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Application of Electromagnetic Technique to Identify Recharge and Discharge Areas for Reforestation in Northeastern Thailand

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Abstract

Areas affected by salinization in northeastern Thailand were studied using data obtained from ground geophysics methods, multi frequency electromagnetic induction terrain conductivity meter, and hydrological data from the routine piezometer method. The electromagnetic technique is not only a useful tool for identifying the spatial distribution of salt content in landscapes, but it may also be applicable for delineating local recharge and discharge areas by comparing results with hydrological data. It could also aid in reforestation planning in large-scale areas for rehabilitation of salt-affected soils.

Keywords : Electromagnetic induction terrain conductivity meter (EITCM), Salinization, Recharge and discharge areas, Reforestation, Northeastern Thailand

Introduction

Secondary salinization of salt-affected soils in northeastern Thailand is mainly due to the rising of shallow saline groundwater in discharge areas after clearing of native *Dipterocarpus* forest in recharge areas. The source of additional recharge to groundwater discharge aquifers is rainfall, which percolates through the root zone of annual, short-rooted and low-water-use cash crops in cleared lands. Salt is then transported and accumulated on soil surfaces by evapotranspiration and capillary action from rising shallow saline groundwater in discharge areas. Halite, of the Mahasarakram Formation founded at the depth of 60 to 100 m from soil surface, is widely accepted as a source of salt in the process of soil salinization. A remedial measure for controlling shallow saline groundwater in discharge areas is to utilize recharge water before it reaches groundwater aquifers (Williamson *et al*., 1989).

Reforestation in recharge areas is recognized as one land management technique for minimizing groundwater recharge. Perennial, deep-rooted, fast-growing and high-water-use trees are planted in recharge areas where groundwater tables rapidly respond to rainfall. The goal of this technique is to intercept and utilize precipitation before it percolates through the root zone to groundwater aquifers (Sedgley *et al*. 1981).

Regarding this method, it is necessary to define significant recharge areas before reforestation schemes are begun (Bullock and Williams, 1987). They can be roughly delineated from topographic, soil and land surface properties but the most accurate, although costly and time-consuming technique, is to study groundwater characteristics (Freeze and Cherry, 1979).

The electromagnetic terrain conductivity technique is a simple and rapid method for delineating the distribution of salt on surface and subsurface soils at depth of 7.5, 15 and 30 m from the soil surface (McNeil, 1980). The low conductivity of upland soils indicates recharge areas while high conductivity indicates a salinity hazard as well as discharge areas (Bullock and Williams, 1987, and Engle *et al*.,1987).

Williams and Arunin (1990) employed the EITCM for predicting recharge and discharge areas from the empirical average ratio of deep to shallow depths of sounding at Nakorn Ratchasima in northeast Thailand. Ratios of greater than or less than one indicate recharge and discharge areas, respectively. Area where terrain conductivity increases with reading depth indicates recharge areas due to adequate leaching of salt and nutrients. In the discharge areas, where salt moves from shallow saline groundwater to soil surfaces, readings decrease with depth of transverse.

The objective of this research was to study the application of the EITCM for delineating recharge areas to be reforested for salinity control.

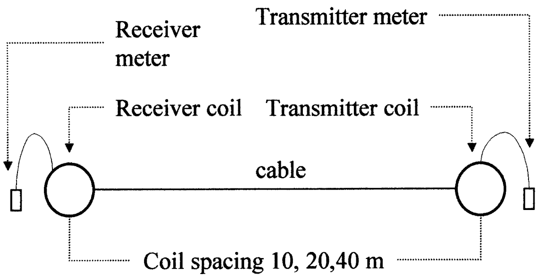
Study area and methodology

Salt affected soils in Ubonrachathani province were selected for studying the application of electromagnetic terrain conductivity for mapping recharge areas. The study area covers 360 square km. Annual average rainfall and evaporation is 1,577 and 2,054 mm, respectively. Soil profile description and type of rocks from soil surface to 30 m depth were recorded during the installation of piezometer. Soils in high terrace were silt and sand while low elevated area soils were silt with increased in clay content. It was founded that soils were underlain with shale, sandstone and siltstone of the Mahasarakram Formation but no salt layers were detected.

The hydraulic head of groundwater from nested piezometers at depths of 5, 10, 15, 20 and 30 meters from soil surface (U1～U90) was used for mapping recharge and discharge areas. The horizontal hydraulic gradients of groundwater at a depth of 5 meter from soil surfaces were contoured and flow lines of groundwater were drawn (Surfer for Windows, 1996). The vertical hydraulic gradient between each depth of nested piezometer was calculated. The downward and upward vertical hydraulic gradient was identified as recharge and discharge areas, respectively (Freeze and Cherry, 1979).

The EITCM measures the bulk apparent electromagnetic terrain conductivity (Ec_a) of soluble salt concentrations in soils (mS/m) to depths of 7.5, 15 and 30 m from the soil surface. The instrument consists of transmitter and receiver coil with diameter of 63 cm and weight of 3 and 7.2 kg, respectively. They are connected to transmitter and receiver meter, respectively. The coil configurations are either vertical or horizontal and are 10, 20 and 40 meter apart (Fig. 1). The transmitter coil generates primary electromagnetic currents in the soil profile, which induce the secondary magnetic field from soluble salts in the soil profile. The magnitude of secondary magnetic field depends on the concentration of soluble salts, moisture and clay contents. The receiver coil determines the primary and secondary magnetic field and calculates the ratio between the two. This ratio yields the apparent electrical conductivity of the soil profile. The depth of soil measured depends on the current frequency, distance between the transmitter and receiver coils and the coil arrangement relative to the soil surface. The coils in the horizontal dipole mode provide the depth of sounding of 7.5, 15 and 30 m from the soil surface (McNeil, 1983).

The EITCM survey was carried out at grid of 1 km and at each nested piezometer using a 10, 20 and 40 m coil separation and horizontal dipoles. The apparent electromagnetic conductivity at depths of 7.5, 15 and 30 m was obtained. Surfer for Windows was used for contouring the apparent electromagnetic conductivity of the soil profile at depths of 7.5, 15 and 30 m from soil surface (Surfer for Windows, 1996). Salinity is classed into non-salt-affected soils (0～80 mS/m), slightly salt-affected soils (80～120 mS/m), moderately salt-affected soils



EITCM in horizontal dipole mode

EITCM in vertical dipole mode

Fig. 1 Electromagnetic induction terrain conductivity meter (EITCM), in horizontal and vertical dipole mode.

(120〜160 mS/m), severely salt-affected soils (160〜200 mS/m) and very severely salt-affected soil (>200 mS/m).

Williams and Arunin (1990) proposed that salinity at different depths in the soil profile determined from EITCM measurements could predict recharge and discharge areas. Areas in which Em values increase or decrease with the depth of the soil profile can be identified as recharge and discharge areas, respectively. Thus, the EM slope can be derived as

$$\text{EM slope} = ((\text{EM30}/\text{EM15}) + (\text{EM30}/\text{EM7.5}) + (\text{EM15}/7.5))/3 \quad (1)$$

$$\text{Recharge area EM slope} > 1 \quad (2)$$

$$\text{Discharge area EM slope} < 1 \quad (3)$$

EM7.5 : Apparent electrical conductivity from soil surface to 7.5 m depth
EM15 : Apparent electrical conductivity from soil surface to 15 m depth
EM30 : Apparent electrical conductivity from soil surface to 30 m depth

The EM slope formulated from this formula was then contoured using Surfer for Windows. The contour of the EM slope was overlain on the recharge and discharge area, which delineated the vertical and horizontal hydraulic gradient of groundwater from the same area.

Results

Groundwater hydrology and the electromagnetic technique was used for investigation of the development of salt-affected soil in northeastern Thailand

Groundwater hydrology

Data from nested piezometers was collected from April 1996 to March 1998. The distribution of horizontal hydraulic head and groundwater flow lines at a depth 5 meter from soil surfaces were drawn using data gathered in April 1997. Groundwater moved from the elevated areas (130〜140 m above mean sea level) to the lower areas of the study area. The pattern of groundwater flows were the same during the period of study. The vertical hydraulic gradients between nested piezometer were calculated. Nested piezometers with downward and upward vertical hydraulic gradients were identified as recharge and discharge areas, respectively. It was found that most of the recharge areas were situated primarily over the horizontal hydraulic head of 122 meter. The depth of ground water ranged from 2.4 to 5.10 m from the soil surface in the recharge areas, while that of the discharge areas was in the range of 1.95 to 3.8 m from soil surface (Fig. 2).

Electromagnetic technique

Soil salinity maps of the study area were prepared and are shown in Fig. 3. The measured apparent electromagnetic terrain conductivity from soil surface to 7.5 m depth ranged from 6 mS/m in the recharge areas to 195 mS/m in the discharge areas. All recharge areas identified by the groundwater hydrology were classified as non-salt affected soils, while the discharge areas were classified as slightly to severely salt-affected soils. The severely salt-affected soil occurred in small areas in the vicinity of U39 and U15 and U16. The bulk apparent electromagnetic terrain conductivity of soils located 15 and 30 m from soil surface ranged from 10〜195 and 8〜220 mS/m, respectively. The boundary of salt affected area at

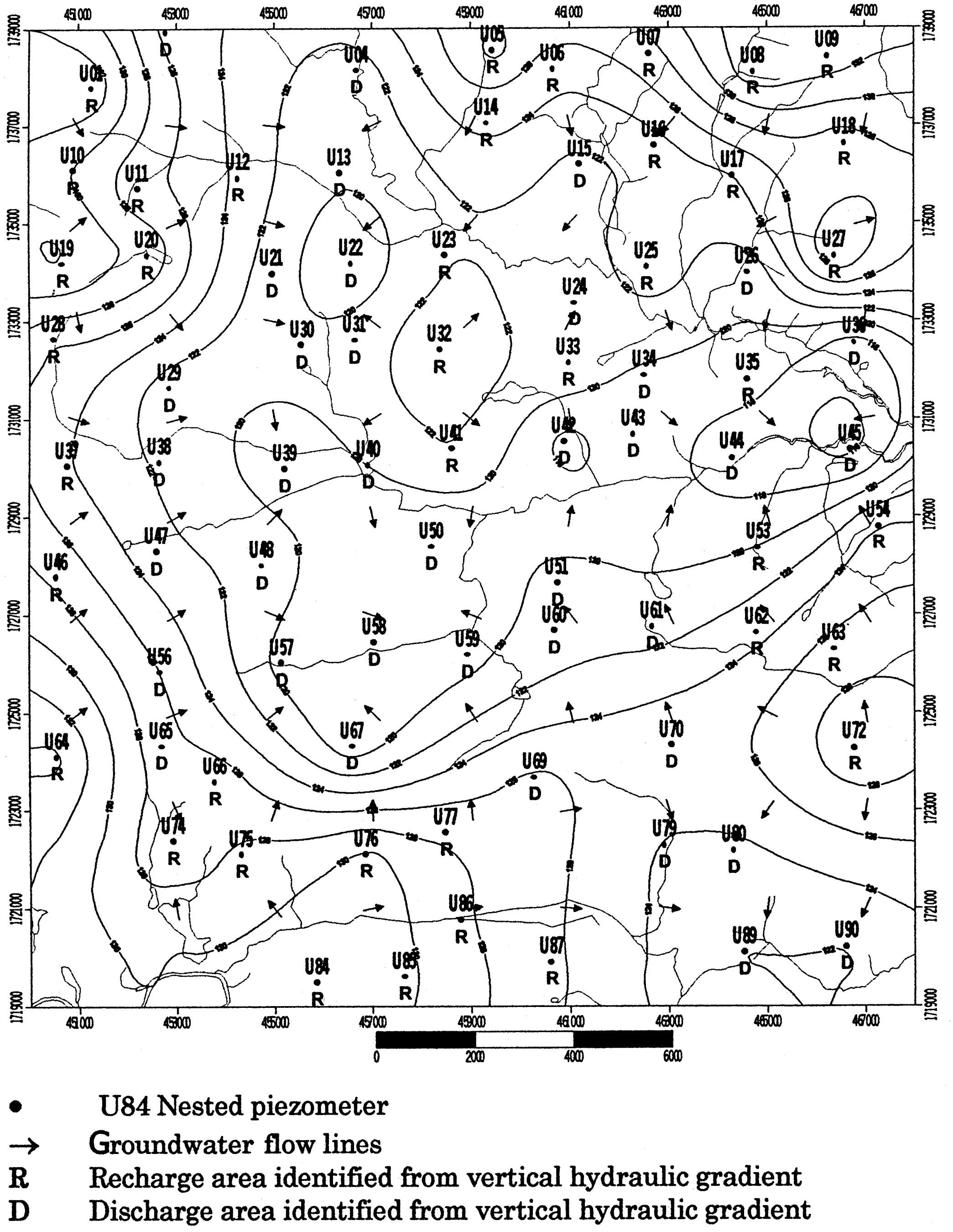


Fig. 2 Distribution of horizontal hydraulic head (m), flow lines of groundwater measured in piezometers at a depth of 5 m from soil surface in April 1997 and recharge [R] and discharge area [D]. Discharge area identified from vertical hydraulic gradient (map scale is in meter).

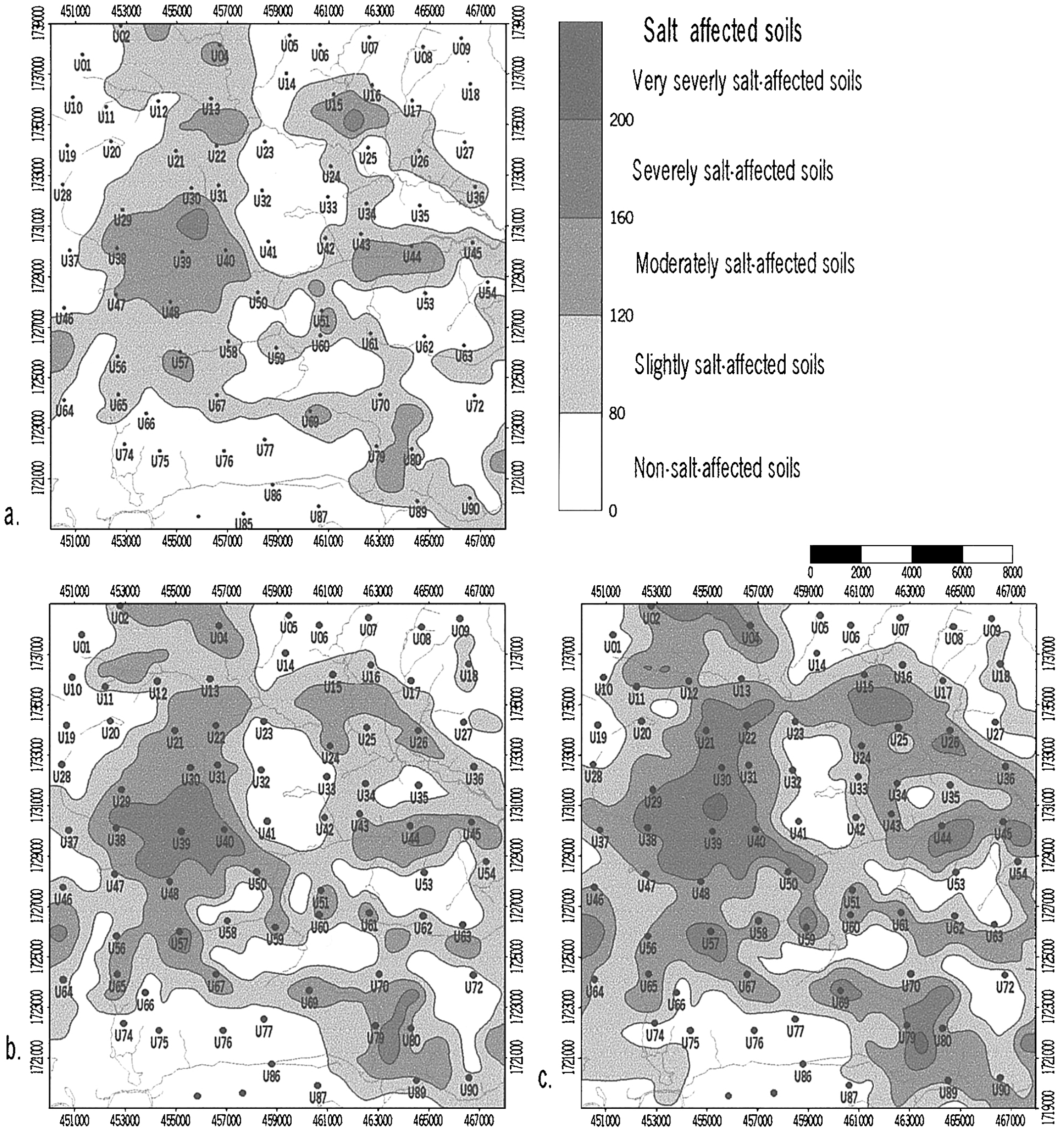


Fig. 3 a, b, c The apparent electromagnetic terrain conductivity (mS/m) from soil surface to 7.5 m (a), 15 (b) and 30 m (c) depth (map scale is in meter).

the depth of 15 and 30 m from soil surface increased with the depth of investigation. The boundary of severely salt affected soil was found at the depth of 30 m.

Recharge and discharge evaluation

The frequency distribution of EM slopes ranged from 0.75 to 3.50. The EM slope was distributed around 1.28. The relationship between the recharge areas and EM slope is illustrated in Fig. 4. The result of this overlay shows that the EM slopes in the recharge areas were more than 1 and could be classified as recharge areas. The EM slopes which were lower than 1 were situated in the salt-affected areas near U41, U42 and U51. But in the rest of the salt-affected soils or discharge areas, EM slopes were greater than 1.

High values of EM slopes were found in very

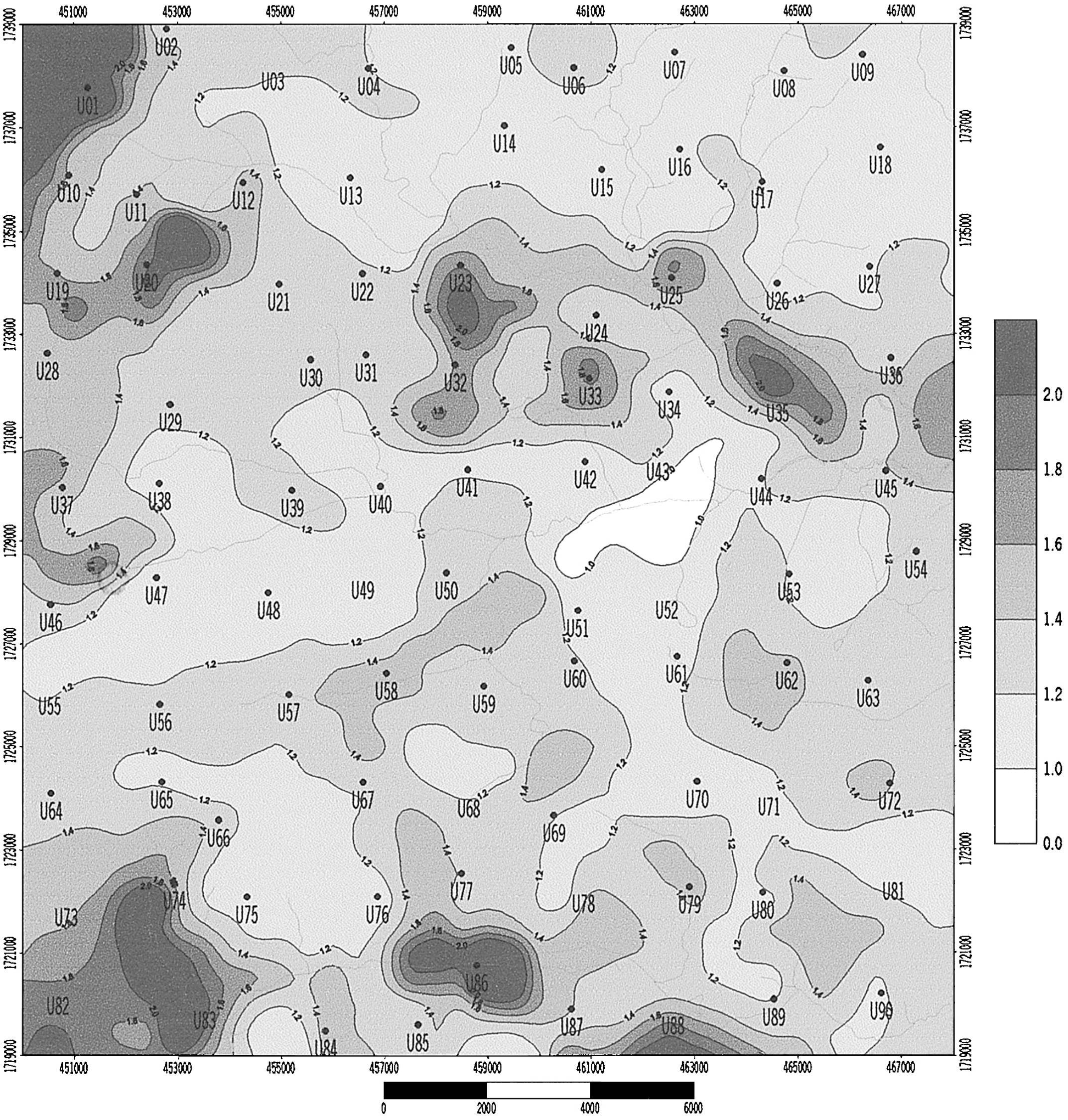


Fig. 4 The distribution of EM slope (map scale is in meter).

low apparent electromagnetic terrain conductivity upland areas which were classified as non-salt-affected soils, while the EM slopes in salt-affected soils ranged from 0.72 to 1.58. The frequency distribution of EM slopes in the discharge areas showed that only 10% were less than 1.

Discussion

Salinization process

The salinization process is affected by water and salt sources, as well as the mechanism of salinization. The major source of water in local recharge areas is rainfall. Recharge occurred in upland areas where coarse-texture-soil, sand and silt exist in the soil profile. The distribution of vertical hydraulic gradient shows the downward movement for the period of time, which is longer than the upward vertical hydraulic gradient. The electrical conductivity of groundwater in the recharge area is low. Groundwater salinity increases along the pathway of groundwater flow. The ionic composition of salty groundwater is dominated by Na and Cl. The ratio of Na and Cl toward 1 with increasing the total dissolved solid (TDS) indicates that halite (NaCl mineral) dissolution is the major source of salt (Williamson *et al*., 1989).

Groundwater in the discharge area rises towards the soil surface to the depth where capillary rise can occur because of the upward hydraulic gradient. The evaporation of saltwater leaves salt in the soil profile. The horizontal hydraulic gradient of salty groundwater in salt-affected soil was very low, which allowed time for the salinization process. The difference in the salinity hazard of salt-affected soil is due to the magnitude of the vertical and horizontal hydraulic gradient in the recharge and discharge areas, the period of upward and downward hydraulic gradient, and the depth of groundwater from the soil surface. Excess water in discharge areas needs to be manipulated by minimizing water input in the recharge areas and water output in the discharge areas.

Salinity level

The EITCM was adopted for delineating salt storage in the landscape. Low Ec_a readings were found in the upland areas indicating that recharge is dominant in these areas. High apparent electrical conductivity was found in the lower slopes and alluvial plains, indicating that salt was discharged and accumulated after evaporation in the surface or near-surface soil. Three depths of sounding provided the distribution of salt content in the soil profile. The increasing Ec_a reading with the depth of sounding in the upland recharge area indicates leaching of soluble salts or nutrients in the soil profile. The reverse of this phenomenon is seen in discharge areas where shallow salty groundwater is discharged to soil surface (Williams and Arunin, 1990). From this study it was determined that salinity in discharge areas increased with depth of sounding. This is probably because these areas are underlain with highly electrically conductive material which is being mobilized from the depth deeper than 30 m to the soil surface by groundwater.

The empirical EM slope is developed for practical determination of salt content in recharge and discharge areas. All of the identified local recharge areas had EM slope values greater than 1 and apparent electromagnetic terrain conductivity of non-salt-affected soil. The EM slope in the salt-affected soils ranged from less than 1 to more than 1 due to a high salt concentration in the deeper depths. These areas may be interpreted as recharge areas. From the results presented here, it can be seen that EM slope is not the proper tool for identifying recharge areas because the value of the EM slope, which is used to divide recharge and discharge areas, varies from place to place. The distribution of the EM slope and the salt concentration in the soil profile should be examined and rejected when the EM slope is greater than 1 in salt-affected soil. In addition, one should consider the relationship of high EM slopes and the amount of recharge to groundwater aquifers. Even though the electromagnetic technique is not successful for identifying recharge areas properly, salt distribution in the soil profile is important data for reforestation program.

Conclusion

The process of salinization can be determined from routine piezometer method that recharge from rainfall occurred in the upland area and discharged to the alluvium plain where upward hydraulic gradient was dominated phenomenon. The source of salt might come from the Mahasarakram formation which underlies salt-affected areas.

The geophysics technique was adopted to investigate hydrosalinity in salt-affected soils. The mapping of soil salinity by EITCM was proven to be very useful in detecting and delineating salinity in landscape where it can not be noticed on the surface soil.

In addition, the empirical approach, using ratios of deep to shallow sounding for identifying recharge and discharge areas did not accurately handle the assumption due to the increasing of Ec_a value with increasing depth of sounding in the discharge area. As the accumulation of soluble salt in the deeper soil profile. Such situation lead to interpret as a recharge area instead of discharge area. This exception can be solved by rejecting the high EM slope data which is in the high salt content profile.

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東北タイ塩類土壌地域における森林再生のための涵養地域と排出地域の決定への地盤電磁誘導法の応用について

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要　　旨

東北タイ・マハサラカム層を主体とした塩類化土壌地域における地下水動態について，地盤電磁誘導法すなわち EITCM（multi frequency Electromagnetic Induction Terrain Conductivity Meter）により得られた測定値，およびピエゾメーター法により得られた観測値が比較検討された。この電磁気学的手法は，地域土壌の塩含有量の空間分布を概略的に識別するために有益な技術ばかりでなく，水文学的データを併用することによって地域的な地下汽水の涵養地域と排出地域の概要を知ることができる有効な手法である。本論では，この手法が当該塩害地の再生を考慮した大規模な森林計画の検討に有効であることを論議し，EITCM による地下水の涵養/排出分布図を作成した。

キーワード：みかけの地盤電導度，塩類化，涵養地域/排出地域，森林再生，東北タイ

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