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ARTÍCULO ORIGINAL

Potential use of hot springs in Namibe province, Angola: preliminary physical-chemical findings

Uso potencial de aguas termales en la provincia de Namibe, Angola: hallazgos físico-químicos preliminares

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Abstract

Namibe province on the southwest coast of Angola has several hot springs (Montipa, Ndolondolo, Pediva, Sayona and Tipa) which can provide water for human consumption, agriculture, tourism and therapeutic purposes. This study is aim to characterize physically and chemically the thermal waters from Ndolondolo and Tipa springs. Water samples were taken, in summer and winter, from the Water Treatment Plant and Wastewater Treatment Plant of the Namibe Provincial Water and Sanitation Company as well as from the Huíla Water and Sanitation Company. Samples were analyzed for color, odor and taste organoleptic parameters, and physicochemical parameters such as turbidity, electrical conductivity, total dissolved solids, pH, temperature, iron, nitrogen and dissolved oxygen. Results show that Tipa thermal water is sulfuric, slightly basic and mesothermal, as it emerges at an average temperature of 40.35°C. In turn, Ndolondolo water emerges at 37.60°C, being mesothermal of telluric origin, alkaline, slightly salty and mesosaline. Values found in both waters, according to the World Health Organization (WHO), make them suitable for human consumption with proper treatment. They can also be used for agricultural irrigation, animal watering and recreational purposes. Both thermal waters are mesothermal, of telluric or meteoric origin, mesosaline and alkaline, although thermal water from Tipa is sulfurous.

Key words: Thermal water; physical-chemical parameters; Tipa; Ndolondolo Namibe

Resumen

La provincia de Namibe, en la costa suroeste de Angola, cuenta con varias fuentes termales (Montipa, Ndolondolo, Pediva, Sayona y Tipa) las cuales. pueden proporcionar agua para el consumo humano, la agricultura, el turismo y con fines terapéuticos. Se realizó un estudio de las aguas termales de las fuentes de Ndolondolo y Tipa, con el objetivo de caracterizarlas física y químicamente. Se tomaron muestras de agua, en verano y en invierno, de la Planta de Tratamiento de Aguas y Planta de Tratamiento de Aguas Residuales de la Empresa Provincial de Agua y Saneamiento de Namibe así como de la Empresa de Agua y Saneamiento de Huíla. Se analizaron en las muestras los parámetros organolépticos color, olor y sabor, y los parámetros fisicoquímicos turbidez, conductividad eléctrica, sólidos disueltos totales, pH, temperatura, hierro, nitrógeno y oxígeno disuelto. Se encontró que el agua termal de Tipa es sulfúrica, ligeramente básica y mesotermal, pues emerge a una temperatura promedio de 40,35°C. A su vez, la de Ndolondolo emerge a 37,60°C, siendo mesotermal de origen telúrico, alcalina, ligeramente salada y mesosalina. Los valores encontrados en ambas aguas, según la Organización Mundial de la Salud, las hacen aptas para el consumo humano con un tratamiento adecuado. También pueden utilizarse para riego agrícola, abrevadero de animales y fines recreativos. Ambas aguas son mesotermales, de origen telúrico o meteórico, mesosalinas y alcalinas, aunque el agua termal de Tipa es sulfurosa.

Palabras clave: Agua termal; parámetros fisicoquímicos; Tipa; Ndolondolo, Namibe

1. INTRODUCTION

Angola is a country rich in natural resources, including extensive hydric sources, with particular emphasis on groundwater as a hydrothermal resource. The province of Namibe, located on the Southwest coast of Angola, has several thermal springs, such as Montipa, Ndolondolo, Pediva, Sayona, and Tipa. These sources can provide water for human consumption, agriculture, tourism and therapeutic purposes; several studies have recommended these waters for the treatment of certain skin conditions, such as acne, eczema, and psoriasis, as well as bone and gastric conditions (Armijo *et al*., 1994; Matz *et al*., 2003; Gonzalez & Mosqueira, 2009; Diegues & Martins, 2010; Santos, 2011).

Throughout history, thermal waters have attracted the interest of the communities inhabiting the areas where they emerge. They have been used for certain rituals, primarily of a religious nature (Navarro-Garcia, 2013; Pascual, 2017) and for therapeutic purposes.

Several studies have been conducted on thermal waters, focusing on their geochemical aspects. Notably, Hategekimana *et al.* (2022) specifically examined the chemical composition of Nyamyumba Hot Springs in Northwest Rwanda and found that the Nyamyumba hot springs are safe to use for swimming and therapeutic activities., while Vasconcelos (2017) characterized the thermal waters of the Santa source in Portugal, particularly the alkaline sulphurous content of waters, which is a feature often found in thermal waters (Vasconcelos, 2017).

According to the physicochemical characteristics of thermal waters, they may or may not be suitable for human consumption. Considering that suitable water is increasingly scarce on the planet, good management of suitable water become mandatory. For example, Sherpa *et al*. (2013) reviewed heavy metals, metals, and traces in several hot waters. They found that only one of the waters was suitable for human consumption, while the other showed high values of total dissolved solids (TDS) concentration.

In addition to studying its physicochemical characterization, Farhat *et al.* (2020) explored the therapeutic potential of these hydrothermal resources and found that one of them is not suitable for consumption due to high fluoride concentrations, while the other is suitable for bathing and other body contact activities. In 2017, Vásquez characterized the thermal waters in the village of Chotén, San Juan district in Porto Rico, through a physicochemical analysis of five water samples (Vásquez, 2017).

Andueza *et al.* (2020) conducted a study that focused on determining the microbiological quality of thermal water in a spa in Ecuador and found thermal water is classified as having powerful conductivity, excessive mineralization, harsh water, with very little dissolved oxygen, neutral pH and hyperthermal.

Researchers in Angola conducted similar earlier studies. For example, Aguiar conducted a comprehensive study in 1934 on the contribution of medicinal hydro mineralogy in Angola (Aguiar, 1934) and found that the waters of Balombo and Botera are hot, clean, colorless, thermomineral, and alkaline. Waring (1965) conducted a study on the thermal waters of Angola, specifically those of Andulo, Chiueca, Montipa, Kitewe, Pediva, and Kambeno, and the results showed that they have temperatures that reach up to 45°C; they originate from faults, and they are alkaline.

From a physical characterization standpoint, Tiago (2017) studied the thermal water from Montipa and its potential applications in medicine, agriculture, tourism, and human consumption and found that it is a clear, odourless, and tasteless hyperthermal water that emerges at an average temperature between 48-49°C. The electrical conductivity is 625 μS/cm, and it is hypomineralized.

Likewise, Abel (2018) conducted a study on the chemical characterization of the water and found that the Montipa thermal waters are classified as moderately complex, as the calcium carbonate levels range from 50-120 mg/L. They are sulfated, with the sulfate ion exceeding 200 mg/L and chlorinated (chloride ion exceeding 200 mg/L). The waters are also alkaline, as the pH value ranges from 8.3 to 9.4 due to significant levels of carbonates and bicarbonates.

Regarding its microbiology, Domingos (2019) also did a microbiological assessment of the Montipa water resource and found that the results obtained from the microbiological analysis showed the absence of Total Coliforms, Salmonella, and Enterococci. Therefore, this water is classified as bacteriologically pure. Finally, a study was conducted with a focus on environmental education and preservation of Montipa's thermal water (Cachapa & Patatas, 2021) to understand better how the community living in the area makes use of this resource and to educate this population on how to benefit from this valuable thermal water.

No study has investigated the characteristics and quality of the Ndolondolo and Tipa thermal waters. In this work, we aim to characterize the water of these two thermal springs, physically and chemically. Hydrochemical studies will be conducted to estimate qualitative and quantitative ratios of the chemical composition, lithology, and the overall quality of these hydrothermal resources.

Results of this study can contribute to decision-making processes by providing valuable information for rational and sustainable utilization of these resources, ultimately benefiting the local populations. This potential contribution is aligned with the goals outlined in the Long-Term Development Strategy for Angola (2025)-Angola 2025, which includes policies on Science, Technology, and Innovation, Natural Resource Valorization, and Economic Activity Structuring, as well as Goals 1, 3, and 6 of the Sustainable Development Goals (SDGs) (UN, 2022), considering that the use of these thermal waters should be seen as an alternative or complement to surface waters. It can contribute to developing the communities where these resources are found.

2. MATERIALS AND METHODS

The study was conducted in the Tipa and Ndolondolo regions.

2.1. Tipa

It is located at the geographic coordinates (Latitude: 15°37'36''S and Longitude: 13°34'78''E) at 391,933 meters above sea level. It is approximately 7 km from the village of Virei, along the road towards Chibia, near the Bero River (Cubal). Figure 1.

Figure 1. The location of the emergence of thermal water in Tipa and the sampling point. Source: Author

The area is sandy with rocks and animals such as goats and cattle. There is also a small group of Kuvale people.

The zone where the thermal water emerges in Tipa is considered a pre-Cambrian area in geological terms. It means that the rocks in this area date back to the Cambrian geological period, which began approximately 541 million years ago. These rocks are metamorphic sedimentary, including schistose limestone, metamorphosed sandstones, conglomerates, and quartzites. The soils in this area are characterized by desert vegetation, with sparse areas of savannah or pastures, as described by Upton *et al*. in 2018.

Hydrogeologically, some groundwater in alluvial aquifers is reported to have high concentrations of iron and sulphate, likely due to low precipitation and high potential evapotranspiration. In specific deltas and low-lying areas of alluvial plains, groundwater quality is influenced by saline water (DNA, 2005).

2.2. Ndolondolo

The word Ndolondolo derives from a rock in the area called "ndolon ndolon," named through the sound it emits. The thermal spring of Ndolondolo is in the Mamué commune, specifically at the foot of Serra das Neves, known by the locals as "O'munda Yevambo." It is the highest point in the municipality, with an altitude of 2,489 meters above sea level. Within its vicinity, there are 285 families, predominantly from the Mukuando tribe, who are traditional cattle breeders (AMC, 2019). Figure 2.

Figure 2. Sampling Location: Ndolondolo and Serra das Neves. Source: Author.

Emergence Site of Ndolondolo Water: The thermal water of Ndolondolo emerges from a specific location in the area. Serra das Neves: Serra das Neves is a mountain range located near Ndolondolo.

On the other hand, the area where the thermal water emerges in Ndolondolo is located at the foothills of the Serra das Neves, a mountain range. This range consists of an inselberg or monadnock, composed of granite rocks that resisted erosion and remained as elevated formations amidst the surrounding flat areas. This mountain range separates the basins of the Coporolo and Bentiaba rivers (Cunha & Martins, 2009).

The soils in this area are poor, sandy, and rocky, with shallow depths. They are rich in calcium carbonate ($CaCO_3$). Additionally, the area has a dry steppe climate (Bs) according to the Köppen climatic classification (Cunha & Martins, 2009).

These geological, lithological, and climatic characteristics are essential for understanding the environment in which the thermal waters emerge in these areas.

2.3. Collection, Packaging, and Transportation of Samples

Sampling: We used 500 mL amber glass pre-sterilized bottles for water sample collection. The samples were collected in the summer and during the winter season. There was a single sampling spot for each case (Tipa and Ndolondolo). Before sampling, the temperature and pH were measured in situ, and the sampling locations were georeferenced. The containers were carefully submerged 15 cm or 30 cm below the water surface to avoid penetration of surface contaminants.

Packaging: After collection, the samples were placed in thermal boxes at 4°C to prevent contamination during transportation, sealed and labelled with relevant information, such as the date, time, and location.

Transportation: The samples were transported to the laboratory or testing facility using suitable transportation methods, APHA (2017).

2.4. Chemical analysis, equipment, and methods

The methodologies to be adopted for each analysis are those recommended by the APHA (2017).

The other parameters, such as Total Dissolved Solid (TDS), Iron (Fe), Nitrogen (N), Dissolved Oxygen (DO), electrical conductivity (EC), and turbidity, will be determined ex situ at the Water and Wastewater Analysis Laboratories of the Provincial Water and Sanitation Companies of Namibe (EPASN) and Huila (EPASH).

For this purpose, the following equipment was used:

- HACH Lange DR 2800 Multiparameter instrument.
- HACH 2100 Qis portable pH meter.
- ISO turbidimeter model HI 98713.

The analysis of the physicochemical parameters was conducted using the techniques outlined in the Table 1.

Table 1. Techniques and units of the analysed parameters

Parameters	Unities	Used techniques
Temperature	^{0} Celsius	Electrometry
Colour, odour, and taste		Sensorial
pH	Sørensen Range	Electrometry
TDS	mg/L	Electrometria
Turbidity	NTU	Nephelometry
Fe^{2+}	mg/L de Fe^{2+}	Photometry
N	mg/L N	Titration
DO	mg/L	Titration
Electric Conductivity (EC)	µS/cm	Electrometry

Source: Adapted from APHA (2017).

2.5. Analysis and data processing

The collected data was analysed and processed using Microsoft Office 365 Excel, for descriptive statistics and the creation of graphs and tables.

3. RESULTS

3.1. Physical-chemical characteristics Tipa and Ndolondolo thermal waters

The following results are the product of fieldwork done at the two where Tipa and Ndolondolo thermal waters are found, in the municipalities of Virei and Camucuio, respectively (Tables 2 and 3).

Table 2. Physicochemical analysis of Tipa thermal water

Parameters	1st S.C.	2nd S.C.	Mean	SD
Aspect	Clear	Clear		
Colour	Colourless	Colourless		
Taste	Slightly salted	Slightly salted		
Odour	sulphurous	sulphurous		
Temperature	40,3 ^{0}C	40,4 ^{0}C	40,35^{0}C	0,07
pH	7,74	7,73	7,74	0,01
Turbidity	1,42 NTU	0,74 NTU	1,08 NTU	0,48
TDS	1749 mg/L	2103 mg/L	1926 mg/L	250,32
Fe	0,05 mg/L	N. A.		0,05
N	0,03 mg/L	0,4 mg/L	0,22 mg/L	0,26
DO	16 mg/L	13 mg/L	14,5 mg/L	2,12
EC	2820 µS/cm	3100 µS/cm	197,99 µS/cm	2960

TDS: Total Dissolved Solids; EC: Electric Conductivity; Fe: Iron, SD: standard deviation; Turb.: turbidity; S.C.: Sample Collection; N: Nitrogen; DO: Dissolved Oxygen. Source: Author.

Table 3. Physicochemical analysis of Ndolondolo thermal water

Parameters	1st S.C.	2nd S.C.	Mean	SD
Aspect	Clear	Clear		
Colour	Colourless	Colourless		
Taste	Slightly salted	Slightly salted		
Odour	Slightly sulphurous	Slightly sulphurous		
Temperature	37,6	37,6	36,7	36,7

pH	9,5	9,1	9,3	0,3
Turbidity	0,5	0,4	0,45	0,07
TDS	506,5	600	553,25	66,11
Fe	0,2	0,3	0,11	0,071
EC	1013	1201	1107	1107

Source: Author

3.1.1. Colour, odour, and taste

Both thermal waters are colourless, meaning they are transparent. The thermal water in Tipa has a slightly saltier taste if compared to the Ndolondolo waters, as shown by the TDS value in each case. Our results show that the thermal water from Tipa is colourless, slightly salty in taste, and has an odour or smell of "rotten eggs" typical of the presence of hydrogen sulphide (H_2S). Based on the levels of nitrogen and Dissolved Oxygen (DO), the existence of eutrophication phenomenon is confirmed (Figure 3). In Ndolondolo's thermal water there is a very light sulphurous smell, which is less intense than the smell of Tipa's.

Figure 3. Algae that form in the thermal spring of Tipa due to eutrophication. Source: Author.

3.1.2. Temperature

According to our results, the temperature of the Tipa thermal water was 40.3ºC (1st sample) and 40.4ºC (2nd sample), with a thermal gradient of 0.1ºC, and an average of 4.35ºC (table 1). As for the Ndolondolo thermal water, no variation was observed between the two samples (Table 2).

These water resources, as they emerge at temperatures above 30°C, can be used for therapeutic purposes.

3.1.3. Hydrogenic potential (pH)

The thermal water from Tipa had values around 7.74 and 7.73 in the 1st and 2nd samples, respectively. There is a minimal difference of 0.01 and an average of 7.735, indicating that it has a slight alkalinity (Table 1).

The Ndolondolo thermal water has a pH of 9.3 (average). This result indicates that it is an alkaline water (Table 2).

For both thermal waters, the difference between the samples collected in the summer (1st sample) and in the winter (2nd sample) are very small, showing that there is no seasonality for the characteristics here evaluated (Tables 1 and 2).

3.1.4. Turbidity

The average content of the analysed samples of Tipa thermal water is lower, specifically 1.08, while for Ndolondolo thermal water is 0.45, which is consistent with the appearance and colour of the thermal waters. SD values indicate that there is little variation for this parameter, in both cases.

3.1.5. Total Dissolved Solids (TDS)

For the thermal water from Tipa, the TDS values have an average of 1 926 mg/L, which explain its salty taste. Considering that the value is above 1 500 mg/L of TDS, this water can be classified as hypersaline.

The TDS results for the Ndolondolo thermal water ranged from 506.5 mg/L (1st sample) to 600 mg/L (2nd sample), with a variation of 93.5 mg/L and an average of approximately 553.25 mg/L, indicating that it has some mineralization but not as high as Tipa thermal waters. It can be classified as mesohaline waters.

3.1.6. Electric Conductivity (EC)

The average result for the electric conductivity (EC) of Ndolondolo thermal water is 1107 μS/cm, reflecting the mineralization degree (Total Dissolved Solids) of this water. On the other hand, for the Tipa thermal waters, there is a high degree of mineralization (high TDS values). For all parameters here presented, Tipa thermal waters show the widest range of EC, with a maximum of 3 100 μS/cm, a minimum of 2 820 μS/cm, and an average value of 2 960 μS/cm.

3.1.7. Iron

For Tipa thermal waters, this parameter was only analysed for the first sample, and for Ndolondolo thermal waters. The average values were 0.11 mg/L of Fe2+, indicating that this parameter falls within the values established by national legislation (Decretory Presidential 261/11) and the WHO (OMS, 2011) as those of good quality.

3.1.8. Nitrogen and Dissolved Oxygen (DO)

This thermal water has a low nitrogen content. The concentration of dissolved oxygen (DO) in the thermal water ranges from 16 (1st campaign) to 13 (2nd campaign) at temperatures of 40.30°C (1st sample) and 40.40°C (2nd sample) respectively, indicating an inverse relationship between DO and temperature increase. This results in an average of 14.5.

4. DISCUSSION

Our study aimed to determine the physicochemical characteristics of the thermal waters of Tipa and Ndolondolo, located in the municipalities of Virei and Camucuio, respectively.

As it has been shown previously, sulphurous thermal waters have many therapeutic effects (Cacciapuoti *et al*., 2020; Farhat *et al*., 2020; Gambari *et al*., 2020). Due to its sulphurous nature, the Tipa thermal water may be recommended for dermatological treatments and for treating musculoskeletal and respiratory conditions (laryngitis, rhinitis, and bronchitis) as well (Larraiza, 2016).

According to Armijo-Valenzuela & San Martín (1994); Reyes (2015), Tipa hydrothermal resource is classified as mesothermal since the temperature the water emerges between 35°C and 45°C; it should be noted that the variation in temperature does not seem to be influenced by seasonality (Feitosa *et al*., 2008).Tipa thermal water, considering its origin and how it emerges at temperatures below 50°C (Pinagua-Espejel, 1998), can be classified as meteoric.

This water resource, due to its emergence at a temperature above 30°C, can be used for therapeutic purposes. According to Farhat *et al.* (2021); Cacciapuoti *et al.* (2020) hot water stimulates oxygenation of the body, improves blood circulation, helps eliminate germs and toxins from the body. Additionally, it stimulates metabolism and the digestive system, enhances relaxation, and promotes the production of endorphins. The increased temperature also aids in the absorption of minerals by the skin.

The pH values exhibited by the Tipa thermal water indicate that it is slightly alkaline. This is in accordance with Feitosa *et al*. (2008), who state that groundwater mostly has a pH ranging from 5.5 to 8.5, with exceptional cases ranging from 3 to 11 (Table 1).

According to Vasquez (2017), turbidity depends on the presence of finely fragmented particles (such as sand, clay, and silt) or organic materials. According to the World Health Organization (WHO) (OMS, 2011) the maximum recommended for human consumption value is 5. The average content of the analysed samples is lower, specifically 1.08, which is supported by the appearance and colour of the thermal wáter (Table 1).

The TDS (Total Dissolved Solids) is directly related to the mineral content of the water, and according to Piveli e Kato (2006.), it is also related its electrical conductivity (EC). For Tipa thermal water, the average TDS values are 1926 mg/L, considering that the value exceeds 1 500 mg/L of TDS (Santos, 2011), this water can be classified as hypersaline. According to the classification proposed by McNeely *et al*. (1979), this hydrothermal resource, with a TDS value between 1 000 ppm and 3 000 ppm, can be classified as slightly brackish water.

Based on the classification proposed by Cortez (2012) Tipa thermal water, with an average TDS value of 1 926 mg/L (TDS values greater than or equal to 1 500 mg/L), can be classified as a highly mineralized water.

As this thermal water has high EC values (2960 µS/cm), according to Freddo (2018), its water has an unpleasant taste, making it not suitable for human consumption, unless it undergoes specific treatments.

According to Reyes (2015), the Ndolondolo thermal water is classified as mesothermal water since it emerges between 35°C and 45°C, and as such, it can be used for therapeutic purposes. According to Farhat *et al*. (2021) and Cacciapuoti *et al*. (2020) hot water stimulates oxygenation of the body, improves blood circulation, and helps eliminate germs and toxins from the body. According to Armijo-Valenzuela and San Martin (1994), due to its temperature, this thermal water is thirst-quenching, stimulating, and resolving. It helps combat muscle contractions and hypertonia.

Taken by its pH values, the Ndolondolo thermal water has considerable levels of carbonates and bicarbonates, as the rocks in this area have a high content of calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$]. Therefore, Szikszay (1993) states that the leaching of these compounds will result in an increase in carbonate and bicarbonate content, making this thermal water alkaline.

Considering the classification proposed by the White Paper (2010) cited by Santos (2011) and considering its total mineralization, the Ndolondolo thermal water, with an average TDS (Total Dissolved Solids) value of 532 mg/L, can be classified as mesosaline (values between 500 and 1 500 mg/L) and according McNeely *et al.* (1979) it´s a fresh water.

The Ndolondolo and Tipa thermal waters fall within the limits set by water quality standards according to Angola national legislation (Decretal Presidential nº261/11) and the WHO (OMS, 2011) for the parameters analysed in this study, except for taste and odour, particularly in the case of the Tipa water regarding the TDS parameter.

The results indicate that the values found in both waters, according to the WHO (OMS, 2011), can be suitable for human consumption with proper treatment. They can also be used for agricultural irrigation, animal watering, and recreational purposes.

This is the first study on the physicochemical characterization of these hydrothermal resources (Tipa and Ndolondolo), and indicates their potential for therapeutic, agricultural, recreational, and water and eco-tourism purposes. Considering the diversification of the economy, the use of these thermal waters should be seen as an alternative or complement to surface waters and may be valuable in pushing the development of the communities where these resources emerge. Our findings may also serve as a tool to assist local policymakers in decision-making and promote investments for various purposes, ranging from therapeutic to tourism.

Considering the characteristics of these waters, further studies will be conducted regarding their chemical composition, particularly of metals. We also aim is to monitor the physicochemical and microbiological parameters to establish an observatory of these thermal waters. From the perspective of water and eco-tourism, a route called the "Thermal Route" may be created in the region of Namibe province.

Therapeutic studies involving patients with dermatological conditions are also planned to be carried out, in order to deeply investigate the potential therapeutic benefits of these waters

4. CONCLUSION

- Both thermal waters are mesothermal, of telluric or meteoric origin, mesosaline, alkaline, although the Tipa thermal water is sulfurous. This is the first study on the physicochemical characterization of these hydrothermal resources (Tipa and Ndolondolo), their potential for therapeutic, agricultural, recreational, and water and eco-tourism purposes. It can also serve as a tool to assist policymakers in decision-making and promote investments for various purposes, ranging from therapeutic to tourism.

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Additional information

Conflict of interest

Authors declare that there is no conflict of interest

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MKA: Data collection, article writing, analysis and interpretation of results. MMCG: Data collection and interpretation of results. AC: Planning and conception of the article. Collaboration and internal review of the article. BC: article writing, internal review of the article. GMT: Data collection, analysis and interpretation of the result. OPS: Data collection, collaboration to article writing. JAPH & BCDD: Correction, organization and interpretation of the results

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