstream and reach the cells. This therapy is effective for treating diseases of cardiovascular, musculoskeletal, and peripheral nervous system. Drinking: drinking radon-mineral water at appropriate level of doses has strong effect on body because it adsorps radon into blood, absorbing more radiation than bathing therapy. Radon in water also helps to improve function, enhance the secretion of gastric juice and the activity of the stomach, and improve the lipid exchange. Inhalating: this therapy is effective for respiratory and circulatory diseases. Enema pumping: enema, pushing radon-mineral water into rectum to treat some intestinal diseases. Mud bathing: covering body with mud containing radon-mineral water to treat diseases relating to joints, nervous system, circulatory system and de featuring with flouride – radon found in the thermal water to treat diseases relating to joints, nervous system, circulatory system, and dermatology.

There has yet been any medical research to evaluate curative effects of the Ngoc Luong thermal mineral water. However, over the years, local people daily come to bathe with Ngoc Luong thermal mineral water because of its effectiveness in treatment of osteoarthritis and cardiovascular diseases (Figure 8).

4. Conclusions

Ngoc Luong thermal mineral water source is in the Vo Am eco-tourism project area, Yen Thuy district, Hoa Binh province, Vietnam. The thermal mineral water belongs to the group of calcium bicarbonate, distributed in the system of fractures, karstic caves of the Dong Giao Formation aged Anizi.

Thermal mineral water has a high temperature (40°C), the content of physico-chemical indicators is stable, meeting the requirements for bottling, bathing, caring and health recovering. Identification of Ngoc Luong water source is of natural thermal mineral water, low mineralization, radon, radium.

The radon and rdium contents of Ngoc Luong thermal mineral water are higher than that of other thermal mineral water sources located around Hoa Binh and Ninh Binh provinces, which is believed to be in relation to the Moc Chau – Tam Diep deep fault. The presence of radon and radium in Ngoc Luong thermal mineral water increase its effect for healing, bathing, and restoring health.

From the fact that the source of Ngoc Luong NKN is very effective for bathing, treating bone, joint and cardiovascular diseases. To improve the efficiency of using Ngoc Luong renewable resources, it is necessary to conduct systematic scientific studies, evaluate the properties of hydrotherapy, thermotherapy, mineralotherapy, and propose procedures for the use of mineral resources. scientific, reasonable, economical, and effective.

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