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Physico-chemical parameters of traditional salt producing springs of Ancient Assam, Northeast India

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Three salt springs of ancient Assam (currently in a part of Assam and Arunachal Pradesh, Northeast India) situated in the Mohong area (Phullung and Khela) and Samkhor have been studied to bring out their physico-chemical characteristics by using ionic concentration ratios along with SEM and EDS techniques. The high TDS values of the studied salt springs (wells) under investigation infers mildly brackish water type. The Disang Group of rocks are the dominant lithotypes connected with the spring. The positive correlation between Na^+ and Cl^- indicates the samples have an origin including halite (NaCl) dissolution, which may imply that the study area's saline and salty springs come from the incongruent dissolution of halite. The larger concentrations of almost all ionic values of Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, and K^+ were found in Phullung and Khela, while lower values were found in Semkhor, which suggests that from Semkhor to Phullung and Khela (*i.e.,* towards northeast), the concentration of salinity increases. The occurrences of the development of crystal phases in the SEM and EDS results also substantiate the salinity increasing trend towards the northeast. The studied samples have lower Na^+/Cl^-, K^+/Cl^- and SO_4^{2-}/Cl^- indicating a deeper aquifer source and minimal anthropogenic impact. The average value of sodium absorption ration (SAR) of 30.62 indicates that the studied water quality is not permissible for agricultural use. The negative BEX values ranging from -20.58 to -203.74 suggest that the aquifer of the studied well are being salinized.

Keywords: Anthropogenic impact, Arunachal Pradesh, Physico-chemical parameter, Salt spring, SEM-EDS, Traditional use

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In mountainous regions, springs play a significant role, as primary source of water for people living there. Springs have been classified based on physico-chemical parameters (water temperature, TDS, hardness, pH etc.), geological aspects (mineralogical composition, lithology, structure, etc.), its source, ecology, human use, and so on[1-3]. It is assumed that the saline or salty springs, conveys vital subsurface information to the surface via its natural water discharge processes[3,4]. Further, in a sedimentary basin the subsurface water can be predominantly salinized by three possible processes such as halite dissolution, connate water, and geological membrane filtration[5-8]. The mineral halite, as well as seawater and salt lakes, have been found all over the world, and the dried-up remains of ancient oceans can be found on the surface of many continents. Salt can be harvested from underground ancient sea beds or produced through evaporation from saltwater or other salty sources. The majority of India's salt supply, approximately seven million tons, is derived from solar evaporation, whereas rock salt is negligible[9]. Processes such as evaporation, solubility, and crystallisation are crucial in salt manufacturing technology.

In ancient times, salt played an important role in historical events such as settlements, population growth and decline, wars, massive demographic shifts, agricultural development, and so on. As a result, without adequate supplies and management of salt water resources, socioeconomic growth is hampered[10]. In North East India, historical records found on the production of salts, their utilization and exchange among tribes, which leads to a number of socio-political developments throughout the region[11]. Traditional salt production regions in ancient Assam are found in the eastern part of the region. Though salt is found throughout the Himalayan Mountain range, the salt-producing sites in this region are concentrated in the Naga-Patkai Hills. The south bank of the Brahmaputra is home to practically all salt production in North East India. "Mohong" was the name given to the region's primary salt-producing area and has several claims on the origin of the word "Mohong"[11]. The Dimasa- Kachari (a tribal group of Assam)

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claims that it derived from Dimasa-Kachari word Mohong means "Salt"[12]. Many claims that it is a Tai word that originates from the two words Mo and hong, meaning- “mine”, and “to boil or prepare”, respectively[12]. The historic Mohong region stretched from Twensang District of Nagaland to Tirap District and Namsai District of Arunachal Pradesh[12]. The name "Mohong" was mentioned several times in medieval chronicles as the most important salt-producing region. The ancient "Mohong" area was situated in the "Patkai Range," referred to as "Sotai Porbat by the local "Kachari" peoples. Salt and Sotai Porbat appear in a number of folk songs.

In past decades, researchers explored a few springs[13,14]; hot springs[15-18]; and salt springs[13] of the Himalayan regions, including Arunachal Pradesh, to understand their source, water quality, microbial diversity, physico-chemical characteristics, vulnerability assessment and so on. Despite the fact that salt has a long history in North East India, no major study into its geological significance has been done. The location of salt wells has been published by organizations such as the Geological Survey of India (GSI). The springs are always found near surface drainage at the bottom of the valley[19]. The measured dimensions of the well ranged within 1 to 2.5 meters deep and 1 to 1.5 meters wide. The rate of recharge for some of the wells estimated by GSI varies between 1 and 3 m^3/h (1000 to 3000 l/h). They suggests that the salinity of the water progressively increases towards north in the region[19]. As a result, three ancient salt-producing areas are taken into account for this research. The Namchang-Borhat-Borduariya-Laptang area (Dibrugarh District of Assam and part of Changlang and Tirap districts of Arunachal Pradesh) and the Sodiya area (Tinsukia District of Assam and Namsai District of Arunachal Pradesh) were included in the historic Mohong area, while Semkhor (Dima Hasao District of Assam) is not a part of the historic Mohong region (Fig. 1). Although salt was considered one of the most important products in shaping the socio-political

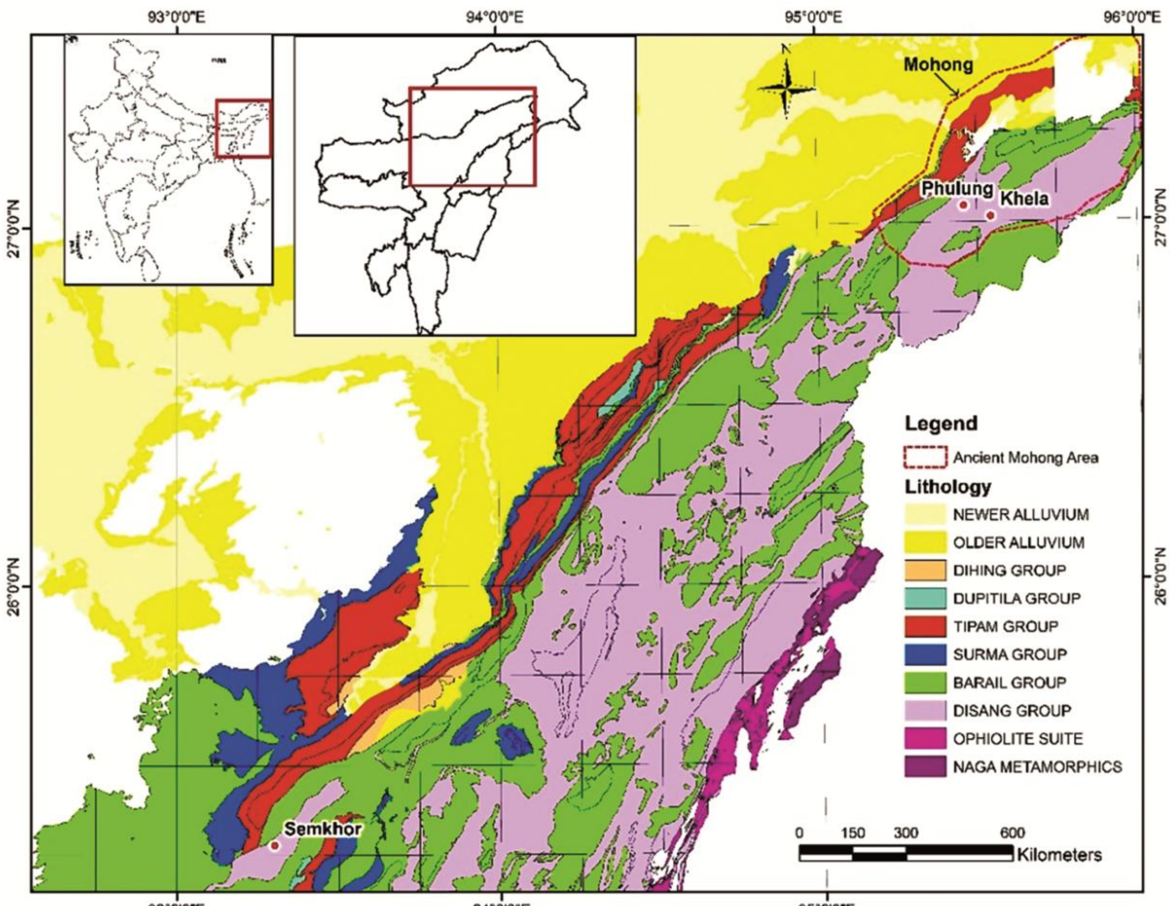

Fig. 1 — Location map of the study area. Sample locations (red circle) and ancient Mohong area (dotted line) are marked in the map. Lithological information is taken from Bhukosh[20]

landscape of North East India, little was known about its geological origins, physico-chemical properties, and availability. There has been no detailed study on its geological and geochemical perspectives so far. The current research will hopefully shed some light on these issues.

Materials and Methods

Location of salt spring

Salts are most commonly found in crystalline solid state in the Himalayan region, and are referred to as "rock salt." Despite the fact that origin of the Himalaya and Naga-Patkai Mountain are geologically similar, no existence of rock salt has been reported in the Naga-Patkai region. The salt found in theses region are brines. Salts aren't exposed to the surface; instead, they form beneath the surface. Salt springs are formed when subsurface salts dissolve in ground water. Spring sources have been discovered in a variety of geological horizons (Fig. 1)[20].

The salt springs are found in the Disang Shale and sandstone of the Barail Group of the Tertiary Assam-Arakan Basin[11] (Table 1). Brines emerge from the bottom of the impervious Disang Shale along with some sand lenses. Due to lack of linkage between a geological formation and its source dating of the salts could not be performed. Because no salt-bearing formations exist in the area and the brine is the clearest, this is most likely the trapped water of the ancient Tethys Sea following Himalayan upheaval[11].

Traditional salt production techniques

The extraction of salt was an important practice during Ahom rule (1228–1826). The primary salt production area was termed as "Mohong" and it was extended from Twensang District of Nagaland to the border of Tirap district of Arunachal Pradesh upto Namsai District[12]. During Medieval chronicles, this area is known as the "Patkai Range," while geologists refer to it as the "Belt of Schuppen," and Kachari people refer to it as "Sotai Porbat." Salt production in the study area still existed as ritual practice only. People used various traditional salt production techniques, dominant practises are basically based on evaporation technique with minor difference and modification[21-24]. To produce salt from the salt spring, local people sometimes dug artificial wells at various places and protect them with hollow tree trunks. Jointed bamboo was coated with clay to minimize the damage to the bamboos during evaporation. Salt production in the area continues till the decline of the Ahom dynasty. Local salt production was later banned by the British government due to its low profitability[11].

Table 1 — Stratigraphic succession of the south-eastern Arunachal Pradesh after GSI[19]

Age	Group	Formation	Description	
Pleistocene to Recent			Alluvium and high-level terraces	
Pliocene		Dihing	Boulder beds and sand	
		Namsang	Coarse pebbly sandstone	
Mio-Pliocene	Naharkatia	Girujan	Variegated clays, minor sand	
		Tipam/Gandhigram	Greenish grey micaceous sandstone, minor lenses of coal	
~~ Unconformity ~~~				
			North of Disang Thrust (Platform facies)	South of Disang Thrust (Geosynclinal facies)
Oligocene	Barail	Tikak Parbat	Sandstone and coal	Greyish green sandstone with intercalation of greenish shale
		Bargolai	Sandstone, clay and minor coal seams	
		Nagaon	Hard well bedded sandstone	
Eocene	Disang		Dark grey shales with interbands of hard, fine grained flaggy,sandstone	
--- Tilung Thrust ---				
Proterozoic	Tilung		Quartz-chlorite/ mica schist with intercalation of quartzite	
--- Namdhapa Thrust ---				
Proterozoic		Namdhapa Crystalline Complex	Biotite granitoid gneiss	

While interacting with local peoples, during field visits, they explained the primitive salt production method by evaporation using clay coated bamboo tubes and show the remanets of open furnace which was made with blocks of rock in dry abandoned salt well of Borduwariya (Fig. 2a). Using similar procedures people still produce salt having cylindrical shape (Fig. 2b).

Sampling and analytical techniques

To understand the physical and chemical parameters of the salt water of Ancient Assam, presently part of Assam and Arunachal Pradesh have been visited. All the springs are situated in a valley with high vegetation. The wells being natural, vary in size, averaging from 2.5 to 3 ft in diameter, and the shafts are often protected by a lining of wood or a hollow tree (Fig. 3 a-c). Out of the visited seven location, three location provides salt water samples and rest are dried. Water samples are collected from three locations in a 1 litter cleaned tarsons bottle with the help of local villagers (as they don't allow any individuals to collect samples from the well) and few parameters such as p^H, salinity, electrical conductivity and total dissolved solids (TDS) tested at department of Geology, J.B. College (Autonomous) using PC Testr 35 multi-parameter (as local people does not allow to bring any instrument to the site). Few chemical parameters have been calculated to evaluate the physico-chemical properties of saltwater using ionic concentration data[11] (Supplementary Table S1). Moreover, Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) elemental analysis has also been carried out at department of Chemistry, Gauhati University, Guwahati to determine the morphology and elemental composition of the sample.

Results

Physical and chemical parameters

The physical parameters measured form the studied samples include appearance, colour and odour. Temperature could not be measured at site as the local villagers do not permit to bring any items near to the well. All the collected samples under study are clear, colourless and odourless (Table 2). The chemical parameter of the salt sample infers pH values from 7.5 to 8.9. Except the sample of Semkhor rest two samples shows the higher concentration of chemical parameters such as higher elcetrical conductivity (EC>1000 μs/cm), total dissolve solid (TDS>640), salinity (>728) etc. (Table 2). The calculated chemical indices like BEX, Na^+/Cl^-, K^+/Cl^-, Mg^{2+}/Ca^{2+}, Ca^{2+}/Mg^{2+}, SAR values ranges from -20.58 to -203.74, 0.47 to 0.54, 0.001 to 0.006, 0.57 to 1.17, 0.86 to 1.76 and 14.70 to 53.53 respectively.

Fig. 2 — Photographs of traditional salt producing methods (a) Remnant of dry abandoned ancient Salt producing furnace at Borduwaria; (b) Traditionally made salt tube at Khela Village

Fig. 3 — Photographs of salt spring during sample collection. Local people collecting samples at (a) Semkhor village, (b) Phullung village and (c) Khela village

Table 2 — Physical and chemical parameters of the studied salt spring sample

Sample ID/Parameters	Semkhor	Phulung	Khela
Physical parameter:			
Appearance	Clear	Clear	Clear
Colour	Colourless	Colourless	Colourless
Odour	Odourless	Odourless	Odourless
Chemical parameter:			
p^H	8.9	7.5	8.0
EC (μs/cm)	11.48	>1000	>1000
TDS (mg/L)	7.35	>640	>640
Salinity (μs/cm)	4.6	>728	>728
BEX	-20.58	-203.74	-100.37
Na^+/Cl^-	0.54	0.47	0.51
K^+/Cl^-	0.006	0.001	0.001
Mg^{2+}/Ca^{2+}	0.96	1.17	0.57
SAR	23.62	53.53	14.70
Ca^{2+}/Mg^{2+}	1.04	0.86	1.76

SEM and EDS

To understand the morphology and elemental composition in the saltwater sample SEM and EDS studies have been performed. The Phulung and Khela sample shows almost well developed NaCl crystal phases and on the otherhand no crystal development occurred in the samples of Semkhor. The repesentative SEM image along with obtained EDS spectrum is shown in Figure 4 (a-c). The studied samples have the concentration of silica (SiO_2), and fluxes (Na_2O, MgO, KCl, CaO, and K_2O) identified in all the sample. The measured values ranges from SiO_2: 3.47 to 9.37 wt%; Na_2O: 33.97 to 40.12 wt%; MgO: 0.47 to 1.03 wt%; KCl: 49.33 to 59.60 wt%; CaO: 0.16 to 0.37 wt% and K_2O: 0.23 wt% (Only Khela salt spring have K_2O concentration).

Discussion

Physico-chemical characteristics of the salt water

Ca–Mg carbonate-related waters are mildly alkaline (pH = 7:5–8:5), with higher pH (up to 12) associated with alkali carbonate solutes and relatively high silica content[25]. Because of the rising concentrations of iron oxide and calcium carbonate, the pH value rises from source to reservoir[26]. The pH values of the salt spring samples analyzed range from 7.5 to 8.9, indicating that the groundwater samples are near neutral to slightly alkaline. Increased salinity was linked to higher electrical conductivity. Furthermore, the electrical conductivity of the brine is determined by the proportion of ionized chemicals present. The concentrations of EC, salinity, K^+, Na^+, Ca^{2+}, Mg^{2+}, and Cl^- in the examined samples are associated with TDS and their correlation coefficients are 1, 1, 0.59, 0.95, 0.58, 0.68 and 0.93, respectively (Table 3). TDS has a substantial effect on the chemical parameters of saline and salty springs, as seen by the correlation coefficients between TDS and EC, salinity, and main ions. A provenance including halite (NaCl) dissolution is suggested by the positive correlation between Na^+ and Cl^- with a correlation coefficient of 1[27,28]. The positive correlation between Na^+ and Cl^- with a correlation coefficient of 1, indicates that the analyzed samples have an origin including halite (NaCl) dissolution. Further, NaCl concentration in the studied Khela, Phulung and Semkhar samples show the values as 3.51%, 5.16% and 0.62% respectively (Supplementary Table S1). In addition, the concentrations of Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, and K^+ steadily increased as the salt crystallized[9]. In Phullung and Khela, larger concentrations of practically all ionic values of Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, and K^+were found, while lower values were found in Semkhor. The investigated salt sample, on the other hand, indicates well-developed salt crystals in Phullung and Khela, whereas the Semkhor sample shows no crystal structures (*i.e.,* condense stage), which accounts for the higher and lower ion concentrations in the samples.

Salinity

The presence of sodium chloride (NaCl) in water causes its salinity. In the end, the lithology of the source rocks, evaporation, and solute losses to minerals regulate solute concentrations[25]. Na^+ is the most prevalent cation in solution, and it is almost often the only cation in solution. As a result, only a few characteristics in seawater are considered for determining the likely cause of salinization: Na^+/Cl^-, K^+/Cl^-, Mg^{2+}/Ca^{2+}, and Ca^{2+}/Mg^{2+} ionic ratios[29-31]. Each potential source of salinization has a distinct chemistry and well-established ionic ratios. A Mg^{2+}/Ca^{2+} ionic ratio greater than 5 indicates that the water has been contaminated[32]. Similarly, seawater that has been diluted with freshwater have distinct geochemical properties[32]. The absence of sea water contamination is indicated by the values of these ratios in the study area, which range from 0.57 to 1.17. Water–rock interaction modifies the geochemical features of these saline fluids, with three proposed mechanisms: (1) base exchange reactions with clay minerals[33]; (2) adsorption onto clay minerals; and (3) carbonate dissolution–precipitation[33,34]. The chemical profile of polluted water resulting from the reuse of

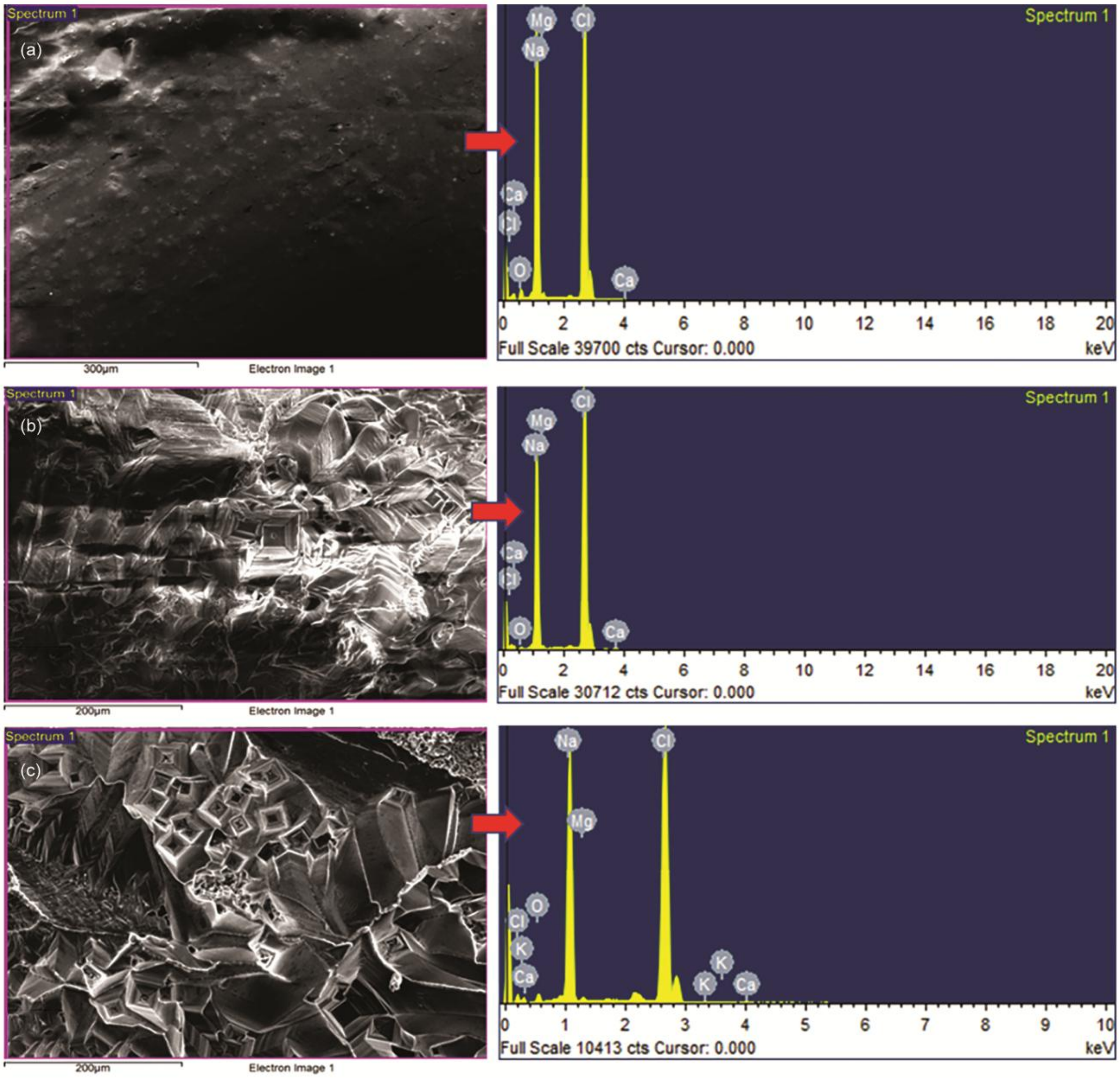

Fig. 4 — Scanning electron microscope (SEM) images showing salt crystals (NaCl), substantiated by Energy Dispersive Spectroscopy (EDS) analysis pattern of (a) Semkhor, (b) Phulung and (c) Khela

Table 3 — Correlation matrix of physical and chemical parameters of the studied salt spring sample

	p^H	*EC (μs/cm)*	*TDS*	*Salinity*	*$*Ca^{2+}$*	*$*Mg^{2+}$*	*$*Cl^-$*	*Na^+*	*$*K^+$*
p^H	1								
EC (μs/cm)	-0.94	1							
TDS	-0.94	1	1						
Salinity	-0.94	1	1	1					
$*Ca^{2+}$	-0.26	0.58	0.58	0.58	1				
$*Mg^{2+}$	-0.37	0.68	0.68	0.68	0.99	1			
$*Cl^-$	-1.00	0.93	0.93	0.93	0.23	0.35	1		
Na^+	-1.00	0.95	0.95	0.95	0.30	0.41	1.00	1	
$*K^+$	-0.84	0.59	0.59	0.59	-0.31	-0.20	0.85	0.81	1

* Data taken from[11]

treated waste water or from urban waste water is highly distinct. The Na^+/Cl^- ratio in sewage effluent is higher than unity, and the SO_4^{2-}/Cl^- ratio is also higher (0.09)[35]. If the Na^+/Cl^- ratio is less than 0.93, salt water incursion appears to be the source of contamination. In the meantime, if it is greater than 0.93, anthropogenic activity is the source of contamination. In the deeper aquifers, lower K^+/Cl^- and SO_4^{2-}/Cl^- levels are found, indicating a lower anthropogenic effect. The concentrations of Na^+/Cl^- (0.47-0.54), K^+/Cl^-, and SO_4^{2-}/Cl^- (as SO_4^{2-} discovered as a tracer) are negligible/low, indicating a deeper aquifer with minimal anthropogenic impact.

Base exchange indices (BEX)

Calculating Base Exchange Indices (BEX), BEX =Na+K+Mg-1.0716Cl [meq/L]) to determine if an aquifer is in the salinization or refreshing process[35]. Negative BEX values ranging from -20.58 to -203.74 suggest that the aquifer is becoming salinized.

Domestic water quality

The following parameters can be used to determine the physico-chemical qualities of water linked to salinity: chloride content, electric conductivity, and total dissolved solids. The Desjardins's classification of water based on TDS level in ppm are ranged as 500 freshwater, 500-1000 fairly fresh to brackish water, and 1000 to 5000 mildly brackish water[36]. The higher TDS> 1000 concentrations in the samples analyzed imply mildly brackish water types. The calculation of characteristics such as sodium absorption ratio is used to determine the appropriateness of groundwater for irrigation (SAR). According to the World Health Organization (WHO), a TDS content of more than 1000 is beyond the allowed limit in drinking water, posing a serious health risk such as coronary and cardiovascular disease, as well as gallstones.

Sodium absorption ratio (SAR)

The value of groundwater for agricultural applications is determined by its salinity and SAR. Salinity is gained in groundwater as a result of weathering of rocks and leaching from topsoil, as well as anthropogenic and climate influences[37]. SAR is a measure of how much sodium ion in water is absorbed by the soil and is stated as: SAR = Na/ (Ca + Mg/2), with concentrations reported in equivalent per million (epm). Richard classification was used to determine the distribution of SAR[38]. The SAR values for the samples range from 14.70 to 53.33, with an average of 30.62 indicating fair quality water for agricultural use.

Concepts for the studied salt spring formation

Saline springs are formed as a result of the existence of salt-bearing formations underneath, such as halite, and the deep-water circulation of groundwater flows[39]. Further, carbonate host rocks may contribute to the saline nature of a spring[13]. Numerous salt springs have been reported in anticlines, faults, fault zones, and other sources like carbonates[39]. The presence of fractures and faults is making an area suitable for groundwater extraction. Once groundwater gradually flows through these structures and flows out, saline springs develop. On the other hand, groundwater circulation from deeper sources, might have arisen while flowing through faults and fold zones, as well as by continuous heat flow and the inconsistency disintegration of evaporites and carbonates. Hence, geological structures play a significant role in shaping these springs.

The study area focuses on the development of saline springs in the Belt of Schuppen. This geological formation comprises a narrow linear strip of imbricate thrust slices that run from NNE to SSW. The belt covers 350 km along the Naga-Patkai ranges and extends 200 km along the strike from Mishmi Thrust to Maibong[40]. It is hypothesized that this belt comprises eight or possibly more overthrusts and recently concluded study infers the presence of five thrust slices[41]. The genesis of the Schuppen Belt is closely linked to the Upper Eocene emplacement of ophiolites along the eastern margin of the Indian Plate.

The origin of imbricate thrusting is attributed to the crustal collision between the Indian Plate and the Burma microplate, an integral part of the Eurasian Plate[42,43]. During the Cenozoic Era (Palaeocene–Eocene), when continental fragments of Gondwana—India, Arabia, and Apulia-collide with the Eurasian plate, the Tethys Sea was closed. The salt spring of the study area occurs primarily in the marine sediments of the Disang Group. It comprised dominantly dark grey shales with interbands of hard, fine grained flaggy, sandstone. The occurrences of carbonates have not been reported in the study area. Hence, the halite and anhydrites might deposited in the ancient sea bed, or what might be called pockets, probably interact with the deep groundwater circulation and move upwards through fractures and fault zones in the studied region or there may be a existence of carbonate body in the deeper aquifers in the study area. Hence, the major ions in the study area's saline and salty springs might come from the incongruent dissolution of halite. The source of the salt springs could be deeper aquifers, indicating that there has been no anthropogenic impact.

Conclusion

The primary goal of this research was to understand the knowledge on the physico-chemical characteristics of ancient Assam's salt springs. The salt springs under investigation are fairly to mildly brackish water type. It is commonly found in river valleys and the prime lithounits is the marine sediments of Disang Group. The major ions in the study area's saline and salty springs might come from the incongruent dissolution of halite. The source of the salt springs could be deeper aquifers, indicating that there has been no anthropogenic impact, which is bad for domestic applications such as agriculture and drinking water. Furthermore, from Semkhor to Mohong, the concentration of salinity increases. Further, we suggest a intesive investigation based on geochemistry and isotopic concentration will provide better understanding of the sources, ages and influences of the present geological setting of the studied brine water.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at https://nopr.niscpr.res.in/jinfo/ijtk/IJTK_23(02)(2024)119-127_SupplData.pdf

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Conflict of Interest

Authors declare that there is no conflict of interest in publication of this article.

Authors' Contributions

RRS, NA and SK collected the samples and sent them for analysis.This manuscript was composed, drafted, edited and compiled by CDT. RRS and NA supervised this research. The location map were developed by SK. All the authors read and approved the paper.

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