ASSESSMENT OF SURFACE WATER QUALITY DISTRIBUTION TO IDENTIFY RISKY AREAS OF REINFORCED CONCRETE STRUCTURE DETERIORATION: A CASE STUDY ALONG SARANARAI ROAD (HIGHWAY NO. 205), NON THAI DISTRICT, NAKHON RATCHASIMA, THAILAND

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Abstract - The aims of this study were to observe, analyze, and classify the surface water quality to identify risky areas of reinforced concrete structure deterioration buildings along Suranarai road (highway No. 205), Non Thai district, Nakhon Ratchasima province, Thailand. Twenty-nine surface water samples were collected from the study area, and temperature, electrical conductivity (EC), resistivity, pH, total dissolved solids (TDS), and salinity were tested by Hanna. Chloride content was analyzed by the titrations method, and ions of Ca^{2+}, Mg^{2+}, K^{+}, Fe^{2+}, and Na^{+}were analyzed by atomic absorption spectroscopy (AAS). From the water quality distribution results, the order of abundance is $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}>Fe^{2+}$. The high chloride, sodium, salinity, and TDS concentrations were dominantly represented in the study area (Dan Chak, Non Thai, and Sai-O sub-districts), indicating the brackish water and some saline water. In addition, the correlation tendency of chloride, sodium, salinity, TDS, iron, and pH values will cause risk effects on highly deteriorated reinforced concrete in the study area. These risk areas are represented in the dense community and lowland area in Non Thai sub-district at the Na Wah pond and Khlong Dan River, respectively. In summary, these obtained results can be used to identify the boundary and location for basic information and guidelines for monitoring and solving problems of reinforced concrete structures to prolong service life and increase efficiency in this saline area.

Keywords - Chloride, Salinity, Saline Soil, Maha Sarakham Formation, Concrete Corrosion.

I. INTRODUCTION

Reinforced concrete is one of the most common materials used by the construction industry worldwide, such as in small private buildings, civil engineering infrastructures (bridges and tunnels), offshore platforms, and dams. These constructures have a necessary range of exposure conditions, including marine and severe environments. The factors that generally influence the corrosion of reinforcement structures are pH value, moisture, oxygen, carbonation, chlorides, ambient temperature, relative humidity, and quality of construction materials and concrete, cover to the reinforcement, initial curing conditions, formation of cracks, geography, etc. [1]. Especially the chloride ion (Cl^{-}) is the most common factor to harm the reinforced concrete structure, and this chloride-induced corrosion is potentially more dangerous than carbonation. In the presence of chlorides, localized pitting corrosion occurs, which is not always associated with early warning signs of surface cracking. Like most aspects of concrete durability, deterioration due to corrosion of the reinforcement can take years (5 to 20) to manifest itself [1].

The salt-affected soils in Thailand can be classified into two types according to their origins, the coastal saline soils (found along the coast in the tidal zone or previously inundated areas by the sea) and the salt-affected soils on the land (found mainly in the northeastern part of Thailand, in lowlands and the shoulders of mounds) [3].

The accumulated salt mainly causes the salinity of the water and soil problems in Northeastern Thailand (NaCl) originating from dissolved rock salt in the Maha Sarakham Formation [2] as shown in Fig. 1. As a result, salt (NaCl) is dissolved in surface water and groundwater. The saline groundwater occurs from dissolving rock salt spent up to the near-surface. Soluble salts such as the chlorides and sulfates of sodium, calcium, and magnesium are most commonly present. Especially sodium and chloride are the most dominant ions, particularly in highly saline soils. The chlorides are generally acidic and can come from several sources, including marine, de-icing salts, chloride-containing rock, agricultural runoff, and wastewater [3].

The soil and water saline problems are a major critical issue in Northeastern Thailand, especially Nakhon Ratchasima province (covering 4,000 km^2). The saline soil area of the Non Thai district, Nakhon Ratchasima province, covered 77.4 km^2, as shown in Fig.2 [3].

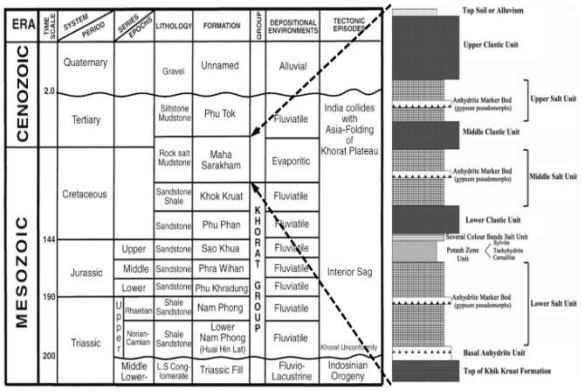


Fig. 1.Stratigraphy of the Khorat Basin, and lithostratigraphy of the Maha Sarakham Formation (modified from Tabakh, et al.[2]).

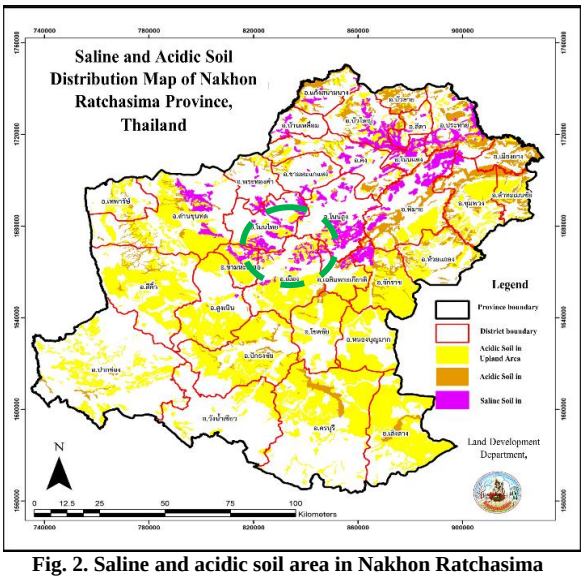


Fig. 2. Saline and acidic soil area in Nakhon Ratchasima Province (modified from Land Development Department, 2022 [3]).

This area's soil and water salinity affect plant growth and water quality, resulting in lower crop yields and degraded stock water supplies [3]. In addition, the salinity also affects reinforced concrete building structures resulting from chloride penetrating reinforced concrete structures to interact with reinforcing steel. This cause makes rust and reduces the load capacity of reinforced concrete structures and their service life.The challenges faced by buildings and preserving durable reinforced concrete buildings along Suranarai road (highway No. 205) have long become a significant problem for those residing in these areas. Therefore, this study's objective was to observe, analyze, and classify the surface water quality to identify risky areas of reinforced concrete structure deterioration in this study area.

II. METHODOLOGY

A. Study Area and sample collection

The study area on both sides of Suranarai road or highway No. 205, located in the Non Thai district, Nakhon Ratchasima province, Thailand (Fig. 3). Originally, the Non Thai district was San Thia district, meaning a place to gather salt. The name refers to the tradition of salt production in the area. This district consists of ten sub-districts, including Non Thai, Dan Chak, Kampang, Samrong, Khang Phlu, Banlang, Ban Wang, Sai-O, Thanon Pho, and Makha. It is located at latitude 15°11' 54" N and longitude 102 04' 10" E, covers a total area of approximately 542 km2 (209.3 sq mi), and has a total population (2015) of approximately 72,039 people [4].

The general topography of the Non Thai district, most of the areas are plateaus interspersed with lowlands. The altitude above sea level is between 200 - 250 m. The sandy loam soil, which retains little moisture and low soil fertility with salt on the surface, is mainly distributed throughout the area. The weather throughout the year has three seasons. The weather is generally quite dry. The average amount of rainfall, temperature, and relative humidity throughout the year is about 924.4 mm, 27.4 %, and 71 %, respectively [4].

This study has observed, measured, and collected 29 surface water samples (of natural and man-made water sources) about 1.5 km from either side of Suranarai Road, with a total distance of about 18 km, located in Dan Chak, Non Thai, and Sai-O sub-district in the Non Thai district (Fig. 3).

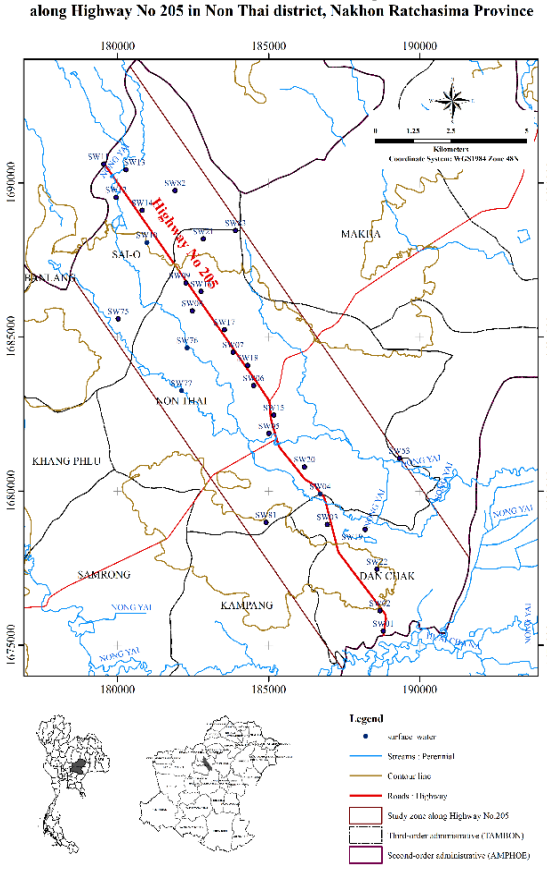


Fig. 3. Study area and location of surface water samples.

B. Water Analysis

The 29 surface water samples in this study were collected between February and May 2022. Water temperature, electrical conductivity (EC), resistivity, pH, total dissolved solids (TDS), and salinity were measured by using Hanna Model EM-410-SS. The chloride content was analyzed by titration according to the Mohr method. Chemical compounds, including Ca^{2+}, Mg^{2+}, K^{+}, Fe^{2+}, and Na^{+}, were analyzed by atomic absorption spectroscopy (AAS).

C. Surface Water Quality Distribution Mapping

The results are applied to ArcMap 10.5 program and shown by the distribution of chloride, salinity, pH, TDS, sodium, and iron content map of surface water in the study area.

D. Water-type classification

This study has been classified the water type as followed in Table 1.

Content of	Water Type Classification					
	From reference			Distribution map of this study		
	Fresh water	Brackish water	Seawater	Fresh water	Brackish water	Seawater
Chloride (mg/l) [5]	1 - 250	500-5,000	19,000	1 - 500	500-19,000	>19,000
Salinity (ppt) [5]	0.001-0.5	1-10	35	<1	1-10	>10
Sodium (mg/l) [6]	<200	5-800	10,000	<200	200-800	800-10,000
TDS (mg/l) [7]	0-1,000	1,000 -10,000	10,000 - 100,000 (Saline) >100,000 (Brine)	0-1,000	1,000 -10,000	10,000 - 100,000
pH [8]	7.45	7.25	7.8-8.1	7.25-7.45	7.00-7.25	7.45-7.80 (Saline) 7.80-8.10 (Brine)

Table 1. Classification of water-type according to various references [5],[6],[7],[8] and distribution map of this study.

III. RESULTS AND DISCUSSION

The twenty-nine of surface water along Highway No. 205 in the Non Thai district was collected from both sides. The distribution of surface water quality consists of pH, TDS, chloride, salinity, sodium, and iron as follows:

The pH value ranges from 7.04-8.27 (avg. 7.59), indicating a weak alkaline characteristic (Table 2) resulting in the abundance of Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} ions. The high pH value is equivalent to the properties of saline seawater representing in sub-district of Dan Chak (SW01 and SW02), Non Thai (SW16 and SW76), and Sai-O (SW14 and SW75), as shown in Fig 4. The pH in these areas can be affected by concrete as this condition allows organisms to generate hydrogen sulfide. The high-temperature averages 28 °C (Table 2), which results in high corrosion [8]. However, the Na Wah Pond near the market and community in the Non Thai sub-district (SW15) has the lowest pH value, indicating a trending higher concrete corrosion rate.

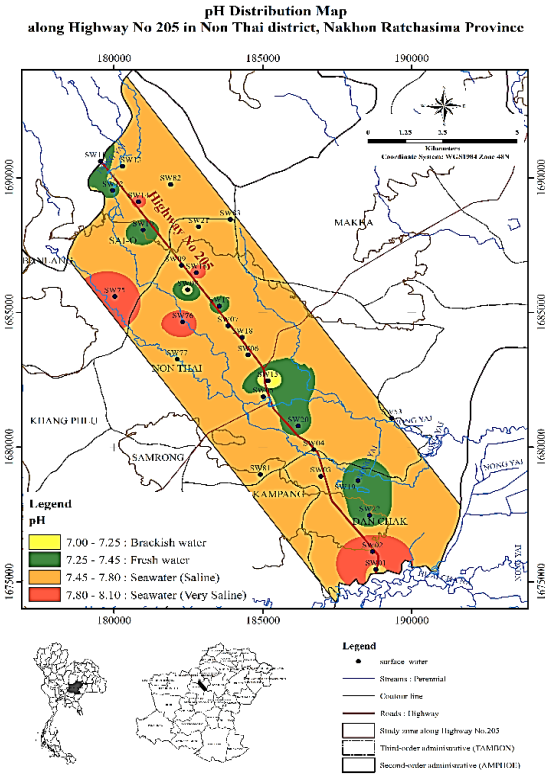


Fig. 4. pH values distribution of surface water in the study area.

The TDS content of water range from 147-6,140 ppm (avg. 1,299.2 ppm), as shown in Table 2, which mainly indicates brackish water (Fig. 5). The Non Thai sub-district represents mainly the brackish water due to the TDS concentration is in the range 1,000-10,000 ppm [7]. The freshwater was mainly represented in Dan Chak and Sai-O sub-districts (Fig. 5).

Chloride (Cl^-) content of water ranges from 1,186-4,548 mg/l (avg. 2,004 mg/l), as shown in Table 2, which mainly indicates the brackish water (Fig. 6). The high concentration of chloride represents in SW15, SW76, SW08, SW06, and SW77, respectively. The highest chloride concentration, about 4,548 mg/l at the Na Wah pond, is close to the Non Thai community market (SW15) in the Non Thai sub-district (Table 2 and Fig. 6). This high chloride content in this location could be derived from a rock formation and wastewater from the community. The high chloride concentration at Khlong Dan river in the Non Thai sub-district (SW77) was caused by halite solution from the river flowing through the salt mine in the Banglang sub-district (Fig. 6).

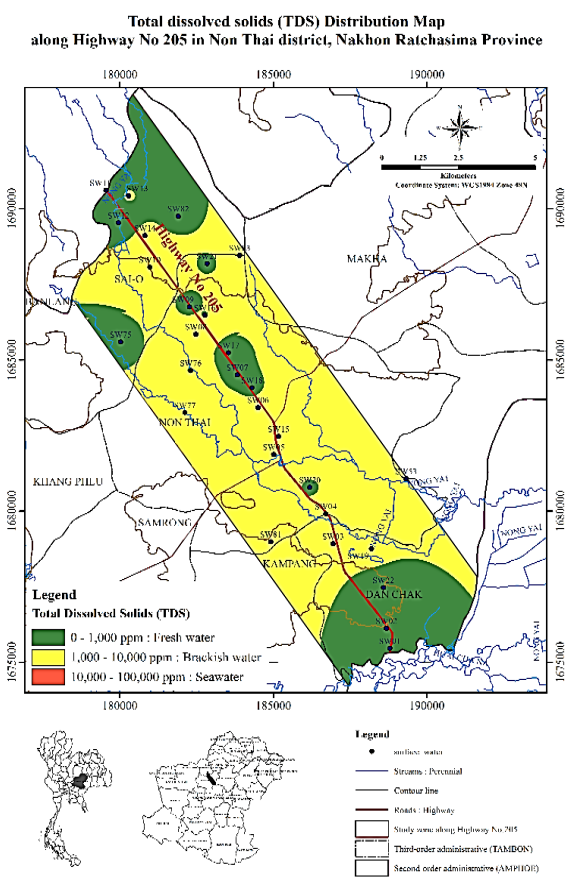


Fig. 5. Total dissolved solid (TDS) distribution of surface water in the study area.

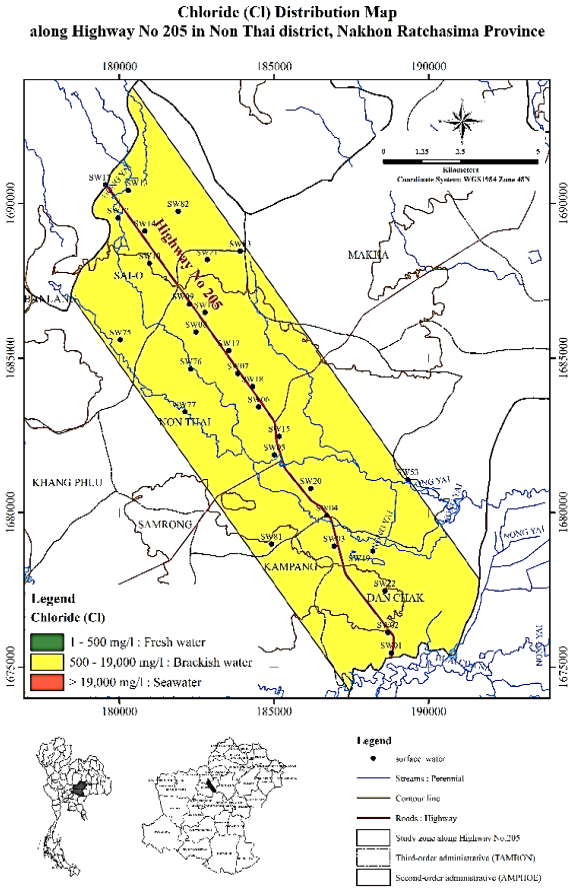


Fig. 6. Chloride distribution of surface water in the study area.

Chloride is one element in saline water that penetrates reinforced concrete structures. However, it does not damage reinforced concrete structures directly. In other words, it infiltrates into reinforced concrete structures to interact with reinforcing steel. Finally, all things, including rust, reduce the load capacity of reinforced concrete structures and their service life. Salinity is a measure of the total dissolved salts in water comprised chiefly of Cl- and Na+ ions. Seawater may have other ions, such as K+, Mg2+, or SO42-. Generally, freshwater from rivers has a salinity value of 0.5 ppt or less. The salinity in this study area ranged from 6-240 ppt (avg. 50.8 ppt), indicating that it was seawater due to the salinity of more than ten ppt, except the samples from Ban Hor Klang village (SW22), as shown in Table 3 and Fig. 7, which salinity was in the range of freshwater.

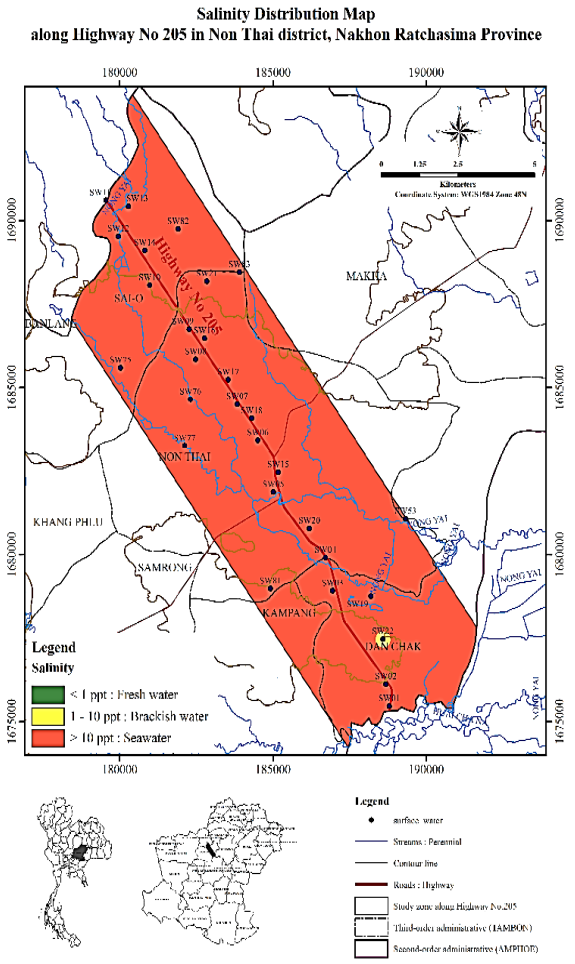


Fig. 7. Salinity distribution of surface water in the study area.

Sodium (Na^+) content was high values in the range of 103.8-628.8 mg/l (avg. 197.6 mg/l), as shown in Table 3 and Fig. 6. The high sodium concentration mainly represented in the southwest area of Highway No. 205 in Non Thai and Dan Chak and part of Kampang sub-districts. The sodium content is related to the salinity hazard resulting from the ions of Sodium (Na+) combined with chloride. It can react with soil resulting in reduced soil permeability [9]. The Na^+- Cl^- type of surface water is dominant in the brackish water type in the Non Thai sub-district (SW04, SW05, SW19, SW20, SW76, SW77, and SW81) and Dan Chak sub-district (SW01, SW02, and SW03), as shown in Fig. 5 and Fig. 8. The Na+ combined with carbonate leads to alkaline soil [10]. The relationship between Na+ ion and pH is dominant in the study area, indicating the salinity concentration (brackish to seawater level) as shown in Fig. 4 and 8.

Iron (Fe^{2+}) ion was low values (Table 2) in the range of 0.003-0.266 mg/l (avg. 0.06), which result could not be more affect the concrete corrosion. The high ion of Fe2+ relates to Na2+ and salinity represented at Ban Dan Krong Krang village (SW08) in the Non Thai sub-district, as shown in Fig. 9.

In general, chloride, salinity, pH, TDS, sodium, iron, and temperature are the most common parameters caused by reinforced concrete failure. All these lead to corrosion of the embedded steel reinforcement, and as the steel corrodes, it expands and exerts pressure on the concrete, eventually, the concrete cracks and spalls.

From the study result in this study area, the concentration of chloride, sodium, salinity, TDS, temperature, and pH distribution in surface water could be the leading cause of the deterioration of reinforced concrete because the chloride and sodium ions penetrate concrete during and after construction. The high concentration of these chemicals corrodes steel bars and deteriorates concrete. The study result showed a low pH value, but chloride, sodium, salinity, and TDS concentration were high. These distributions are shown at the Na Wah Pond, near the market and the community in the Non Thai sub-district (SW15), Khlong Dan River in the Non Thai sub-district (SW77) followed by the river area (lowland) that flows through the salt mine in the Banlang sub-district, was a high-risk area of reinforced concrete structure, respectively.

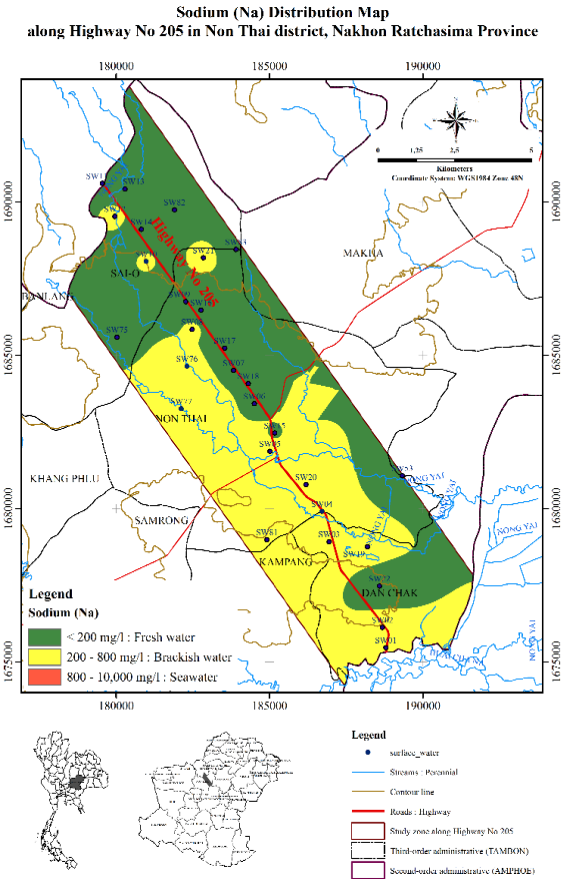


Fig. 8. Sodium distribution of surface water in the study area.

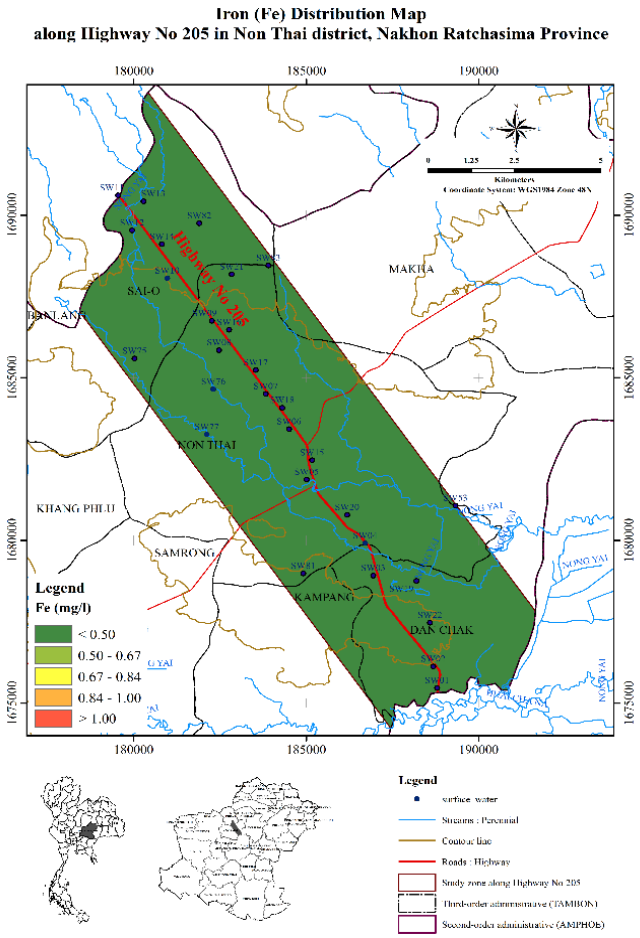


Fig. 9. Iron distribution of surface water in the study area

No.	ID.	UTM (Zone 48P)		Area Name	Temp.	pH	EC	Resistivity (Ω)	TDS	Salinity	Ca	Mg	K	Na	Fe	Cl
		(x) E	y (N)		°C		µS/cm	µS. cm	ppm	ppt	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	SW01	188794	1675469	Lam Chiang Krai Bridge, Dan Chak sub-district	28	7.74	616	616	811.6	32	57.1	17.6	3.75	218.5	0.003	-
2	SW02	188684	1676127	Ban Nong Kra Sang , Dan Chak sub-district	33	8.27	930.67	930.67	537.37	21	37.5	9.65	3.75	238.5	0.006	-
3	SW03	186943	1678924	Dan Chak Sub-district Administrative Organization, Dan Chak sub-district	35	7.77	443	443	1130	44	46.25	18.7	6.4	245.5	0.015	-
4	SW04	186711	1679916	Kong Kang Bridge, Dan Chak sub-district	28	7.64	388.33	388.33	1290	50	75.85	24.2	5.5	217	-	1186.44
5	SW05	185014	1681877	Huay Tha Kare Weir, Non Thai sub-district	28	7.53	339.67	339.67	1470	57.7	69.8	25.2	6.5	223.5	0.003	1384.18
6	SW06	184507	1683424	Pond across Wat Jorakae School, Non Thai sub-district	36	7.79	322.33	322.33	1550	60.7	9.15	0.788	12.6	177.25	0.133	1977.40
7	SW07	183831	1684506	Pond at FishingEquipment Shop, Non Thai sub-district	35	7.66	817.67	817.67	611.47	24	5.7	0.439	4.15	168.25	0.185	-
8	SW08	182477	1685850	Ban Dan Krong Krang. Non Thai sub-district	36	7.16	167.67	167.67	2980	116.7	11.7	3	0.211	222.5	0.266	2274.01
9	SW09	182266	1686754	Ban Khok Phom, Non Thai sub-district	29	7.47	732.33	732.33	682.90	26.7	10.8	0.692	0.3	115.25	0.072	-
10	SW10	180979	1688064	Marketing Organization for Farmers Nakhon Ratchasima Office, Sai-O sub-district	36	7.28	268.67	268.67	1860	73	63.45	24.7	10.5	213	-	1581.92
11	SW11	179550	1690614	Bridge at NonThai and Phra Tong Kham district boundary, Sai-O sub-district	29	7.19	991.67	991.67	504.17	20	55.5	13.6	4.5	184.5	0.005	-
12	SW12	179955	1689536	Khok Sawai Temple, Sai-O sub-district	28	7.40	688.33	688.33	726.67	27.7	40.15	15.6	11.4	238.25	0.006	-
13	SW13	180285	1690429	Wong Wilai Farm, Sai-O sub-district	33	7.68	486.33	486.33	1030	40	13.35	2.5	0.703	108.5	0.075	-
14	SW14	180822	1689114	Khok Sawai Municipality Office, Sai-O sub-district	32	7.88	483	483	1030	40.7	11.4	3	0.218	117.5	0.057	-
15	SW15	185170	1682471	Na Wah Pond near Non Thai Market, Non Thai sub-district	30	7.04	81.5	81.5	6140	240	15.05	6.75	12.25	195.5	0.031	4548.02
16	SW16	182764	1686481	Ban Khok Phom, Non Thai sub-district	33	7.98	514	514	972.63	38	6.95	0.932	0.703	119.25	0.115	-
17	SW17	183538	1685238	Ban Khok Phom, Non Thai sub-district	33	7.35	1160	1160	431.70	17	12.5	4.15	19.15	119	0.177	-
18	SW18	184304	1684082	Jorakea Temple, Non Thai sub-district	32	7.63	852	852	586.90	23	43.55	14.1	7.5	186.5	0.02	-
19	SW19	188193	1678760	Dan Chak Temple, Non Thai sub-district	31	7.25	329.33	329.33	1520	59.7	69.8	23.1	10.8	256	0.016	1779.66
20	SW20	186188	1680786	Behide PTT Gas Station, Non Thai sub-district	33	7.40	588.67	588.67	849.67	33	48.85	17.7	5.8	246.5	0.012	-
21	SW21	182842	1688187	Ban Mai, Non Thai sub-district	28	7.58	531.33	531.33	940.70	36.7	50.55	16.7	5.95	254	0.012	-
22	SW22	188584	1677476	Ban Hor Klang, Dan Chak sub-district	33	7.26	294.03	3400	147.03	6	15.9	0.425	0.717	121	0.067	-
23	SW53	189325	1681072	Khlong Tha Kare River, Non Thai sub-district	29	7.62	2750	363.67	1370	54	12.55	4.55	5.05	116.75	0.078	1384.18
24	SW75	180028	1685594	Non Pha Phee, Pond, Sai_o sub-district	32	8.11	918.67	1090	459.3	18	9.75	3.05	0.197	109.75	0.05	-
25	SW76	182307	1684648	Ban Dan Kong Kang, Non Thai sub-district	34	8.08	1960	510	980.3	38.3	70.5	20.75	5.4	247	-	-
26	SW77	182119	1683263	Khlong Dan River, Non Thai sub-district	33	7.55	6590	151.67	3290	129	131.5	49.1	11	628.75	-	2471.75
27	SW81	184915	1678988	Khlong Ban Non Phattana Bridge, Non Thai sub-district	33	7.51	3320	301.33	1660	64.7	85.9	32.9	7.5	217.5	0.019	1977.4
28	SW82	181902	1689754	Ban Bu, Sai-O sub-district	34	7.67	1670	598.67	835.13	33	16.25	4.2	3.35	121.75	0.12	
29	SW83	183903	1688456	Ban Mai, Sai-O sub-district	34	7.49	2510	398.67	1250	49	12.55	3.6	0.475	103.75	0.055	1483.05
Max					36	8.27	12170	3400	6140	240	131.5	49.1	19.15	628.75	0.266	4548.02
Min					28	7.04	294.03	81.5	147.03	6	5.7	0.425	0.197	103.75	0.003	1186.44
Avg					32.0	7.59	2593.31	639.53	1298.19	50.81	38.27	12.47	5.74	197.62	0.06	2004.37
SD					2.66	0.30	2304.07	598.65	1159.84	45.36	31.09	11.80	4.81	99.17	0.07	932.83

Table 2. The surface water quality along Highway No. 205 in the Non Thai district, Nakhon Ratchasima province, Thailand.

IV. CONCLUSION

The surface water quality along Suranarai road (highway No 205) in the Non Thai district, Nakhon Ratchasima province, represented the order of abundance is $Na+>Ca^{2+}>Mg^{2+}>K^{+}>Fe^{2+}$. The high chloride, sodium, salinity, and TDS concentrations were dominantly represented in the study area, indicating the brackish water and some saline water. The pH value is equivalent to the properties of saline seawater represented in the Dan Chak, Non Thai, and Sai-O sub-districts. The Non Thai sub-district, such as the Na Wah pond (SW15) and Khlong Dan River (SW77), was the high deterioration reinforced concrete risk area zone, which is a lowland and dense community. In addition, the correlation tendency of chloride, sodium, salinity, TDS, iron, and pH values will cause risk effects on highly deteriorated reinforced concrete in the study area. These obtained study results can be used as basic information for determining the boundary and location of water quality distribution for a guideline to monitoring and solving the problem of reinforced concrete structures from saltwater corrosion. This will extend the service life and increase the efficiency of the reinforced concrete structures in this saline area. However, this research will also need to study the relationship with groundwater quality along with the concrete structure properties in the study area.

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