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Van Hong Nguyen "Evaluation of geo-physics methods to study the effects of land use on salinity in rice production systems in the Vietnam Mekong Delta", University of Hohenheim, 2023

Introduction

Rice stands as a fundamental dietary staple for more than half of the world's population, underscoring its enduring significance amidst global population growth. Asia leads in rice production, with Vietnam contributing approximately 6% to the global output. Despite its relatively modest share, Vietnam boasts the distinction of being the world's third-largest rice exporter. The bulk of Vietnam's rice exports come from the Vietnam Mekong Delta (VMD), where extensive enhancements to canal systems have been implemented over decades. This substantial investment has yielded tangible results, enabling rice cultivation in certain VMD regions to occur up to three times annually. Consequently, rice production in the VMD surpasses domestic demand, facilitating substantial exports. Notably, the VMD accounts for roughly half of Vietnam's national rice production and an impressive 90% of its rice exports.

The development of agriculture in the VMD is exposed to various threats such as climate change, land subsidence, and freshwater shortage. The decrease in the freshwater availability of the VMD is closely related to the increase in the number of upstream dams. Especially in the dry season when water demand is high, the pressure of water resources for irrigation and the subsistence of the millions of people leads to overexploitation of groundwater which is a main reason caused land subsidence in the VMD. In addition to freshwater shortages and land subsidence, mainly due to artefacts, the VMD is one of the third largest deltas in the world to be particularly threatened by sea-level rise due to climate change.

Climate change, land subsidence and scarcity of freshwater put the VMD, a low-lying delta with an average elevation of less than 1 m above mean sea level, at risk from saltwater intrusion, particularly during the dry season. In the dry season, droughts become more frequent, causing negative impacts on agriculture and livelihoods, and leading to salinization of the soil. Every year in the dry season, approximate 1.8 million ha of land in the VMD is affected by saline water. Seawater usually intrudes into the major rivers of the VMD from the coast to the inland for about 40 to 60 km. However, an increase in saltwater intrusion has been observed in the VMD over the last two decades, with the distance of saltwater intrusion increasing to about 90 km in the drought year of 2006 and reaching 110 km in 2020.

This results in elevated salinity levels of the water in the primary canals, which then leaks into or is pumped into the secondary and tertiary canals. This occurs primarily during the dry season between December and April. During this season, rice cannot be grown due to the unavailability of fresh water in the canals and a lack of rain. When the fields are left fallow,

the risk of salt intrusion from shallow saline groundwater through capillary increases.

In some areas of the VMD, the availability of freshwater does not determine rice production, but shrimp production. Formerly productive rice fields have been converted to shrimp farms because the salinity in the canal and the fields is too high to produce rice for most of the year, except during the heavy rainy season. This transition not only leads to salinization of the current fields, but also affects rice cultivation in the surrounding areas and reduces the quality of the limited freshwater source.

Research questions and Objective of the research

Addressing the impact of salinity on rice production in the VMD requires a comprehensive approach to assess salinity from the topsoil to the subsoil layers. Saltwater intrusion into lowland areas through the canal system or capillary rise of saline water from near surface saline water tables may result in salt accumulation in the topsoil.

Through land-use maps of the VMD in rice production system, there seems to be a direct link between changes in land-use systems and increasing salt intrusion due to reduced freshwater volume flow in the Mekong River combined with sea level rise.

To address the above concerns, such as what is the potential source of salinity in the VMD, is it from irrigation with saline water or is it from the soil, is there a link between salinity and rice production systems, this study was carried out in different rice production systems using geophysical methods.

The principal objective of the study is (1) to evaluate the application of geo-physics methods, using Electrical Resistivity Tomography (ERT) and Electro Magnetic Induction (EMI), in soil salinity in rice production systems, with emphasis on the salinization of the topsoil and subsoil, and (2) to figure out if the rice production system affects the salinity of soil or vice versa. The specific objectives are:

1. to test the capability of the ERT method using ARES II to detect salinity of near surface water tables in order to evaluate potential risks of capillary rise of saline ground water to the rice production systems

2. to investigate topsoil salinity, and compare the versatility and accuracy of EMI and ERT to develop a new mapping technique for topsoil salinity, and

3. to map saline near surface groundwater under the rice fields at a provincial scale with the comprehensive ERT measurement.

Methodological approach

Soil salinity was evaluated by using geophysical methods, the non-invasive and robust methods, for the case study in the VMD. Geoelectric surveying is a non-invasive and cost-effective method for exploring the structure of the earth's subsurface. Geophysical methods were used in this study including Electromagnetic Induction (EMI) and Electrical Resistivity Tomography (ERT). EMI measures electrical conductivity, while ERT measures electrical 'resistivity, which is the inverse of conductivity and is closely related to soil salinity. ERT was employed to assess salinity of the subsurface to a depth of 40 m, while EMI was used to detect topsoil salinity up to 1.5 m depth.

The case study, Tra Vinh province, in the VMD was chosen for the soil salinity investigation. Soil salinity measurement was conducted during dry season in different land-use types related to rice production systems in the VMD. The field measurements were carried out. in two consecutive dry seasons, the dry season of 2019-2020 and dry season of 2020-2021. The first measurement was carried out at five case study sites with different cropping patterns to validate the ERT data and to compare the two geophysical methods to determine the best method for investigating soil salinity in the VMD. The second measurement campaign, ERT and EMI were measured in the extensive survey in the landscape scale, with the measurement sites selected along four typical geological transects in the Tra Vinh province to map soil salinity and to figure out the relationship between land-use and salinity.

As this was the first time that geophysical methods were used to investigate soil salinity in the VMD, five boreholes were drilled to a depth of 40 m to validate the ERT measurement of subsurface salinity.

Tue results of soil salinity from geophysical methods were then stalked with land use map using for rice production systems was obtained using Sentinel-1A synthetic aperture radar satellite images for the period of November 2020 to December 2021 to evaluate the relationship between land use and soil salinity.

Results

Geophysical methods used in the research provided detail results in the different soil depths. For first assessment of subsoil salinity, the research shows the resistivity values smaller than 3 Ω m were clearly identified as indicative for a saline water table for the case study in the VMD, and this resistivity appears in the shallow depths beneath rice fields, varies from 3-5 m depths. The results also show a direct link between the depth of the saline water table and the proximity to the sea, but not to the rice production system (single, double, or triple cropping).

In the second assessment, both topsoil salinity and subsoil salinity were taken into account. In general, topsoil salinity is not a critical issue in the study area compared to potential salinity from the near surface water table. Salt contamination of above 300 mS m^{-1} was found in some double-cropped rice fields, whereas in triple-cropped rice fields salinity was below 200 mS m^{-1}. Results clearly show a relation between topsoil salinity and proximity to the saline water sources.

Elaboration of subsurface resistivity maps by extracting data from 2D ERT profiles has allowed the identifying areas at high risk of salinization under rice fields. In our case study, these are delineated as double-cropped rice fields where the saline water table is likely to start at a depth of 1 m. This cropping pattern is mainly distributed along rivers or near the coast, where salinity of the shallow aquifers is directly recharged by the rivers or by tidal fluctuations from the sea. In addition, the double cropped rice fields are also known to be exposed to topsoil salinity due to inappropriate irrigation.' In general, the link between land use types and saline groundwater is unclear. The only link found was between shrimp farming and saline groundwater, which occurs at a depth of about 1 m. Rice production systems were not found to be associated with saline groundwater.

Furthermore, we would like to prove for the first time the capability of ERT and EMI in evaluating soil salinity in the rice cultivation fields in the VMD. In addition, we suggested the powerful methods to capture and monitor saltwater intrusion into the rice fields from top to subsurface, which is necessary to improve and protect rice production.

List of thesis publications

Nguyen, V.H., Germer, J., Duong, V.N., Asch; F. (2023). Soil resistivity measurements to evaluate subsoil salinity in rice production systems in the Vietnam Mekong Delta. Near Surface Geophysics 21(4), 288-299. http://doi.org/10.1002/sg.12260

Nguyen, V.H., Germer, J., Asch, F. (2023). Evaluating topsoil salinity via geophysical methods in rice production systems in the · Vietnam Mekong Delta Journal of Agronomy and Crop Science. http://doi.og/I0,III/jac,12676

Nguyen, V.H., Germer, J., Pham, T.D., Asch, F. (2023). Mapping saline groundwater under rice-paddy fields in Vietnam's Mekong Delta. Near Surface Geophysics. (Submitted and under review)