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Review

Physicochemical Nature and Therapeutic Potential of Thermal Springs: An Overview

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Abstract

In this article physicochemical characteristics and therapeutic potentials of world's renowned thermal springs including Manghopir (Pakistan), Shrgalijuut (Mongolia), Ranong (Thailand), Kusatsu (Japan), Southern/Nothern part of Limpopo (South Africa), Arkansas (USA), Selangor Malaysia and Ikogosi (Nigeria) were reviewed and compared. Themal springs were characterized by flame photometery, graphite furnace atomic absorption spectroscopy, ion chromatography, inductively coupled plasma atomic emission spectroscopy, X-ray flourescent spectrometry, atomic absorption spectroscopy and titrations (argentometric, acidemetic & complexometric). They are classified on the basis of pH, temperature and mineral contents. The common mineral contents in these springs include 0.67-621.99 mg/L sodium, 0.67-189 mg/L potassium, 2.06-84 mg/L calcium, 0.00-56 mg/L magnesium, 0.12-12 mg/L fluorides, 0.00-982.62 mg/L chlorides, 0.15-442 mg/L sulphates and 4.3-494 mg/L bicarbonates. Their temperatures were found in the range of 26.0-90.50 °C with the pH 2.0-9.7 and TDS value of 104.74-2188 mg/L. The mineral concentration in most thermal springs is highly ideal for the treatment of numerous diseases including atopic dermatitis, psoriasis, rosacea, diabetes, rheumatoid arthritis, ankylosing spondylitis, osteoarthritis, chronic rhinosinusitis, chronic bronchitis/asthma, obesity, wounds healing and cardiovascular diseases. For curative purposes, the body is soaked in thermal waters or water may be used in the form of drinking/inhaling.

Keywords: Thermal Springs, Soaking/bathing, Nutrient's intake, Disease's Treatment

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Introduction

Thermal springs release the hot water whose temperature is considerably higher as compared to that of ground water. They are generally emerged along the deep faults and fissures of earth from which the ground water is releases into the surface. Disintegration of radioactive elements, exothermic reactions and geothermal energy cause the high temperature of thermal springs. These springs are comprise of high concentration of dissolved solids and variety of minerals like alkali metals, alkaline earth metals, carbonates, bicarbonates, sulphates, trace elements and gases [1]. There are reports that thermal spring water is highly effective in the treatment of various diseases e.g., atopic dermatitis, cardiovascular diseases, inflammatory arthritis, ankylosing spondylitis, rheumatic disease, asthma and rhino sinusitis. Moreover, it is commonly believed that soaking in hot spring helps overcoming joint pains and strained muscles [2, 3]. Absorption of minerals through soaking is fractional and the amount absorbed into the body is concentration dependent [4]. The hot mineral water contains over 80 essential nutrients and minerals which are highly important for about 7000 enzymatic processes necessary for human body's metabolism. Many elements found in such waters possess therapeutic properties. Balneology which involves the use of natural thermal mineral water in order to treat a number of diseases, has a long history [5]. Animals are believed to discover the medicinal properties of thermal springs; they used this water to cure their feet wounds or to maintain their body temperature and hence, mankind began to explore the therapeutic properties of hot springs. In 1986, thermal springs were declared as an alternative treatment option to obtain good physical and mental health. Thus medical hydrology has been accepted as complementary medicine and an emerging new discipline by World Health Organization [6].

Though the thermal springs are natural sources of important nutrients and minerals for balneotherapy, however, reported studies also suggest that they may also contain toxic elements such as arsenic and mercury so care should be exercised regarding appropriate and precise use of thermal springs [7]. The presence of metal contents in balanced amounts is compulsory as their exceeding concentration in water may also lead to environmental issues [8-11].

Keeping in view the use of thermal springs for curative purposes, the physicochemical characteristics and therapeutic potentials of thermal springs of World's renowned thermal springs e.g., Manghopir (Pakistan) [12], Shrgalijuut (Mongolia) [13], Ranong (Thailand) [14], Kusatsu (Japan) [15], North and Southern Part of Limpopo (South Africa) [7, 16], Arkansas (USA) [17], Selangor (Malaysia) [18] and Ikogosi (Nigeria) [19] are reviewed in this article. Table 1 displays the brief geology, sampling and methodology of the investigated springs.

Table 1. **Brief geology, sampling and methodology of the investigated springs.**

Springs	Sampling	Methodology	Geographic location and geology	References
Manghopir (Pakistan)	26 samples from different sites (closed bath and open bath)	Titrations (Argentometric, acidemetic & complexometric) for Cl, HCO_3, Alkalinity, Gravimetric analysis for Ca, Mg & TDS. Flame photometer for Na & K	About 1.3 km from north Karachi at the base of Haller mountains range 35p/11 Lat. 24.59`E and 67.06` above sea level	[12]
Shargalijuut (Mangolia)	23 samples were collected from the said spring	Digital instruments for pH, Temp and conductivity. Na and K by inductively coupled plasma optical spectrometry, Ca and Mg by Trilon-Bititratin method, Argentometric, Acidematic titrations for HCO_3, Cl, SO_4	About 60 km north-east of Bayankhongar city; spring covers the banks of the river between the peaks Myangan Ugalzat Uul (3483m) and shargalijuut Uul (3137m) in the Gobi region	[13]
Ranong (Thailand)	Samples were collected from two hot spring Rashwani (father well) & Porn rang	TDS by titration K, Ca, Mg, Na, F, Cl, SO_4 , HCO_3 by chromatographic technique, Fe, Mn Pb by graphite furnace atomic absorption spectroscopy	2 km east of Ronong town, porn-rang, hotspring located in Ngao national park and far larger than rashwani hot string	[14]
Kusatsu Onsen (Japan)	Samples collected from 6 major hot springs in the Kusatsu hot springs	Flame emission spectroscopy (FE), inductively coupled plasma atomic emission spectroscopy (ICP-AES) and ion chromatography	Located at the eastern foot of Kasatsu-Shirane volcano are all strongly acidic	[15]
Limpopo North & South (Africa)	5 samples (southern part) 8 samples (from northern part)	Chemical analysis conducted by institute of water , climate and soil (ARC, Pretoria)	Includes various lithologies, Goud plaats-Hot river Gneiss suite and Beit Bridge complex. Surface geology indicated as quartzite, shall and red shally sand stone.	[7, 16]
Arkansas (USA)	Sample were colleted from all the hot spring area	Gravimetric analysis was done for all ions	50 miles distance from little rock and 75 miles east of the Oklahoma line. 500 feet above sea level and lies at the easterly base of the mountain complex Ouachita range	[17]
Selangor (Malaysia)	Samples were collected from 11 hot springs	Energy dispersive X-ray Flourescent spectrometry (EDXRF) for Na,K,Ca,S, and Ion chromatography for SO_4 and Cl	Western part of the Peninsular Malaysia along the main range Granite Bathiolith	[18]
Ikogosi (Nigeria)	Samples collected from (OOzing point of warm and cold springs and their mixing point	TDS by gravimetric analysis, Na, K, Mg, Ca by Alpha 4 Atomic Absorption Spectrometer other ions analysed by standard procedures	Its underlain by a group of slightly migmatised to non-migmatised para-schists and meta-igneous rocks (quartized quartz and granulites).	[19]

Numerous studies involving the patients and Murine models were also reviewed for the treatment of diseases including atopic dermatitis [20-22], psoriasis [23-25], rosacea [26], diabetes [27, 28], rheumatoid arthritis [29], ankylosing spondylitis [30], osteoarthritis [31-33], chronic rhinosinusitis [34], chronic bronchitis/ asthma [35, 36], obesity [37], wound healing [3] and cardiovascular diseases [38, 39]. Other literature consulted include that of physical and chemical nature [2, 4-7, 14, 16, 40-50], geological influence on chemical composition [7, 16, 51], classification of thermal springs [6, 40], ways of using the thermal mineral water for curative purposes [52-57] and therapeutic potential of thermal springs [58-65].

Physical and chemical nature of thermal springs

The physicochemical properties of world's eight renowned thermal springs are given in Table 2.The temperature and pH lies in the ranges of 26-90.50 °C and 2.0-9.7, respectively; the total dissolved solids lie between 104.74 and 2188 mg/L, but most thermal springs contain their values less than 400 mg/L. Common cations present in thermal water include K^+, Na^+, Mg^{+2} and Ca^{+2}. The magnesium (Mg), calcium (Ca), potassium (K) and sodium (Na) contents lie in the ranges of 0.00-56 mg/L, 2.06-84 mg/L, 0.67-189 mg/L and 0.67-621.99 mg/L, respectively. Anions present in hot springs include Cl^-, SO_4^{-2} and HCO_3^- with their concentrations in the ranges of 0.00-982.62 mg/L, 0.15-442 mg/L and 4.3-494 mg/L, respectively. Most of the thermal springs do not have fluoride ions; however, some thermal springs contain the F^- ions in range of 0.00-11 mg/L. Fluorides are present in less amount than Cl^-, SO_4^{-2} and HCO_3^- in most of the thermal springs. Trace elements found in hot/thermal springs include majorly zinc (Zn), iron (Fe), strontium (Sr), lithium (Li), selenium (Se), bromide (Br^-) and iodide (I^-) ions. The gases such as H_2S, NH_3, He, Ne and Rn are also reported in hot/thermal springs [2, 4-7, 14, 16, 40-50].

Table 2. **Physical and chemical properties of world's eight renowned thermal springs regions.**

	Mongopir (Pakistan) [12]	**Shrgalijuut (Mongolia) [13]**	**Ranong (Thailand) [14]**	**Kusatsu (Japan) [15]**	**Southern Part [7] Limpopo (South Africa)**	**Northern Part [16] Limpopo (South Africa)**	**Arkansas (USA) [17]**	**Selangor (Malaysia) [18]**	**Ikogos (Nigeria) [19]**
Temp* (C°)	47	50-90.50	61-65.3	60-67	40-60	26-67.5	32-62	36.7-67.9	35.20-37.0
pH	7.2-7.6	8.2-9.7	7.56-7.74	2	6-9	7.35-9.70	4.52-7.70	7.14-8.98	6.1-7
TDS (mg/L)	2180-2188	-	210-230	-	<450	104.74-1385	>400	225-376	170-514
Cations (mg/L)									
Sodium	544-555	62.5-105	10.2-13.8	53.7	21.98-151.6	10.59-621.99	4	33.68-81.91	0.67-0.71
Potassium	21-25	1.3-1.9	150-189	16	2.9-6.13	0.99-21.79	1.5	1.47-56.81	0.67-0.84
Calcium	80-84	1.8-7.2	18.7-20.6	72	13-36.13	1.31-79.37	45	2.44-19.77	2.06-2.67
Magnesium	56	0.4-0.5	0.36-0.51	39	1.8-6.44	0.00-27.60	4.8	_	4.22-4.32
Anions (mg/L)									
Fluoride	-	0.00-1.37	0.12-0.89	12	0.95-11	0.18-6.50	0.2	_	_
Chloride	584-599	13-26	18.3-23.2	343	2.21-138.5	19.43-982.62	1.8	7.06-20.66	0-0.004
Sulphate	437-442	25-66	8.1-12.1	611	2.16-92.82	2.98-226.00	8	0.15-1.51	30-81
Bicarbonate	395-494	97-170	4.3-5.7	-	102-213.5	-	165	_	35-51.5

Temp* = Temperature

Geological influence on chemical composition

The origin of hot springs is owed to the local presence of deep geological structures such as faults, folds, fractures, and dykes providing means of circulation to depth and return of heated water to surface. The amount of dissolved salts, nutrients and trace elements found in thermal waters are dependent on regional differences in climate, geology, soil and vegetation [7]. The less saline water comes out from crystalline rocks where as the saline water is found to be associated with sedimentary rocks [16]. The physico-chemical nature of hot water depends on mixing with fresh precipitation, rock or water interaction in deep formations, residence time of hot water in migration pathway, migration depth, composition of infiltrating solution etc [51].

Classification of thermal springs

Thermal springs are classified on the basis of temperature, pH and dry waste [6, 40].

1. There are three types of thermal springs according to temperature:
   (i) Hypothermal springs: The temperature ranges from 20 to 30°C in these thermal springs.
   (ii) Thermal springs: The temperature of these thermal springs is in the range of 30 to 50°C.
   (iii) Hyper-thermal springs: The temperature of these thermal springs is above 50°C.

2. The thermal water is classified on the basis of pH into six classes:
   (i) Alkaline springs $9 \leq$ pH
   (ii) Weak alkaline springs $7.5 \leq$ pH< 9
   (iii) Neutral springs $6 \leq$ pH< 7.5
   (iv) Weak acid springs $4 \leq$ pH< 6
   (v) Acid springs $2 \leq$ pH<4
   (vi) Strong acid springs pH< 2

3. Hot springs may be classified into following three categories depending upon their dry waste material:
   (i) Minerals from 1-1.5 g/L
   (ii) Middle minerals from 0.2- 1.0 g/ L
   (iii) Oligo minerals less than 0.2 g/ L

Ways of using the thermal mineral water for curative purposes

For the therapeutic purposes, the thermal/hot mineral waters can be used internally or externally. The important ways of using the thermal/hot minerals waters are as follows:

Balneotherapy

The immersion of the body (except head) or body parts into the water for the treatment and cure of diseases is called bathing or soaking [52]. The minerals and other substances in the water are transferred to the skin and blood streams through the process of osmosis [53]. The osmotic pressure, mineral concentration, pH, the nature/amount of mineral contents [54], fat/water solubility due to structure of membrane and fluid condition of the individual [55] affect the osmotic transfer and the movement of minerals into the body. Medical balneotherapists have noted that even small amounts of therapeutic minerals absorbed into the body through skin have a significant therapeutic value [56].

Hydropenia (mineral water drinking cure)

Ingestion of mineral water is another treatment method which aimed at modification of metabolic activities, gastro-intestinal, renal and urodynamic functions. The mineral water can also be taken as a substitute for drinking and supplementation of minerals.

Inhalation

Mineral waters and some other natural gases present in thermal/hot springs (mainly radon) are used *via* the respiratory tract. It has beneficial effects on the respiratory functions and mucosa of respiratory tract. After inhalation substances get absorbed and induce systemic effects [57].

Therapeutic potential of thermal springs

Table 3. **Studies reported on therapeutical potential of thermal springs.**

Subject	Water Classification	Pathology	Mode of Therapy	Treatment Duration	Results	References
Murine model	Na-HCO_3	Atopic dermatitis	Balneotherapy	5 mins daily for one week	Effective and safe	[20]
70 patients	Acidic plus Mn 1.4 mg/L, I 0.3 mg/L		Balneotherapy	10 mins twice daily for two months	Useful for controlling the skin symptoms of acute flares of AD	[21]
104 children	Na and Mg rich water		Balneotherapy	Once daily (20 min) for 2 weeks	Effective for mild to moderate AD	[22]
Murine model (Oxazolone indu ced mice)	Sulphurous mineral	Psoriasis	Balneotherapy	20 min x 2/day for 3 weeks	Somatostatin plasma concentration was increased. Significant reduction in PASI score	[23]
71 adult patients with PASI score greater than 10	Sodium and magnesium rich water		Balneotherapy	3 weeks	Minor therapeutic effects with saline spa water alone, and no beneficial effect of bathing to enhance phototherapy	[24]
Patients with mild to severe psoriasis	Selenium rich water		Immersion and drinking	3 weeks	Improvement in psoriatic plaques	[25]
Patients	Na, Ca, sulphate bi-carbonate and fluoride	Rosacea	Balneotherapy	3 weeks	Significant down regulation of TNF α, IL-1α and VEGF gene expression. Benefits observed in rosacea and psoriasis	[26]
Murine Model (alloxan induced diabetic rats)	Sulphurous and alk aline water Andrade junior	Diabetes	Ingestion	3 weeks	Reversed the hyperglycemic state and improved SOD synthesis. Beneficial effects for diabetics	[27]
35 patients (46-74 years old)	Sulphurous-bicarbonated-calcic-magnesian mineral water		Ingestion	375mL/day 14 days	Reduction blood glycaemia levels. Effective for type-2 diabetes.	[28]
41 patients	Rich in sodium chloride and sulfate	Rheumatoid arthritis	Mineral water baths and mud packs	2 weeks	Temporary improvement in clinical indices	[29]
14 patients	Mineral water (Na, Ca, Mg, Cl, SO_4 HCO_3),	Ankylosing spondylitis	Balneotherapy and mud packs	2 weeks	Improvement in morning stiffness and significant reduction in the use of analgesics and NSAIDs	[30]
Murine model (Wistar rats)	Sulfurous rich water	Osteoar-thritis	Balneotherapy		Reduced cartilage destruction and oxidative damage	[31]
46 patients (57 to 85 years old)	Sodium-bicarbonate with fluoride and chloride ions		Balneotherapy	3 weeks 20 min/day	Effective in advanced knee arthritis	[32]
Murine Model (Old female NMRI mice)	Na, K, Mg, bi-carbonates sulphate and H_2S		Balneotherapy	30 min/day for 12 to 16 weeks	Found effective as anti-inflammatory and analgesic	[33]
80 patients with CRS	Sulphurous mineral with Na, Ca, Mg, chlorides, nitrat es and H_2S	Chronic rhinosin-usitis	Warm vapors inhalation and nasal irrigations	12 days to 3 months	Significant reduction in Serum concentration of IgE, effective for CRS	[34]
39 patients	salt-bromide-iodine	Chronic bronchitis / asthma	Inhalation	2 weeks	Reduces proportion of neutrophils in induced sputum, may have mild anti-inflammatory effect on the airways	[35]
Heavy smokers (50-75 years old)	Sulphurous mineral water		Inhalation	10 days	Reduction of NO shows anti-inflammatory effect	[36]
50 women (average age 35)	Borebole (klaipeda region) Na, Ca, Sulphate and bicarbonate	Obesity	Balneotherapy	15-20 min, 5 times/ week, for 3 weeks	Improvement in skin condition and reduction of hypodermic body fat content	[37]
Murine model (100 male rats)	Calcic-magnesic-sulphate mineral	Cardiova-cular	Ingestion	120 days	Regulating the enzymes responsible for bile acid and cholesterol metabolism	[38]
12 Hypercholester olemic patients	Bicarbonate-rich water		Ingestion	1.25 Liters for 8 weeks	Decrease in basal TG and VLDLTG and VLDL cholesterol. Effective for hypercholesterolemia	[39]
Murine Model 9 Nude rats)	Carbonated with sodium (42°C)	Wound healing	Bathing at 42°C	15 min every three days for 8 weeks	Increase vessel density and reduced inflammatory cells of wound area	[3]

Bicarbonate mineral water

Bicarbonate natural mineral waters are alkaline with small amount of minerals having diuretic characteristics. The bicarbonate minerals have positive effects on digestive tract and play a vital role in the prevention of cardiovascular diseases [58].

Sulphurous mineral waters

Sulphurous mineral water is abundant in hydrogen sulphite (HSO_3^-) and possesses the ability to cure internal organ disorders e.g., ischemia, adverse affects on kidney and nervous system and high blood pressure [58, 59]. Sulphurous mineral waters contain beneficial anti-pruritic and anti-inflammatory keratoplastic effects [60]. Its anti-fungal and bactericidal effects have enabled its applications in the treatment of tinea carports, infected leg ulcers, tinea versicolor, tinia capitis and tinia corporis. Sulphurous bathing has been considered useful for immunomediated conditions including atopic dermatitis and contact dermatitis psoriasis. It was recently concluded that the sulphurous minerals water can play a pivotal role in immune-regulation in the skin [61].

Salt mineral waters

Chlorides are often found in combination with sodium and are the main constituents of “salt mineral waters”. Such waters from mineral thermal springs are particularly valued and believed to improve the joint movements, muscle strengthening and improve/maintain functional mobility. Well known for its anti-inflammatory effects, it is also applied to treat successfully a variety of pathological conditions, such as issues of gastrointestinal system [61-65].

Calcic mineral waters

Calcium along with the bicarbonate content maintains an alkaline environment and helps in improving the acid-base balance in blood. The positive effects of calcium-rich mineral waters on bone mineralization have been verified [58].

Magnesia mineral waters

Such waters are characterized by the presence of magnesium as an essential ingredient. The presence of magnesium with sulphate, bicarbonate and calcium minerals in waters can induce the therapeutic activity in functional disorders of biliary tract. High range of magnesium is important for oddi sphincter relaxation and allows the bile flowing and also supports biliary ducts activity [58].

Conclusion

Thermal springs are the natural sources of many minerals depending on the geographical and geological conditions of the region and site. They are classified on the basis of pH, temperature and mineral contents. Presence of more than 80 essential nutrients and minerals in thermal springs enables them to possess therapeutic potential and makes them highly ideal for the treatment of numerous diseases including atopic dermatitis, psoriasis, rosacea, diabetes, rheumatoid arthritis, ankylosing spondylitis, osteoarthritis, chronic rhinosinusitis, chronic bronchitis/asthma, obesity, wounds healing and cardiovascular diseases. For curative purposes, the body is soaked in thermal waters or water may be used in the form of drinking/inhaling. The investigations on world's renowned thermal springs including Monghopir (Pakistan), Shargali Juul (Mongolia), Ranong (Thailand), Kusatsu (Japan), Southern/Nothern part of Limpopo (South Africa), Arkansas (USA), Selangor (Malaysia) and Ikogosi (Nigeria) contain 4-621 mg/L sodium, 0.99-189 mg/L potassium, 0.3-84 mg/L calcium, 0.00-56 mg/L magnesium, 0.00-11 mg/L fluorides, 0.00-982 mg/L chlorides, 0.00-442 mg/L sulphates and 10-494 mg/L bicarbonates. Their temperatures were found in the range of 32.0-90.5 °C with the pH 2.0-9.7 and TDS value of 104.74-1857 mg/L. Thermal springs classified on the basis of pH, temperature and mineral contents.

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