Environment and Natural Resources Journal

Volume 22
Issue 5
2024

Distribution of Salinity in Surface Water Surrounding Salt Mines in Non Thai and Phra Thong Kham Districts, Nakhon Ratchasima Province, Thailand

Bantita Terakulsatit*, Sakchai Glumglomjit, Thanyalak Anuphan, and Namthip Nongse

School of Geotechnology, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand

ARTICLE INFO

Received: 30 Jan 2024
Received in revised: 14 Aug 2024
Accepted: 19 Aug 2024
Published online: 4 Sep 2024
DOI: 10.32526/ennrj/22/20240022

Keywords:
Saline water/ Saline soil/ Sodium adsorption ratio/ Water quality/ Chlorite content

*** Corresponding author:**
E-mail: tbantita@sut.ac.th

ABSTRACT

Nakhon Ratchasima Province faces significant challenges due to saline soil and water, resulting from natural salt rock deposits and salt mining activities. This study investigates the physicochemical properties, salinity distribution, and surface water quality in Non Thai and Phra Thong Kham District. A total of 75 samples were collected, with 48 from Non Thai and 27 from Phra Thong Kham. The analysis focused on properties such as temperature, electrical conductivity (EC), pH, total dissolved solids (TDS), salinity, chloride, sodium, calcium, and magnesium. Water quality was assessed using standards from the Thai Department of Health and the World Health Organization. Additionally, the Sodium Adsorption Ratio (SAR) was employed to evaluate irrigation suitability, and ArcGIS 10.5 was utilized to map salinity and water quality distribution. Results indicated that surface water pH remained relatively neutral and within acceptable limits. However, salinity levels varied from 0.5 to 30 ppt, indicating brackish to saline conditions. In several areas, concentrations of salinity, sodium, and chloride exceeded standard limits. Factors such as proximity to salt mines, water flow direction, lower terrain, and smaller reservoirs were linked to increased salinity, with Phang Thiam Subdistrict in Phra Thong Kham District showing the highest levels. The SAR index further indicated that water quality in Phra Thong Kham was unsuitable for domestic use and irrigation, unlike Non Thai. Further research in other salt mine areas are essential for a deeper understanding of salinity distribution, which is crucial for assessing risks and making informed decisions to protect public health and the environment.

1. INTRODUCTION

The rock salt formation in Thailand is located in two basins (Sakon Nakhon and Khorat Basins) of the Khorat Plateau in Northeastern Thailand (Figure 1). The total rock salt reserve is estimated to be at least 18 trillion tons (Akhrajanthachot, 2010). Both basins contain three layers of evaporated deposits within the Maha Sarakham salt-bearing strata (Suwanich et al., 1986) as shown in Figure 2.

Salt mines in Thailand are mainly distributed in the northeastern region, including Chaiyaphum, Khon Kaen, Maha Sarakham, Udon Thani, Sakon Nakhon, Nakhon Phanom, and Nakhon Ratchasima Provinces. The Nakhon Ratchasima Province, in particular, hosts a significant number of salt mines, scattered across various areas such as Phimai, Non Sung, Dan Khun Thot, and Phra Thong Kham Districts (DPIM, 2009). Salt mines are usually in the form of halite and are extracted from evaporite formations, originating from dissolved rock salt in the Maha Sarakham Formation (El Tabakh et al., 1999). The salt mining activities in these areas have various impacts on the region in multiple dimensions, such as social, economic, and environmental aspects (DPIM, 2010).

Citation: Terakulsatit B, Glumglomjit S, Anuphan T, Nongse N. Distribution of salinity in surface water surrounding salt mines in Non Thai and Phra Thong Kham Districts, Nakhon Ratchasima Province, Thailand. Environ. Nat. Resour. J. 2024;22(5):464-475. (https://doi.org/10.32526/ennrj/22/20240022)

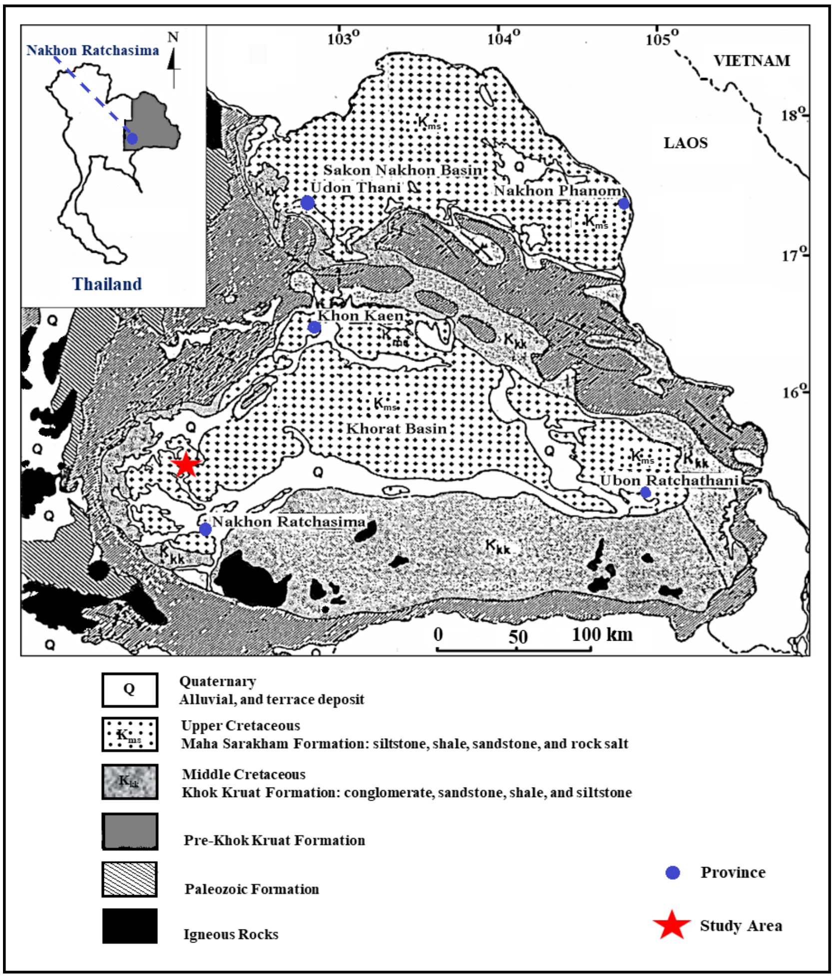

Figure 1. Sakon Nakhon and Khorat Basins in Northeastern Thailand containing rock salt (modified from Utha-aroon, 1993).

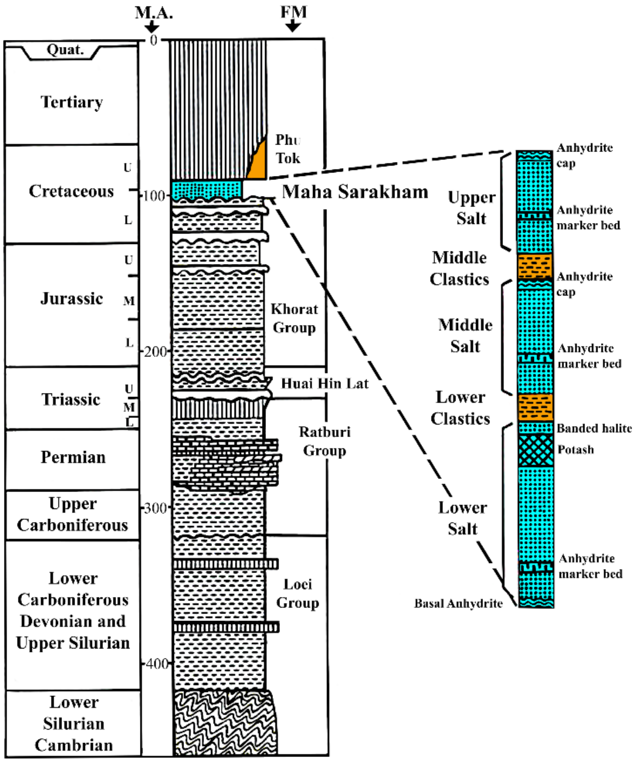

Figure 2. Lithostratigraphy and subdivisions of the Khorat Group and the Maha Sarakham Formation (modified from Suwanich, 1986).

The environmental impacts of salt mining in the Non Thai and Phra Thong Kham Districts of Nakhon Ratchasima Province have given rise to salinity issues in surface water, groundwater, and soil. This situation is exacerbated by the presence of saline soil and water originating from salt rock formation in the area (Wannakomol, 2005; Thongwat, 2018; Thongwat and Terakulsatit, 2019). The major causes of salinity are salts dissolving in groundwater and accumulating on the ground surface, sodium chloride, and shallow groundwater table depth depending on geomorphology, geology, and structural geology (Phoemphon and Terakulsatit, 2022; Wannakomol and Terakulsatit, 2018). Typically, this region encounters challenges associated with moderately to extremely saline soil (Figure 3), resulting in less prevalent cultivation of crops during the dry season compared to other regions. Additionally, issues related to the depletion of surface water and the presence of saline groundwater can be observed. The quality of the water is deemed inappropriate for consumption due to its excessive salinity (Royal Irrigation Department, 2020; Environment and Pollution Control, 2022). Furthermore, aside from the environmental impact of salt mining, certain regions are currently experiencing land subsidence (Wannakomol and Terakulsatit, 2018).

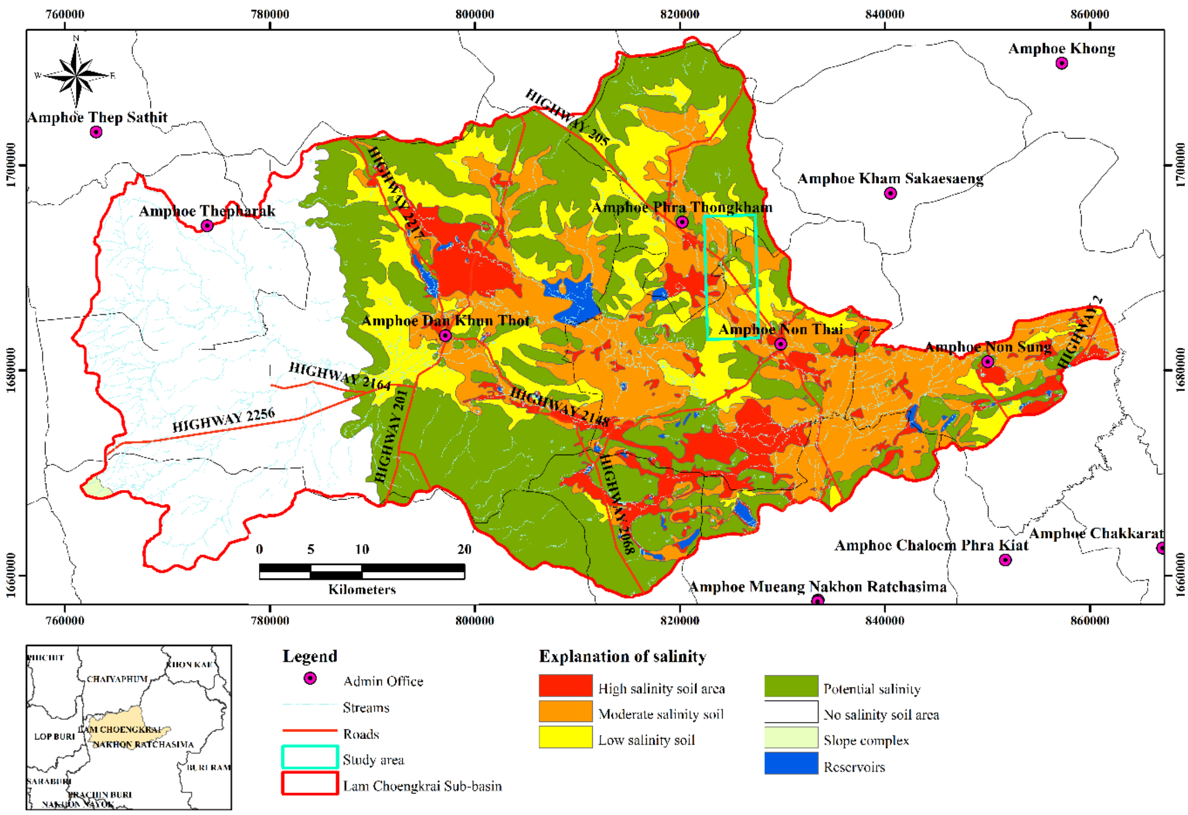

Figure 3. Saline soil area in Lam Chiang Krai River Basin in Non Thai and Phra Thong Kham Districts, Nakhon Ratchasima Provinces (modified from Royal Irrigation Department, 2020)

The unresolved conflict between the community and salt mine operators regarding the environmental impacts has resulted in a lack of understanding and awareness among community members (Green News, 2024; Prachathai News, 2023). The root cause lies in the dissemination of inaccurate information within the academic environment and the absence of proactive strategies to address associated issues. This has led to persistent conflicts without resolution. The community faces ongoing challenges due to water shortages, significantly impacting livelihoods, society, and the local economy near the salt mine. Thus, good management practices in salt mining are crucial for minimizing the negative impacts on both society and the environment in the long run. Monitoring and assessing the environmental impacts in the areas surrounding these salt mines helps to track the various impacts while assisting in managing and preventing the adverse effects that may occur. To address these issues and empower the community, this research aims to comprehensively investigate and assess the physical and chemical properties, as well as the distribution of salinity and surface water quality in the Non Thai and Phra Thong Kham Districts of Nakhon Ratchasima

Province. The anticipated outcomes of this study will serve to furnish the community with valuable insights into surface water quality and salinity within the study area. This information can be utilized in diverse applications, ensuring suitability and safety for purposes such as consumption, agriculture, and livestock. Furthermore, the findings will play a key role in developing water management strategies specifically suited to the needs of the study area.

2. METHODOLOGY

2.1 Study area

The study area encompasses coordinates 0178000E to 0183000E and 1689000N to 1695000N, covering 30 km^2. It is situated in two Districts, namely Non Thai (Sai-O and Non Thai Subdistrics) and Phra Thong Kham (Phang Thiam and Nong Hoi Subdistrics) within Nakhon Ratchasima Province (Figure 4). The salt mine is centrally located in the Phang Thiam Subdistrict of Phra Thong Kham District and the Banlang Subdistrict of Non Thai District (Figure 4), located at 15.25697 N and 101.98809 E (DPIM, 2009).

The general topography of this study area consists of plateaus interspersed with lowlands, with altitudes ranging from between 200 and 250 meters above sea level (LICD, 2022). The region features gently rolling low hills, except in mountainous areas where undulations are more pronounced. Flat valleys are found along various rivers, such as Lam Chiang Krai, Khlong Non Phao Phi, Khlong Sawai, Khlong Dan, Khlong Yang, and Khong Hut Phi Man (Royal Irrigation Department, 2020). The southern part of the study area is lower than the northern, influencing the flow direction of streams and canals, generally moving from northwest to southeast.

The prevalent soil type is sandy loam to coarse loamy, known for having low moisture retention, diminished fertility, and surface salt distribution (Land Development Department, 2021). The climate has three distinct seasons, with a general tendency toward dry conditions (Thongwat, 2018). Annual averages for rainfall, temperature, and relative humidity were approximately 924.4 mm, 27.4°C, and 71%, respectively.

2.2 Water samples and analysis

A total of 75 surface water samples in this study were collected between December 2022 and January 2023. This research involved the observation, measurement, and collection of 75 surface water samples in the area from both natural (canals) and man-made (reservoirs, ponds, and pools) water resources. Specifically, 48 samples (NT samples) were collected from Non Thai District, and 27 samples (PK samples) from Phra Thong Kham District in Nakhon Ratchasima Province (Figure 4). Water temperature, electrical conductivity (EC), pH, total dissolved solids (TDS), and salinity were measured using the Hanna Model EM-410-SS. The chloride content was analyzed by titration method according to the Mohr (Skoog et al., 1996). Chemical compounds, including ions of sodium (Na), calcium (Ca), and magnesium (Mg), were analyzed using Inductively Plasma Optical Emission Spectroscopy (ICP_OES) at the Suranaree University of Technology Laboratory, Thailand.

2.3 Sodium adsorption ratio (SAR) evaluation

The assessment of water samples for irrigation purposes involves the computation of the adjusted SAR index, following the methodology proposed by Lesch and Suarez (2009). The irrigation water classification is based on the correlation between the SAR and EC of the water samples. SAR is a pivotal parameter in determining the appropriateness of water for irrigation, serving as an indicator of the alkali/sodium hazard to crops. The SAR is determined using Equation (1) as follows:

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{\text{Na}}{\sqrt{\text{Ca+Mg}}} \quad (1)$$

Based on the SAR values, the water type, quality, and suitability for irrigation as shown in Table 1.

Table 1. Classification of irrigation water based on SAR (Guettaf et al., 2017)

SAR values	Quality	Type of water and suitability for irrigation
<10	Excellent	Low-sodium water is suitable for all types of crops and soils, except for crops sensitive to sodium.
10-18	Good	Medium sodium water is suitable for coarse-textured or organic soil with good permeability. But relatively unsuitable in fine-textured soils.
18-26	Fair	High sodium water is harmful to almost all types of soil; requires good drainage, and the addition of high-leaching gypsum.
>26	Poor	Very high sodium water is unsuitable for irrigation.

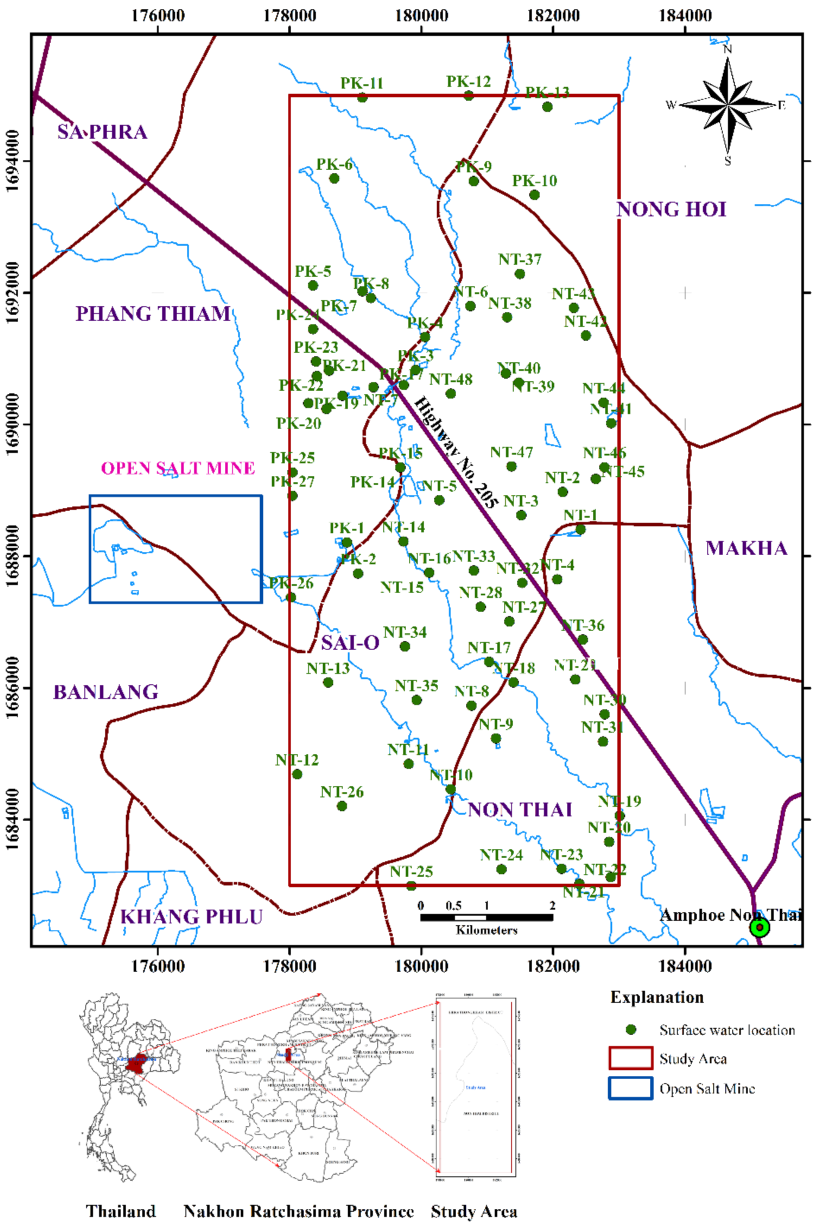

Figure 4. Study area and location of surface water samples around the salt mines in Non Thai and Phra Thong Kham Districts, Nakhon Ratchasima Province.

2.4 Water quality distribution mapping

The physicochemical parameters were applied to the ArcGIS 10.5 programmed and represented by the distribution of TDS, EC, salinity, chloride, sodium, and SAR content map of the surface water in the study area. Then, some physicochemical parameters were compared with the recommended limits set by the Department of Health (DoH, 2020) in Thailand and the World Health Organization (WHO, 2020) standards, as shown in Table 2.

Table 2. Criteria for assessing the quality of drinking water concerning saltwater adherence to the standards established by the DoH (2020) in Thailand and WHO (2022).

Parameters	Unit	DoH (2020)	WHO (2022)
pH (at 25°C)	-	6.5-8.5	6.5-8.5
Total dissolved solids (TDS)	mg/L	500	1,000
Electrical conductivity (EC)	µS/cm	2,000	2,500
Salinity	ppt	0.5	0.5
Chloride (Cl)	mg/L	250	250
Sodium (Na)	mg/L	200	200

3. RESULTS AND DISCUSSION

The results of surface water are predominantly clear, both from natural sources and human-made sources, with some areas having slight turbidity, especially for water sources used in agriculture and community areas affected by various human activities. Water temperatures vary with air temperatures, generally falling within the standard range of natural water sources in Thailand of 20 to 35°C.

3.1 General physical properties of surface water

As presented in Table 3, the pH value of most water is within the standard range of 6.5 to 8.5. This pH range does not have direct health implications, but it may harm agricultural water quality. The pH values in Non Thai District and Phra Thong Kham District range from 7.5 to 8.5, indicating a relatively neutral pH. The NT-5 sample exhibited acidic water with a pH of 6.53, while the PK-16 sample, taken from a large pool near the salt mine, showed alkaline water with a pH of 8.48. The distribution of these pH values correlates with the concentrations of Na, Ca, Mg, K, and salinity.

Figure 5(a) illustrates the distribution of TDS in surface water. Most samples exhibit TDS levels above 1,000 mg/L, surpassing the drinking water standard (DoH, 2020; WHO, 2022). In some instances, the TDS ranges from 600-1,000 mg/L, representing a rare distribution that exceeds the drinking water standard of the DoH (2020). However, it aligns with the WHO standard for good water quality, as the TDS level remains below 1,000 mg/L. It is essential to note that elevated TDS levels may pose concerns for consumers, leading to issues such as excessive scaling in water pipes, heaters, boilers, and household appliances (WHO, 2022). The presence of unusual tastes, such as saltiness and bitterness, may indicate water contamination. However, a few small areas in this study recorded TDS levels lower than 600 mg/L.

The EC of water in the study area ranges mainly between 2,500 and 10,000 µS/cm (Figure 5(b)). The water is brackish to salinity water and unsuitable for human consumption but acceptable for animal husbandry. The results were compared with the recommended limits of the drinking water standards, with values above 2,500 µS/cm (WHO, 2022) constituting highly saline water, requiring soil leaching. Additionally, areas near the salt mine have EC values exceeding 10,000 µS/cm, indicating extreme salinity. However, in the northern, eastern, and southern parts of the study area, values are below 1,500 µS/cm, which is within the drinkable water standard (DoH, 2020; WHO, 2022).

Table 3. Results of physical and chemical properties of surface water in the study area.

No	ID	MSL (m)	Water resources	pH	TDS (ppm)	EC (µS/cm)	Temp (°C)	Salinity (ppt)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SAR
1	NT-1	186	Reservoir	7.41	598	1,197	27.30	0.60	713	46.94	11.84	386	93.00
2	NT-2	186	Pond	7.23	1,054	2,107	27.30	1.10	728	53.46	19.71	676	85.11
3	NT-3	187	Pond	7.36	463	925	27.30	0.40	1,149	27.45	6.38	1,224	197.55
4	NT-4	181	Pond	7.12	1,973	3,946	27.10	2.20	801	96.04	27.54	290	72.05
5	NT-5	185	Pond	6.53	2,639	5,272	27.30	3.00	990	141.30	39.76	1,674	73.57
6	NT-6	190	Pool	7.49	1,547	3,092	24.70	1.50	307	67.41	21.97	837	32.42
7	NT-7	190	Khlong Yang	7.60	673	1,354	24.90	0.60	115	41.05	11.71	354	15.87
8	NT-8	182	Pond	7.49	1,567	3,134	27.20	1.70	2,694	67.36	23.82	1,030	282.13
9	NT-9	181	Pond	7.63	484	967	27.00	0.40	117	37.43	7.48	322	17.46
10	NT-10	180	Khlong Non Phao Phi	7.27	4,484	8,968	27.20	5.20	53	126.10	68.49	3,027	3.81
11	NT-11	182	Pond	7.63	5,668	11,320	27.30	6.70	55	84.04	150.00	3,928	3.62
12	NT-12	182	Pond	7.26	900	1,801	27.40	1.00	47	77.62	32.69	612	4.49
13	NT-13	191	Reservoir	7.42	134	269	27.30	0.10	5	31.45	4.34	161	0.76
14	NT-14	185	Khlong Yang	7.53	301	602	27.40	0.20	42	37.32	7.19	258	6.34
15	NT-15	185	Khlong Sawai	7.21	2,571	5,143	27.90	2.90	47	166.60	46.44	1,674	3.24
16	NT-16	183	Pond	7.37	1,178	2,355	27.90	1.30	47	52.55	15.22	773	5.75
17	NT-17	182	Pond	7.11	3,906	7,808	27.80	4.60	50	264.10	88.12	2,640	2.65
18	NT-18	181	Khlong Sawai	7.30	1,035	2,070	27.80	1.10	46	60.31	17.59	676	5.23
19	NT-19	180	Khlong Sawai	7.51	1,366	2,733	27.80	1.50	46	57.43	18.89	902	5.28
20	NT-20	178	Reservoir	7.57	914	1,828	27.60	1.00	46	25.30	11.03	612	7.57

Remarks: Higher Cl content; Higher SAR content

Table 3. Results of physical and chemical properties of surface water in the study area (cont.).

No	ID	MSL (m)	Water resources	pH	TDS (ppm)	EC (µS/cm)	Temp (°C)	Salinity (ppt)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SAR
21	NT-21	180	Pond	7.02	297	595	27.70	0.20	57	19.13	5.87	225	11.43
22	NT-22	179	Khlong Dan	7.16	2,719	5,441	27.90	3.20	51	88.71	39.95	1,868	4.52
23	NT-23	177	Khlong Dan	7.32	2,860	5,719	27.70	3.40	49	110.50	41.24	1,996	4.01
24	NT-24	177	Pond	7.31	867	1,735	27.70	0.90	-	43.76	18.43	580	-
25	NT-25	181	Pond	7.51	495	990	27.70	0.50	94	32.24	17.67	354	13.31
26	NT-26	188	Pond	7.22	1,599	3,198	27.60	1.70	44	201.10	80.11	1,127	2.65
27	NT-27	182	Pond	7.52	906	1,812	27.40	0.90	-	54.09	15.18	547	-
28	NT-28	181	Pond	7.05	1,795	3,592	27.20	2.00	46	119.30	36.13	1,191	3.67
29	NT-29	183	Pond	7.22	6,142	12,290	27.40	7.40	56	167.90	106.40	4,315	3.40
30	NT-30	179	Pond	7.55	1,505	3,010	27.20	1.60	46	60.65	23.56	966	5.03
31	NT-31	180	Pond	7.48	514	1,027	27.30	0.50	-	14.82	4.97	322	-
32	NT-32	186	Pond	7.47	191	383	27.50	0.10	24	22.41	3.31	193	4.73
33	NT-33	182	Pond	7.04	5,930	11,850	27.20	6.90	55	386.60	107.20	4,025	2.49
34	NT-34	182	Pond	7.33	1,664	3,328	27.40	1.80	49	59.20	10.87	1,063	5.80
35	NT-35	182	Pond	7.67	533	1,066	27.40	0.50	119	30.62	8.17	354	19.04
36	NT-36	181	Pond	7.28	772	1,544	27.80	0.80	-	36.16	13.24	483	-
37	NT-37	193	Pool	7.40	1,799	3,606	27.40	2.00	345	79.24	65.56	1,143	28.66
38	NT-38	191	Pool	7.44	361	722	27.30	0.30	71	31.03	8.11	242	11.33
39	NT-39	191	Pool	7.10	2,391	4,743	27.30	2.70	-	88.41	31.96	1,530	-
40	NT-40	188	Pool	7.26	2,191	4,389	27.20	2.40	446	106.80	34.70	1,401	37.48
41	NT-41	187	Reservoir	7.33	861	1,722	27.30	0.90	197	46.69	14.13	564	25.27
42	NT-42	189	Pool	7.39	1,548	3,092	26.70	1.70	256	149.10	28.81	998	19.17
43	NT-43	190	Canal	7.53	972	1,944	26.80	3.50	596	167.20	93.92	2,061	36.90
44	NT-44	185	Reservoir	7.60	1,014	2,028	26.70	1.10	222	56.28	17.12	660	25.85
45	NT-45	187	Pond	6.82	3,431	6,861	26.80	3.90	717	164.80	66.10	2,302	47.15
46	NT-46	183	Pond	7.37	736	1,472	26.70	0.80	182	73.94	13.18	483	19.45
47	NT-47	186	Pool	7.36	1,462	2,924	27.00	1.60	289	77.92	44.76	934	26.07
48	NT-48	187	Pool	7.35	2,792	5,585	26.70	3.20	706	76.65	31.40	1,707	67.90
49	PK-1	187	Reservoir	7.34	944	1,888	27.30	1.00	2,893	41.47	13.27	580	391.02
50	PK-2	184	Pool	7.40	2,479	4,958	27.20	2.80	2,134	49.39	21.97	515	252.62
51	PK-3	190	Khlong Yang	7.25	751	1,498	24.90	0.70	161	40.95	11.02	483	22.31
52	PK-4	188	Khlong Yang	7.47	625	1,241	25.10	0.50	81	39.29	10.67	338	11.47
53	PK-5	190	Pool	7.34	905	1,801	26.90	1.00	111	52.21	18.17	81	13.17
54	PK-6	194	Pool	7.14	4,094	8,193	26.90	4.80	867	219.60	89.90	2,608	49.29
55	PK-7	193	Pool	7.23	413	827	27.00	0.40	67	33.54	9.04	258	10.29
56	PK-8	191	Khlong Kud Phi Man	7.29	818	1,636	27.00	0.80	180	55.36	16.70	161	21.17
57	PK-9	191	Pool	7.40	249	497	27.30	0.20	69	13.54	5.29	193	15.82
58	PK-10	195	Pool	7.23	2,441	4,953	27.20	2.80	254	203.80	150.40	1,658	13.48
59	PK-11	195	Pool	7.06	3,267	6,534	26.70	3.80	678	152.90	73.13	2,061	45.08
60	PK-12	195	Pool	7.32	2,971	5,938	26.70	3.40	682	128.00	43.32	1,964	52.11
61	PK-13	198	Pool	7.68	154	308	26.80	0.10	6	71.96	4.05	129	0.72
62	PK-14	187	Pool	7.22	2,282	4,567	27.40	2.60	387	197.70	53.61	1,546	24.39
63	PK-15	187	Pond	7.42	1,174	2,348	27.40	1.30	244	89.35	21.50	773	23.17
64	PK-16	189	Pool	8.48	9,689	19,380	27.80	12.80	6	74.81	118.50	6,698	0.42
65	PK-17	189	Pool	8.10	4,423	8,790	27.50	5.10	1,183	67.67	60.87	2,866	104.34
66	PK-18	189	Pond	8.02	2,220	4,436	27.70	2.50	471	96.37	56.98	1,481	38.06
67	PK-19	187	Pool	7.50	21,340	42,680	27.80	28.10	96	398.80	282.40	15,939	3.66
68	PK-20	188	Pond	7.61	8,013	16,010	27.70	9.90	-	255.00	139.10	5,764	-
69	PK-21	189	Pond	7.67	2,045	4,091	27.60	2.30	-	130.60	60.43	1,352	-
70	PK-22	192	Pond	7.64	1,177	2,353	27.70	1.20	185	115.30	38.38	773	14.89

Remarks: Higher Cl content Higher SAR content

Table 3. Results of physical and chemical properties of surface water in the study area (cont.).

No	ID	MSL (m)	Water resources	pH	TDS (ppm)	EC (µS/cm)	Temp (°C)	Salinity (ppt)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SAR
71	PK-23	190	Pond	7.55	1,174	2,349	27.70	4.20	5,161	87.20	63.54	2,447	420.36
72	PK-24	190	Pond	7.64	2,687	5,370	27.80	3.10	4,796	112.90	48.10	1,803	377.98
73	PK-25	186	Pool	7.29	272	5,344	27.60	3.00	-	42.59	27.26	1,707	-
74	PK-26	183	Khlong Non Phao Phi	7.24	8,313	16,620	27.60	10.10	67	189.70	127.10	5,732	3.76
75	PK-27	185	Pond	7.38	677	1,353	27.20	0.70	1,875	42.33	11.78	419	254.90
	Max.	**198**		**8.48**	**21,340**	**42,680**	**27.9**	**28.10**	**5,161**	**398.80**	**282.4**	**15,939**	**420.36**
	Min.	**177**		**6.53**	**134.3**	**268.70**	**24.7**	**0.10**	**4.56**	**13.54**	**3.31**	**80.50**	**0.42**
	Avg.	**186.1**		**7.39**	**2,231.9**	**4,526.94**	**27.21**	**2.70**	**529.35**	**95.05**	**42.52**	**1,546.9**	**52.35**
	S.D.	**4.8**		**0.26**	**2,960.4**	**5,902.54**	**0.65**	**3.84**	**987.77**	**76.60**	**46.40**	**2,161.8**	**95.46**

Remarks: Higher Cl content; Higher SAR content

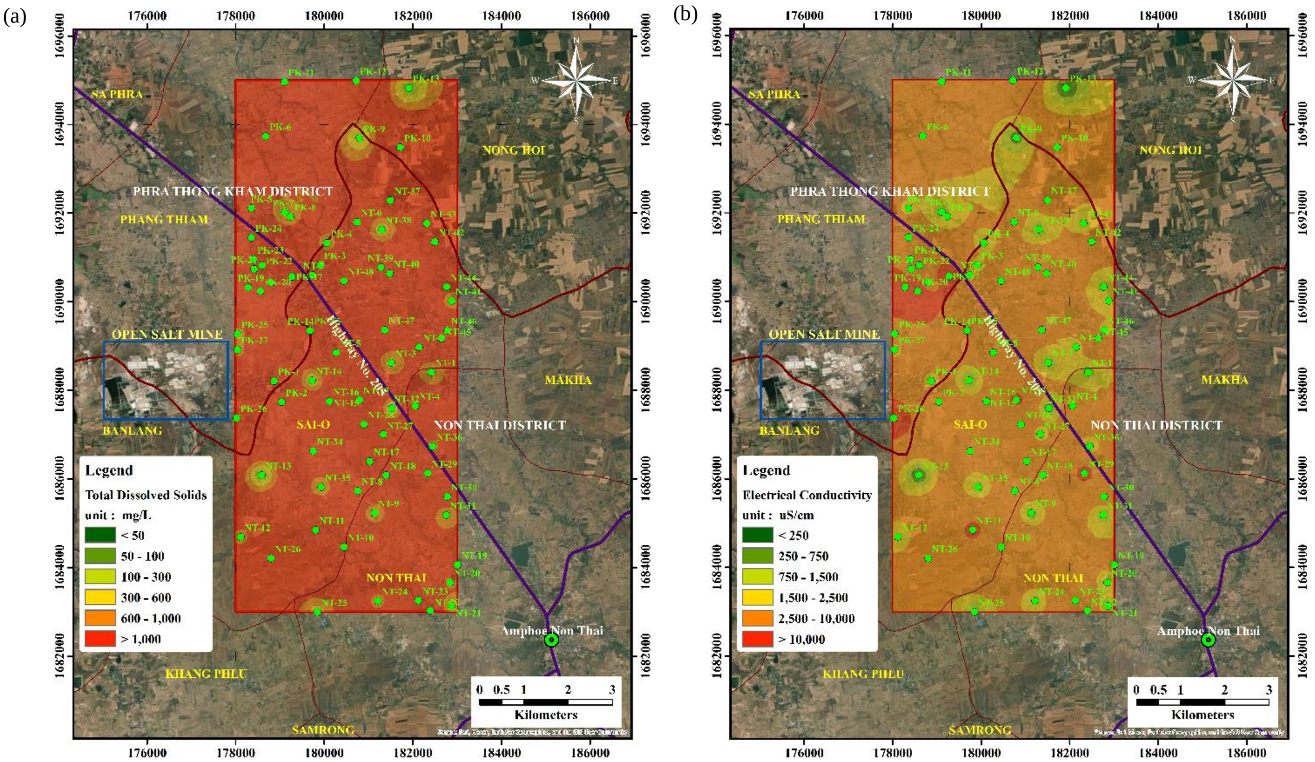

Figure 5. Distribution map of (a) total dissolved solids (TDS), and (b) electrical conductivity (EC) in the study area.

3.2 Salinity and chemical property distribution

The distribution of surface water salinity is illustrated in Figure 6(a). Salinity values range from 0.5 to 30 ppt, categorized as brackish water (1-10 ppt) to saltwater (over 10 ppt) according to the LEO EnviroSci Inquiry (2011). Regions with higher salinity, such as the 28.1 ppt reading in Phang Thiam Subdistrict (PK-19 sample) and Phra Thong Kham District, are associated with pools in proximity to salt mines. This phenomenon is attributed to surface runoff and sodium infiltration. Conversely, lower salinity (below 0.5 ppt) indicates freshwater suitable for human consumption, agriculture, and livestock.

The distribution of chloride (Cl) content, as depicted in Figure 7(b), has surpassed the standard limit of 250 mg/L. Concentrations of Cl ranging from 1,000 to 5,000 mg/L are observed across various communities and farmlands. Notably, the PK-19 sample from Phang Thiam Subdistrict in Phra Thong Kham District records the highest Cl content at 15,939 mg/L and is situated approximately 1 km from the salt mine.

High levels of chloride can give water and beverages a salty taste, usually noticeable at 200-300 mg/L for sodium, magnesium, and calcium chlorides. In the study area, chloride concentrations over 250 mg/L are likely to be tasted, though some people might get used to it (WHO, 2022). However, in the northern and southern regions, chloride levels are generally below 250 mg/L, making the water suitable for consumption and use, according to DoH and WHO standards.

Figure 7(a) shows the sodium (Na) distribution, particularly in the western and eastern regions where most values exceed 500 mg/L. Water from the eastern region of this study area contains 200-300 mg/L of sodium, exceeding the drinking water standard of 200 mg/L (WHO, 2022). Areas with lower sodium concentrations, particularly those in the north and south can be found, aligning with the drinking water standards.

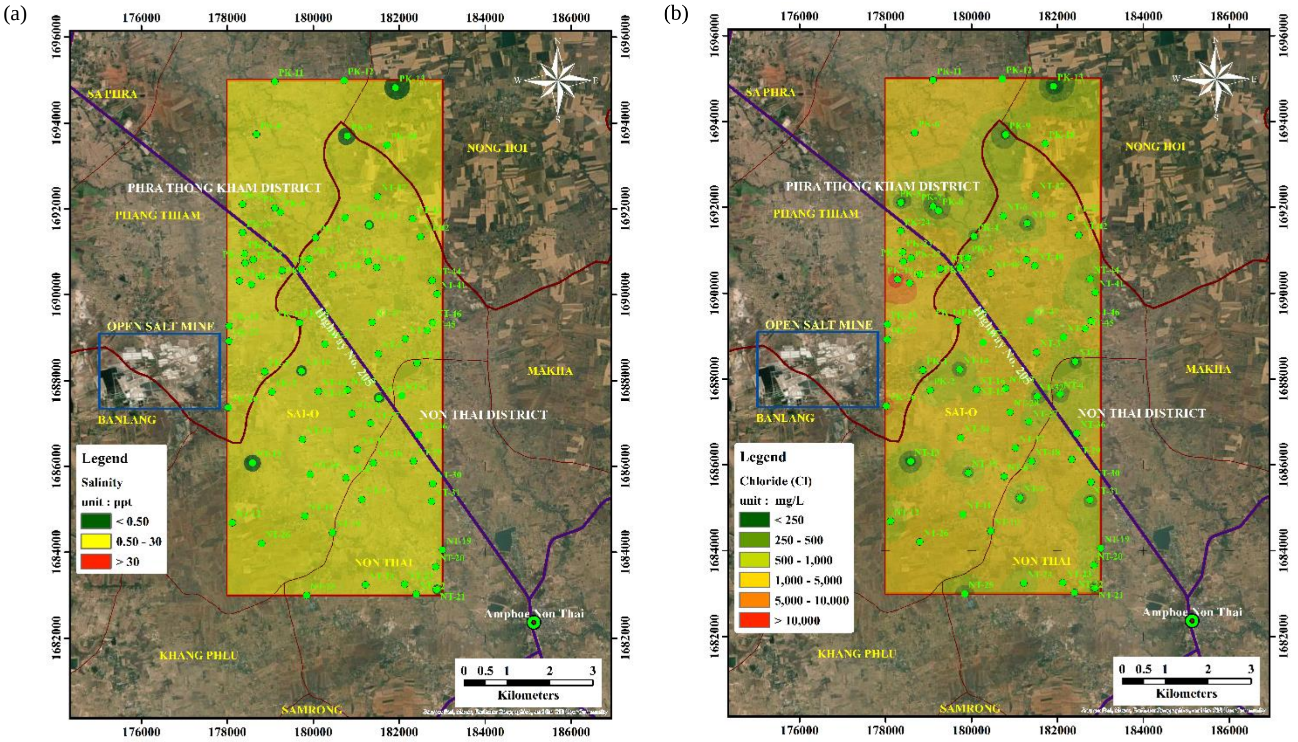

Figure 6. Distribution map of (a) salinity, and (b) chloride (Cl) in the study area

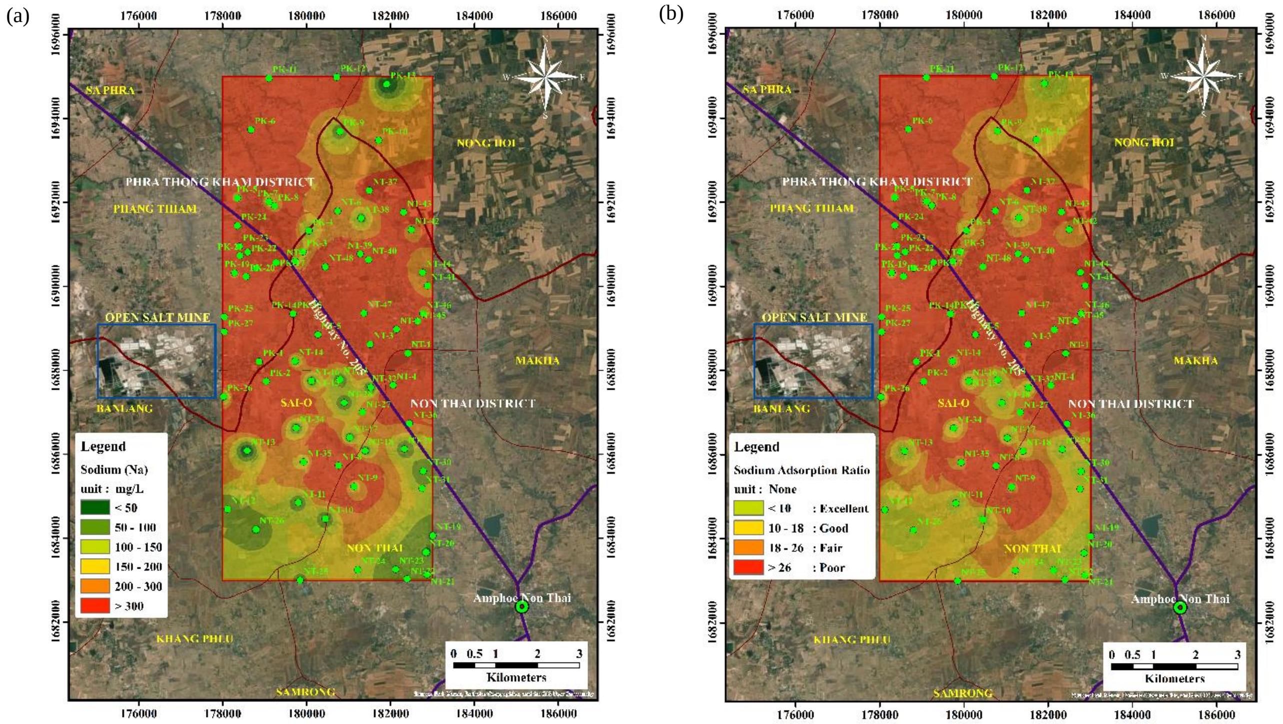

Figure 7. Distribution map of (a) sodium, and (b) Sodium Adsorption Ratio (SAR) in the study area

Based on the findings from the comparison of salinity and water quality across diverse water sources, the primary determinants influencing salinity include the proximity of the location to the salt mine and the lower altitude of the area. Additionally, the nature and scale of water resources play a crucial role. Specifically, water sources such as pools or small ponds exhibit higher salinity levels than larger reservoirs, rivers, and canals, which constitute flowing waterways and generally have lower salinity compared to other types of water sources.

3.3 Sodium adsorption ratio (SAR) evaluation

Based on the SAR values derived from this study, the range extends from 0.42 to 420.4, with an average SAR of 52.35 (Table 3). The SAR distribution in the Non Thai District generally remains below 10 (Figure 7(b)), indicating excellent water quality and a low susceptibility to sodium-related issues in crops (Guettaf et al., 2017). However, specific localized areas within the Non Thai District exhibit notably high SAR values exceeding 26. These elevated values suggest severely compromised water quality, posing a significant risk of sodium-related problems (Guettaf et al., 2017). Consequently, irrigation in these areas is considered unwise and requires extensive leaching to mitigate the potential detrimental effects. Conversely, the Phra Thong Kham District consistently shows SAR values exceeding 26 (Figure 7(b)), indicative of extremely poor water quality, rendering the water reservoirs unsuitable for irrigation. Despite this, isolated areas within the district exhibit low SAR values, suggesting fair to good water quality, and emphasizing the need for nuanced water management strategies in specific regions.

3.4 Dispersion of water salinity levels within each examined region

According to the salinity water distribution, several influencing factors contribute to saline water presence, encompassing the proximity of salt mines, low-lying topography, water flow direction (Thongwat, 2018), geological characteristics such as soil and rock types, the presence of rock salt, and the occurrence of joints and fractures in the formation (Royal Irrigation Department, 2020; Phoemphon and Terakulsatit, 2022; Wannakomol, 2005). Additionally, the size and nature of the water resource play a significant role in shaping salinity patterns. It is noteworthy that smaller, static sources, exemplified by pools, often exhibit higher salinity levels in comparison to larger, flowing waterways. The severity of salinity levels in the study area is further categorized based on specific villages and subdistricts.

3.4.1 Non Thai District

Areas with severe salinity distribution in Non Thai District can be determined as follows:

(i) Non Thai Subdistrict

The analysis of the salinity distribution in Non Thai Subdistrict encompasses seven villages ranked in descending order of severity: Ban Non Wai, Ban Non Thai, Ban Dan Tai, Ban Khok Phrom, Ban Dan Krong Krang, Ban Rai, and Ban Mai.

Ban Non Thai (NT-29 sample) encompasses a small agricultural pond situated at an altitude of 183 m. It registers the highest Cl concentration at 4,315 mg/L and a high salinity level of 7.4 ppt (Table 3). Additionally, the area exhibits the highest SAR value of 282.13 and a Na concentration of 2,694 mg/L. Another region, including Ban Non Wai and Ban Dan Tai, also showcases Cl levels surpassing 2,000 mg/L and salinity exceeding 5 ppt, indicating the presence of very saline water (Thongwat, 2018), which is unsuitable for use and consumption (DoH, 2020; WHO, 2022).

(ii) Sai O Subdistrict

The salinity distribution in the Sai O Subdistrict involves five villages, arranged in descending order of severity based on water salinity: Ban Sai O, Ban Khok, Ban Kut Chik, Ban Sawai, and Ban Khok Nong Phai.

The Ban Sai O area (NT-33 sample) encompasses a small agricultural pond situated at the highest altitude of 182 m, featuring a Cl concentration of 4025 mg/L and a salinity level of 6.9 ppt (Table 3). Additionally, Ban Sai O, Ban Kut Chik, and Khok Noi exhibit chlorite concentrations exceeding 2,000 mg/L and salinity levels surpassing 3.5 ppt, indicating the presence of extremely salty water, which is unsuitable for use and consumption (DoH, 2020; WHO, 2022).

3.4.2 Phra Thong Kham District

The areas in Phra Thong Kham District with severe salinity distribution can be determined as follows:

(i) Phang Thiam Subdistrict

The salinity distribution results for Phang Thiam Subdistrict, cover seven villages. Arranged in descending order of water salinity severity, they are Ban Phang Thiam, Ban Yang Sam Ton, Ban Bueng Noi, Ban Chai Pha Nao, Ban Thonglang, Ban Non Sai Yong, and Ban Nong Pho.

Ban Phang Thiam Subdistrict (PK-19 sample) accommodates a large agricultural pond situated at an altitude of 187 m and is approximately 1 km away from the salt mine. This area demonstrates the highest Cl concentration at 15,939 mg/L and a high salinity of 28.1 ppt (Table 3). Furthermore, Ban Bueng Noi (PK-23 sample) displays the highest SAR value recorded at 420.36, along with a Na concentration of 5,161 mg/L (Table 3). Consequently, Ban Bueng Noi, Ban Thonglang, and Ban Non Sai Yong experienced elevated salinity levels, exceeding a SAR of 100. This indicates a severe level of saline quality, rendering it unsuitable for both use and consumption (DoH, 2020; WHO, 2022).

(ii) Nong Hoi Subdistrict

The results of the salinity distribution in the Nong Hoi Subdistrict, encompass two villages. These villages in descending order of severity based on water salinity are Ban Nong Hoi and Ban Tanon Hak, respectively.

The Nong Hoi Subdistrict encompasses small agricultural ponds situated approximately 7 km away from the salt mine. Ban Nong Hoi (PK-10 sample), positioned at an elevation of 195 m, exhibits a low Cl concentration of 129 mg/L and a low salinity of 0.1 ppt (Table 3). These values indicate good saltwater quality, although it is unsuitable for human consumption (DoH, 2020; WHO, 2022). In contrast, Ban Thanon Hak (PK-13 sample), situated at an elevation of 198 m, showcases a low Cl concentration of 1,658 mg/L and a high salinity of 2.8 ppt. These characteristics demonstrate good water quality, deeming it suitable for both use and consumption.

4. CONCLUSION

Most of the surface water in Non Thai and Phra Thong Kham Districts showed relatively neutral pH values. However, the TDS and EC values in many samples, surpassed the drinking water standards set by Thailand's DoH and the WHO. Elevated salinity, chloride, sodium, and SAR levels were concentrated near salt mines, influenced by surface runoff and sodium infiltration.

Non Thai District: (i) Non Thai Subdistrict, Ban Non Wai, Ban Non Thai, Ban Dan Tai, Ban Khok Phrom, Ban Dan Krong Krang, Ban Rai, and Ban Mai exhibited elevated chloride concentrations and salinity levels, rendering the water unsuitable for both consumption and use. (ii) Sai O Subdistrict, Ban Sai O displayed extremely salty water, making it unsuitable for consumption.

Phra Thong Kham District: (i) Phra Thong Kham Subdistrict Ban Phang Thiam demonstrated the highest chloride concentration and salinity, rendering the water unsuitable for both use and consumption. (ii) Nong Hoi Subdistrict revealed brackish to saline water in Ban Nong Hoi, while Ban Tanon Hak exhibited good water quality deeming it suitable for both use and consumption.

In summary, the study found that brackish to saline water is prevalent in the central and northern areas around the salt mine, with Phra Thong Kham District showing higher salinity levels, making the water unsuitable for domestic use and irrigation compared to Non Thai District. Key factors influencing salinity include proximity to the salt mine, lower terrain, seasonal changes, water flow direction, geological formations, and the size of water sources. The highest salinity risk is in areas near salt mines and their direct water flow paths, particularly in low-lying regions. Smaller water sources tend to have higher salinity. Water quality in this area is inconsistent, while some areas still have usable water. Additional research is necessary in other salt mine regions of Nakhon Ratchasima Province and beyond to gain a clearer understanding of salinity distribution. This work is crucial for assessing risks and making informed decisions to effectively manage and protect public health and the environment in areas surrounding salt mines.

ACKNOWLEDGEMENTS

This work was financially supported by (i) Suranaree University of Technology (SUT), (ii) Thailand Science Research and Innovation (TSRI), and (iii) National Science, Research and Innovation Fund (NSRF) under the grant numbers: NRIIS 179329. Special thanks go to Ms Mallika Nguanthaisong and the Geotechnology laboratory staff for their assistance with the laboratory work.

REFERENCES

Akhrajanthachot B. Potash and salt mine in the North-Eastern of Thailand. Proceedings of the Thai-Lao Technical Conference on Geology and Mineral Resources; 2010 Sep 7-8; Bangkok, Thailand: Rama Gardens Hotel; 2010.

Department of Health (DoH). Notification of the Department of Health on Criteria for Recommendation of Drinking Water

Quality Surveillance, B.E. 2563 (A.D. 2020). Thailand: Ministry of Public Health; 2020 (in Thai).

Department of Primary Industries and Mines (DPIM). General mining concession information [Internet]. 2009 [cited 2024 Jan 10]. Available from: https://www1.dpim.go.th/mne/mn.php?nox=&pltname=&status=*&ore1=&ore2=&prov=30&b1dx=00&b1mx=00&b1yx=0000&b2dx=00&b2mx=00&b2yx=0000&a1dx=00&a1mx=00&a1yx=0000&a2dx=00&a2mx=00&a2yx=0000. (in Thai).

Department of Primary Industries and Mines (DPIM). Study of saline soil in the Nakhon Ratchasima salt production area [Internet]. 2010 [cited 2024 Jan 10]. Available from: https://envi-mining.dpim.go.th/modules.php?m=article&op=detailnewsupdate&NUID=19. (in Thai).

El Tabakh M, Utha-Aroon C, Schreiber BC. Sedimentology of the cretaceous Maha Sarakham evaporites in the Khorat Plateau of northeastern Thailand. Sedimentary Geology 1999;123:31-62.

Environment and Pollution Control. Report Summarizing Water Quality Results Surface Water Resources, 4th Quarter, Fiscal Year 2022. Nakhon Ratchasima. Thailand: Pollution Control Department, Ministry of Natural Resources and Environment; 2022 (in Thai).

Green News. Revealing the cause of heavy saltwater spread “Khorat mine dug into the water source - will continue. Must make a new EIA” [Internet]. 2022 [cited 2024 Jan 24]. Available from: https://greennews.agency/?p=32079. (in Thai).

Guettaf M, Maoui A, Ihdene Z. Assessment of water quality: A case study of the Seybouse River (North East of Algeria). Applied Water Science 2017;7:295-307.

Land Development Department. Appropriate Agricultural Promotion Guidelines Nakhon Ratchasima Province. Thailand: Land Development Department, Ministry of Agriculture and Cooperatives; 2021.

LEO EnviroSci Inquiry. Lehigh University. Chloride and Salinity [Internet]. 2011 [cited 2024 Jan 29]. Available from: https://ei.lehigh.edu/envirosci/watershed/wq/wqbackground/chloridebg.html.

Lesch SM, Suarez DL. A short note on calculating the adjusted SAR index. Transaction of American Society of Agricultural and Biological Engineers 2009;52(2):493-6.

Local Information Center for Development (LICD). Basic Information of Nakhon Ratchasima Province. “General geography of Non Thai and Phra Thong Kham Districts”. Nakhon Ratchasima, Thailand: Local Information Center for Development of Nakhon Ratchasima; 2022 (in Thai).

Phoemphon W, Terakulsatit B. Assessment of groundwater potential zones and mapping using GIS/RS techniques and analytic hierarchy process: A case study on saline soil area, Nakhon Ratchasima, Thailand. AIMS Geosciences 2022; 9(1):49-67.

Prachathai News. “Villagers demand a solution to the problems affecting the Dan Khun Thot” [Internet]. 2023 [cited 2024 Jan 24]. Available from: https://prachatai.com/journal/2023/12/107123. (in Thai).

Royal Irrigation Department. Developing Water Resources to Solve Drought and Flood Problems in the Lam Chiang Krai Basin 2019. Nakhon Ratchasima, Thailand: Thailand Ministry of Agriculture and Cooperatives; 2020 (in Thai).

Skoog DA, West DM, Holler FJ. Fundamentals of Analytical Chemistry. 7th ed. USA: Thomson Learning, Inc; 1996.

Suwanich P. Potash and rock salt in Thailand. In: Nonmetallic Minerals Bulletin No. 2. Bangkok, Thailand: Economic Geology Division, Department of Mineral Resources; 1986.

Thongwat W. Relationship between Soil Salinity and Chloride Content in Groundwater in Saline Soil Areas of Nakhon Ratchasima Province [dissertation]. Nakhon Ratchasima: Suranaree University of Technology; 2018.

Thongwat W, Terakulsatit B. Using GIS and map data for the analysis of the relationship between soil and groundwater quality at saline soil area of Kham Sakaesaeng District, Nakhon Ratchasima, Thailand. International Journal of Materials and Metallurgical Engineering 2019;13(1):32-9.

Utha-aroon C. Continental origin of the Maha Sarakham evaporates Northeastern Thailand. Journal of Southeast Asian Earth Sciences 1993;8(1-4):193-203.

Wannakomol A. Soil and Groundwater Salinization Problem in the Khorat Plateau, Northeast Thailand [dissertation]. Berlin, Germany: Freie University; 2005.

Wannakomol A, Terakulsatit B. Study and the land subsidence risk level mapping in the rock salt production area of Nakhon Ratchasima Province by using Synthetic Aperture Radar and Geophysical Data. Nakhon Ratchasima, Thailand: Suranaree University of Technology; 2018.

World Health Organization (WHO). World Health Organization’s (WHO) Guidelines for Drinking-Water Quality. 4th ed. Geneva, Switzerland: World Health Organization; 2022.