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Original Article

The relationship between geological factors and the distribution of saline soil: A case study in the Khon Kaen Basin of Thailand

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Abstract

Soil and groundwater salinity poses a serious problem in Khon Kaen Province of Thailand and causes major reductions to crop productivity. In this study, aerial photo interpretation, field studies, and borehole lithology log data were analyzed to explore the spatial relationship between geological structure and the distribution of salinity. The results show that geological structures play an important role in determining the salinity distribution. Slight and moderate salinity are generally found over syncline structures and rock formation boundaries, whereas severe salinity is generally found over anticline structures and around depressions containing rock salt. All three categories of salinity (slight, moderate, and severe) are encountered along fractures associated with braided streams and faults associated with meandering streams. The electrical resistivity tomography results showed that the depth of saline groundwater was between 5 and 30 m and its distribution was related to geomorphology. Salinity distributions are natural occurrences controlled by subsurface geological structures and geomorphology.

Keywords: electrical resistivity tomography, soil salinity distribution, saline groundwater, geological structure, rock salt

1. Introduction

Dryland salinity has become a major environmental problem in northeast Thailand and is caused by natural processes that include rock salt deposition, saline, and groundwater flow and human activities such as deforestation, groundwater pumping, local salt production, and irrigation (Arunin & Pongwichian, 2015; Wongsomsak, 1986). Saline soil is found in almost every province in the northeast region. According to recent reports (DLD, 2010; 2014), nearly 3,360 sq km (30.86% of the area) in Khon Kaen Province are affected by soil salinity which is more than other provinces in the region. Several studies (Sattayarak & Polnajan, 1997; Rattanajarurug, 1999; Suwanich, 1983; Suwanich, 2007; Tabakh *et al.*, 1998; Utha-Aroon, 1993) showed that the primary accumulation of salts in the soil is a natural occurrence in direct correspondence with the existence of rock salt formations that are widely distributed over the region at various depths. The migration of dissolved salt in groundwater is controlled by subsurface geological structures and fractures. Human activities can exacerbate soil salinity problems. For example, dams constructed in or nearby saline soil areas can elevate the local hydraulic gradient that, in turn, may drive higher dissolved salt content leading to extensive distributions of saline soil over a wide area (Holmes & Talsma, 1981; Weinthal, 2002). Shallow and deep groundwater flow dissolves rock salt and the ions subsequently migrate upwards to the surface. Evaporation then dries out the salts leaving a white crust on the ground during the dry season (DMR, 2005; 2006). Salinity can be classified as slight (<10%), moderate (10-50%) and severe (>50%) (Arjwech, Wanakao, Archwichai, & Wannakao, 2014). There are a number of serious environmental issues associated with high-salinity geological

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environments. Saline groundwater even in small quantities renders groundwater unsuitable for domestic, agricultural, environmental, and industrial uses (Abd-Elhamid & Javadi, 2011). Saline soil causes the land to become unsuitable for cultivation (Arunin, 1996) and salt accumulation impairs the growth of crop plants and depletes the annual crop productivity (Arunin, 1984; Yuvaniyama, Arunin, & Takai, 1996).

This research aimed to explore the spatial correlation between subsurface geological structures and the distribution of saline soils in the Khon Kaen Basin which includes the Prayeun, Baan Faang, and Muang districts of Khon Kaen Province. The information found in this study can be used for making land management and planning decisions that decrease the growth of salt-affected soil areas due to human activities such as irrigation, urban expansion, agriculture, and construction of dams and reservoirs.

2. Study Area

The study area is located in Khon Kaen Province, Thailand and covers about 1,000 sq km in the three main districts of Phra Yun, Ban Fang, and Muang that contain severely salt-affected soils (Figure 1). High salinity causes major problems with crops in these regions. The study area is characterized by an undulating terrain with an elevation of 157-205 m above sea level. The dominant occupation in the region is farming with most cropping done under rainfed conditions. Rice cultivation is suitable in the gently undulating alluvial plains of the lowlands. Throughout the region, the soils are generally infertile due to high levels of salinity. While sugarcane grows well in the upland areas, generally poor soils and inadequate drainage remain a persistent threat to productive agriculture elsewhere. Soil salinity can be observed directly by the appearance of white salt crusts on the ground surface and indirectly by indicators such as the occurrence of salt-tolerant plants (Figure 2). However, salt crusts in many areas have not been noticed recently due to changes in land use from agriculture to residential and light industrial development. Rapid development, including construction of many buildings, has expanded into the saline soil areas.

3. Methodology

An interpretation of aerial photography was conducted to examine the relationship between geomorphology and saline soil distribution over the study site. Geological borders, distribution of sediments, and geological structures such as fractures were identified from aerial photography. Available data included soil data, topographic data, existing land use, previous saline soil maps, groundwater data, geographical data, and borehole data of a loess study on the campus of Khon Kaen University. Field studies on geological outcrops and sediment quarries and saline soil mapping were conducted after interpretation of the aerial photography. The analysis of the data enabled us to map the detailed geology and suggest a new saline-soil distribution of the study area.

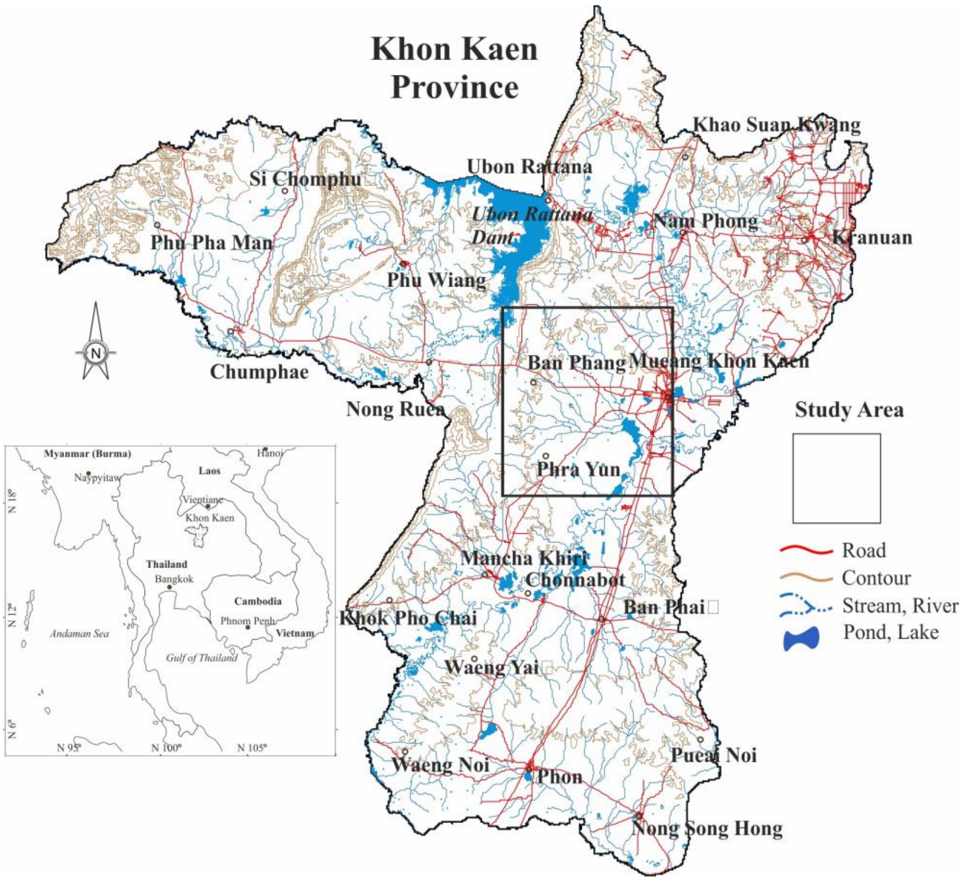

Figure 1. Map of Khon Kaen Province, Thailand.

Figure 2. View of the study area and data collection in the field around urban area where ERT line 2 was carried out.

Lithology well logs and rock salt data were also available from 20 core holes (K-47, K-49, K-50, K-53, K-57, K-58, K-59, K-60, K-107, K-108, K-109, K-110, K-111, K-112, K-113, K-114, K-115, K116, K-117, and K-118) from depths of 150-500 m that were drilled for potash exploration in the Muang and Baan Fang districts by the Department of Mineral Resources (DMR, 1997). The exploration region covered an area of 82 km^2. Core holes were analyzed and at each location compared with surface geology. The lithology logs were then combined as cross sections to identify rock salt and the subsurface structure in the area.

Two lines of 2D electrical resistivity tomography (ERT) (ERT line 1 and ERT line 2) were carried out to examine the depth and distribution of saline groundwater in two areas characterized by different geomorphology: Khon Kaen University and Baan Si Than (Figure 3). Resistivity data were collected during the rainy season in September 2014 with the Syscal R1 Plus multi-channel imaging system with an internal switchbox and 48 steel electrodes. The Wenner-Schlumberger array was used with electrode separations of 5 and 2 m, depending on accessibility limitations to the area, and profile lengths of 2,775 and 94 m and the expected depths of the investigation were 45 and 15 m, respectively. The ERT data were analyzed using the RES2DINV (Loke, 2004) programs which have capabilities for 2D pseudo-section plotting, data editing, forward modeling, and inversion. The electrical resistivity model, which corresponds to the geological structure, fresh water, and saline groundwater zones, can be obtained from this program. It can discriminate the resistivity contrast between the presence of saline groundwater with very low resistivity values and fresh water zones. The inverted resistivity model is then used to determine the depth and distribution of the saline groundwater.

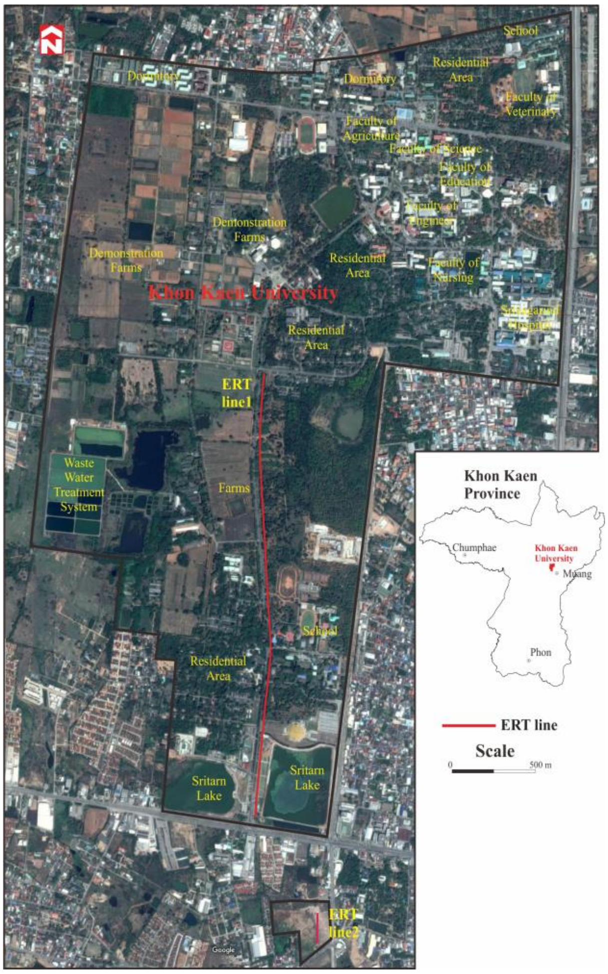

Figure 3. Schematic plan view of the ERT lines.

4. Results and Discussion

A geologic map and a saline soil distribution map of the study area were previously derived by interpretation of aerial photography and field geological observations. The updated maps based on those found in Arjwech *et al.* (2014) are shown in Figures 4 and 5.

4.1 Geology

The study area was located in the Khon Kaen Basin located at the west rim of the Khorat Plateau tectonic province. The near-surface is composed of unconsolidated material categorized as Quaternary alluvial and Quaternary terrace soils. Loess and gravel deposits were found locally on the terrace with thicknesses that varied from a few meters to more than 5 m. Petrified wood is commonly observed on the terrace north of study area. Fine-grained alluvium, in turn, covers the gently undulating plain regions of the study site.

The Quaternary sediments, along with the sparse Phu Tok Formation, overlay mudstone, siltstone and rock salt of the Maha Sarakham formation. The latter formation constituted four different salt units which principally consist of basal anhydrite, lower salt, potash zone, a variegated salt unit,

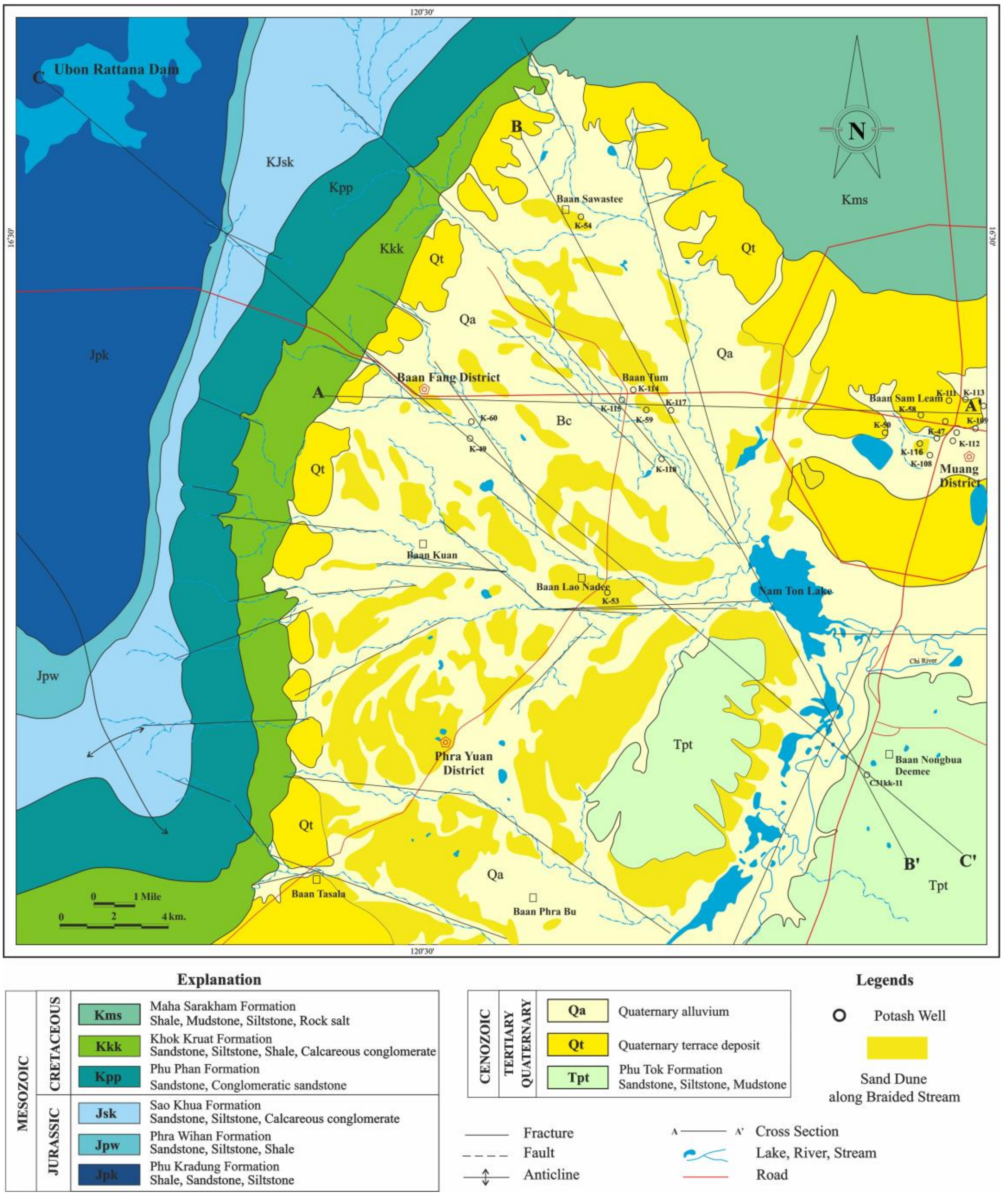

Figure 4. Geologic map of Khon Kaen.

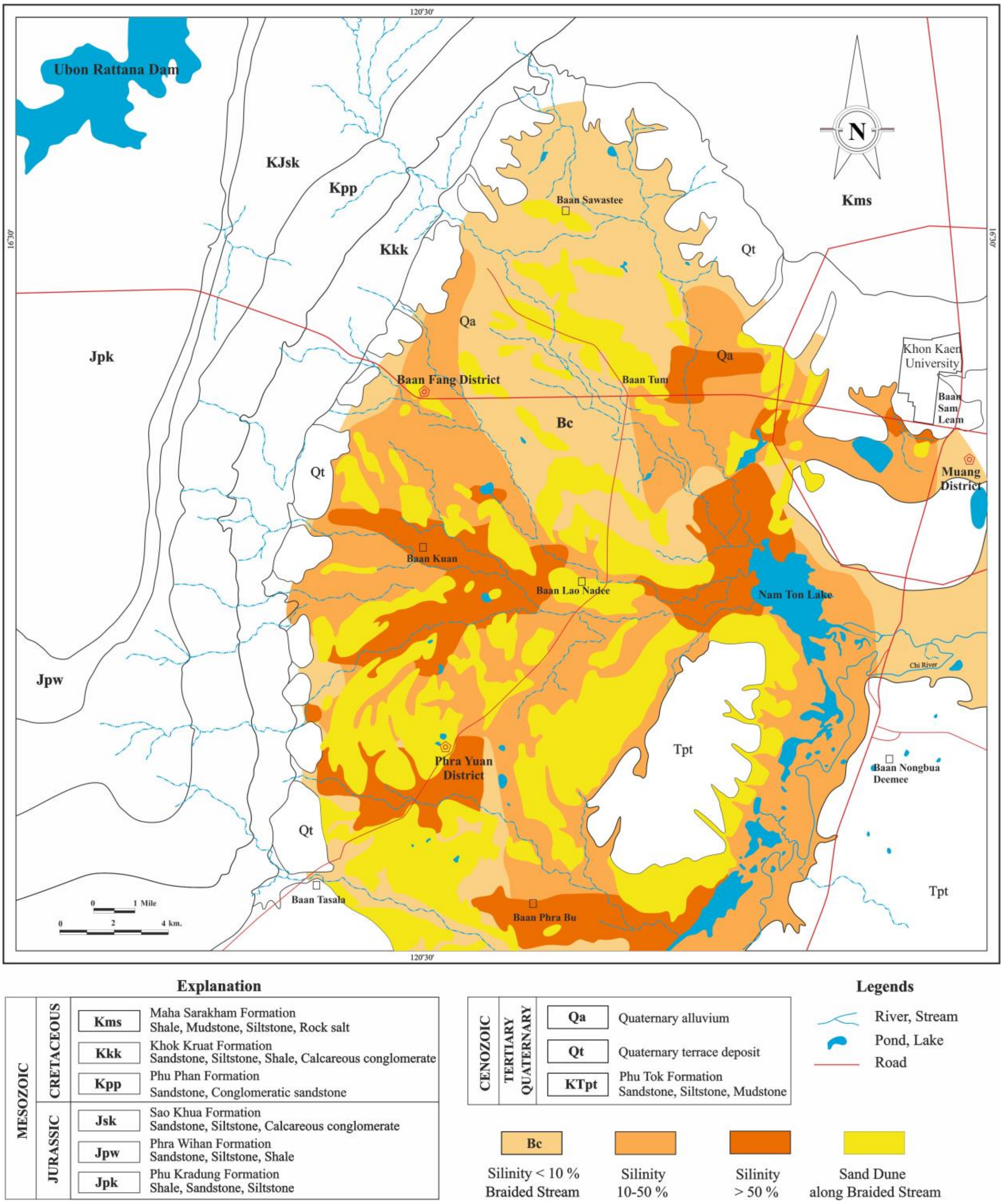

Figure 5. Map of salinity distribution in Khon Kaen Province.

lower clastic, middle salt, middle clastic, upper salt, and upper clastic. The thicknesses ranged from 10 meters to more than 200 m, depending on whether the local geological structure was controlled by rock salt deposition. The Maha Sarakham Formation was underlain by Cretaceous sandstones, shales, and siltstones of the Khok Kruat Formation. The Khok Kruat and an older rock formation, the Mesozoic red bed of Khorat Group, were well exposed in the west, which is recognized to be the rim of the Khorat plateau.

4.2 Pattern of saline soil distribution

Salt-affected soil was classified into slight (salty dust found among soil textures in less than 10% of the area), moderate (salty dust found among soil textures in 10-50% of the area), and severe (salty dust found among soil textures in more than 50% of the area). The salinity distribution is related to the surface geology with most of the entire study area classified as slight to severe salinity. The study site spans an area of braided stream in the Phra Yeun, Baan Fhang, and Baan Tum districts, and also contains part of the floodplain of the meandering Chi River. The high-saline distribution is especially dominant around synclinal geological structures and along mapped rock interfaces.

A distribution of high salinity was found along the braided stream pattern with particularly large values found at Nam Ton Lake where small streams converge, transporting fine grain sediments that fill up the lake. Severe salinity soils commonly develop along fractures or the braided stream at the Baan Bo Kae, Baan Pra Bu, Baan Kean, Baan Tum, and Baan Pra Yeun districts.

Soil salinity is also spatially correlated to agricultural land use. For example, slight or non-salt affected areas were found on terraces where cassava and sugarcane are cultivated. However, severe salt affected areas were found in low-lying regions or floodplain environments where rice cultivation is common. It was found that changes in land use or leveling of the ground surface for agricultural development can lead to higher salinity accumulation. Artificial soil fill in the low-lying portions of urban and residential areas can impact the natural groundwater system and cause the occurrence of higher salinity accumulations.

4.3 Geology and subsurface structure

The geologic cross-section in the east-west transect (A-A') is shown in Figure 6. The uppermost rock salt layer is raised up as part of an anticlinal structure to a minimum depth of 120 m at Baan Tum where severe salinity was observed. A synclinal structure was found between Baan Fhang and Baan Tum where slight and moderate salinity at the ground surface is commonly observed. These results imply that the thickness and depth of the rock salt layer plays an important role in determining the surface soil salinity distribution.

The geologic cross-section in the northwest-southeast transect (B-B') is shown in Figure 7. The anticlinal structure or salt dome found under Baan Tum plunges northwestward to Baan Sawastee and southeastward to Nam Ton Lake. The minimum depth of the uppermost rock salt layer is 160 m. The Phu Tok Formation that overlies the rock salt thickens southeastward to more than 400 m at Baan Nongbua Deeme.

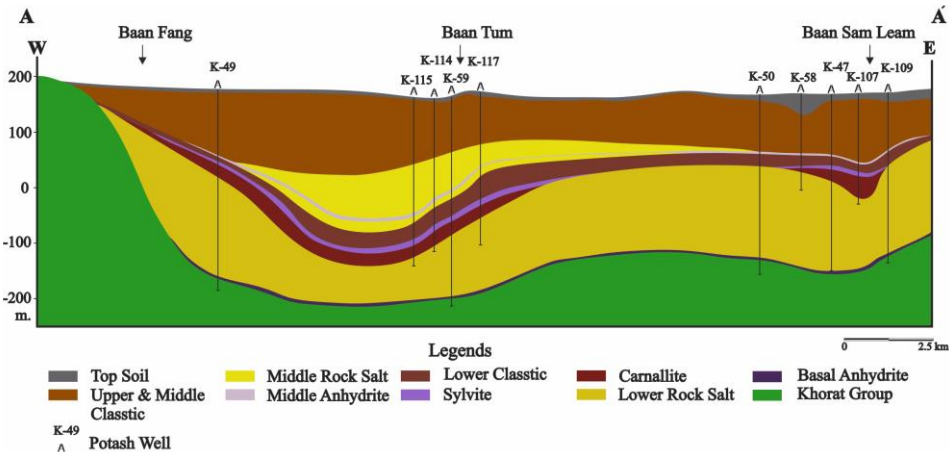

Figure 6. Cross section A-A' showing characteristic of subsurface rock salt related to saline soil distribution.

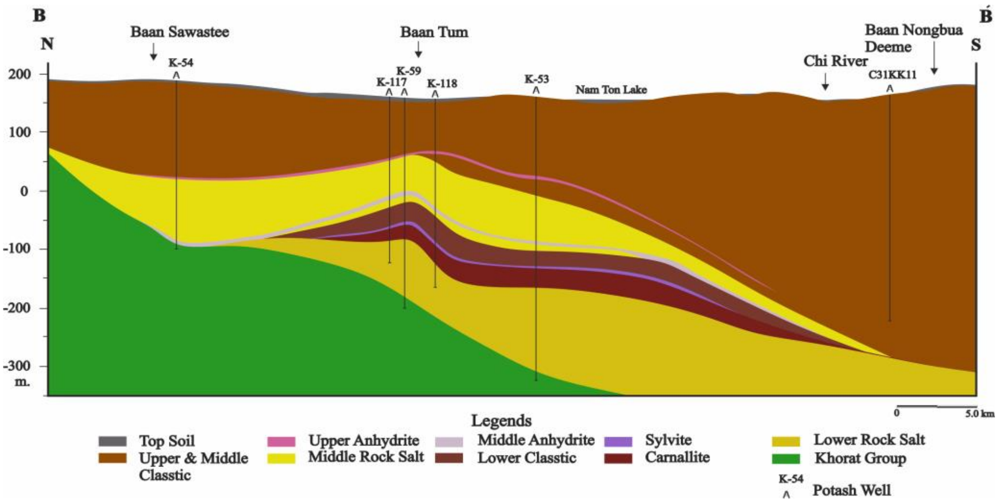

Figure 7. Cross section B-B' showing characteristic of subsurface rock salt related to saline soil distribution.

4.4 Factors affecting salinity distribution

The distribution of salinity in the study area, which is controlled by structural geology and fractures, can be classified into five main types.

4.4.1 Salinity distribution along the contact zones between rock formations

Salinity was observed along the contact zone between the Maha Sarakham and Khok Kruat Formations. The contact zone is located along the west rim of the Khorat plateau. The dip direction within the contact zone gently trends eastward. This causes groundwater to flow in this direction downward from the elevated area that contains older rocks. The resulting shallow interflow system dissolves rock salt. The dissolved salt ions then migrate upward to the ground surface. Salinity is mostly slight along the contact zone itself.

4.4.2 Salinity distribution over anticlinal and synclinal structures

The effect of the Tertiary tectonics and subsequent sediment loading caused synclinal and anticlinal structures to develop that can mobilize rock salt. Severe salinity was observed as a white, circular feature on the ground over the salt dome or anticlinal structure that is located at Baan Tum and Baan Ped. The rock salt outcrops were observed in places. By way of contrast, light salinity was observed at locations overlying the synclinal structure between Baan Tum and Baan Fang.

4.4.3 Salinity distribution around depressions of rock salt

Saline soil has been observed as a white crust along the margin of Nam Ton Lake. The saline deposits are due to dissolution of the underlying rock salt, forming a ring structure. The depression, within which the lake is located, is characterized by radial fractures. Streams have developed along weak zones of the fractures, the salinity gradually occurs along narrow straight streams. Salinity was found to range from slight to severe on the lake margin.

Water in the lake is salty almost all year round except during the rainy season. At this time, surface runoff flows in and rain water falls on the lake. The ground surface is commonly wet. In the dry season, evaporation leaves a white salt crust which was found abundantly on the ground surface in the low-lying plain surrounding the lake.

4.4.4 Salinity distribution along faults and fractures

The Chi River developed along a pre-existing fault zone. Salinity along this meandering river is mostly associated with deep groundwater flow systems. Moderate salinity was observed nearby the river. Salt-affected areas were clearly evident in paddy fields along the river terraces and also within the floodplain.

Salt distribution due to fractures is related to the depression of rock salt and tectonic events. As mentioned above, depression causes radial fractures to emanate from the center of Nam Ton Lake. Later tectonic events can extend these fractures. The resulting shallow interflow and deep groundwater flow along these fractures caused moderate and severe salinity to appear nearby the stream (Figure 8).

4.4.5 Salinity distribution caused by a dam

The Ubon Rattana dam is located in the north-northwest part of the study area. Its reservoir covers ~500 sq km. The dam has a great capacity to elevate the local hydraulic gradient. This may drive large amounts of rock salt dissolution resulting in a spatially extensive distribution of saline soil across the recharge area. However, a detailed study of the effects the dam has on soil-salinity is reserved for future work.

4.5 ERT survey

Resistivity values extracted from these images were classified into three zones according to the recommendations of Freeze and Cherry (1979) Taylor (1993) and Harvey (20 09): lower resistivity values less than 1 ohm-m represented saline groundwater; resistivity values between 1 and 5 ohm-m represented brackish groundwater; and resistivity values over 5 ohm-m represented fresh groundwater.

4.5.1 ERT line 1

Saline soils are not evenly distributed over the study area but can typically be observed mainly in the low-lying discharge area in the southwest adjacent to the Khon Kaen University campus. ERT Line 1 was carried out on the campus of Khon Kaen University with a total length of 2,775 m that crossed from a low gentle terrain to a high terrace and the depth of penetration was about 45 m. After five iterations, the inversion process converged with a RMS misfit of 11.5. The inversion result (Figure 9) showed a trend of increasing salinity (decreasing electrical resistivity) downward and toward the south on the low gentle terrain. A shallower, fresher water layer characterized by higher electrical resis-tivity was apparent at the surface along the entire profile. Brackish groundwater, marked by moderate electrical resis-tivity, existed at the intermediate depth of 10 m, while saline groundwater (low resistivity) occurred deeper than 35 m. In the same manner, brackish and saline groundwater existed at greater depths toward the North. The deep saline zones did not appear beyond 2,400 m along the profile.

4.5.2 ERT line 2

The location selected for ERT Line 2 is a partially barren, abandoned swampy area enclosed by higher dry land. The area was reclaimed for future commercial and residential development. Observation of salt crust and salt-tolerant plants indicated the presence of saline soil. The length of the ERT Line 2 was 94 m in length and the depth of penetration was about 45 m. After five iterations, the inversion process converged with a RMS misfit of 1.2. The resulting resistivity image showed that a shallow zone of brackish groundwater (resistivity values of 1-5 ohm-m) persists along the entire survey line (Figure 10). However, this area is better classified as severe, in terms of soil salinity, due to the extensive salt

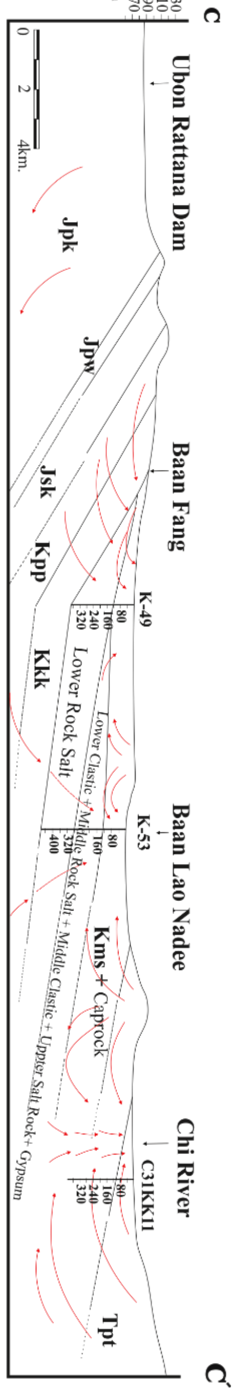

Figure 8. Cross section C-C' showing characteristic of shallow interflow and deep flow system related to saline soil distribution along braided stream and meandering stream.

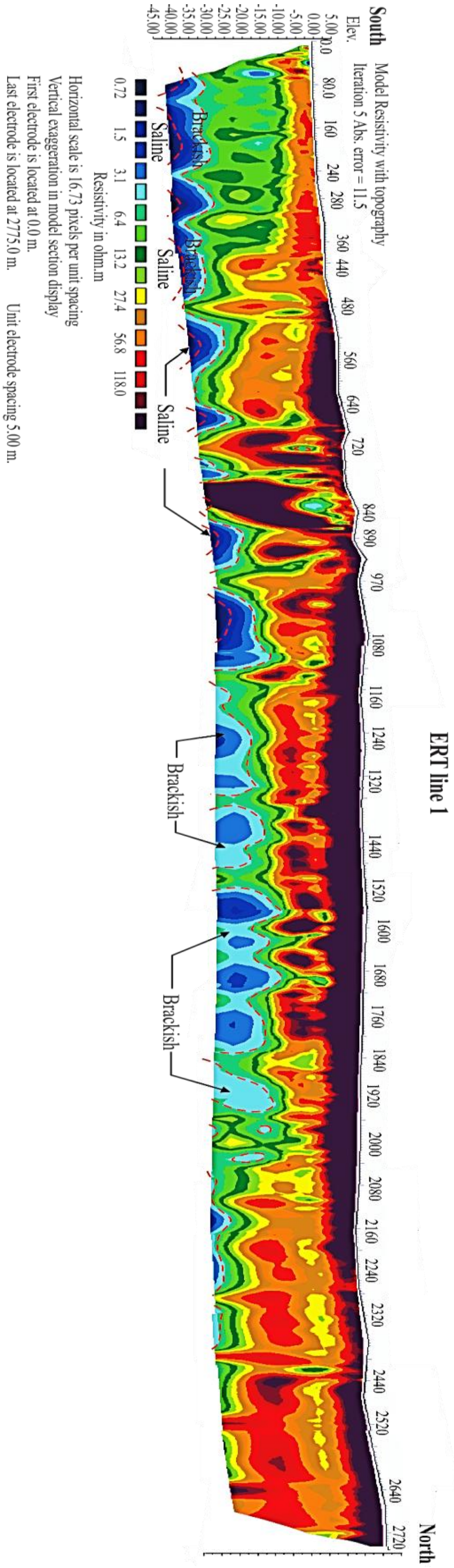

Figure 9. ERT imaging results of ERT line.

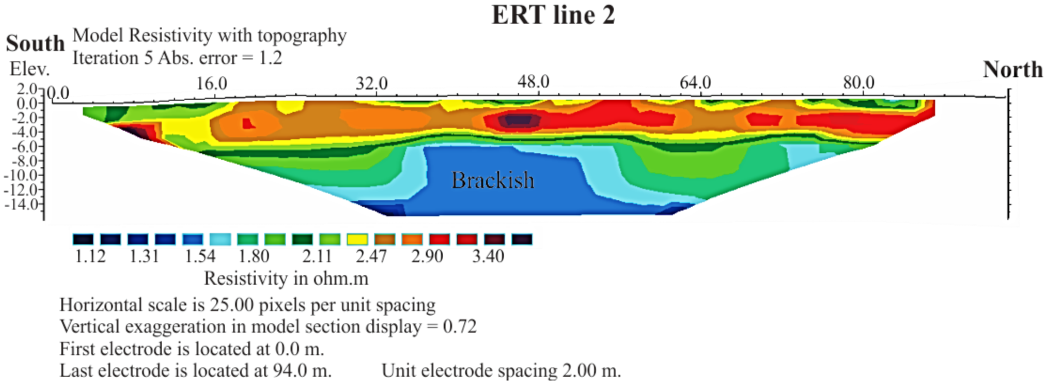

Figure 10. ERT imaging results of ERT line 2.

crust accumulation on the surface. The ERT result indicated only brackish groundwater at depth. The severe saline soil in this area is a surficial effect within the discharge area, perhaps with highly saline groundwater at depths beyond the ERT depth of investigation.

From these two ERT lines, it can be said that the existing saline groundwater is related to the geomorphology within the area. Saline groundwater exists mostly on the low gentle plain that can be identified as a discharge area. However, saline groundwater exists deeper at the higher terrace which can be identified as a recharge area. Also, groundwater depths and salinity levels may be different in other seasons. Salt crust and salt tolerant plants also indicated the presence of saline groundwater. Results from ERT were used to support aerial interpretation and identify saline soil boundaries.

5. Conclusions

Soil salinity distribution, due to either natural occurrence or human activity, has a close spatial relationship to subsurface geological structures and geomorphology. Data from aerial photo interpretation, field studies, ERT geophysical imaging, and information obtained in the course of potassium mineral resource exploration found that the distribution of saline soils was spread widely over low-lying floodplains of meandering and braided drainage streams. The salinity distribution in this case is a natural occurrence controlled by subsurface geological structures, including fractures and faults. The dissolved salt ions migrate upward to the ground surface via shallow interflow and deep groundwater flow systems. Slight and moderate salinity were generally found over syncline structures and at the boundary zones between different rock formations, whereas severe salinity was more commonly distributed over anticline structures and on the surrounding areas of depression of rock salt.

The presence of saline groundwater is controlled by the underlying geology and the surface geomorphology. The source of salt in the present study was halite of the Maha Sarakam Formation, which is generally located at depths greater than 100 m. Saline groundwater exists mostly on the low gentle plain identified as a discharge area. Moreover, since saline groundwater was not indicated on the higher terrace, this region may be identified as a recharge area. Rock salt likely does not exist within the high-terrace area. Instead the Quaternary terrace soils directly overlay the crystalline basement rocks that are older than the Maha Sarakham formation.

6. Recommendations

A future study will focus on the salinity effects caused by thick layers of construction fill in the recharge area. It will be determined whether the construction activities have caused an increase in salt accumulation on the ground surface. A further investigation will also aim to determine whether the Ubon Rattana dam located in the northwest of study area has also caused the increase in salt accumulation on the ground surface due to a deep groundwater flow system induced by a high hydraulic gradient.

Acknowledgements

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