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# IDENTIFICATION OF THE BEST AGRICULTURAL MANAGEMENT PRACTICES WITH BETTER GREENHOUSE GAS BENEFITS IN SALINITY AFFECTED AREAS OF SOUTH ASIA


The following collaborators worked on this project:

1. Dr Erandathie Lokupitiya, University of Colombo, Sri Lanka, erandi@sci.cmb.ac.lk
2. Prof. Madhoolika Agrawal, Banaras Hindu University, India: madhoo58@yahoo.com
3. Dr Tofayel Ahamed (with technical support from Prof. G. Miah), Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh; tofayela@gmail.com
4. Naveed Mustafa (with technical support from Dr. Bashir Ahmed), Alternate Energy and Water Resources Institute, National Agricultural Research Center (NARC), Pakistan; rana_naveedmustafa@yahoo.com
5. Prof. Keith Paustian, Colorado State University, USA; keithp@nrel.colostate.edu

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## Project Overview

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| **Project Duration** | **:** | 2 Years |
| **Funding Awarded** | **:** | USD 63,994 |
| **Key organisations involved** | **:** | 1. University of Colombo, Sri Lanka Dr Erandathie Lokupitiya,<br>2. Banaras Hindu University, India: Prof. Madhoolika Agrawal,<br>3. Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh; Dr Tofayel Ahamed (with technical support from Prof. G. Miah)<br>4. Alternate Energy and Water Resources Institute, National Agricultural Research Center (NARC), Pakistan; Naveed Mustafa (with technical support from Dr Bashir Ahmed)**,**<br>5. Colorado State University, USA; Prof. Keith Paustian |

### *Project Summary*

Climate change due to increased greenhouse gas (GHG) emissions from human activities has been a major environmental concern during the last few decades. Sea level rise is a significant impact on climate change. Sea level rise and various anthropogenic activities including irrigation malpractices have led to saltwater intrusion, affecting the agricultural areas of South Asia. In addressing climate change-related issues, both mitigation of GHG emissions and adopting appropriate adaptation measures to minimize the impacts are necessary. In addressing the salinity issue, remedial measures adopted on salt-affected soils to reduce the salinity effect could enhance future climate change if they cause high levels of net GHG emissions. Therefore, this study was conducted to find the best agricultural management practices for the salt-affected soils in rice cropping systems of four South Asian countries (i.e. Sri Lanka, India, Bangladesh, and Pakistan) considering net GHG emissions and other socio-economic benefits associated with the adopted measures. The outcome of this project will be employed to raise awareness among farmers to adopt climate-friendly best management practices (BMPs) for salt-affected soils and make recommendations for policymakers in developing adaptation policies and strategies within the respective countries and the region as a whole.

**Keywords**: Climate change, salinity, agriculture, management practices, greenhouse gas emissions

### Project outputs and outcomes

Project outputs:

- Review of background information
- Study of country-wise and region-wise salinity levels and extents
- Collection of information relevant to different management practices in salt-affected rice areas
- Measurement of GHG emission estimated from salinity-affected soils under paddy and selection of BMP/s

Project outcomes:

- Compilation of salinity levels within South Asian countries
- Country-wise (and region-wise) salinity maps
- Enhanced knowledge on salinity-management practices used across the South Asian region
- Recommendations for farmers on BMP/s
- Establishment of a network of relevant in-country collaborators and regional collaborators within the project area

## *Key facts/figures*

- **Sri Lanka**: Twenty-two sites covering the wet zone of Sri Lanka, extending within the districts under paddy cultivation (i.e. Galle (7 sites), Matara (5 sites), Gampaha (3 sites), Kalutara (5 sites), and Colombo (2 sites)) were surveyed for salinity levels; similarly, 50 sites within Jaffna and 13 sites in Mannar districts were studied for dry zone salinity levels, and Madampe in Puttalam district was surveyed for the Intermediate zone.
- The observed salinity levels ranged from low- and medium- to high salinity; however, the majority of the surveyed salinity-affected sites had high salinity.
- Sri Lanka was threatened by the extreme events (i.e. droughts and floods mostly) due to climate change during the project period, and the country was ranked as No 2 under the Global Climate Risk Index. Thus only the sites in two districts (i.e. Mannar and Puttalam) could be studied for GHG levels under different management practices, although a substantial number of sites could be surveyed for mapping salinity in both wet zone and dry zone.
- Out of all the management options, the management option which had a combination of transplanting, the addition of organic matter, and intermittent irrigated water levels was identified as the BMP in terms of the net GHG emissions and overall productivity (i.e. yield) giving socio-economic benefits

- **India**: Indo-Gangetic plains stretch of 200 km covering three districts of Varanasi, Mirzapur and Chanduali of Uttar Pradesh state, India was mapped for salinity levels; altogether 46 sites were surveyed in India. The observed salinity levels ranged from low- and medium- to high salinity. Greenhouse gas measurements under different salinity-management practices were conducted at six sites out of the 46 sites surveyed (i.e. Rajatalab (RJT), Beerbhanpur (BBN), Mirzamurad (MZM), Baraipur (BRP), Dharhara (DHR) and Salaempur (SLM) sites).
- Although rice-wheat and rice-fallow are the most common cultivation sequence of IGP region, with respect to rice yield and GHG emissions, the best sequence is rice-fallow with organic amendments and appropriate irrigation practices.
- Application of inorganic fertilizers alone increases the GHGs emissions but organic amendments seem to be the best option for improving salinity as well

## *Potential for further work*

**Sri Lanka**: Given the impact from bad weather, the GHG measurements in Sri Lanka had to be restricted to sites in two districts only and the measurements could be conducted only one season per site. Therefore, it has been planned to conduct further measurements in sites representing the other districts and for additional season/s.

**India**: Different combinations of amelioration practices for soil salinity reclamation can be tried such as the use of cow dung manure, gypsum and biochar to reduce greenhouse gas emissions such amendments can be assessed further for benefits incurred in reducing salinity and GHGs emissions and enhancing rice yield.

### *Publications*

Jaiswal, B., & Agrawal, M. (2020). Carbon Footprints of Agriculture Sector. In *Carbon Footprints* (pp. 81-99). Springer, Singapore.

The following publications listed are relevant to presentations made at international conferences:

Lokupitiya, E., Agrawal, M., Pandey, D., Ahamed, T., Mustafa, N., Sirisena, D.N., Seneviratne, G., Udagedara, S. & Paustian, K. (2017). Best Management Practices with Low Greenhouse Gas Emissions for Salinity Management in Paddy Soils of South Asia.

Archana, A.S., Lokupitiya, E., Sirisena, D.N., & Seneviratne, G. (2018). Determining the Best Agricultural Management Practices for Salt-Affected Coastal Paddy Soils in Sri Lanka Considering Net Greenhouse Gas Emission Along with Other Socioeconomic Benefits. International Conference on Climate Change-2018 (ICCC 2018), February 15-16, 2018, Book of Abstracts. The International Institute of Knowledge Management (TIIKM), Colombo, Sri Lanka. P 75.

Lokupitiya, E., Agrawal, M., Vathani, A., Ahamed, T., Mustafa, N., Ahmad, B., Pandey, D., Seneviratne, G., & Paustian, K. (2018). Coastal salinity intrusion and food security in South Asia: best management practices with greenhouse gas benefits. International Conference on Agricultural GHG Emissions and Food Security – Connecting research to policy and practice. September 10 – 13, 2018 Berlin, Germany. Claudia Heidecke, Hayden Montgomery, Hartmut Stalb, LiniWollenberg (Eds.). Volume of Abstracts. p. 75.

Opatha, K. N., & Lokupitiya, E. (2019). Study of salinity levels and impact of saltwater intrusion on coastal paddy areas of wet zone of Sri Lanka. Proceedings Symposium on agrobiodiversity for climate change adaptation, food and nutrition. Mainstreaming Agrobiodiversity Conservation and Use in Sri Lankan Agro-ecosystems for Livelihoods and Adaptation to Climate Change (BACC) Project & Mainstreaming Biodiversity Conservation and Sustainable Use for Improved Human Nutrition & Wellbeing-Biodiversity for Food and Nutrition (BFN) Project, Colombo, Sri Lanka. p. 71.

### *Awards and honours*

Opatha, KN and Lokupitiya, E. 2019. Study of salinity levels and impact of saltwater intrusion on coastal paddy areas of wet zone of Sri Lanka. Symposium on agrobiodiversity for climate change adaptation, food and nutrition. Mainstreaming Agrobiodiversity Conservation and Use in Sri Lankan Agro-ecosystems for Livelihoods and Adaptation to Climate Change (BACC) Project & Mainstreaming Biodiversity Conservation and Sustainable Use for Improved Human Nutrition & Well-Being-Biodiversity for Food and Nutrition (BFN) Project, Colombo, Sri Lanka.

**Award for best poster presentation.**

Pull quote/s:

"There is no proper estimation on saline areas in Sri Lanka; Farmers do not have any idea about salinity conditions in their paddy fields; Nothing is being done to overcome the ill effect of soil salinity"- Mr DN Sirisena, Former Deputy Director, Rice Research Development Institute, Sri Lanka; this was quoted from his remarks during a workshop held in the past, which shows the importance of our project in terms of addressing the salinity issue.

"There are many dimensions to this problem. Since the study sites were situated in the Indo-Gangetic plain which feeds major population of India, expanding rate of salt-affected soil at different stages of degradation is a cause of concern for farmers wellbeing. Marginal farmers have adopted unsustainable agronomic practices due to unavailability of required resources. Through this project we realized how soil health deterioration could contribute to gas flux initially and later reduce the plant yield."- Dr Suruchi Singh, Research Associate, Department of Botany, Banaras Hindu University, India

### *Acknowledgements*

We acknowledge Prof Gamini Seneviratne, National Institute of Fundamental Studies, Kandy, and Mr DN Sirisena, former Deputy Director Rice Research Development Institute of Sri Lanka, Mr. RangaPallawela from Janathakshan, and other local collaborators and farmers from Sri Lanka, India, Pakistan, and Bangladesh, for their invaluable support extended for this project.

# 1. Introduction

The threat to global food security due to increased salinity in agricultural soils has been a significant concern. South Asia is responsible for about one-third of the global rice production and about one-fifth of the global wheat production among a variety of other crops (FAO, 2015). The agricultural areas within the countries in the region are variably affected by saltwater intrusion due to sea-level rise and irrigation practices. It has been estimated that worldwide 20% of total cultivated and 33% of irrigated agricultural lands are affected by high salinity.

Furthermore, the salinized areas are increasing at a rate of 10% annually for various reasons, including low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water and poor cultural practices. It has been estimated that more than 50% of the arable land would be salinized by the year 2050 (Jamil et al., 2011).

According to the IPCC Fifth Assessment report, sea level will further rise at least by 26-98 cm (based on the scenario) compared to the current level by the end of 21st century. The number of people annually affected by coastal flooding will increase, and ~60% of this increase will occur in South Asia, along the coasts from Pakistan through India, Sri Lanka and Bangladesh (Church et al., 2013).

Agriculture plays a vital role in the economies of the member countries of South Asia. As a region, agriculture employs about 60 per cent of the workforce yielding about 20 percent of the total GDP. However, South Asia has been identified as the second-lowest in terms of regional-level food security around the world and more and more R & D activities are needed for improving the agriculture and food security in the region (Bishwajit, 2014).

A significant part of agricultural lands in this region, particularly in Bangladesh, India, Pakistan, and Sri Lanka are already witnessing soil salinity as the major challenge for crop production. In Sri Lanka, about 0.1 million ha of paddy lands are affected by salinity (De Alwis and Panabokke 1972), and Coastal salinity is particularly exited in districts Mannar, Puttalam, Jaffna, Trincomalee, Ampara, Hambantota, Galle, Kalutara and Matara (Senanayake et al., 2017). India has 6.73 M ha salt-affected soil including coastal area, of which 2.5 Mha lies in the Indo-Gangetic plain (IGP; National Remote Sensing Agency, 2008). In Bangladesh, ~30 per cent of the arable land is in the coastal zone, of which ~1.2 m ha soils have become saline (Islam et al., 2011); part of salinity intrusion in Bangladesh has also been due to conversion of croplands to shrimp farming (and overexploitation of natural resources).

Crop production, especially the production of rice which serves as the staple food in the region, has already been severely affected. In this study we have mostly focused on the coastal salinity caused by salt-water intrusion due to sea-level rise. However, inland salinity has been considered for some critical regions such as the IGP of Indian subcontinent, which has got degraded mostly due to salinity.

Management practices significantly impact GHG emissions from agricultural soils (Lokupitiya and Paustian, 2006). Currently, the countries in the region have adopted a range of salinity management practices including salt-tolerant varieties, irrigation water management, crop intensification and other changes in cropping patterns (e.g. double cropping) and tillage practices, in addressing the salinity issue (Sirisena et al., 2010; Abedin and Shaw, 2013). Recent studies indicate that certain cultivation systems and management practices could help soil to act as significant GHG sink (Pandey et al., 2013). However, the remedial measures adopted on salt-affected soils could enhance or feedback on future climate change if they cause high levels of net GHG emissions. The overall objectives of this project are to determine the best agricultural management practices for the salt-affected soils in the South Asian region considering net greenhouse gas emissions along with the other socio-economic benefits associated with the adopted measures and providing recommendations to the farming community and the policymakers at the national and regional level based on the project findings.

The differences in the national circumstances particularly in relation to the geography of the salinity-affected paddy areas, differential weather patterns (including extreme weather) across the region, and inability to conduct the planned research simultaneously due to certain barriers associated with institutional policy processes, etc.,led to certain deviations in the methodology and project findings (than what was planned at the proposal stage). Thus some of the information in the following sections has been reported focusing on specific countries.

## 2. Methodology

### Synthesis and harmonization of geo-data on salinity occurrence and site selection within each country

This study initially focused on climate change impacts due to sea-level rise and saltwater intrusion in coastal regions. However, geographic distance and inaccessibility to coastal salinity areas/sites was a significant challenge/constraint faced by the project collaborators. Therefore, the site/s selected for the study varied across the countries- Sri Lanka considered only the sites with salinity impacted due to sea-level rise, and inland salinity had to be considered in the rest of the countries.

Initially, a comprehensive literature survey was conducted to collect the information available on coastal agricultural areas facing salinity problem in Bangladesh, India, Pakistan, and Sri Lanka, using published scientific literature, reports and other data sources from Governmental and Non-Governmental organizations. Several studies in the region have incorporated information on salt-affected area extents, measurements on soil salinity/electrical conductivity and pH, and other relevant information, in evaluating the level of impact from salinity in the suitable salt-affected areas (e.g. Miah et al., 2010, Sirisena et al., 2010). The information was analysed considering the spatial scale of the problem, history and degree of salinity information, and crops and cropping practices affected (with particular emphasis on rice crop), and any land-use change/s due to salinity problem. The sites were selected based on such available information (including any maps), and site-level measurements on the above parameters were made and in-person surveys were conducted to supplement the existing data available within each country.

The number of sites surveyed and selected for GHG measurements is described below:

- **Sri Lanka**: Twenty-two sites covering the wet zone of Sri Lanka, extending within the districts under paddy cultivation (i.e. Galle (7 sites), Matara (5 sites), Gampaha (3 sites), Kalutara (5 sites), and Colombo (2 sites)) were surveyed for salinity levels (Table A1 and Figure A1); similarly, 50 sites within Jaffna and 13 sites in Mannar districts were studied for dry zone salinity levels, and Madampe in Puttalam district was surveyed for the Intermediate zone. The observed salinity levels range from low-and medium- to high salinity. Sri Lanka was threatened by the extreme events (i.e. droughts and floods mostly) due to climate change during the project period, and the country was ranked as No 2 under the Global Climate Risk Index, only the sites in two districts (i.e. Mannar and Puttalam) could be studied for GHG levels under different management practices.

- **India**: Indo-Gangetic plain stretch of 200 km covering three districts of Varanasi, Mirzapur and Chanduali of Uttar Pradesh state, India was mapped for salinity levels; altogether 46 sites were surveyed in India. The observed salinity levels ranged from low- and medium- to high salinity. Greenhouse gas measurements under different salinity-management practices were conducted at six sites out of the 46 sites surveyed (i.e. Rajatalab (RJT), Beerbhanpur (BBN), Mirzamurad (MZM), Baraipur (BRP), Dharhara (DHR) and Salaempur (SLM) sites).

**Evaluation of the salinity levels and conventional and new practices followed by farmers for rice management on saline soils within selected study areas**

Existing Information including the agricultural statistics and information obtained from the officers at the Agricultural Extension Services were used to collect information on the management practices and socioeconomic data in selected regions and sites within each country. In addition to that, farmer surveys were executed to collect targeted information from the farmers. The data collected included the location, crop management practices, geophysical variables (e.g., soil type, geographical coordinates) salinity, crop yields, and socioeconomic data including any information on the costs, crop price, and farmer income. The farmers' perception of the problem, the level of acceptance concerning the adoption of the different new management techniques along with their advantages and disadvantages were also documented and studied. The crop production trends at the study sites (including paired comparisons with and without the BMPs) were analysed statistically to determine the impact of the adopted management practices.

In the above analyses, site/s proposed by the officials of the agricultural extension services had to be considered mostly, as the farmers were already utilizing various combinations of BMPs recommended by them. Greenhouse gas emissions were measured under different selected BMPs or combinations and compared, as described below; however, multi-criteria decision analysis (MCDA; Cinelli et al., 2014) could not be conducted, as planned, due to insufficient site-level socioeconomic data (partly due to less confidence and reluctance by farmers in providing certain personal information).

**Estimation of greenhouse gas (GHG) emissions, including soil carbon, to assess the global warming impact of management on saline-affected soils in rice production systems**

Greenhouse gas emissions were measured/estimated using field plots with the chosen BMPs in the respective rice-growing areas within each country. Soil carbon stocks were measured for paired comparison (saline vs non-saline soils and before and after remedial management practices). Similarly, closed-chamber measurements (Hutchinson and Livingstone, 1993) of methane ($CH_4$), nitrous oxide ($N_2O$), and carbon dioxide ($CO_2$), the three main GHGs emitted from rice paddies, were taken and analysed using gas chromatography. The number of seasons and sites sampled varied by country, depending on the in-country situations, including the weather impact. The collected data on GHG emissions were analysed statistically to see if there was a significant difference in the emissions with and without the adoption of the chosen BMPs.

**Dissemination of project findings**
The project findings were shared with other stakeholders including researchers and farmer organizations through progress meetings and international meetings/conferences. Further information dissemination has been planned through news articles/items, extension products, scientific journal articles, and by extending this research further.

**The project team who conducted the research work included the following in-country collaborators and researchers:**

**Sri Lanka**: Prof. Gamini Seneviratne from Institute of Fundamental Studies (IFS) (support through Gas Chromatography facilities). Mr DN Sirisena, Deputy Director, Rice Research and

Development Institute (RRDI; support through sharing experiences and served as the key link to the agricultural department officials). Ms Archana Vathani (postgraduate student) and Ms KaushalaOpatha (undergraduate student) at University of Colombo were involved in conducting the research work.

**Bangladesh**: Dr.TofayelAhamad was technically supported by Prof. G. Miah in preparation of the salinity maps and data collections including GHG measurements. The soil analyses were supported by Prof. Mohammed Jahangir from the same university.

**India**: Prof Madhoolika Agrawal was in-charge of the research work carried out in India. Dr.Divya Pandey, Senior Research Fellow, Laboratory of Air Pollution and Global Climate Change of Baranas Hindu University, and a group of young scientists (listed in the Appendix), supported Prof. Agrawal in data collection, preparation of salinity maps, and GHG measurements.

**Pakistan**: Mr Naveed Mustafa will be working closely with the research team of Dr Bashir Ahmed, Climate Change & Geo-Informatics Programme Leader NARC, Pakistan. Dr Bashir Ahmed will serve as a senior team member (Hydrologist) and Dr Arshad Ashraf will serve as a GIS/Remote Sensing Specialist. This team will develop the regional map using country-wise salinity maps.

**Additional site-specific information and methodological details relevant to specific countries are provided below:**

**Sri Lanka:**
The salinity levels in several salt-affected areas of both wet zone and dry zone of Sri Lanka were measured using the soil samples collected at randomly selected sampling locations. Areas of salinity affected paddy soils in Jaffna & Mannar districts of Northern Dry Zone of Sri Lanka were identified with the help of Agriculture Department. Identified areas were marked District Divisional Secretariat (DSD) wise in the district map/s. Soil samples were collected in the identified locations, and the sampling points were demarcated by the Global Positioning System (GPS). Soil texture, pH, and electrical conductivity (EC; in 1:5 soil: water extract) were measured in the collected samples. Electrical conductivity values will be used in preparing thematic map on soil salinity. District wise maps of soil salinity have been prepared using Arc GIS 10.0. The current maps will be further improved to indicate the different levels of salinity (Table 2.1; DN Sirisena, personal communication; RRDC, 2013). Similarly, selected sites from salt-affected areas in 5 districts of the Wet Zone of Sri Lanka (Table 2.2) were visited and soil samples were collected. Each site was visited twice in two-week intervals and 6 samples of soil were collected randomly from each paddy site.

Table 2.1. Salinity ranking based on measured EC (dS $m^{-1}$)

| 1:5 (soil: water) | Saturate extract | Effect |
|---|---|---|
| <0.15 | >2.0 | None saline |
| 0.16 – 0.30 | 2 - 4 | Slightly saline |
| 0.31 – 0.60 | 4 - 8 | Moderately saline |
| 0.61 – 1.20 | 8 - 16 | Very saline |
| >1.20 | >16 | Highly saline |

(Source: DN Sirisena, personal communication; RRDC, 2013)

Statistical analyses were carried out using Minitab Version 18.0. Two sample t-tests were carried out for comparison of saline vs non-saline sites and the salinity levels during wet period vs dry period at each site. Socioeconomic data were analysed as the percentage values based on the responses of the paddy farmers for different questions in a questionnaire prepared for the purpose.

Table 2.2. The sampling sites in districts of the Wet Zone of Sri Lanka

| District | Site |
|---|---|
| Colombo | Kahapola ( 1 site) |
| Gampaha | Katana (2 sites) |
| Kalutara | Walagedara (1 site)<br>Iththapana (1 site)<br>Paadagoda (1 site) |
| Galle | Bentota (1 site)<br>Ranthotuwila (2 sites)<br>Weragoda (1 site)<br>Ambalangoda (1 site)<br>Ahungalla (1 site)<br>Gonapinuwala (2 sites) |
| Matara | Dickwella (2 sites)<br>Godagama (2 sites)<br>Mirissa (1 site) |

The paddy cultivation has been dramatically affected by the alternating droughts and floods in the country, which has been ranked as No. 2 under the Global Climate Risk Index. The prevailing weather delayed project initiation, and by far the GHG measurements and gas chromatography analyses under different BMPs (along with soil carbon and bulk density measurements) could be conducted at only two sites (Table 2.3), although a significant number of sites could be surveyed for measuring salinity for preparation of the maps during the study period, as described above.

Table 2.3. Soil physicochemical properties (0-15 cm depth) at the beginning of the project at the two experimental sites used for GHG measurements in Sri Lanka.

| Soil physicochemical properties | Madampe[1] | Mannar[2] |
|---|---|---|
| Bulk density | 0.98 $g/cm^3$ | 1.23 $g/cm^3$ |
| pH | 3-4 | 5.5-7.5 |
| Soil organic carbon content | 0.46% | 0.54% |
| Electrical Conductivity (EC; saturated) | 3-4 | 3-4 |

1- Madampe site (7.4972oN, 79.8413oE) is located on the western coast of Sri Lanka in the intermediate zone with an annual rainfall of 1500-2000mm; 2- Mannar site (8.7748oN, 79.9891oE) is located on the northern coast of the dry zone of Sri Lanka 1-with an annual rainfall of 1000-1250mm in Maha season.

## Experimental design for GHG measurements in field plots under different BMPs:

Table 2.4 depicts the setup of the experiment in plots provided with four different treatments (i.e. a combination of management practices in each, including one control).

Table 2.4. Applied BMPs in different plots of the selected sites

| Plots | Mgt* 1 (a) | Mgt 2 (b) | Mgt 3 (c) | Control (d) |
|---|---|---|---|---|
| water level until milking | 2-3 cm | 2-3 cm | intermittent | regular |
| organic matter addition | Yes | Yes | Yes | No |
| broadcasting (B) or transplanting (T) | B | T | T | B |

Mgt*- Management combination

Newly improved saline tolerant variety BG 310 was cultivated (which has a response for salinity levels up to 8 dS/m). Average crop duration is 100 days. After proper ploughing, puddling and levelling (at the same time compost was also mixed with the soil for the relevant plots). 28-days old seedlings were manually transplanted at a density of 2 seedlings per hill with spacing of 15cm x10 cm (row-to-row and plant-to-plant). All four plots were uniform and had the same dimensions (4x5 $m^2$). Pest management and weed management were done as needed.

**Gas sampling and estimation**

Closed chamber method was used to collect gas samples from plots. The fan was connected and activated five minutes before sampling. A 20-ml syringe was used to obtain gas samples from chambers and the collected samples were transferred into pre-evacuated gas-tight vacutainers. The temperature inside the chamber was measured at every sampling. Samples were collected at 0-minute, 30-minute and 1-hr intervals (intervals between 11 am to 12 noon weekly). Collected gas samples were analyzed using gas chromatography (Shimadzu Model 9 AM) equipped with a flame ionization detector (FID) and thermal capture detector (TCD). Carboxin 1010 capillary column width 30 mm x 0.32 mm was used to detect the GHG and Helium was used as the carrier gas at a flow rate of 30 ml/ minute and Hydrogen as the fuel gas. The injector, the column and the detector temperature were maintained at $150^o$ C, $40\ ^o$ C and $200\ ^o$ C respectively.

The following equation was used to estimate GHG emissions:

$$F = S*V/A$$

Where,
F is the $CO_2/CH_4$ flux from the paddy field which is expressed in mg $m^{-2}$ $hr^{-1}$
S is the slope of regression obtained by plotting concentration of $CO_2$ $V_s$ time as recorded during sampling
A is the area covered by the chamber ($m^2$)

**Plant growth analysis**

Plant growth parameters (leaf area, leaf number and tiller number) were measured at weekly intervals. Leaf area was measured by a portable laser leaf area meter (Model LI 3000C, USA). Rice yield was determined from the total plot area by harvesting.

**India:**

During the first year of study, soil was sampled from a stretch of over 200 km where the salinity affected land was reclaimed by using various agronomic strategies (organic fertilizer, inorganic N and gypsum salt) and quantified pH, conductivity, SAR, CEC, ESP, etc. to rank the site for the level of salinity. The contour mapping was done to make the salinity level at geographical grids more apparent. Out of the mapped sites, six reclaimed landmasses of the region were selected for further study; i.e., Rajatalab(RJT) and Beerbhanpur (BBN) with lower salinity and Mirzamurad (MZM), Baraipur (BRP), Salaempur(SLM) and Dharahara (DHR) with higher salinity were selected for further studies (Table 2.5). Farmers were interviewed to know about their reclamation strategies adopted in the past and any change in yield of rice if observed. The adopted practices for reclamation included usage of organic and chemical fertilizers, managed irrigation practices and changing genotypes of the rice crop and rotation of crops.

Table 2.5. Study site characterization of the sites in India

| Site | Clay (%) | EC (dS $cm^{-1}$) | Fertilizers used | Irrigation | Cation | Cropping sequence |
|---|---|---|---|---|---|---|
| Rajatalab (RJT) | 8 | 0.19 | Organic fertilizer | Underground Aquifer | K>Mg> Na>Ca | Rice-wheat |
| Beerbhanpur (BBN) | 11 | 0.34 | Mainly chemical | Underground Aquifer | Ca>Mg>K>Na | Rice-wheat |
| Mirzamurad (MZM) | 12 | 0.50 | Organic + Chemical | Canal irrigation | Ca>K> Mg>Na | Rice-mustard |
| Baraipur (BRP) | 8 | 1.35 | Mainly chemical | Canal irrigation | Ca>Mg>K>Na | Rice-wheat |
| Dharhara (DHR) | 10 | 1.65 | Mainly organic | Canal Irrigation | Ca>K> Na>Mg | Rice-fallow |
| Salaempur (SLM) | 12 | 2.52 | Mainly chemical | Canal Irrigation | Ca>K> Na>Mg | Rice-wheat |

Soil pH, EC (in 1:5 soil: water extract), texture, and total organic carbon (Walkley and Black, 1934) were assessed and cation exchange capacity (CEC) was measured using ammonium acetate as cation extractant and the exchangeable cations were then assessed by Atomic absorption spectrophotometer (Model AAnalyst 800, Perkin–Elmer, USA). CEC, Sodium absorption ratio (SAR). Exchangeable sodium percentage (ESP) and Exchangeable sodium ratio (ESP) were calculated using standard formula from exchangeable cations (Harron et al., 1983). Total cation concentrations were analyzed by using Atomic absorption spectrophotometer after diacid digestion with perchloric acid and nitric acid in 4:9 ratios. Anions were estimated by ion chromatography. Soil (0.5 g) was ultrasonicated in 25 ml of extra pure water and then filtered through 25 µm filter paper. Then filtrate was analysed by Metrohm ion chromatography (930 compact IC, Switzerland) which uses Metrosep C4 column for cations and MetrosepA Supp.5 column for anions. From each site, 15 plants were harvested and weight of 1000 grains was quantified.

Significantly different means for different parameters between different sites were calculated using one-way ANOVA. The statistical analysis of all data was performed by using the SPSS software (version 16.0).

**Pakistan:**
The tabulated overall project progress by Pakistan collaborators including additional methodological information is given in Annex 1 (Table A1).

**Bangladesh:**
The progress presentation by collaborator/s from Bangaladesh at the Progress review workshop held on January 2019 in Colombo, Sri Lanka is given in Annex 2.

## 3. Results & Discussion

### Sri Lanka

**Sites in Intermediate zone and Dry Zone (Madampe and Mannar, respectively):**

The area of the field study in Madampehas acid-sulphate soil with a pH range of 3.0 to 4.0. Only 50 -60 % of the crops survived in the broadcasting plots as the plants could not tolerate the salinity through 90 % of the seeds were germinated: after 14 days the tips of the leaves were burnt and wilt off eventually.

The salinity tolerance increases with age during the tillering phase of growth and it decreases from panicle formation stage to the flowering stage leading to reduced grain yields. The strawweight and total number of tillers seem to be less affected than grain yield and the number of productive tillers. Also, high salinity can delay the setting of the inflorescence, while increasing the number of sterile spikelets (FAO, 2019). Keeping the right soil moisture content during tillering phase to milking phase would help the crops to produce high yields. Application of inorganic fertilizers causes $N_2O$ emission. Organic amendments seem to be quite effective in improving salinity while limiting $N_2O$ emission to undetectable levels, as we observed in the current study (Table 3.1; $N_2O$ not reported due to very low concentrations)

Table 3.1. Variation in physiological parameter and yield characteristics

| | Mgt 1 | | Mgt 2 | | Mgt3 | | Control | |
|---|---|---|---|---|---|---|---|---|
| | Madampe | Mannar | Madampe | Mannar | Madampe | Mannar | Madampe | Mannar |
| CH4 Average (mg/m2 hr) | 0.5562 | 0.904 | 0.5656 | 0.8643 | 0.3237 | 0.5804 | 0.37833 | 0.509 |
| CO2 Average (mg/m2 hr) | 249.6 | 209.31 | 194.11 | 213.37 | 261.31 | 200.98 | 327.73 | 258.22 |
| Seedling height (cm) | 26-28 | 28-30 | 31-33 | 31-33 | 31-33 | 31-33 | 26-28 | 28-30 |
| Number of tillers per plant | 8 | 8 | 10 | 14 | 12 | 14 | 6 | 8 |
| Leaf area (cm2 per hill at flowering stage) | 158.78 | 163.42 | 174.64 | 189.36 | 191.28 | 192.56 | 156.24 | 162.92 |
| Number of panicle bearing tillers | 7 | 8 | 10 | 13 | 12 | 12 | 6 | 8 |
| Number of grains per panicle | 160 | 172 | 184 | 178 | 180 | 192 | 152 | 164 |
| Number of filled grains per panicle | 88 | 92 | 126 | 128 | 126 | 130 | 93 | 90 |
| Yield kg/20 m2 | 5.6 | 6.4 | 9.7 | 13.1 | 9.9 | 12.8 | 4.8 | 6.8 |

$CO_2$ was emitted throughout the growth of rice. High $CO_2$ flux during the initial growth stages of rice could be attributed to high organic carbon. From panicle initiation stage to flowering stage $CO_2$ emission was sunk due to the rapid increase in the rate of photosynthesis which eventually decreased towards the harvesting stage (Figures 3.1 and 3.2).

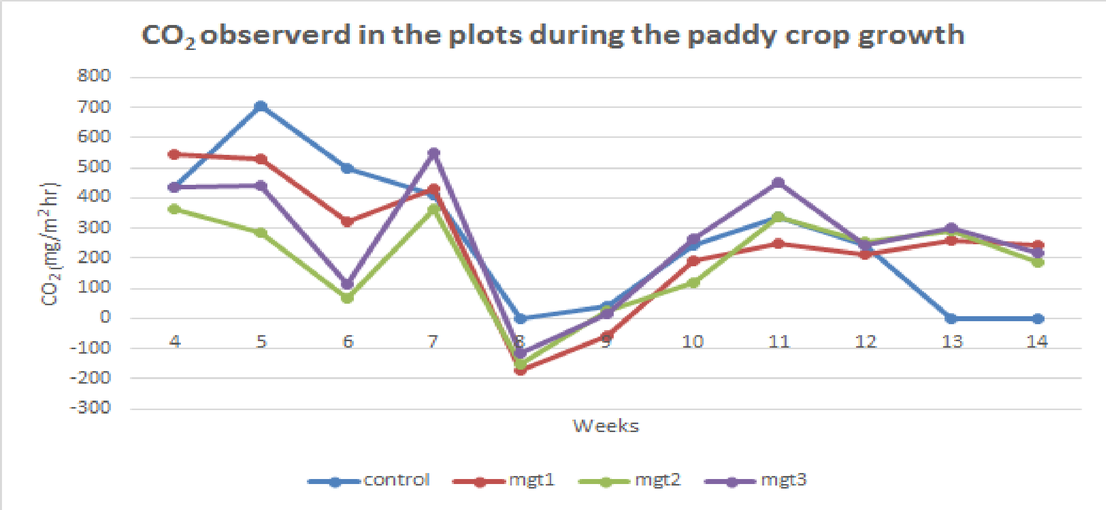


Figure 3.1. The flux of $CO_2$ over time in Madampe

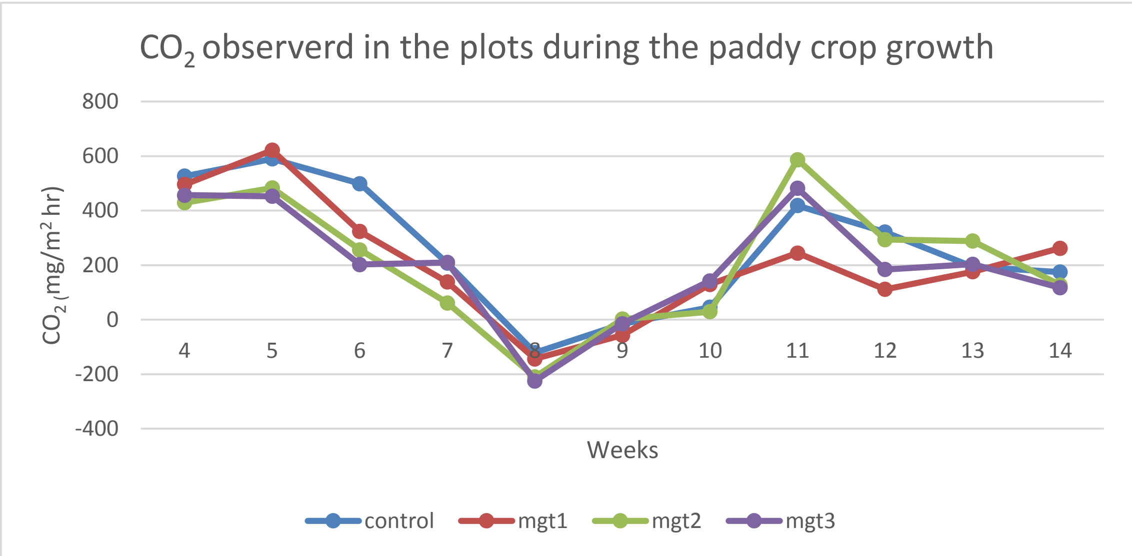


Figure 3.2. The flux of $CO_2$ over time in Mannar

The $CH_4$ emission gradually increased until the eighth week and gradually decreased until the 14th week. Mgt 1 and Mgt 2 showed the highest emission levels due to flooded irrigation method (Figures 3.3 and 3.4).

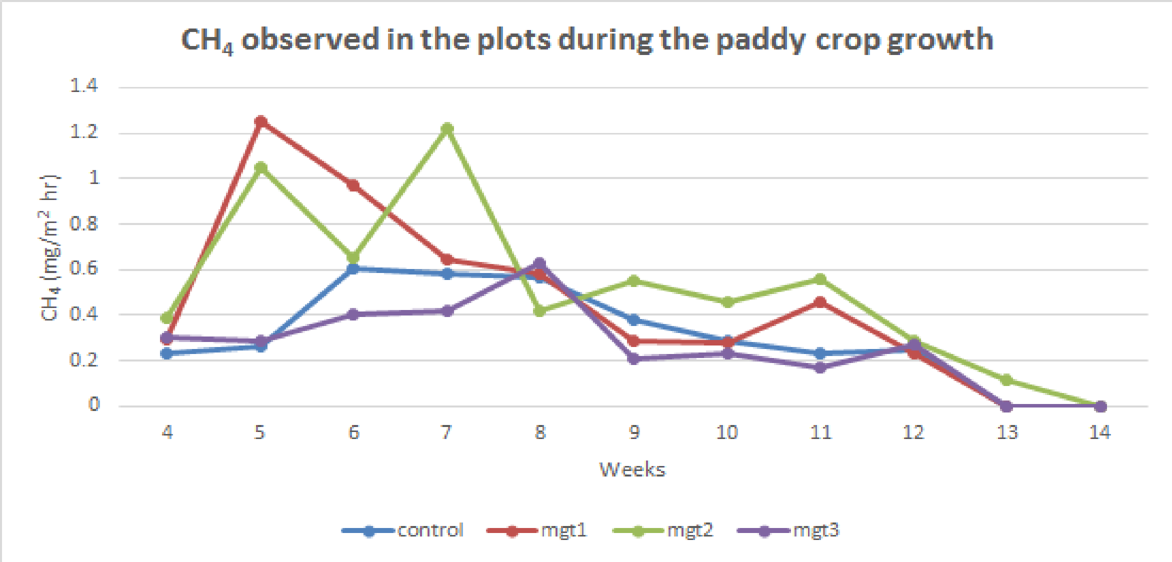

Figure 3.3. The flux of CH4 over time in Madampe

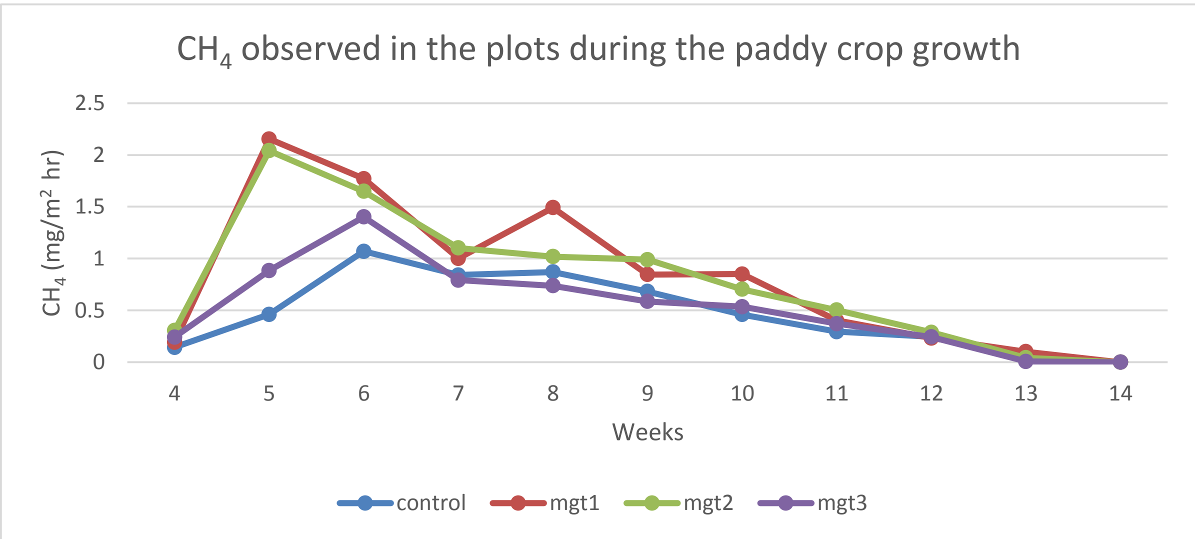

Figure 3.4. The flux of CH4 emitted over time in Mannar

The salinity maps of Jaffna and Mannar Districts are given in Figure 3.5. These maps will be further improved to indicate different levels of salinity, utilizing site-level EC measurements.

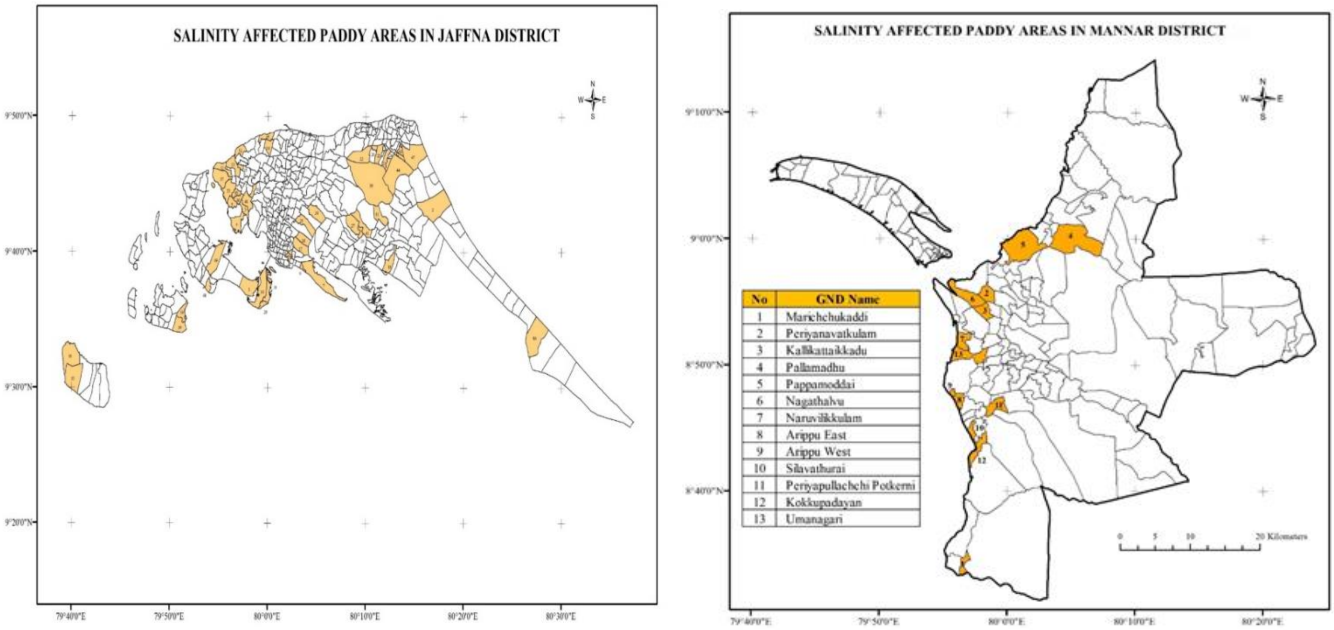


Figure 3.5. Sites in the wet zone: Measured coastal salinities for the sites in wet zone districts are illustrated in Figures 3.6, 3.7, and 3.8 (Opatha, 2018).

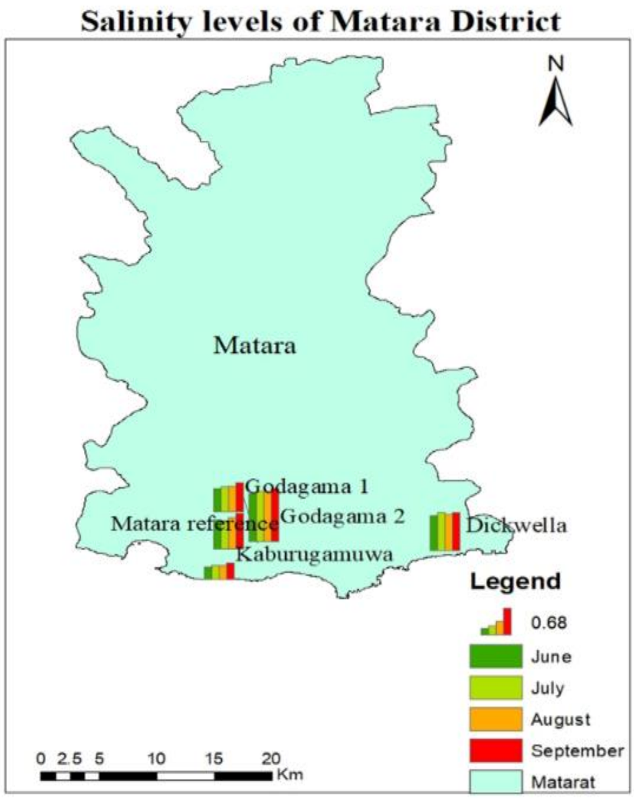


Figure 3.6. Maps showing the change of the salinity levels of the Matara district with time (The height of the bars indicates the variation over time)

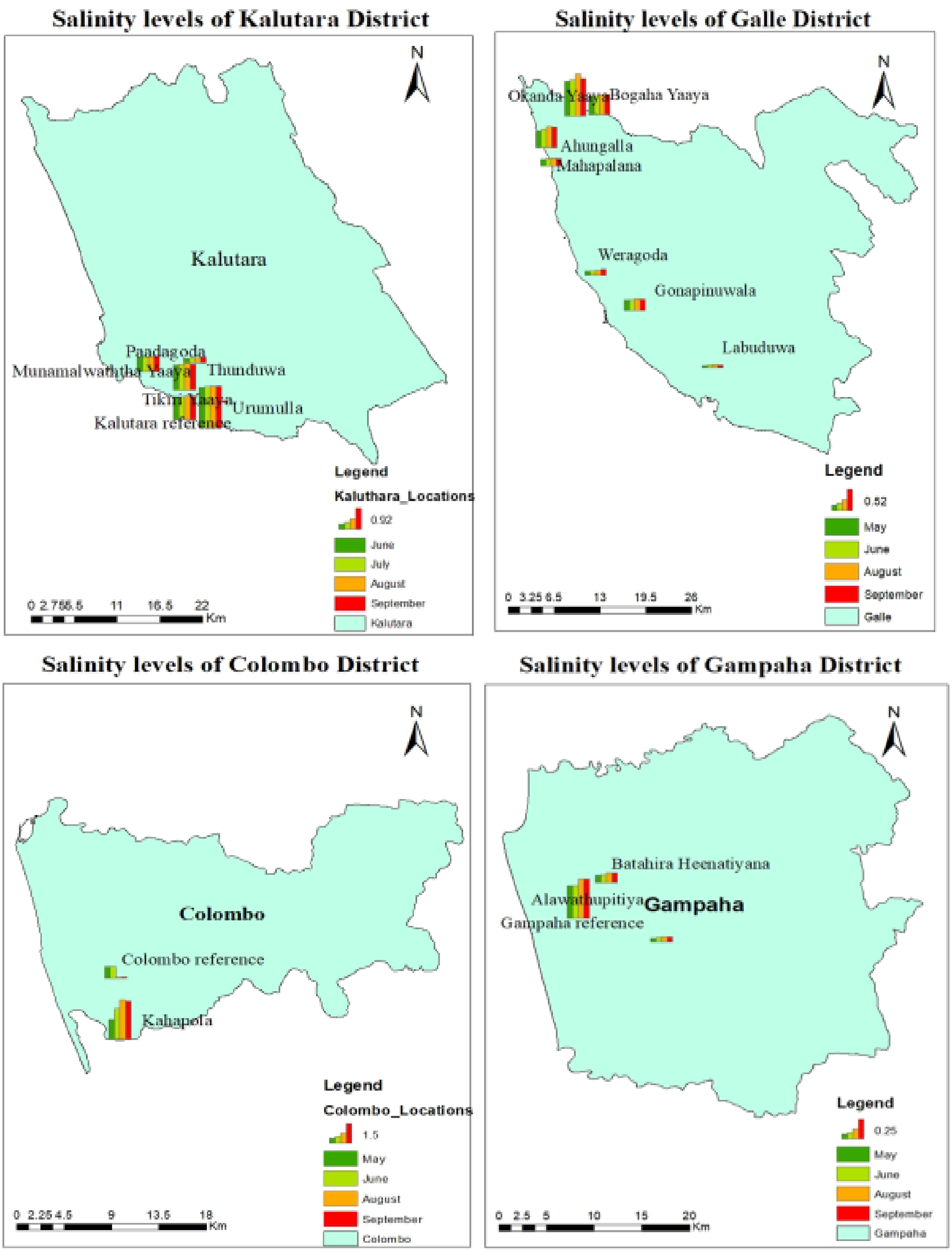


Figure 3.7. Maps showing the change of the salinity over time (monthly changes) in Colombo, Gampaha, Kalutara, Galle districts (The height of the bars indicates the variation over time)

The majority of the saline sites surveyed had high salinity, with EC values greater than 0.6 dS $m^{-1}$in 1:5 extract; the highest salinity levels over 2.8 dS $m^{-1}$ were observed at Kahapola site in Colombo District during the dry period in August and September in 2018.

The district-level maps were prepared separately for the salinity levels in dry and wet periods. Figure 3.8 shows the variation shown for Colombo district. According to the statistical analyses, there was a significant difference ($p < 0.05$ for t-tests) between the saline and non-saline soils in the sites surveyed for salinity. In general, all the districts had higher salinity in August, which is considered a dry month, and the salinity levels were low in May and June. Overall, the salinity in the dry period was comparatively higher than the wet period for all the districts as well. However, there was no statistically significant difference between the salinity during dry period and wet period across the majority of the sites. Few sites showed a statistically significant difference between the mean salinity in the wet period and dry period (i.e. reference (non-saline) sites of Kalutara, Colombo, Galle, and salinity-affected sites at Godagama, Mahapalana, and Weragoda).

In the farmer responses towards the socioeconomic survey, it was found that majority of the farmers do not use salt-tolerant varieties in their fields even though the salinity levels are high. Instead, many of them use traditional paddy varieties since they believe them to have a high tolerance for salinity conditions. It was observed that in the salinity-affected areas the application of chemical (inorganic)) fertilizers by farmers is minimum, and they mostly use a combination of paddy husk, Gliricidia (*Gliricidiasepium*), dried cow dung, and straw to desalinize the land. According to the farmers, leaving rice residues (i.e. straw) in the field after harvesting helps in controlling the salinity levels up to a certain extent. Application of gypsum has also helped them reduce salinity levels. Gypsum provides a direct source of calcium ions (Ca2+) to replace exchangeable sodium and the sodium can then be leached from the soil with irrigation water or rainfall (Gharaibeh, Eltaif, & Shra, 2010).

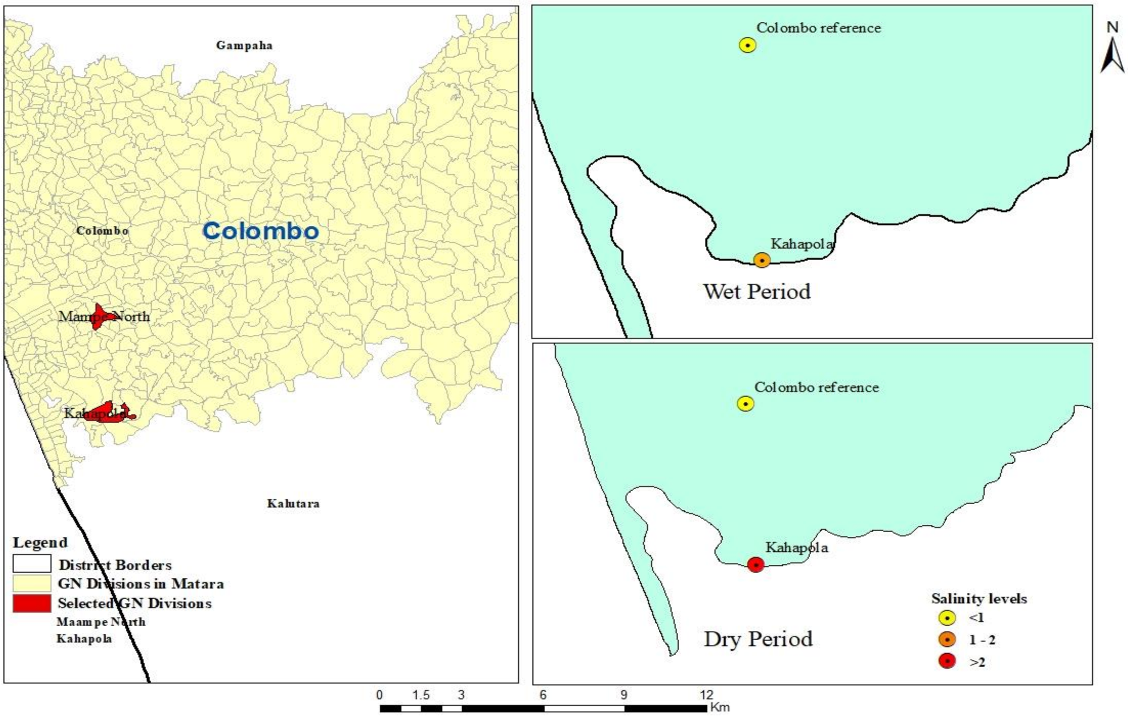


Figure 3.8. Salinity map of Colombo District for wet and dry periods

**India**

Soil mapping is necessary for spatial planning of land management, so we mapped our study region by sampling soils from 48 sites and the mapped region revealed the predominance of medium salinity in most of the part while severe saline areas were observed close to the western bank of Ganges in Chandauli district. Salinity map along with the study sites are shown in Fig. 3.6. Low to medium salinity was more predominant at most of the latitudes and longitudes. The lowest saline areas are more localized in the Varanasi district farther from the eastern bank of Ganges (Figure 3.8). The maximum value of 10 is the result of extrapolation (Figure 3.9).

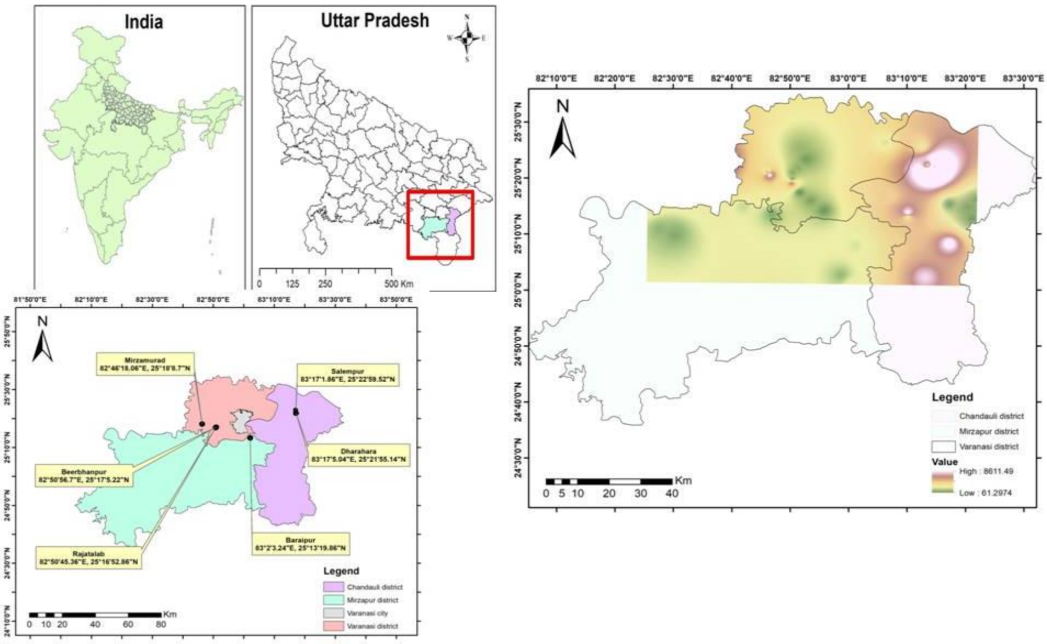


Figure. 3.8. The study sites in India and the salinity map of study sites

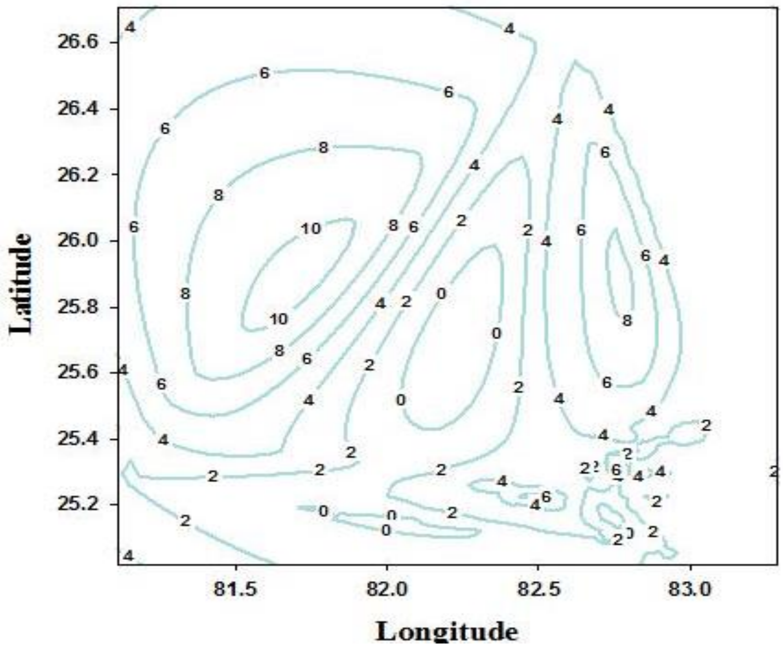


Figure. 3.9. Contour map for salinity levels in the region

During the study duration, the rainfall was more during 2018 than at 2017, but the temperature was uniformly high thus more of underground aquifer or open canal water was used for irrigation. Based on EC and soil sodium concentration, highest salinity was recorded at SLM followed by DHR, BRP, MZM and BBN and least in RJT. In the higher salinity area, canal irrigation is predominant which probably has led to upward movement of salt by rising water table caused due to over-irrigation the fields. High rainfall during 2018 in higher clay containing soil of MZM, SLM and DHR created a water-logged condition which resulted in appearance of secondary salinization. Exceptionally high calcium in saline area of MZM and DHR may have caused drainage congestion. RJT showed minimum content of all measured cations except Zn during 2018 while highest salinity at SLM during both the years is because of high sodium content. BRP displayed highest calcium and MZM showed highest potassium and magnesium during 2018 (Tables A3 and A4). In general, high concentrations of studied cations and anions were observed during 2017 than during 2018 with few exceptions. Significant increases in rainfall lead to increases in leaching, loss of nutrients and increasing acidification depending upon the buffering pool existing in soils (Karmakar et al., 2016). MZM showed increased in Na at harvest during 2017 and 2018, while at SLM, Na reduced at harvest during 2017 and increased during 2018 (Tables A3 and A4). This suggests that poor field drainage even with good rainfall can lead to accumulation of salinity contributing ions. Higher sulphate ion at SLM could be due to addition of gypsum or pyrite (Tables A3 and A4).

The pH was maximum at SLM followed by DHR and the minimum was at BBN both during 2017 and 2018 (Tables A5 and A6). The EC of high saline soil was higher during harvest compared to early-stage soil. On the other hand, at low to medium saline soils there were no changes in EC. This change reflects malpractices (untimely addition of inorganic nutrients specially urea) during cultivation at high saline soil. The EC during initial age corresponded to pH increase while during harvest there was a negative correlation between the two. Decreasing soil pH directly increases the solubility of few ions, thus increases the EC.

CEC is a measure of cations that can be retained on the soil particle surface. Negative charges on the surfaces of soil particles come mainly from clay bind positively charged atoms or molecules (cations) but also allow these to exchange with other positively charged particles in the surrounding soil water (McKenzie et al., 2004). Different sites showed different trends for CEC, which suggest more role of agricultural practices adopted. During 2017, maximum CEC was observed at MZM at early growth stage and harvest. During 2018, CEC was highest at MZM but at harvest, maximum CEC was observed at BRP (Tables A5 and A6). Although SAR which is a measure of the amount of sodium relative to calcium and magnesium in the soil water and other related parameters like ESP and ESR were higher at SLM during 2017 (Table A5). This shows the higher possibility of nutrient binding with the negative charges at MZM.

Maximum organic carbon was observed at BBN at early stage and RJT at harvest during 2017 while during 2018, the organic content was lesser at harvest at RJT (Tables A5 and A6). This could lead to high $CO_2$ emissions during rice cultivation (Munoz et al., 2010).

**Gaseous emissions**

Sites with low to medium salinity (RJT, MZM and BRP) acted as a source of $N_2O$ during vegetative growth in standing water (Table 3.2). Maximum $N_2O$ emission was observed at MZM where maximum clay was observed which created a water-logged condition. Saturated soils favouring anaerobic processes lead to denitrification and thus $N_2O$ emission.

Table 3.2. The flux of nitrous oxide (mg/m$^2$/h) at different growth stages during the time of rice cultivation

| Sites | V | PR | R | PoR | F |
|---|---|---|---|---|---|
| RJT | 0.048 | 0.058 | 0.157 | 0.330 | 0.691 |
| BBN | - | 0.126 | 0.090 | 0.332 | -0.27 |
| MZM | 0.346 | -0.036 | 0.099 | -0.977 | 0.757 |
| BRP | 0.137 | -0.068 | 1.009 | -0.048 | 0.690 |
| DHR | -0.126 | 0.190 | 0.383 | - | -0.267 |
| SLM | -0.048 | -3.500 | -0.148 | - | 0.780 |

V: Vegetative; PR: Pre-reproductive; R: reproductive; PoR: Post reproductive; F: Fallow

The $NH_4^+$fertilizers cause higher $N_2O$ emissions under saturated conditions (Tenuta and Beauchamp, 2003). However, no significant correlation between $N_2O$ emissions and pH-value were found (Pilegaard et al., 2006). More nitrogen input was made on sites with medium to high salinity to get a better yield. N- Fertilizer application during reproductive stage onset led to $N_2O$ emission at all sites except SLM, with maximum at BRP having medium salinity. Consumption of $N_2O$ at all the growth stages of rice at SLM may be attributed to low mineral concentration of N (Chapwis-Lardy et al., 2007), even the medium saline soil showed consumption of $N_2O$ at pre-reproductive and post-reproductive stage when N-fertilizer was not applied. $N_2O$ emission observed at RJT during all the growth stages except vegetative stage of rice was attributed to nitrification of soil microbes.

$CO_2$ remained positive for most of the duration of rice cultivation and there were no temporal trends (Table 3.3). There was also an estimated net $CO_2$ sink in medium saline soil of BBN and BRP during the pre-reproductive stage and DHR during post-reproductive which could be attributed to anaerobic environment where respiration is reduced (Wang et al., 2017). The reason for temporal variations in $CO_2$ was the difference in carbon levels at different sites, which released different levels of $CO_2$ upon warming. RJT with high organic carbon released lesser $CO_2$ during vegetative stage owing to the higher utilization efficiency of plants growing under low salinity as well as the waterlogged anaerobic environment created for rice transplantation. Ploughing and irrigation are widely reported o increase soil respiration by exposing the organic matter and its availabilities for microbial activities (Lal, 2004). Fertilizer application also improves microbial activities resulting into the pulses of $CO_2$ emissions as observed during pre-reproductive stage upon N-application except BBN and BRP where the peak was rather achieved at reproductive stage due to poor drainage of the soil (Contosta et al., 2011).

Table 3.3. The flux of carbon dioxide (mg/m$^2$/h) at different growth stages during the time of rice cultivation

| **Sites** | **V** | **PR** | **R** | **PoR** | **F** |
|---|---|---|---|---|---|
| RJT | 304.9 | 84921.0 | 91.8 | 3820.0 | 875.5 |
| BBN | 551.4 | -8460.1 | 2011.0 | 1722.3 | 1015.5 |
| MZM | 313.3 | 2781.4 | 411.6 | 1474.4 | 3645.5 |
| BRP | 931.3 | -1211.4 | 10027.0 | 47.80 | 3086.6 |
| DHR | 324.9 | 924.9 | 418.7 | -156.5 | 12665.0 |
| SLM | 360.3 | 12.5 | 753.5 | 33.90 | 1045.9 |

V: Vegetative; PR: Pre-reproductive; R: reproductive; PoR: Post reproductive; F: Fallow

Table 3.4. The flux of methane (mg/m$^2$/h) at different growth stages during the time of rice cultivation

| **Sites** | **V** | **PR** | **R** | **PoR** | **F** |
|---|---|---|---|---|---|
| RJT | -0.26 | 0.292 | -0.195 | -0.195 | 0.380 |
| BBN | -0.069 | 0.214 | 0.058 | -0.063 | -0.630 |
| MZM | 0.0079 | 0.195 | -0.029 | -0.360 | 0.593 |
| BRP | 0.0088 | 0.136 | -0.323 | -1.21 | -0.490 |
| DHR | 0.0015 | 0.147 | -15.57 | -1.03 | -0.667 |
| SLM | 0.00035 | 0.069 | -1.63 | 0.437 | 0.210 |

V: Vegetative; PR: Pre-reproductive; R: reproductive; PoR: Post reproductive; F: Fallow

The sites with low to medium salinity majorly acted as sink of $CH_4$ except at pre-reproductive stage at RJT (Table 3.4). The increase in $CO_2$ at RJT and BBN offset the $CH_4$ increase during vegetative growth. Also, aerobic soil oxidizes $CH_4$ due to stronger methanotrophy and weak methanogenesis. At the pre-reproductive stage, positive methane values suggest predominance of methanogenesis. High saline soil of SLM constantly acted as source of $CH_4$

except during pre-reproductive stage whereas least saline soil only acted as source of $CH_4$ during pre-reproductive stage.  High saline soil at DHR with better organic amendments disrupted methanogenesis and thus negative values were obtained at later stages of growth.

**Rice yield**

Salinity caused negative impacts on plants by nutrient imbalances and disturbances in plant-water relationship, leading to a loss in crop yield. During 2017, maximum rice yield was observed at RJT with minimum salinity levels followed by DHR and minimum yield was observed at BBN (Fig. 5), while at SLM, reproductive parts did not set. During 2018, maximum yield was maintained at DHR while minimum yield was observed at SLM (Figure 3.10).

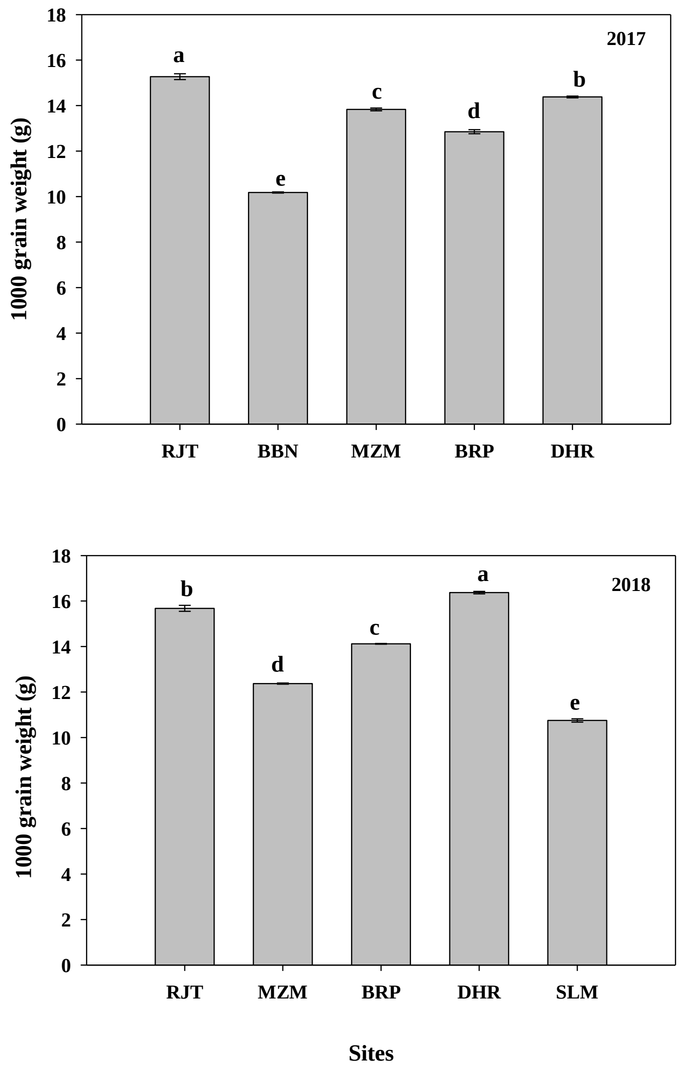


Fig.3.10. Test weight (1000 grain weight) of rice at different sites varying in salinity levels during 2017 and 2018

## 4. Conclusions

- Generation of salinity risk assessment map for agricultural areas in India, Pakistan, Bangladesh, and Sri Lanka/South Asia,): Salinity in the surveyed region ranged from low - medium-high levels and the identified reasons for salinity are salinity intrusion in coastal areas due to sea-level rise, evapotranspiration, poor irrigation practices and usage of fertilizers having high salt index. Completion of salinity maps is still underway in the majority of the countries.

- Identification of the conventional and new management practices followed by farmers which offer better management of salinity impact: High saline soil which could not be used for cultivation was made fertile by applying dye, urea, single super phosphate, potash, pyrite and gypsum and by regular cultivation. To improve the soil quality and texture, organic matter including cow dung and straw, Gliricidia, etc., were also used.
- The assessment of salinity levels, yield responses and socio-economic returns under different management practices: The salinity levels in non-saline and saline sites studied in Sri Lanka mainly in wet zone, showed statistically significant difference. The yield losses under saline conditions were significant compared to the non-saline one but organic amendments have helped improve the soil conditions and yield as observed at DHR site, India, and some sites in Sri Lanka, based on the farmer surveys.
- Integration of agronomic yield, socio-economic returns and net GHG emissions to identify the best and more sustainable practices: Application of inorganic fertilizers alone increases the GHGs emissions but organic amendments seem to be the best option improving salinity as well Farmers seem to have realized this and the application of chemical fertilizers were the minima in most salinity-affected soils. Although Rice-wheat and rice-fallow are the most common cultivation sequence of IGP region, concerning rice yield and GHG emissions, the best sequence is rice-fallow with organic amendments and appropriate irrigation practices. Based on the findings for Sri Lanka, transplanting seedlings is the most effective way to minimize the crop loss. Rearing nurseries in good soil and then transplanting to salinity-affected soil has been one of the sustainable BMPs. Out of all the management options, Mgt 3, which had transplanting, the addition of organic matter, and intermittent irrigated water levels was identified as the BMP in terms of the net GHG emissions and overall productivity (i.e. yield) giving socio-economic benefits.

## 5. Future Directions

**Sri Lanka**: Greenhouse gas emission sampling through measurements were restricted only to two sites due to the impact from unexpected extreme weather conditions, although the surveying salinity for mapping could be done across a substantial number of sites. Further sites and seasons need to be sampled for GHG emissions.

**India**: An experiment can be planned with many other amendments approaches along with different genotypes of rice.

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*APPENDIX*

## Annex 1

Progress Report of **"Identification of the best agricultural management practices with better greenhouse gas benefits in salinity affected areas of South Asia**" (Pakistan Side)

***Naveed Mustafa**** and ***Dr. Bashir Ahmad*****
* Senior Scientific Officer
** Principal Scientific Officer
Climate, Energy and Water Research Institute (CEWRI), National Agricultural Research Centre (NARC), Park Road Chack Shahzad, Islamabad, Pakistan

Table A1. Project progress shown by Pakistan

| S. No | Specific Objective | Progress |
|---|---|---|
| **1.** | Review the overall salinity status in agricultural lands in the region | Report developed through Review the overall salinity status in agricultural lands of Pakistan. |
| **2.** | Synthesis and harmonization geo-data on salinity occurrence | Synthesis and harmonization Geo-Data Salinity Occurrence<br>• Map of Cropping Pattern of Rice Growing areas of Pakistan<br>• Map of Surface salinity of Rice Growing areas of Pakistan<br>• Map of Ground Water Quality of Rice Growing areas of Pakistan<br>• Map of soil types Pakistan<br>• Map of Surface salinity of Rice Growing areas of Punjab<br>• salinity of Rice Growing areas of Sindh |
| **3.** | Identification of 'best management practices' (for salinity amelioration on rice systems) within selected sub regions in each country using multi-criteria selection methods | Through literature survey and FDGs with rice grower's farmers and meetings with research and extensions departments identified following 'best management practices' (for salinity amelioration on rice systems) of Pakistan.<br>• Water use efficiency and conservation<br>• Irrigation System Design<br>• Identification of Water and Soil Amendments for the Specific Site Conditions<br>• Controlling erosion and Run off<br>• Leaching and flushing<br>• Raised Crop beds<br>• Adding Calcium<br>• Cultivation, Topdressing, and Soil Modification<br>• Drainage and Sand-Capping<br>• Nutritional Practices on Saline and Sodic Sites<br>• Change in date of transplanting |
| **4.** | Assessment of the impact of management on greenhouse gas emissions (GHGs; | For assessment of greenhouse gas emissions (GHGs) in Rice growing areas of saline-affected soils through satellite data in Rice |

| | | |
|---|---|---|
| | including soil carbon) in saline-affected soils under rice production systems | Growing areas of Sheikhupura district of Punjab.<br>• Location map of Sheikhupura district of Punjab, Pakistan<br>• Map of Surface salinity (Strongly Saline) of Sheikhupura district of Punjab, Pakistan<br>• Map of Surface salinity Medium Saline) of Sheikhupura district of Punjab, Pakistan<br>• Map of Surface salinity (Slightly Saline) of Sheikhupura district of Punjab, Pakistan<br>• Map of soil types Sheikhupura district of Punjab, Pakistan |
| **5.** | Integration of agronomic yield, socio-economic returns and net GHG emissions (objectives 3-4) to identify and recommend the best and more sustainable, climate-friendly practices. | For assessment of greenhouse gas emissions (GHGs) in Rice growing areas of saline-affected soils through satellite data in Rice Growing areas of Sheikhupura district of Punjab. The LANDSAT MSS, LANDSAT+ images downloaded for accurately assessment of area under rice cultivation. The Sheikhupura district of Punjab is identified for assessment of Green House Gasses (GHGs) such as Methane from Paddy Rice through using Geo-Informatics tools. As Punjab, 66% area under rice cultivation as compare to 24% in Sindh, 1% in KPK and 6% only in Balochistan of rice grown area.<br>For assessment of Methane production from paddy rice through satellite data in Rice Growing areas following data downloaded.<br>o **LANDSAT Data**<br>▪ LANDSAT MSS<br>▪ LANDSAT ETM<br>▪ LANDSAT ETM+<br>o **MODIS Data**<br>▪ MOD16A2-ET<br>▪ MOD11A2-LST<br>o **Statistical Data**<br>▪ Statistical Data of Rice Growing Areas of Pakistan (Statistical Division of Pakistan)<br>o **Meteorological Data** (Pakistan Meteorological Department)<br>▪ Temperature<br>▪ Rainfall (Precipitation)<br>▪ Humidity<br>o **TRRMM Data**<br>The analysis of above data in progress. |
| **6.** | Establishment of a network of in-country and regional collaborators within the project area | For Establishment of a network of in-country following National Research Institute identified which are working on different aspect of rice.<br>• Rice Research Institute, Kalashah Kaku (Lahore), Punjab |

| | | |
|---|---|---|
| | | • Rice Research Institute, Kala Shah Kaku, Punjab<br>• Rice Research Station, Bahawalnagar, Punjab<br>• Rice Research Institute, Dokri, Sindh<br>The networking developed during execution of this project with regional collaborators will continue for future consortium linkage for development of new proposals in the same lines. |

## Annex 2

### Progress of Bangladesh

The progress presentation by Bangaladesh delegate at the Progress review workshop held on January 17-18, 2019 in Colombo, Sri Lanka

**Salinity intrusion in situation in the countries within South Asia and Project Progress**

Prof. Tofayel Ahamed
BSMRAU, Bangladesh

Presenter: Md Abiar Rahman, BSMRAU

18 January 2019

Progress Review Meeting of the Project "Identification of the best agricultural management practices with better greenhouse gas benefits in salinity affected areas of South Asia"

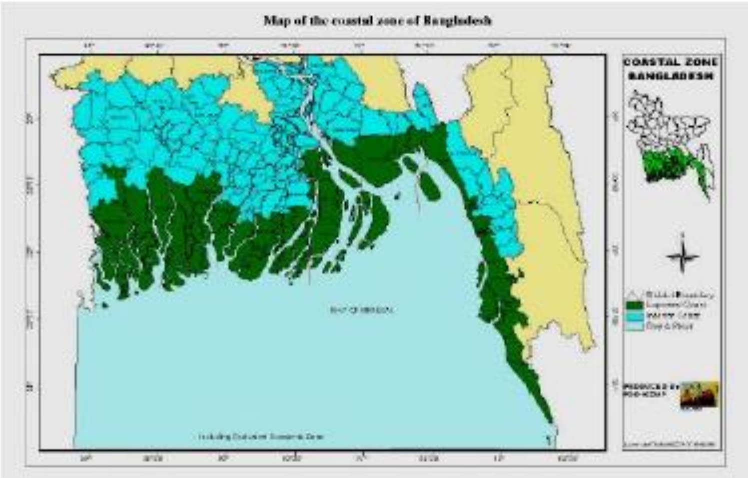
**About Bangladesh**

- **143,998 km$^2$** - Area
- **162** million - Population
- **1751** USD - Income per capita
- **24.3%** - Poverty Rate
- **98.7%** - Enrolment rate in primary education
- **72%** - Literacy
- **71** years – Life

Temperature : Winter - 7.22 - 22.77 $^0$C
Summer - 23.88 - 38.5 $^0$C
Average Rainfall: Annually 1429 to 4338 mm

## Coastal region

- The coastal region of Bangladesh contributes to about 20% of the country's landmass and 15% of the total population.
- Out of 2.85 million hectares of the coastal and offshore areas about 0.83 million hectares are arable lands, which cover over 30% of the total cultivable lands of Bangladesh.




### Vulnerability context

**Natural**

- Cyclone and tidal surge, flood & water logging, erosion, salinity intrusion.
- Change of temperature, rainfall pattern, and sea level.

**Anthropogenic**

- Brackish water shrimp aquaculture
- Salt production
- Use of agrochemicals
- Settlement, urbanization and transportation
- Industrial and commercial activities
- Human population growth
- Over exploitation of natural resources

Brackish water shrimp farming

Salt production

Use of agro-chemicals

Settlement

## Impacts: Overall

- Water logging / flash flood
- Drought
- Sedimentation
- Erosion
- Sea level rise

### Impacts: Agriculture


- Decline in soil fertility
- Soil and water pollution
- Decline in crop productivity
- Increase in pest and disease infestation
- Decline in livestock population
- Decline in fisheries resources
- Decline in homestead production system
- Food insecurity

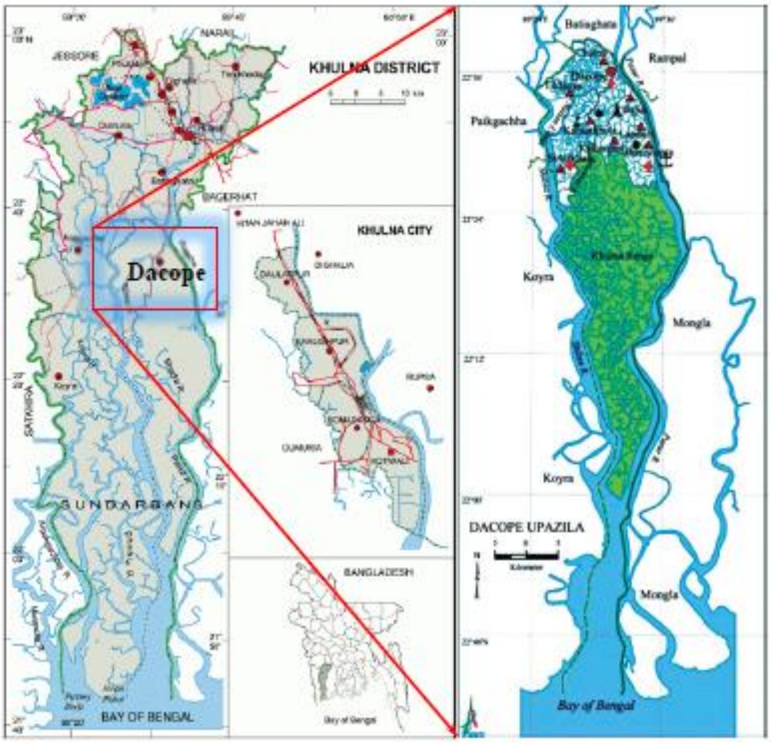


### Impacts: Ecosystem

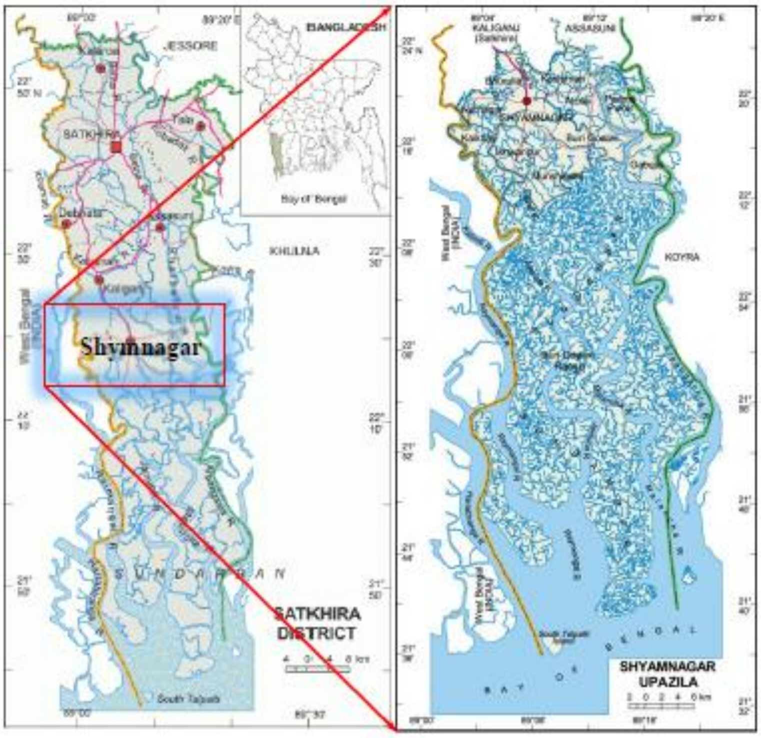

- Poor communication
- Poor infrastructures
- Poor sanitation
- Scarce of drinking water
- Shortage of poultry and livestock feed
- Shortage of biomass fuel
- Decline forest resources
- Loss of biodiversity
- Displacement



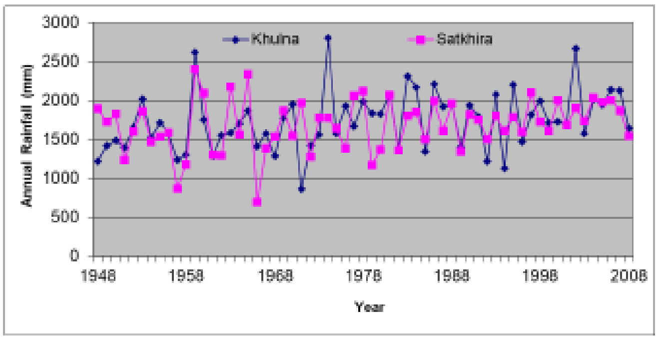
**Study Area of Khulna District**

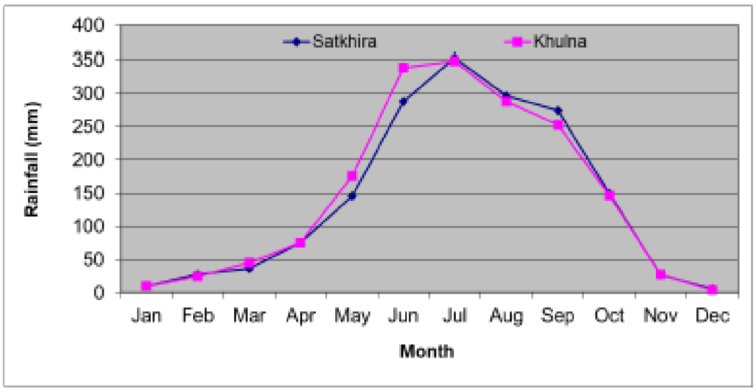



**Study Area of Satkhira District**

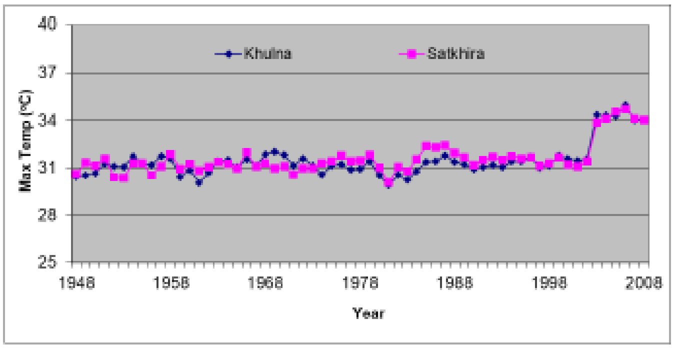


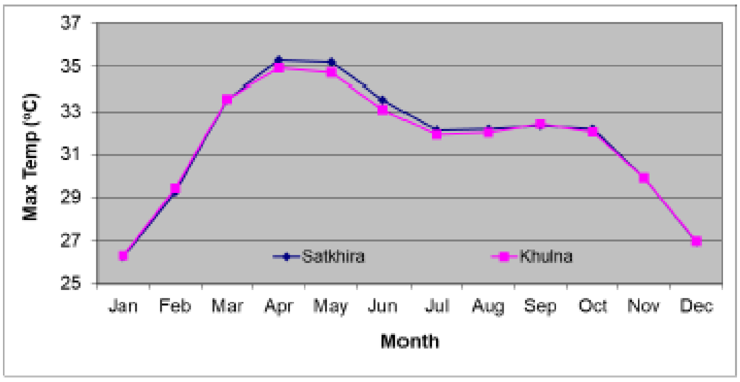
Long term trend of rainfall



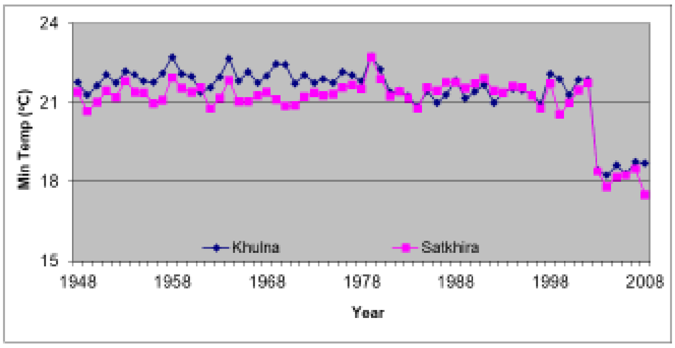



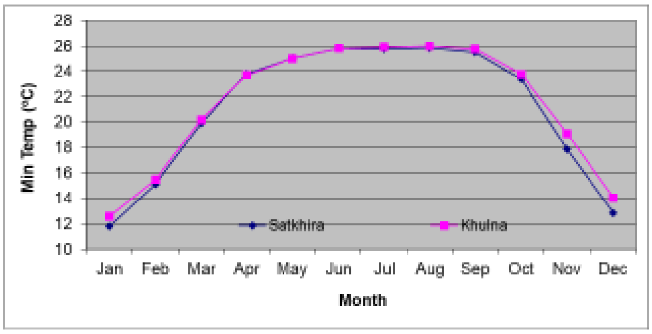

Long term trend of maximum temp

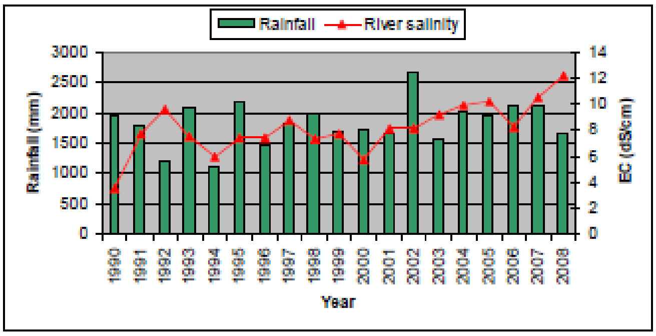


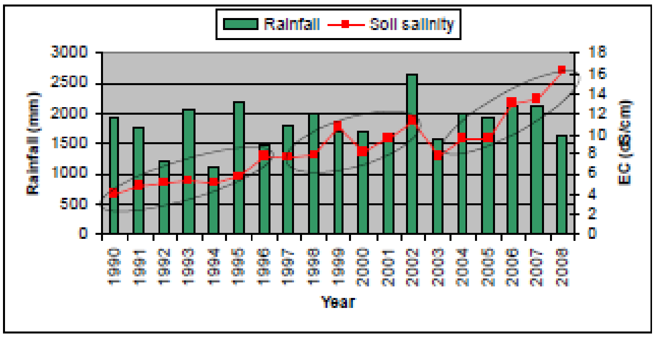
Long term trend of minimum temp



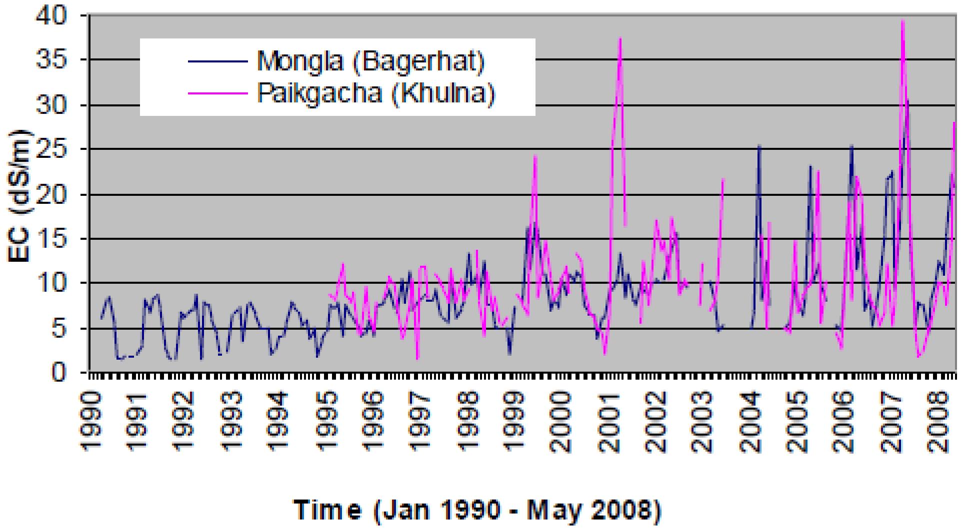




Salinity now beyond the reach of rainfall

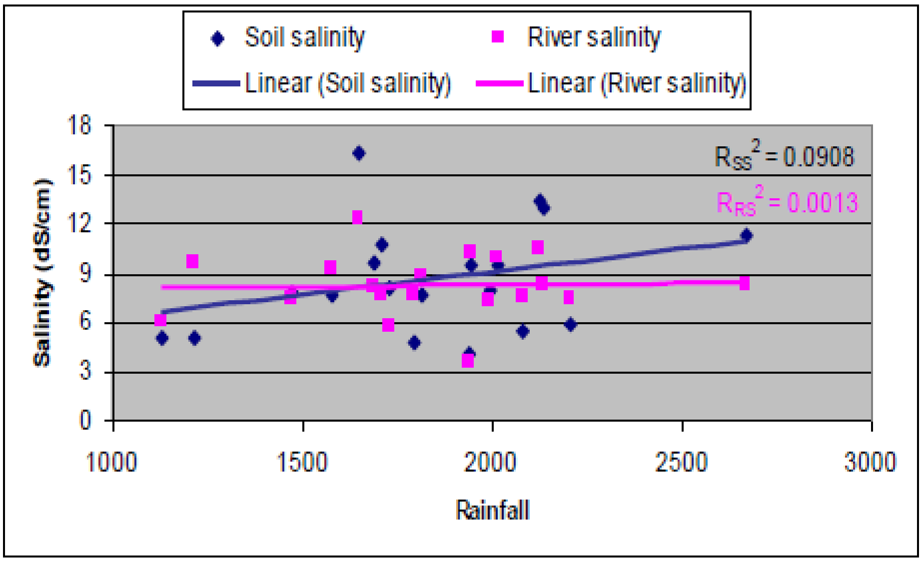


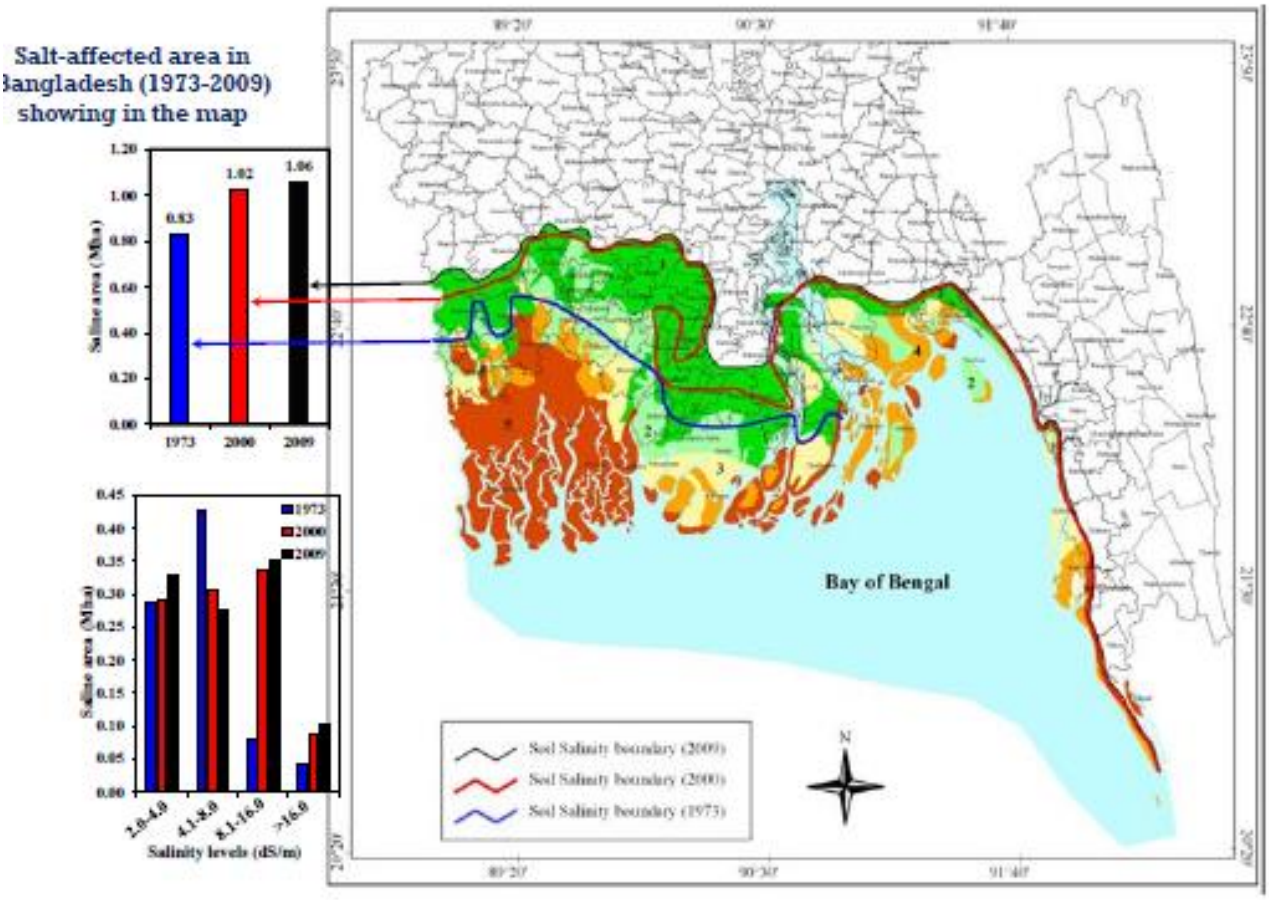
**Long term trends of soil salinity in the SW Region**

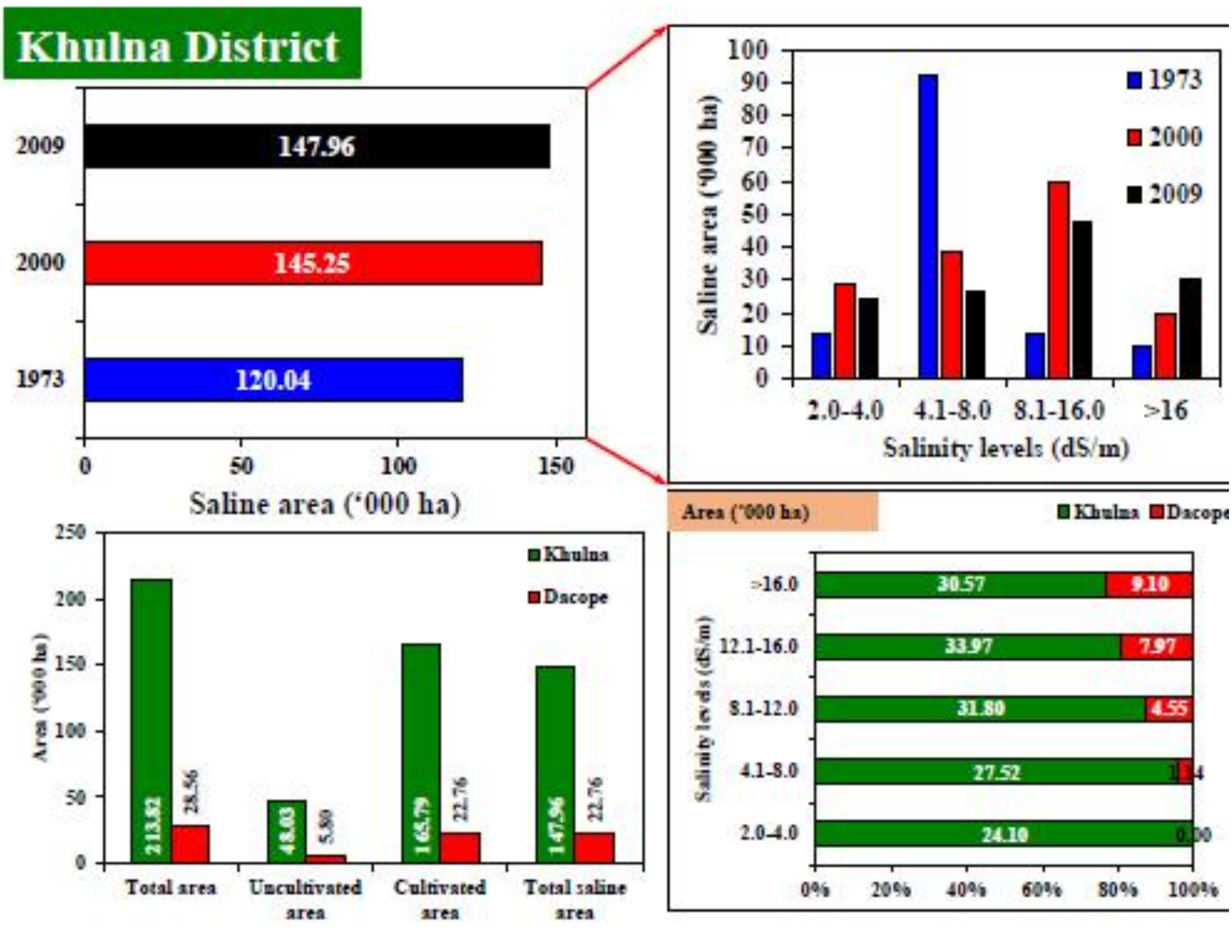


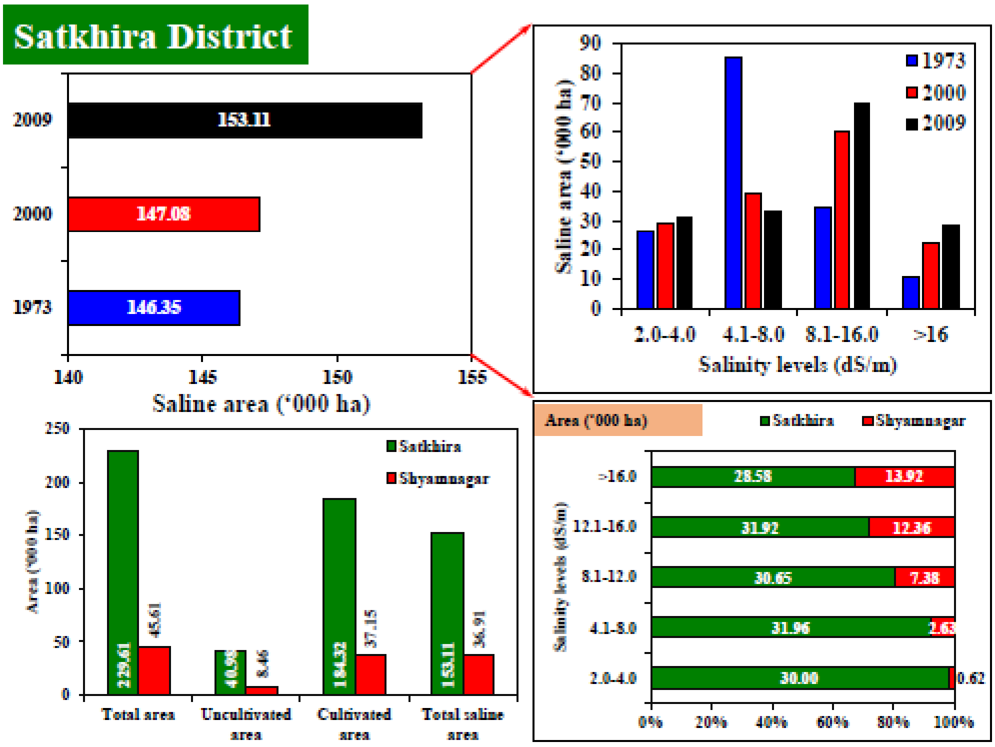

Source: SRDI

**Relationships between rainfall and salinity**



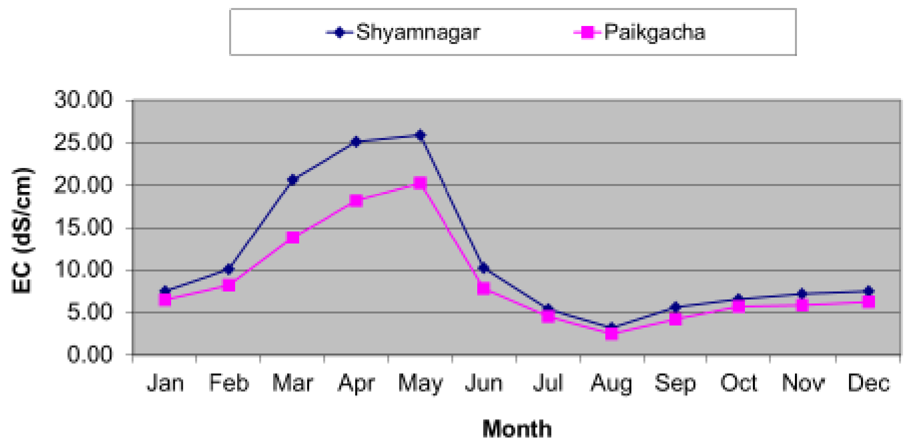

Salt-affected area in
3angladesh (1973-2009)
showing in the map
Saline area (Mha)
0.83
1.02
1.06
1973
2000
2009
Salinity levels (dS/m)
2.0-4.0
4.1-8.0
8.1-16.0
>16.0
Bay of Bengal
Soil Salinity boundary (2009)
Soil Salinity boundary (2000)
Soil Salinity boundary (1973)
N


Khulna District
2009
2000
1973
147.96
145.25
120.04
Saline area ('000 ha)
Saline area ('000 ha)
Salinity levels (dS/m)
2.0-4.0
4.1-8.0
8.1-16.0
>16
Area ('000 ha)
Khulna
Dacope
Total area
Uncultivated area
Cultivated area
Total saline area
213.82
28.56
48.03
5.80
165.79
22.76
147.96
22.76
Area ('000 ha)
Khulna
Dacope
Salinity levels (dS/m)
>16.0
12.1-16.0
8.1-12.0
4.1-8.0
2.0-4.0
30.57
9.10
33.97
7.97
31.80
4.55
27.52
24.10
0.00

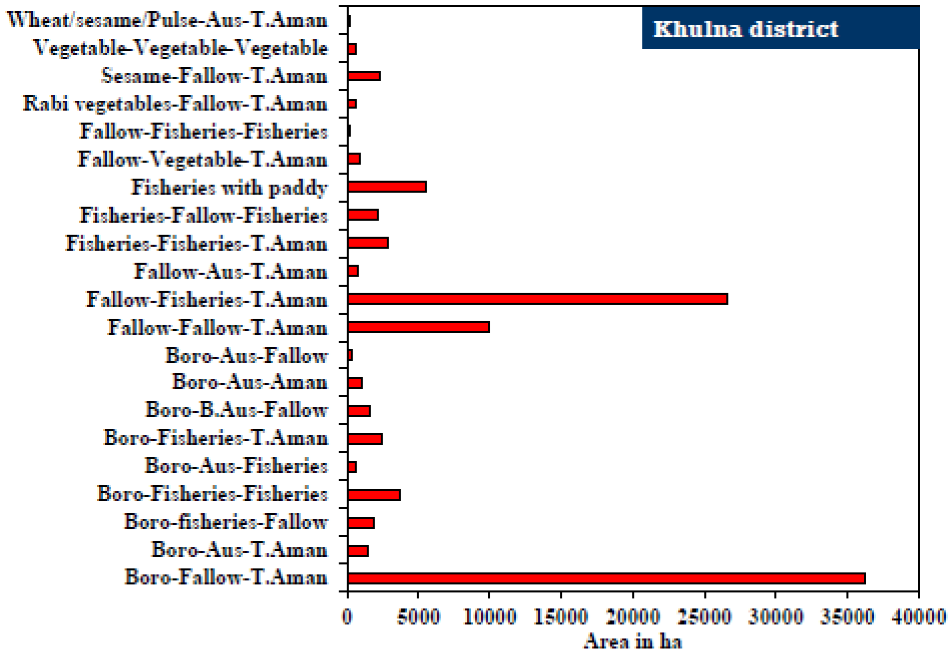



## Salinity Status

Cropland soil salinity measured in study areas



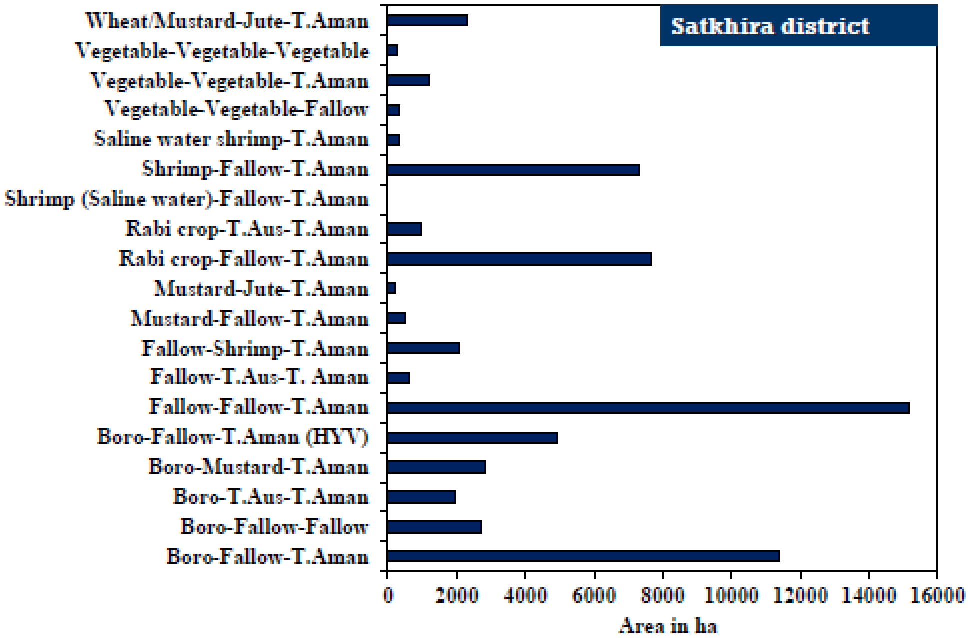
Major cropping pattern in Coastal area




Major cropping pattern in Dacope upazila of Khulna district

| Sl No | Name of cropping pattern | Area (ha) | Area % |
|---|---|---|---|
| 1 | Fallow-Fisheries-T.Aman | 15253 | 81.8 |
| 2 | Boro-Fallow-T.Aman | 1915 | 10.3 |
| 3 | Rabi vegetable-Fallow-T.Aman | 630 | 3.4 |
| 4 | Fallow-Aus-T.Aman | 520 | 2.7 |
| 5 | Vegetable-Vegetable-Vegetable | 186 | 1 |

### Major cropping pattern in Coastal area




### Major cropping pattern in Shymnagar upazila of Satkhira district

| Sl No | Name of cropping pattern | Area (ha) | Area % |
|---|---|---|---|
| 1 | Fallow-Fallow-T.Aman | 7426 | 53.2 |
| 2 | Shrimp-Fallow-T.Aman | 4314 | 29.8 |
| 3 | Fallow-T.Aus-T.Aman | 595 | 4.3 |
| 4 | Rabi crop-Fallow-T.Aman | 377 | 2.7 |
| 5 | Vegetable-Vegetable-Fallow | 342 | 2.4 |

## Decline in soil fertility

| Location | Organic matter content (%) | |
|---|---|---|
| | Shyamnagar | Dacope |
| Rice field | 1.82 | 1.41 |
| Veg. garden | 2.57 | 1.54 |
| Home garden | 2.06 | 2.54 |
| Shrimp farm | 2.06 | 1.92 |
| BARC (1999) | >3.5 (Satkhira) | >3.5 (Khulna) |


Some Activities



Some Activities

**Progress**

- Questionnaire survey
- Soil fertility status of different land use practices
- Gas measurement

## AGENDA

**Progress Review Meeting of the Project "*Identification of the best agricultural management practices with better greenhouse gas benefits in salinity affected areas of South Asia*"**

Organized by

Asia Pacific Network for Global Change Research (APN) and University of Colombo

**Date: January 17, 2019**

**Venue: Berjaya Hotel Colombo, Mount Lavinia, Sri Lanka**

| | |
|---|---|
| **8.30 am** | **Registration** |
| **9.00 am** | **Workshop Inauguration** |
| **9.05 am** | **Opening remarks:Project overview and objectives and targets of the workshop**<br>*- Dr.ErandathieLokupitiya, Senior Lecturer, University of Colombo* |
| **9. 30 am** | **Soil salinity and management practices adopted in Sri Lanka**<br>*- Mr. DN Sirisena, Former Director, Horticultural Crop Research andDevelopment Institute, Gannoruwa, Peradeniya* |
| **10.00 am** | **TEA BREAK** |
| **10.15 am** | **Salinity intrusion situation in the countries within South Asia and the project progress**<br>**India**-<br>- *Dr.Madhoolika Agrawal, Professor, Baranas Hindu University, India* |
| **11.00 am** | **Bangladesh-**<br>- *Prof. Dr. Md. Abiar Rahman, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh* |
| **11.45** | ***Pakistan***<br>**-** *Mr. Naveed Mustafa, Senior Scientific Officer, National Agricultural Research Centre, Islamabad, Pakistan* |
| **12.00 noon** | **Lunch** |
| **12.45 pm** | **Salinity intrusion situation in the countries within South Asia and project**<br>**Progress contd:**<br>**Sri Lanka**-<br>*Dr.ErandathieLokupitiya, Ms Archana Vathani, and Ms KaushalaOpatha, University of Colombo, Sri Lanka* |
| **1.30 pm** | **Multi criteria decision analysis as a tool for decision making**<br>*Dr.ShamenVidanage, Programme Coordinator, International Union for Conservation of Nature (IUCN)* |
| **3.30 pm** | **TEA BREAK** |
| **3.45 pm** | **Community Participation in Salinity Management**<br>*Mr. RangaPallawala, CEO, Janathakshan* |
| **4.30 pm** | **Workshop adjournment** |

**(January 18, 2019- Meeting of the project collaborators on way forward)**

**Presentations made at conferences and workshops (other than the progress review workshop held in January 2019)**

E. Lokupitiya, M. Agrawal, D. Pandey, T. Ahamed, R.N. Mustafa,D.N. Sirisena, G. Seneviratne, S. Udagedara and K. Paustian. 2017. Best Management Practices with Low Greenhouse Gas Emissions forSalinity Management in Paddy Soils of South Asia. International Conference on Climate Change-2017 (ICCC 2017), February 16-17, 2017, Colombo, Sri Lanka.

E. Lokupitiya. 2017 (Invited presentation). Identification of best agricultural practices with better GHG benefits in salinity-affected areas in South Asia. Science-Policy Dialogue. South/Southeast Asia. Climate change: Low carbon and adaptive Initiatives in Asia. Organized by Asia-PacificNetwork for Global Change Research (APN). 6-8 February, 2017, Thailand.

Archana, A.S., Lokupitiya, E., Sirisena, D.N., and Seneviratne, G. 2018. Determining the Best Agricultural Management Practices for Salt-Affected Coastal Paddy Soils in Sri Lanka Considering Net Greenhouse Gas Emission Along with Other Socioeconomic Benefits. International Conference on Climate Change-2018 (ICCC 2018), February 15-16, 2018Colombo, Sri Lanka.

E. Lokupitiya1, M. Agrawal, A. Vathani, T. Ahamed, N.Mustafa, B. Ahmad, D. Pandey, G. Seneviratne, K. Paustian. 2018. Coastal salinity intrusion and food security in South Asia: best management practices with greenhouse gas benefits. International Conference on Agricultural GHG Emissions and Food Security – Connecting research to policy and practice. September 10 – 13, 2018 Berlin, Germany.

Opatha, KN and Lokupitiya, E. 2019. Study of salinity levels and impact of salt water intrusion on coastal paddy areas of wet zone of Sri Lanka.
Proceedings Symposium on agrobiodiversity for climate change adaptation, food and nutrition. Mainstreaming Agrobiodiversity Conservation and Use in Sri Lankan Agro-ecosystems for Livelihoods and Adaptation to Climate Change (BACC) Project
&Mainstreaming Biodiversity Conservation and Sustainable Use for Improved Human Nutrition & Well-being-Biodiversity for Food and Nutrition (BFN) Project. May 23-24, 2019, Colombo, Sri Lanka.

Jaiswal, B., Pandey, B., Singh, S. and Agrawal, M. 2017. Characterization of salinity affected agricultural areas in and around Varanasi. National Symposium on Water and Soil Management for Agriculture and Livelihood Security under Climate Change. September 8-9, 2017, Sunbeam Suncity, Varanasi, Uttar Pradesh, India.

Jaiswal, B., Singh, S., Agrawal, M. 2018. Estimation of rice performance under varying level of salinity stress. International Symposium on Environmental, educational and biological research for human welfare (EEBRHW-2018). March 25-26, 2018, Department of Agronomy, Institute of Agricultural Sciences, BHU, Varanasi, Uttar Pradesh, India.

Jaiswal, B., Singh, S. and Agrawal, M. 2018. Assessment of rice performance under different gradient of salinity stress. National conference on Prospects and Retrospects of Life Sciences in India (PRLS-2018). February 25-26, 2018, Department of Botany, Udai Pratap College, Varanasi, Uttar Pradesh, India.

Jaiswal, B., Singh, S., Agrawal, M. 2018. Impact of soil salinity on rice productivity in agricultural areas of Varanasi district. National symposium on Science, Technology and Ecosystem for Sustainable Rural Development. December 6-8, 2018, Mahatma Gandhi chitrakootGramodayaVishwavidya, Chitrakoot, Madhya Pradesh, India.

Jaiswal, B., Singh, S., Agrawal, M. 2019. Impact of soil salinity on wheat plant performance. National symposium on Current Trends and Future Prospects in Plant Science Research (CTPSR- 2019). February 1-3, 2019, Department of Botany, Institute of Science, BHU, Varanasi, Uttar Pradesh, India.

*Funding sources outside the APN*
Sri Lanka: University of Colombo; India: CICERO, DST-FIST and UGC

List of Young Scientists

Sri Lanka:

- Ms Archana Vathani, MPhil (part-time) student at University of Colombo
- Ms Kaushala Opatha, Demonstrator at University of Colombo (involved in part of the current project as her undergraduate (Honors) research project)
- Mr. Susantha Udagedara, Coordinator/Adaptation at Third National Communication Project, Ministry of Mahaweli Development and Environment of Sri Lanka (Supported in the pilot project conducted in the past)

India:

- Dr.Divya Pandey,Alexander von Humboldt Post-doctoral fellow, Leibniz Centre for Agricultural Landscape Research, Zalf, Germany; pandey.divyaa85@gmail.com: helped in chamber designing and flux calculation. Dr Pandey learned on how to design gas chambers for rice fields and also on dealing with challenges of saline soils.
- Ms Bhavna Jaiswal, Junior Research Fellow, Department of Botany, Banaras Hindu University, Varanasi, India; jaisbhavna27@gmail.com. Ms Bhavna worked extensively on soil, gas and plant sampling and related analyses. She has learned many related scientific techniques and also interacted with farmers.
- Dr Bhanu Pandey, Scientist, Natural Resource and Environment Management Group, CSIR-Central Institute of Mining and Fuel Research, Dhanbad, India; bhanubot@gmail.com: Dr Pandey worked for a short time in this project as RA and contributed initially with salinity mapping. He gained firsthand knowledge on field exposure and farmers interaction.
- Dr Suruchi Singh, RA-APN project, Department of Botany, Banaras Hindu University, Varanasi, India; suruchibhu79@gmail.com. Dr Suruchi worked for fulfilling the objectives of this project. She contributed in salinity mapping of this region and in sites selection and then all gas and soil sampling. She has tried to trace various dimensions of this problem and worked to come up with some explanation for otherwise a complex issue.

Glossary of Terms

*Include list of acronyms and abbreviations*

| Abbreviations used | Acronym expansion |
| --- | --- |
| IGP | Indo-Gangetic Plain |
| GHG | Greenhouse gas |
| UP | Uttar Pradesh |
| EC | Electrical Conductivity |
| OC | Organic carbon |
| N | Nitrogen |
| $CO_2$ | Carbon dioxide |
| $N_2O$ | Nitrous oxide |
| $CH_4$ | Methane |
| RJT | Rajatalab |
| BBN | Beerbhanpur |
| MZM | Mirzamurad |
| BRP | Baraipur |
| DHR | Dharahara |
| SLM | Salempur |
| CEC | Cation exchange capacity |
| ESR | Exchangeable sodium ratio |
| ESP | Exchangeable sodium percentage |
| SAR | Sodium absorption ratio |
| mg $g^{-1}$ | Milligram per gram |
| mg/$m^2$/h | Milligram/ meter square/ hour |
| meq | Milliequivalent |
| µS | MicroSiemen |
| V | Vegetative |
| PR | Pre-reproductive |
| R | Reproductive |
| PoR | Post-reproductive |
| F | Fallow |

Table A2. Details of the selected sites for salinity measurements in wet zone, Sri Lanka

| Name of the paddy field | District | Gramaniladari Division | Extent | Name of the canal/river close by | Geographic Coordinates (latitude, longitude) |
|---|---|---|---|---|---|
| MahadeniyaYaaya (Kahapola) | Colombo | Kahapola | 38 acres | BolgodaOya | 6.7483295 79.9243355 |
| Maampe North Yaaya (Colombo reference) | Colombo | Maampe North | 12 acres | No canal | 6.8066768 79.9243355 |
| BabarendaYaaya (Dickwella) | Matara | Babarenda East | 25 acres | Polgahahenaela | 5.9621796 80.0704053 |
| KaburugamuwaYaaya | Matara | Kotavila South | 15 acres | Lamasooriya canal | 5.9501168 80.4917954 |
| KalatiyawalaYaaya (Matara reference) | Matara | Kotavila North | 22 acres | No canal | 5.9629142 80.499036 |
| Lepgewila (Godagama 1) | Matara | Godagama | 48 acres | Nilwala river project and associated canals | 5.9678115 80.5214951 |
| Madawila (Godagama 2) | Matara | Godagama | 260 acres | Nilwala river project and associated canals | 5.9695044 80.5235534 |
| UrumullaYaaya | Kalutara | Gammala West | 10 acres | Samantharaela/ Benthara river south bank | 6.3927954 80.1040549 |
| TikiraawaYaaya | Kalutara | Iththapana South | 20 acres | Benthara river south bank | 6.4013393 80.0778001 |
| ThibirigahawelaYaaya (MunamalwaththaYaaya) | Kalutara | Lewuwanduwa West | 10-15 acres | Munamalwaththa canal (Benthara river south bank) | 6.4492618 80.086464 |
| Mahaaminekubura (Paadagoda) | Kalutara | Kotapitiya | 6 acres | Parakkuela/Muuela | 6.4383366 80.0322218 |
| JalatharaYaaya (Kalutara reference) | Kalutara | Pareigama South | 15 acres | Pareigamaela | 6.4004534 80.1110058 |
| DabadureiYaaya (Alawathupitiya) | Gampaha | Alawathupitiya | 10 acres | Dadugamoya | 7.1163991 79.8862635 |
| Gandara Yaaya (BatahiraHeenatiyana) | Gampaha | Heenatiyana | 85 acres | Maaduwaoya | 7.153619 79.9126706 |
| HiriliyaddaYaaya (Gampaha reference) | Gampaha | Kiridivita | 40 acres | Hiriliyaddaela | 7.0916693 79.9647785 |
| MaaswelYaaya (Mahapalana) | Galle | Kandemulla | 10 acres | Maaswelaela | 6.3593172 80.0374312 |
| HeenelaYaaya (Gonapinuwala) | Galle | Gonapinuwala East | 45 acres | Heenela/ Thotagamu river | 6.1436046 80.1324327 |
| BibileKubura (Ahungalla) | Galle | Doowemodara | 10 acres | Doowemodara | 6.341073 80.027047 |
| DoowamandawalaYaaya (Weragoda) | Galle | 72 C Weragoda | 8 acres | Lanka ela | 6.230614 80.187475 |
| OkandaYaaya | Galle | Moragoda | 22 acres | Okandaela | 6.3911214 80.0858061 |
| BogahaYaaya | Galle | Moragoda | 22 acres | Gan iniela/ Ambalanduwaela | 6.4030872 80.1041488 |
| ThotakuburuYaaya (Thunduwa) | Galle | Thunduwa East | 30 acres | Benthara river left bank | 6.4157128 80.0737794 |
| Labuduwa (Galle reference) | Galle | Labooduwa | 1 acre | No canal | 6.0722098 80.2366053 |


**Figure A1. Some images of the selected sites (include both saline and non-saline soils of the surveyed wetzone sites in Sri Lanka; Figure courtesy-KaushalaOpatha)**


**Figure A1.(Contd.) Images of the selected sites in wet zone, Sri Lanka**

Table A3. Variations in sulphate, phosphate, Na, K, Zn, Ca and Mg (mg $g^{-1}$) contents during vegetative and harvest stages of rice (2017) in Indian sites. Values are ± S.E, n=9. Different letters within a group of column indicate significant difference among sites (difference at $p<0.05$ according to Duncan's test).

| **Vegetative** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sites | Phosphate ($PO_4^{2-}$) | Sulphate ($SO_4^{2-}$) | Na | K | Zn | Ca | Mg |
| RJT* | - | - | - | - | - | - | - |
| BBN | 7.82±0.19$^{a}$ | 1.27±0.09$^{a}$ | 1.89±0.09$^{c}$ | 5.27±0.59$^{b}$ | 0.069±0.003$^{c}$ | 10.27±1.08$^{a}$ | 5.44±0.15$^{ab}$ |
| MZM | 1.65±0.11$^{d}$ | 1.13±0.38$^{a}$ | 1.98±0.04$^{c}$ | 6.98±0.18$^{a}$ | 0.092±0.003$^{c}$ | 0.092±0.003$^{e}$ | 5.84±0.19$^{a}$ |
| BRP | 3.78±0.90$^{c}$ | 1.06±0.23$^{a}$ | 2.56±0.05$^{b}$ | 4.70±0.38$^{d}$ | 0.412±0.02$^{a}$ | 0.412±0.02$^{b}$ | 3.76±1.56$^{abc}$ |
| DHR | 5.37±0.46$^{b}$ | 1.16±0.23$^{a}$ | 2.73±0.33$^{b}$ | 5.39±0.53$^{b}$ | 0.109±0.01$^{c}$ | 0.109±0.01$^{d}$ | 2.78±0.86$^{bc}$ |
| SLM | 5.73±0.23$^{b}$ | 1.89±0.23$^{a}$ | 4.66±0.15$^{a}$ | 5.00±0.07$^{c}$ | 0.192±0.02$^{b}$ | 0.192±0.02$^{c}$ | 2.23±0.21$^{c}$ |
| **Harvest** | | | | | | | |
| Sites | Phosphate ($PO_4^{2-}$) | Sulphate ($SO_4^{2-}$) | Na | K | Zn | Ca | Mg |
| RJT | 3.53±0.16$^{a}$ | 1.44±0.08$^{ab}$ | 1.76±0.04$^{c}$ | 3.80±0.36$^{bc}$ | 0.074±0.004$^{b}$ | 2.49±0.11$^{d}$ | 1.20±0.002$^{c}$ |
| BBN | 3.21±0.17$^{b}$ | 0.942±0.08$^{d}$ | 1.79±0.13$^{c}$ | 5.01±0.47$^{bc}$ | 0.072±0.02$^{b}$ | 4.14±0.04$^{c}$ | 0.531±0.05$^{d}$ |
| MZM | 1.74±0.16$^{bc}$ | 1.26±0.10$^{bc}$ | 2.65±0.16$^{b}$ | 7.27±0.70$^{a}$ | 0.089±0.01$^{a}$ | 6.21±0.66$^{b}$ | 1.85±0.03$^{b}$ |
| BRP | 1.97±0.20$^{c}$ | 0.996±0.04$^{d}$ | 2.03±0.28$^{c}$ | 3.58±0.37$^{c}$ | 0.071±0.01$^{b}$ | 25.42±0.61$^{a}$ | 1.95±0.15$^{b}$ |
| DHR | 1.92±0.08$^{c}$ | 1.06±0.05$^{cd}$ | 2.06±0.08$^{c}$ | 5.26±0.47$^{b}$ | 0.058±0.002$^{c}$ | 5.01±0.05$^{bc}$ | 2.49±0.04$^{a}$ |
| SLM | 1.43±0.09$^{c}$ | 1.63±0.12$^{a}$ | 4.11±0.24$^{a}$ | 4.26±0.15$^{b}$ | 0.059±0.003$^{c}$ | 4.37±0.33$^{c}$ | 1.17±0.05$^{c}$ |
| | | | | | | | |

*RJT site was not part of the study; Sodium, Na; Potassium, K; Zinc, Zn; Calcium,Ca; Magnesium, Mg.

Table A4. Variations in sulphate, phosphate, Na, K, Zn, Ca and Mg (mg $g^{-1}$) contents during vegetative and harvest stages of rice (2018) in Indian sites. Values are ± S.E, n=9. Different letters within a group of column indicate significant difference among sites (difference at $p<0.05$ according to Duncan's test).

| Vegetative | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sites | Phosphate ($PO_4^{2-}$) | Sulphate ($SO_4^{2-}$) | Na | K | Zn | Ca | Mg |
| RJT | 2.18±0.33$^{a}$ | 0.493±0.05$^{ab}$ | 1.36±0.16$^{b}$ | 3.44±0.33$^{c}$ | 0.074±0.01$^{a}$ | 0.176±0.02$^{b}$ | 0.181±0.01$^{d}$ |
| BBN | 1.19±0.02$^{c}$ | 0.504±0.18$^{ab}$ | 1.78±0.14$^{b}$ | 6.06±0.16$^{ab}$ | 0.071±0.0001$^{a}$ | 0.344±0.09$^{b}$ | 0.313±0.002$^{b}$ |
| MZM | 1.28±0.05$^{bc}$ | 0.729±0.21$^{ab}$ | 1.51±0.16$^{b}$ | 6.45±0.83$^{a}$ | 0.071±0.003$^{a}$ | 0.380±0.05$^{b}$ | 0.304±0.01$^{b}$ |
| BRP | 1.33±0.07$^{bc}$ | 0.338±0.05$^{b}$ | 1.43±0.11$^{b}$ | 3.75±0.47$^{c}$ | 0.067±0.004$^{a}$ | 0.850±0.04$^{a}$ | 0.380±0.01$^{a}$ |
| DHR | 1.69±0.01$^{b}$ | 0.764±0.02$^{a}$ | 1.69±0.23$^{b}$ | 4.89±0.75$^{abc}$ | 0.062±0.004$^{a}$ | 0.381±0.10$^{b}$ | 0.276±0.03$^{bc}$ |
| SLM | 1.06±0.04$^{c}$ | 0.364±0.06$^{b}$ | 2.29±0.13$^{a}$ | 4.54±0.58$^{bc}$ | 0.061±0.003$^{a}$ | 0.345±0.03$^{b}$ | 0.245±0.01$^{c}$ |
| **Harvest** | | | | | | | |
| Sites | Phosphate ($PO_4^{2-}$) | Sulphate ($SO_4^{2-}$) | Na | K | Zn | Ca | Mg |
| RJT | 1.86±0.05$^{a}$ | 0.652±0.12$^{a}$ | 1.52±0.24$^{b}$ | 6.53±0.99$^{ab}$ | 0.078±0.002$^{a}$ | 0.147±0.01$^{c}$ | 0.203±0.01$^{bc}$ |
| BBN | 1.34±0.07$^{b}$ | 0.382±0.10$^{a}$ | 0.930±0.15$^{b}$ | 5.98±0.31$^{abc}$ | 0.080±0.003$^{a}$ | 0.343±0.03$^{b}$ | 0.328±0.01$^{ab}$ |
| MZM | 1.42±0.03$^{b}$ | 0.677±0.11$^{a}$ | 1.62±0.51$^{ab}$ | 7.18±0.54$^{a}$ | 0.081±0.003$^{a}$ | 0.288±0.01$^{b}$ | 0.299±0.01$^{ab}$ |
| BRP | 1.45±0.01$^{b}$ | 0.174±0.06$^{a}$ | 1.38±0.05$^{b}$ | 4.44±0.18$^{c}$ | 0.066±0.003$^{b}$ | 0.848±0.02$^{a}$ | 0.348±0.04$^{a}$ |
| DHR | 1.33±0.01$^{b}$ | 0.182±0.05$^{a}$ | 1.63±0.14$^{ab}$ | 4.91±0.58$^{bc}$ | 0.066±0.004$^{b}$ | 0.326±0.02$^{b}$ | 0.168±0.08$^{c}$ |
| SLM | 0.918±0.05$^{c}$ | 0.938±0.68$^{a}$ | 2.50±0.32$^{a}$ | 4.79±0.15$^{bc}$ | 0.065±0.003$^{b}$ | 0.322±0.06$^{b}$ | 0.251±0.02$^{abc}$ |

Sodium, Na; Potassium, K; Zinc, Zn; Calcium,Ca; Magnesium, Mg.

Table A5. Variations in pH, EC (µS), CEC (meq 100g$^{-1}$ soil), ESR, SAR, ESP and OC (%) during early and harvest stages of rice (2017) in the sites of India.Values are ± S.E, n=9. Different letters within a group of column indicate significant difference among sites (difference at $p<0.05$ according to Duncan's test).

| **Vegetative** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sites | pH | EC | CEC | ESR | SAR | ESP | OC |
| RJT* | - | - | - | - | - | - | - |
| BBN | 7.98±0.02$^{d}$ | 184.6±0.29$^{d}$ | 13.20±0.32$^{c}$ | 2.29±0.32$^{c}$ | 6.62±0.28$^{a}$ | 69.43±1.66$^{a}$ | 1.61±0.03$^{a}$ |
| MZM | 8.07±0.08$^{d}$ | 193.4±0.80$^{d}$ | 14.95±0.42$^{b}$ | 1.69±0.05$^{a}$ | 5.75±0.02$^{b}$ | 62.93±0.62$^{bc}$ | 1.39±0.08$^{b}$ |
| BRP | 8.57±0.11$^{c}$ | 504.8±7.16$^{c}$ | 10.49±0.12$^{a}$ | 1.08±0.05$^{d}$ | 3.45±0.12$^{d}$ | 51.83±1.06$^{d}$ | 0.598±0.0001$^{d}$ |
| DHR | 9.03±0.12$^{b}$ | 626.7±36.5$^{b}$ | 10.09±0.21$^{c}$ | 1.89±0.04$^{b}$ | 5.08±0.09$^{c}$ | 63.36±0.47$^{b}$ | 0.838±0.02$^{c}$ |
| SLM | 9.84±0.02$^{a}$ | 2525.4±48.1$^{a}$ | 10.54±0.21$^{a}$ | 1.58±0.07$^{c}$ | 4.59±0.18$^{c}$ | 61.10±1.14$^{c}$ | 0.558±0.02$^{d}$ |
| **Harvest** | | | | | | | |
| Sites | pH | EC | CEC | ESR | SAR | ESP | OC |
| RJT | 7.78±0.03$^{d}$ | 108.6±5.20$^{c}$ | 12.23±0.37$^{d}$ | 4.08±0.23$^{a}$ | 9.14±0.45$^{a}$ | 80.22±0.86$^{a}$ | 1.94±0.01$^{a}$ |
| BBN | 7.84±0.07$^{d}$ | 156.2±5.39$^{bc}$ | 19.62±1.29$^{b}$ | 1.86±0.20$^{bc}$ | 6.91±0.56$^{ab}$ | 64.63±2.56$^{ab}$ | 1.66±0.05$^{b}$ |
| MZM | 8.13±0.06$^{c}$ | 183.7±10.7$^{c}$ | 23.38±0.571$^{a}$ | 0.847±0.07$^{d}$ | 4.28±0.29$^{cd}$ | 45.69±2.12$^{c}$ | 1.72±0.39$^{b}$ |
| BRP | 8.00±0.09$^{cd}$ | 298.9±3.87$^{b}$ | 16.78±1.37$^{bc}$ | 0.783±0.28$^{d}$ | 3.19±0.89$^{d}$ | 40.96±9.64$^{c}$ | 1.12±0.02$^{d}$ |
| DHR | 8.42±0.13$^{b}$ | 361.7±8.51$^{b}$ | 13.59±1.69$^{cd}$ | 2.00±0.038$^{b}$ | 5.91±1.43$^{bc}$ | 63.77±6.95$^{b}$ | 1.22±0.04$^{c}$ |
| SLM | 9.03±0.08$^{a}$ | 1705.8±52.3$^{a}$ | 18.03±0.03$^{b}$ | 0.958±0.05$^{cd}$ | 4.12±0.17$^{cd}$ | 43.80±1.41$^{bc}$ | 1.14±0.01$^{cd}$ |

*RJT site was not part of the study. EC, electrical conductivity; CEC, cation exchange capacity; ESR, exchangeable sodium ratio; SAR, sodium adsorption ratio; ESP, exchangeable sodium percentage; OC, organic carbon

Table A6. Variations in pH, EC (µS), CEC (meq $100g^{-1}$ soil), ESR, SAR, ESP and OC (%) during early and harvest stages of rice (2018) in Indian sites. Values are ± S.E, n=9. Different letters within a group of column indicate significant difference among sites (difference at $p<0.05$ according to Duncan's test).

| **Vegetative** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sites | pH | EC | CEC | ESR | SAR | ESP | OC |
| RJT | 7.79±0.04[c] | 130.6±4.79[f] | 2.39±0.04[a] | 0.089±0.004[b] | 0.195±0.01[c] | 8.17±0.32[b] | 5.44±0.38[a] |
| BBN | 7.72±0.02[d] | 174.6±3.80[d] | 10.11±0.82[a] | 0.015±0.002[d] | 0.069±0.004[d] | 1.52±0.16[d] | 2.31±0.10[b] |
| MZM | 7.82±0.003[c] | 140.7±1.27[e] | 11.42±0.29[a] | 0.045±0.01[c] | 0.214±0.024[c] | 4.34±0.43[c] | 2.26±0.22[b] |
| BRP | 7.93±0.01[b] | 187.1±0.53[c] | 10.25±1.63[a] | 0.053±0.01[c] | 0.230±0.012[c] | 5.05±0.62[c] | 1.74±0.22[c] |
| DHR | 8.04±0.01[a] | 205.6±0.29[b] | 10.99±0.59[a] | 0.084±0.01[b] | 0.380±0.033[b] | 7.77±0.71[b] | 1.93±0.27[c] |
| SLM | 8.08±0.003[a] | 270.7±2.31[a] | 10.54±0.35[b] | 0.190±0.02[a] | 0.811±0.07[a] | 15.95±1.14[a] | 1.16±0.14[c] |
| **Harvest** | | | | | | | |
| Sites | pH | EC | CEC | ESR | SAR | ESP | OC |
| RJT | 7.50±0.07[c] | 103.3±9.40[e] | 2.75±0.15[b] | 0.090±0.01[cd] | 0.206±0.011[cd] | 8.26±0.58[c] | 1.39±0.06[a] |
| BBN | 7.65±0.09[c] | 122.2±3.41[de] | 10.97±0.19[a] | 0.018±0.002[e] | 0.082±0.01[d] | 1.73±0.18[e] | 1.11±0.06[b] |
| MZM | 7.81±0.01[b] | 146.8±1.84[d] | 11.52±0.23[a] | 0.055±0.004[de] | 0.258±0.022[c] | 5.18±0.38[d] | 0.754±0.05[c] |
| BRP | 7.85±0.03[b] | 338.0±1.06[b] | 12.29±0.83[a] | 0.116±0.010[bc] | 0.545±0.032[b] | 10.37±0.79[bc] | 0.207±0.02[e] |
| DHR | 7.93±0.03[b] | 288.1±6.49[c] | 11.70±0.13[a] | 0.138±0.01[b] | 0.631±0.04[b] | 12.12±0.66[b] | 0.747±0.02[c] |
| SLM | 8.09±0.03[a] | 399.3±16.39[a] | 11.22±1.05[a] | 0.190±0.03[a] | 0.826±0.09[a] | 15.89±1.97[a] | 0.511±0.05[d] |
| | | | | | | | |

EC, electrical conductivity; CEC, cation exchange capacity; ESR, exchangeable sodium ratio; SAR, sodium adsorption ratio; ESP, exchangeable sodium percentage; OC, organic carbon