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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

W. Thongwat, B. Terakulsatit

***Abstract*—**The study area is Kham Sakaesaeng District in Nakhon Ratchasima Province, the south section of Northeastern Thailand, located in the Lower Khorat-Ubol Basin. This region is the one of saline soil area, located in a dry plateau and regularly experience standing with periods of floods and alternating with periods of drought. Especially, the drought in the summer season causes the major saline soil and saline water problems of this region. The general cause of dry land salting resulted from salting on irrigated land, and an excess of water leading to the rising water table in the aquifer. The purpose of this study is to determine the relationship of physical and chemical properties between the soil and groundwater. The soil and groundwater samples were collected in both rainy and summer seasons. The content of pH, electrical conductivity (EC), total dissolved solids (TDS), chloride and salinity were investigated. The experimental result of soil and groundwater samples show the slightly pH less than 7, EC (186 to 8,156 us/cm and 960 to 10,712 us/cm), TDS (93 to 3,940 ppm and 480 to 5,356 ppm), chloride content (45.58 to 4,177,015 mg/l and 227.90 to 9,216,736 mg/l), and salinity (0.07 to 4.82 ppt and 0.24 to 14.46 ppt) in the rainy and summer seasons, respectively. The distribution of chloride content and salinity content were interpolated and displayed as a map by using ArcMap 10.3 program, according to the season. The result of saline soil and brined groundwater in the study area were related to the low-lying topography, drought area, and salt-source exposure. Especially, the Rock Salt Member of Maha Sarakham Formation was exposed or lies near the ground surface in this study area. During the rainy season, salt was eroded or weathered from the salt-source rock formation and transported by surface flow or leached into the groundwater. In the dry season, the ground surface is dry enough resulting salt precipitates from the brined surface water or rises from the brined groundwater influencing the increasing content of chloride and salinity in the ground surface and groundwater.

***Keywords*—**Environmental geology, soil salinity, geochemistry, groundwater hydrology.

I. Introduction

THE salinity of the soil is naturally occurred by rock salts, dissolved and dispersed in the lowland and the groundwater table is very shallow by the groundwater. The deforestation is another serious cause of the saline soil crisis. When chloride concentration in soil is high, that will affect the growth of plants. The plants were damaged by disrupting their intake of water and interfering with the absorption of nutrients, caused by an excessive salt in the soil [1]. Generally, groundwater contaminants occurred when flow through the sediment. The ions in sediment are dissolved and accumulated in the water, may later be found high concentrations. The ions dissolved in groundwater are both occurred by human activities and natural. The human activities are effluent from private, municipal septic systems, and some agricultural chemicals. The natural sources include rock-water interactions, saline seeps, and minor atmospheric contributions. Especially, summer period found salt exposed on the ground in several places [2].

The saline groundwater is a cause of saline soil in the Northeast of Thailand. Drought, the saline groundwater was seeping to the surface by capillary movement, then crystallize on the ground [3]. It has recently been reported that about 29% of the present arable land is affected by salinity [4]. Kham Sakaesaeng District is in Nakhon Ratchasima Province, located in the Lower Khorat-Ubol Basin. This region is the one of saline soil areas, which affect the salinity soil and groundwater. The objective of this study is to determine the relationship of physical and chemical properties between the soil and groundwater, focusing the investigations into the content of chloride and salinity, and create the map the distribution of saline soil and groundwater in study area according to the season.

II. General Geology and Hydrogeology of KHORAT-UBON Basin

The Khorat Plateau of northeastern Thailand contains a large evaporate basin of Cretaceous age. It is divided into a northern (Udon-Sakon Nakhon) Basin and a southern (Khorat-Ubol) Basin. The evaporate beds are included in the Maha Sarakham Formation [5]. A major source of salinity, the Rock Salt of the Maha Sarakham Formation is exposed or lies close to the surface [6]. This formation divided into six units from bottom to top as follows: the lower salt, the lower clastics, the middle salts, the middle clastics, the upper salt and the upper clastic, shown in Fig. 1 [7].

The Khorat Plateau Basin is defined by the large area of Mesozoic era (mainly Cretaceous) continental sedimentary rocks of the Khorat Group. Stratigraphy of the Khorat-Ubol Basin was shown in Fig. 2. The lower Khorat units consist of

W. Thongwat and B. Terakulsatit are with the School of Geotechnology, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima, 30000 Thailand (e-mail: wannida.thongwat@gmail.com, tbantita@sut.ac.th).

Huai Hin Lat Formation, Nam Phong Formation, Phu Kradung Formation, Phra Wihan Formation, Sao Khua Formation, Phu Phan Formation, and Khok Kruat Formation. The upper Khorat Units consists of Maha Sarakham Formation and Phu Tok Formation [8].

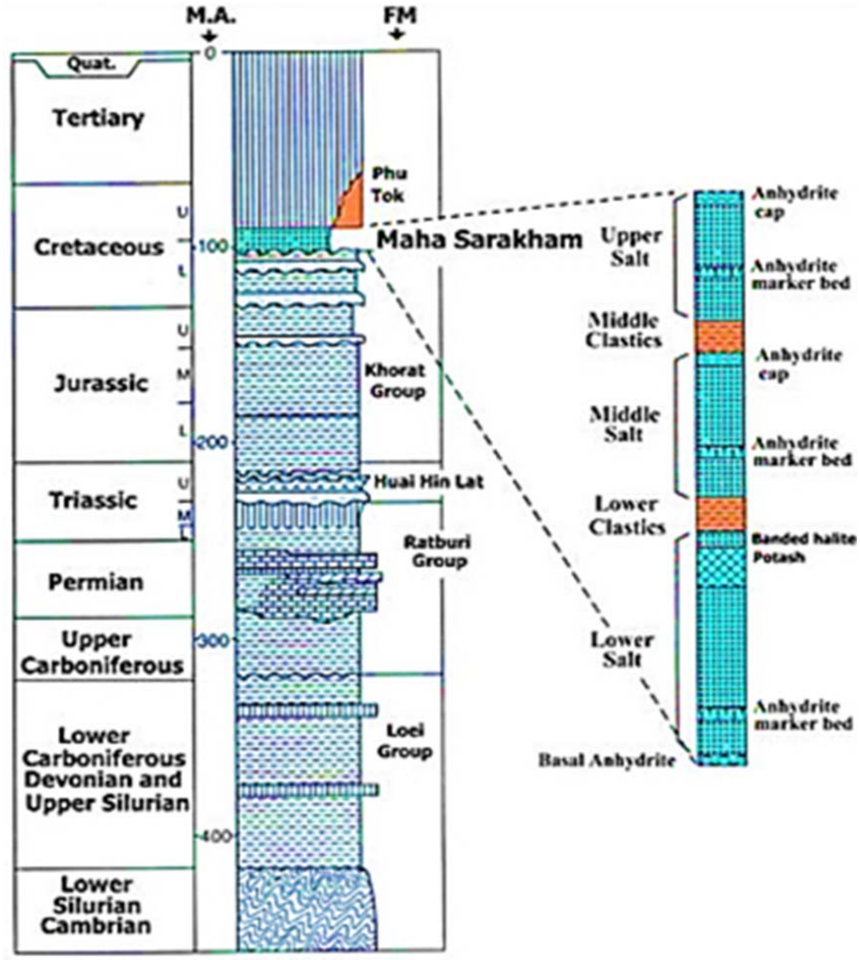

Fig. 1 Lithostratigraphy and subdivisions of the Khorat Group and the Maha Sarakham Formation (modified after [7])

Hydrogeology characteristics of Nakhon Ratchasima Province are mostly underlain by consolidated rocks, composed of sandstone, shale, and siltstone of Mesozoic age [10]. The aquifer can be divided into two types as follows:

1. The unconsolidated aquifer is found in two deposits: Alluvial deposits and High Terrace and Colluvium deposits.

- Alluvial deposits: aquifers in these deposits occur along the Mun and Lam Takhong Rivers. The aquifer is formed as a narrow and elongate strip following east-west directions. Groundwater is stored in sand and gravel layers at a depth between 10 and 30 m. The layers were built up by meandering streams. They mainly consist of sand and gravel which is interbedded with thin layers of clay. However, groundwater in this layer hydraulically interconnected.
- High terrace and colluvium deposits: These deposits form aquifer in the hilly area south of Nakhon Ratchasima Province and in the floodplain area where they are overlain by Alluvial deposits. Groundwater is commonly found in sand and gravel at two distinct depth intervals: 20-40 m and 50-70 m below ground surface. A layer of fine-grained material separates the two sand and gravel layers with a thickness of about 10 m.

2. The consolidated aquifer is recognized in eight formations.

- Phu Tok Formation: It is not well cemented and slightly soft when compared to the underlying formations. It mainly comprises of claystone, siltstone, and sandstone. The formation is competent and usually forms a good aquifer. Groundwater in this formation is poor, due to high sodium chloride content.
- Maha Sarakham Formation: Its most shallow occurrence is found at depth of around 80 to 100 m below ground surface. From the seismic section profile, the upper surface of the rock salt is generally smooth and gently

inclined to the North-East. Principally, the formation acts as an aquitard due to the non-existing primary porosity. Groundwater can only be trapped in the formation where it may be in contact with overlying porous rock units. Most salt mines pump brine water from such aquifers.

- Khok Kruat Formation: Groundwater mainly occurs in spaces of fractures and bedding planes of sandstone, shale, and siltstone. Groundwater quality in this formation is generally good. However, saltwater can be found in the areas where the rock is in contact with the Maha Sarakham Formation.
- Phu Phan Formation: The unit is characterized by massive coarse quartz sandstone with some conglomerate. The unit that varies from 100 to 400 m in thickness was deposited forms nearly flat top hills to undulating terrain. Yield ranges of 1 to 10 m^3/h can be expected from drilled well penetrated to the fractured zone of the aquifer. Groundwater is generally good quality occasionally high iron contents. This formation is not flowing artesian although several flowing wells have been drilled.
- Pha Wihan Formation: This unit that varies from 50 to 297 m in thickness consists of a massive highly resistant white to pink, thick bedded, well-sorted quartz sandstone, with thin beds of laminated red siltstone. Groundwater is good quality.
- Sao Khua Formation: This unit is composed of sandstone and siltstone, varying in thickness from 400 to 720 m. Yield from many boreholes in Sao Khua aquifer range from 5 to 10 m^3/h with exceptionally good quality water.
- Phu Kradung Formation: This unit has an average thickness of about 972 m outcrop and sub outcrop around the Khorat Plateau. It is composed of shale, siltstone, sandstone, and conglomerate. Yield ranges of 10 to 40 m^3/h better than Phu Phan and Pha Wihan Formations. Groundwater quality in term of TDS is generally less than 50 mg/l.
- Nam Phong Formation: Consists of a sequence of siltstone, sandstone, and conglomerates. The total thickness of the formation is 1,456 m. The aquifer rests on the Pre- Khorat erosional surface west of the northern part of the Khorat Plateau.

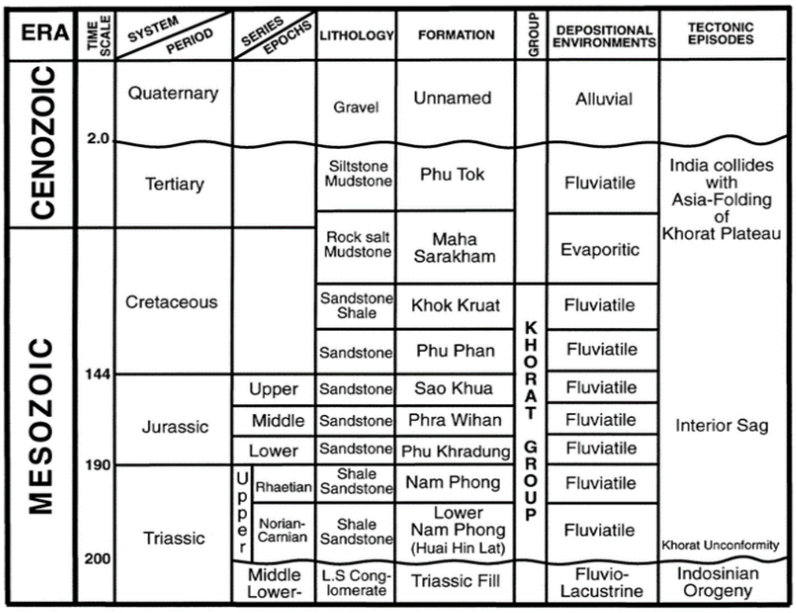

Fig. 2 General Stratigraphy of the Udon-Sakon Nakhon Basin and the Khorat-Ubol Basin [9]

The main cause of saline soil is caused by rock salt (Maha Sarakham Formation), dissolved and moved by groundwater. The salt moves rapidly to the surface by a fault in a salt dome, as the pathway for upward movement of the saline groundwater. the groundwater dissolves the salt domes is a catalyst to the saline soil crisis. The gravity is the capillary force which pulls the brine up to the surface, then the water evaporates from the brine and salt crystallizes on the topsoil [4].

III. Study Area

The Nakhon Ratchasima Province is located in northeastern Thailand. The provincial area covers approximately 20,493.964 km^2. The provincial average climate, the temperature is 27.4 °C, the relative humidity is 71% and the average annual rainfall is 1,028.1 mm.

Kham Sakaesaeng District, Nakhon Ratchasima Province is the study area (Fig. 3) that consists of seven subdistricts including Non-Mueang, Mueang Kaset, Nong Hua Fan, Chiwuek, Pha-Ngat, Kham Sakaesaeng, and Mueang Nat. Generally, the usage of land in this area is dominant and is restricted to rice, cassava, and sugar cane field crops and forest. However, the utilization of the area is not sufficiently effective due to the affected by salt accumulation in soil and

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groundwater.

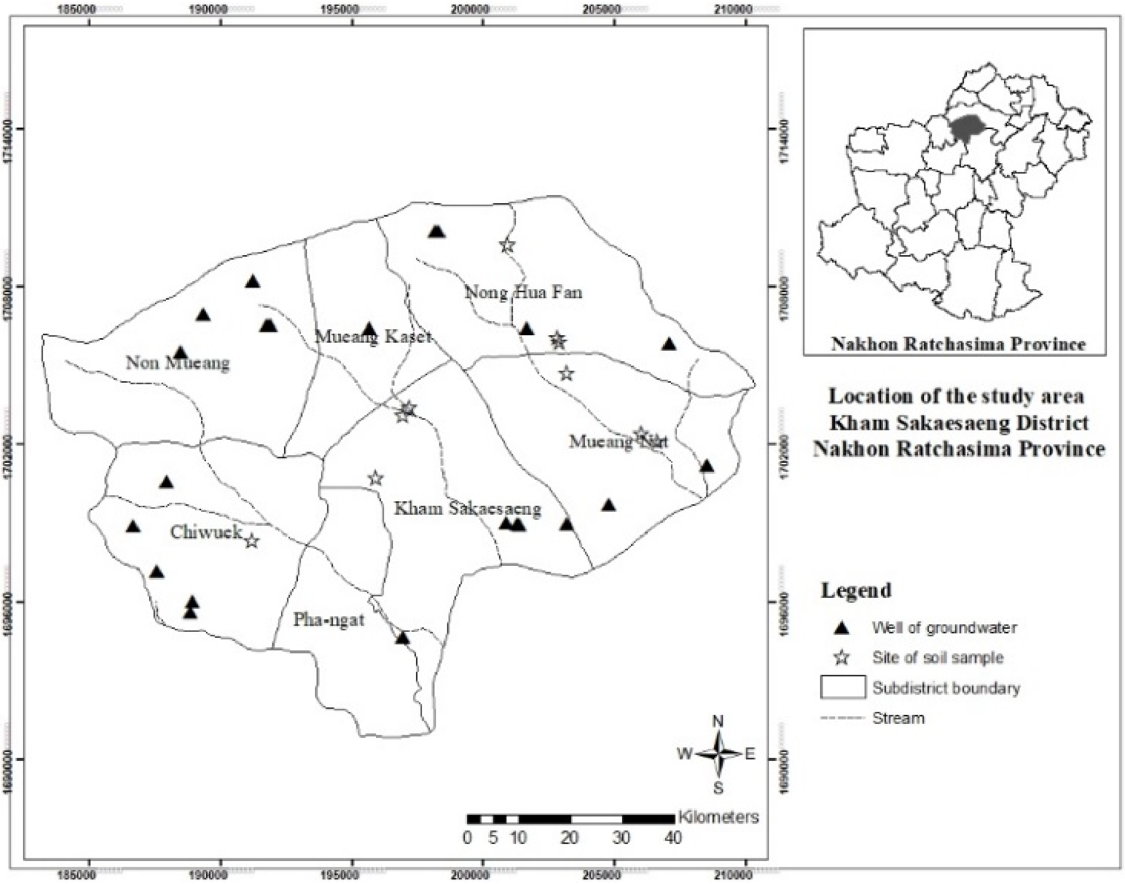


Fig. 3 Location of the study area, Kham Sakaesaeng District, Nakhon Ratchasima Province

IV. Methodology

A variety of secondary data was obtained from various regional and local government offices. The data included land use maps from the Land Development Department, annual rainfall data from the Meteorological Department, the quality of surface water data from the Pollution Control Department, and borehole log and groundwater data from the Groundwater Resource Department. All of these datasets were compiled together to locate appropriate soil, groundwater, and surface water sampling locations. The soil and groundwater samples were collected during the rainy season on October 2017, and the summer season on May 2018.

A. Soil Samples

In the study area, there are seven soil sampling sites, consisting of Mueang Kaset Subdistrict (Ban Rim Bung), Nong Hua Fan Subdistrict (Ban Nong Hua Fan and Ban Non Ban Na), Chiwuek Subdistrict (Ban Chiwuek), Kham Sakaesaeng Subdistrict (Ban Non Jan, and Band Non Jang), and Mueang Nat Subdistrict (Ban Sema, Ban Mueang Nat, and Ban Mueang Nat). These locations of soil sampling site were shown in Table I. The soil samples were collected at a varying depth from 15-30 cm below the ground surface, then kept in plastic bags and sent to the laboratory. The determination of soil properties included pH, EC, TDS, chloride content, and salinity content. The measurement of soil samples on a soil solution of three parts of the soil and one part of water extract then left the soil solution for two days [11], then extract the water from the soil solution by the filter press. The measurement of EC, TDS, and salinity has used the probes into the soil solution directly. The chloride content was analyzed by titration of the soil solution.

B. Groundwater Samples

There are 22 groundwater sampling wells, consisting of Non Mueang Subdistrict (Ban Taluk Hin, Ban Non Mueang, Ban Ngio, Ban Khum Mueang, and Ban Sa Kruat), Mueang Kaset Subdistrict (Ban Khu Mueang), Nong Hua Fan Subdistrict (Ban Non Maklue, Ban Non Maklue, Ban Jod, and Chomchon Nong Hua), Chiwuek Subdistrict (Ban Hua Bung, Ban Nong Pho, and Ban Non Phak Chi), Kham Sakaesaeng Subdistrict (Ban Nook, Ban Namab, and Ban Bu La Kro), and Mueang Nat Subdistrict (Ban Sema, and Ban Nong Pho Namab). These locations of groundwater well were shown in Table I. The groundwater samples were collected after pumped out for five minutes. The groundwater and surface water samples were measured on the sites for pH, EC, TDS, and salinity content. The chloride content in the water samples was analyzed in the laboratory by the titration.

C. Interpolate

The interpolated of soil samples were analyzed for a relationship with the interpolated of groundwater. All the parameter values were input into ArcMap 10.3 program. Then, the maps presented the results of the chloride content and salinity content in soil and groundwater.

V. Results and Discussion

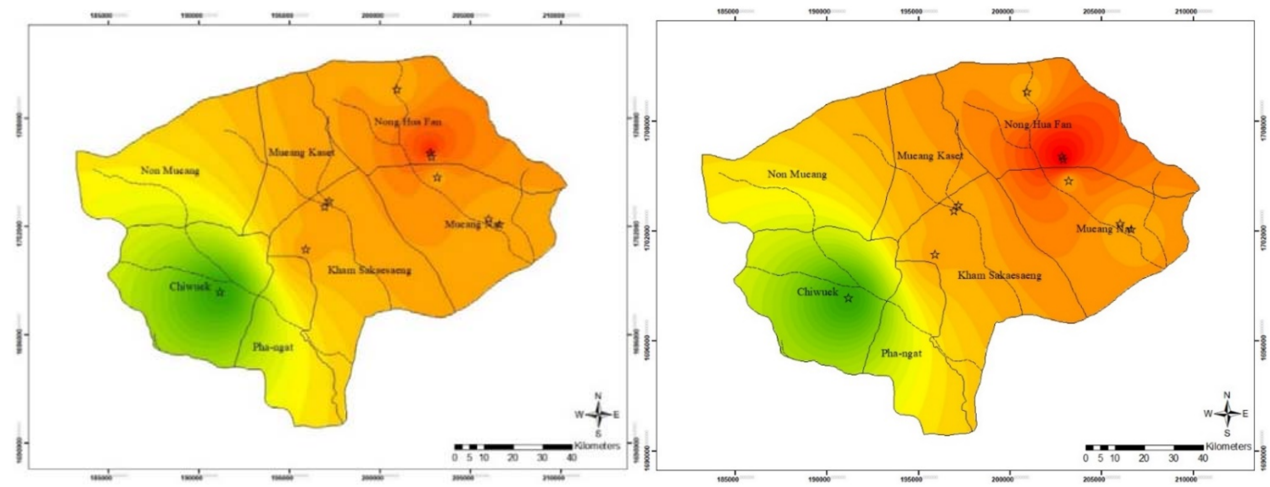
The result of the relationship between the quality of saline soil and groundwater according to the season was shown in Table I, Figs. 4 and 5. The main components of the soil in the study area are sand, clay, and silt. The soil sample has 6.14-6.91 pH. The EC of sand is lower than 150 µs/cm indicating the non-saline, which has negligible effect on plant growth. However, the EC is higher than 300 µs/cm indicating the saline, which is harmful to plant growth. The EC and TDS of soil sample are moderately low in the rainy season and high in the summer season, respectively. At Ban Nong Hua Fan 1 site represented the highest values in the summer season as 10,712 µs/cm of EC, and 5,356 ppm of TDS, respectively. The high content of EC and TDS in the soil sample related to the chloride and salinity contents (Table I).

The groundwater has 6.13-7.00 pH showing a positive correlation with the pH of the soil. The TDS of groundwater depends on the season (Table I), representing the lower than 1,000 ppm that indicates the fresh water (TDS as 0-1,000 ppm) in the rainy season. The summer season has 1,000-4,300 ppm of TDS, which indicates the brackish water (TDS as 1,000-10,000 ppm) [12].

Generally, the salinity of the fresh or non-saline water is less than 0.5 ppt. The brackish water is range from 0.5-35 ppt of salinity, and the salinity is higher than 35 ppt indicates a very saline water or seawater. The salinity of groundwater in the study area has 0.07-4.32 ppt in the rainy, and 0.24-4.38 ppt in the summer season indicating the brackish water.

The content of salinity, chloride, EC, and TDS in the groundwater also are similarly correlated with the soil. The high contents of salinity and chloride were related to the low-topography indicate to the groundwater flow direction led to the accumulation of saline water in the low attitude and the groundwater was also near to the soil surface. In the rainy season, the groundwater quality represents the fresh water, then turn to the brackish and saline water in the summer season. For example, the Chumchon Nong Hua Fan School site is the highest content as 4.38 ppt of salinity, 7,305.28 mg/l of chloride content, 4,297 ppm of TDS, and 8,594 µs/cm in the period of drought. The groundwater in this site is not suitable for consumption and agriculture due to the groundwater turn to saline water.

Figs. 4 and 5 exhibit the distribution of chloride and salinity contents that interpolated and displayed as a map by using ArcMap 10.3 program according to the season. The results of saline soil and saline groundwater in the study area were related to the low-lying topography (MSL less than 200 m), drought area, and salt-source exposure. The study area has the rock salt member of Maha Sarakham Formation adjacent to the soil surface and in some areas exposed to a salt layer [3]. The shallow saline groundwater has been found in Kham Sakaesaeng District and caused by rock salt that represented by the electrical survey [13], [14]. The saline soil area is easy to observe from the crystallized of salt are covered on topsoil. The eroding and weathering of salt from the source rock salt and movement of salt usually occurs in the rainy season. The movement of salt is caused by the flow of surface water and leached into the groundwater. Drought, the topsoil is dry enough is dry enough to result in salt crystallizes and rises from the saline groundwater, that influences the increasing content of chloride and salinity in the ground surface and groundwater. The problem was caused by groundwater dissolution of salts and accumulating them at the soil surface, the shallow saline groundwater is a factor that can influence topsoil salinity [15].



(a) (b)

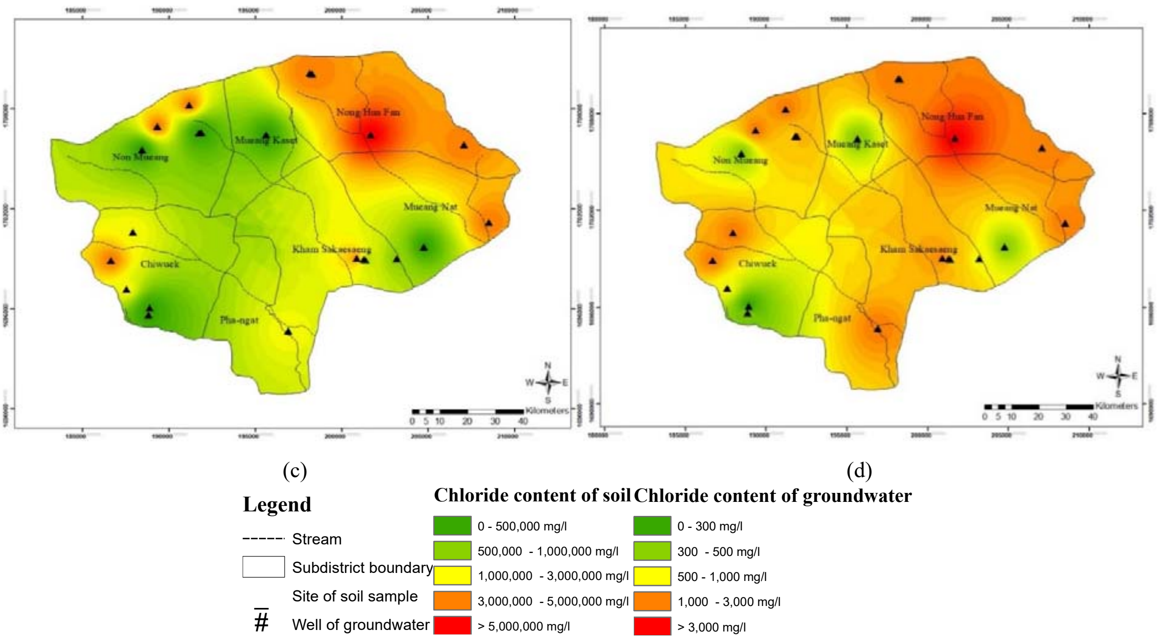


Fig. 4 Chloride content map at (a) soil sample in the rainy season, (b) soil sample in summer season, (c) groundwater sample in the rainy season, and (d) groundwater sample in the summer season

TABLE I
PHYSICAL AND CHEMICAL PROPERTIES OF SOIL AND GROUNDWATER SAMPLES

Samples	Location	Mean Sea Level (MSL, m)	pH		EC (us/cm)		TDS (ppm)		Salinity (ppt)		Cl- (mg/l)	
			Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer	Rainy	Summer
Soil	Ban Rim Bung	190	6.67	6.59	226	2,104	113	1,052	0.10	0.51	1,050,809.26	1386308.61
	Ban Nong Hua Fan 1	186	6.35	6.67	7,434	10,712	3,717	5,356	4.82	14.46	2,911,881.09	9,216,736.66
	Ban Nong Hua Fan 2	187	6.26	6.55	6,380	9,436	3,190	4,718	4.15	5.74	4,177,916.35	5,532,574.07
	Ban Non Ban Na	201	6.63	6.84	256	2,580	128	1,290	0.13	1.01	1,114,111.03	1,709,147.41
	Chiwuek Temple	192	6.64	6.72	1,658	10,306	829	5,153	0.08	0.49	215,225.99	745,061.48
	Ban Nong Jan School	186	6.46	6.14	5,836	6,040	2,918	3,020	2.43	4.03	2,373,816.11	4,025,992.11
	Ban Non Jang	194	6.28	6.91	3,374	5,894	1,687	2,947	1.65	3.94	2,253,542.76	3,962,690.35
	Ban Sema	174	6.35	6.76	964	3,068	482	1,534	0.50	0.87	1,310,346.49	1,892,722.71
	Mueang Nat Temple	188	6.32	6.53	2,480	5,626	1,240	2,813	1.39	2.56	1,493,921.60	2,677,920.74
	Ban Mueang Nat	177	6.39	6.48	186	1,004	93	502	0.08	0.72	1,057,139.44	1,569,883.72
Groundwater	Ban Non Mueang School	207	6.94	6.51	1,046	1,670	515	835	0.51	0.53	215.73	1,095.37
	Ban Taluk Hin	221	6.64	6.08	1,020	1,034	490	517	0.24	0.55	227.89	414.00
	Ban Ngio School	212	6.57	6.14	2,092	2,114	1,069	1,074	1.06	1.60	1,124.24	1,968.94
	Ban Khum Muang	214	6.38	6.8	1,826	1,856	823	988	0.89	0.90	1,051.32	1,076.16
	Ban Sa Kruat	206	6.55	6.84	1,080	1,432	568	716	0.53	0.56	258.27	683.66
	Ban Khu Mueang School	200	6.88	6.52	604	1,086	302	537	0.36	0.59	133.69	437.54
	Chumchon Nong Hua Fan School	184	6.15	6.47	8,156	8,594	3,940	4,297	4.32	4.38	6,168.12	7,305.28
	Ban Non Makluea Temple	213	6.58	6.21	2,870	3,438	1,435	1,719	1.35	1.43	1,815.49	2,175.90
	Ban Non Makluea School	212	6.85	6.19	2,248	2,890	1,247	1,487	1.36	1.48	1,952.23	2,311.79
	Ban Jod School	198	6.43	6.66	2,286	3,996	1,166	1,998	1.28	1.45	1,739.53	2,310.77
	Chiwuek 1	199	6.68	6.08	738	960	368	480	0.36	0.49	240.04	358.54
	Chiwuek 2	207	6.13	6.85	1,989	2,248	995	1,247	1.17	1.39	832.54	2,060.40
	Ban Hua Bung	200	6.48	6.64	284	1,020	137	490	0.07	0.24	45.58	227.90
	Ban Nong Pho	207	6.5	6.57	1,278	2,092	637	1,069	0.64	0.81	525.66	948.01
	Ban Non Phak Chi School	209	6.18	6.19	2,228	2,890	1,150	1,487	1.19	1.43	1,450.88	2,217.99
	Ban Nook 1	185	6.78	6.22	960	1,178	498	587	0.51	0.99	595.54	1,266.29
	Ban Nook 2	182	6.08	6.13	960	4,002	480	2,050	0.49	0.88	376.77	805.20
	Ban Nook School	182	6.78	6.19	2,160	3,204	1,082	1,602	1.15	1.31	1,777.51	1,190.33
	Ban Namab	184	6.52	7	1,086	1,200	537	600	0.29	0.59	443.62	734.55
	Ban Bu La Kro	177	6.53	6.7	1,682	2,894	842	1,447	0.88	0.97	786.97	1,253.37
	Ban Sema School	176	6.07	6.98	2,532	2,998	1,266	1,494	1.19	1.42	1,815.49	1,975.01
	Ban Nong Pho Namab School	182	6.36	6.52	366	1,086	184	537	0.25	0.61	237.00	492.48

Remarks: The blue highlights are the brackish soil and groundwater, and pink highlights are the saline soil and groundwater.

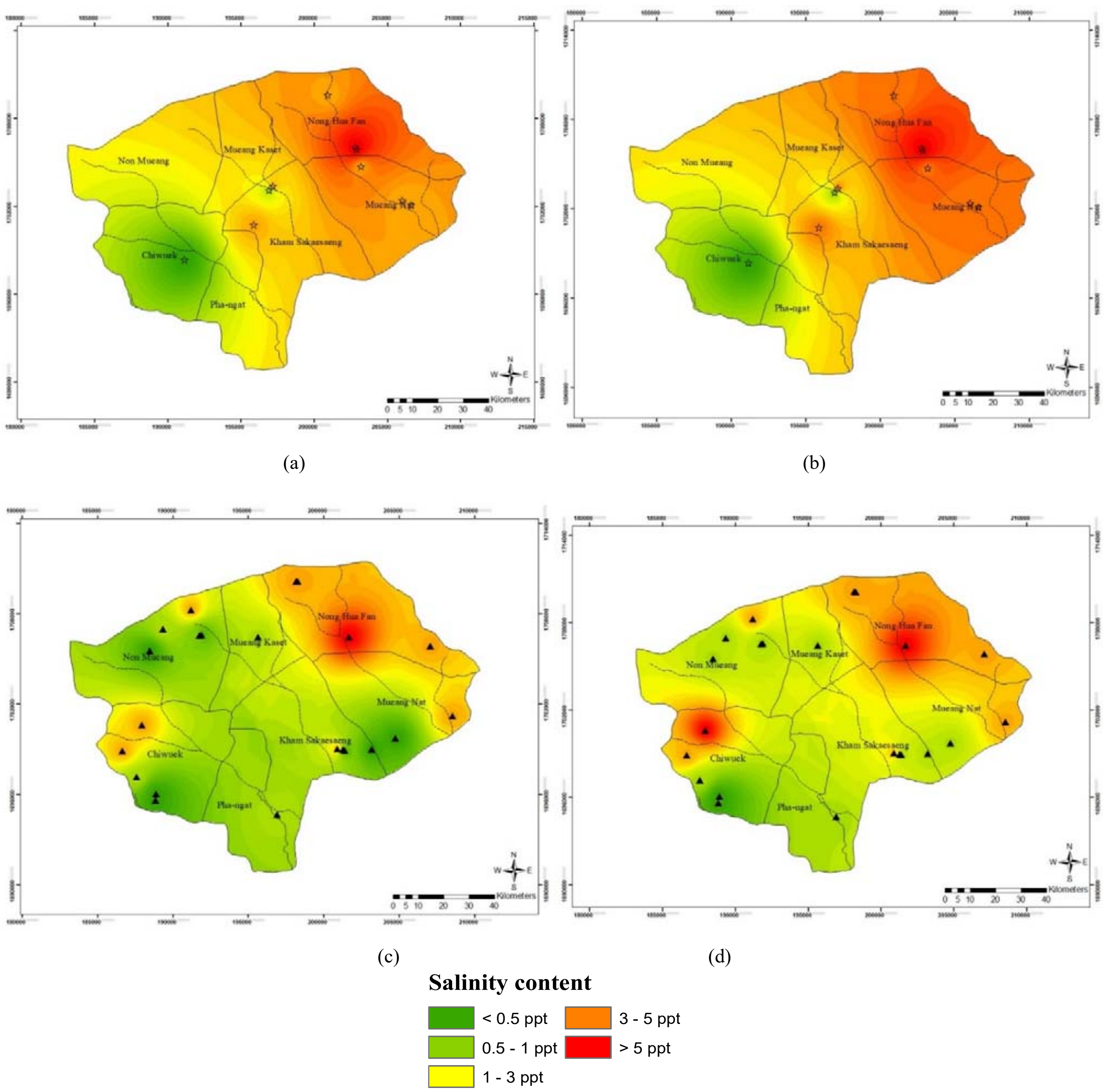


Fig. 5 Salinity content map at (a) soil sample in the rainy season, (b) soil sample in summer season, (c) groundwater sample in the rainy season, and (d) groundwater sample in the summer season

VI. Conclusion

The quality of soil and groundwater was investigated in both the rainy season (October 2017) and the summer season (May 2018). The salt affected study areas in the dry season, which influenced by the salinity of groundwater and the topsoil underlay by Maha Sarakham Formation. The salinity of soil occurred in the same direction as the groundwater flow, which represented in the low-topography (MSL less than 200 m). Some location is a high-elevated area (MSL about 200 to 300 m), the groundwater level is not near the surface causing to the non-saline area. The groundwater is an important pathway that can bring a salinity from deep aquifers to the soil and surface water. The drought period, the groundwater dissolved the salt rock of Maha Sarakham Formation and the salt move upward from the source to surface by groundwater, which makes to the exceed evaporation and precipitation causing to the high salinity content in the topsoil. The usage of GIS can be mapping the distribution of the salinity and chloride contents in both soil and groundwater and classified the non-saline and saline area according to the season. It can be concluded that the salinity soil relates to the season and the flow direction of groundwater, which indicated by the gently increased of chloride and salinity contents in groundwater.

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