INTRODUCTION

Indian agriculture in the 21st century is structurally dissimilar, diverse, more robust, and superior to the one existing in the past. Over the last few decades, impressive growth in the agricultural sector has been seen in India. It ranks in the second position globally. It contributes 22% to the total GDP and provides a source of employment to over 60% of the population (Silva *et al.,* 2017). However, the present agriculture sector faces an important threat of providing sufficient food supply without causing any stress to the natural environment. The world population is increasing rapidly, and it is estimated that if the population is not brought under control, it will cross 9.6 billion by 2050. Hence, global food production will have to be increased to maintain the current level of food supply (Chand, 2019).

It is already known that every plant undergoes various kinds of stress, for example, water and nutrient deficiencies, lack of optimum pH values, and high soil strength. In addition, plant growth can be profoundly affected by salinity, waterlogging, and inundation. Out of all kinds of environmental stress a plant faces, salt-affected soils have become major concerns at regional, state, national, and international levels. Salinity stress is the major abiotic stress that drastically affects plant growth and crop productivity. This can also be considered a major cause of land degradation that makes the lands unsuitable for cultivating crops. Hence, researching alternatives to solve the salinity issue is very important to meet food supply requirements. Suitable management practices to control salinity problems must be implemented to prevent the loss of yield that may cause a financial crisis to the farmers too. Therefore, strong networking among researchers, farm advisors, and farmers is needed to enhance the management of salinity problems. Plants with high economic value and salt tolerance have been recommended as eco-engineering tools for alternative agricultural production and re-vegetation in salt-affected agricultural and coastal zones (Hossaain, 2018).

Soil salinity harms soil biodiversity as well as microbial activities. Plants growing on salt land are subjected to various common stresses like water and nutrient deficiencies, extreme pH values, and high soil strength. In addition, plant growth can be profoundly affected by salinity, waterlogging, and inundation. When nature needs to be sustained for the future usage, the concept of "sustainable development" comes into the picture, which needs to be brought practically into use, even at the local level. Agriculture sector is also vulnerable to climate change, i.e., high temperatures tend to reduce crop yields and instead favour weed and pest proliferation. Due to temperature rise and changes in water availability, adverse effects would be witnessed by irrigated crop yields (Subardja and Widyastuti, 2016).

It is also observed that people now do not prefer farming as their profession because of various reasons. The ones that have been already practicing agriculture are now seen to move their occupation from farming to other civil work due to loss of interest and challenges they face. To overcome this issue, there is a need to increase the incomes of farming households, diversify the production of crops, empower women, strengthen agricultural diversity and productivity, and design careful price and subsidy policies that should encourage the production and consumption of nutrient-rich crops. This will help the agricultural sector flourish by stabilizing the country's economic backbone and increasing employment in the agriculture sector (Umesha, 2018).

Goa is a tiny state located on the West Coast of the Indian peninsula. It is divided into two districts: North Goa and South Goa, which are further divided into 12 talukas. It covers a wide range of landforms, water bodies, and climate that has potential for cereals and crops plantation, fruits, vegetables, flowers, dairying, poultry, piggery, rabbitry, and fishery. Sandy beaches, estuaries, and promontories characterize the 65-mile (105-km) coastline of mainland Goa. At the same time, the interior region has low, forested plateaus that merge with the wooded slopes of the Western Ghats on the eastern edge. Goa has agriculture favouring climate, i.e., equable, with high temperatures generally in the 35^{o}C and low temperatures in the 15^{o}C throughout the year, and has a warm to a humid tropical environment. A southwest monsoon blows between June and September. The state receives about 300 mm on average of rainfall annually, most occurring during the monsoon period (June - October). The soils that are predominantly found in the state are laterite (74%), alluvial and marshy (11.7%), coastal sandy (10.11%), and saline (4.8%). The pH value ranges from 4.5 being acidic to 6.5 being basic. These soils are rich in organic matter and respond well to nitrogen (N) and phosphorus (P) fertilizers (ICAR, 2019).

The state has made remarkable progress in the agriculture sector and other spheres of economic upliftment. The agriculture and forests in Goa have been parallel in keeping Goa green, covering nearly 65% of the state's total area. One of the chief land types existing in Goa is the *"Khazan Land."* It consists of low-lying areas to cultivate monsoon paddy crops, followed by *rabi* vegetables. In some areas, pisciculture is also practiced by regulating water flow. These *Khazans* are also referred to as coastal wetlands formed by the river or sea activity. Creating a well-designed network of bunds would protect the agricultural fields and adjoining villages from tidal flows and make these land excellent for *Kharif* and *Rabi* crops production. The control, conservation, and management of water in the paddy field are best done by constructing bunds. This bund is usually made from locally available stone, mud, and clay known as *'chanoyu'* used as a matrix between the two outer layers of the outer bund to withstand the tidal waves. The farmers build the inner bunds with straw, mud, and stones, which protect them from nutrient leaching.

Another important aspect is the *sluice gates* mainly made out of wood or concrete and are built at the mouth of the creek entering farmland to control the water levels, flow during high tide, and maintain salinity in the farmlands. At the end of the *khazan* lands, a depression called '*poim*' is present at the lowest level of the low tide to act as a repository for excess water and protects agricultural fields from high tides (Bose, 2007). Traditionally, farmers prefer *'Korgut'* paddy during the rains, while during the summers, since the water near the river is saltier, they opt to grow vegetables, pulses, onions, and peas. *Khazan* lands were initially owned by the community or '*gaunkaris*' (village residents), which had few farmers managing the system. They would resolve any issue concerning the agriculture system (Kamat, 2004).

The state is sustained by nine independent river - Terekhol, Mandovi, Zuari, Chapora, Saleri, Sal, Talpona, Canacona, and Galgibaga which serves as the lifelines of the state. An area dominated by these rivers forms an intricate wetland, tidal marshes, and cultivated paddy fields interconnected by canals, inland lakes, bays, lagoons, and creeks governed by normal tides. These rivers provide water resources for various agriculture and industrial sector. These are also famous for eco-tourism, which forms the state economy and provides employment to the common people (Borkar, 2019).

Galgibagaa river is selected as the study area. It is one of the important rivers in the South Goa (Canacona), and two rivers, namely Mashem and Lolyem are the main feeders of Galgibag river. It originates from hilly areas of Uttar Kannada district of Karnataka and enters Canacona near Mule, and flows northwest till Poinguinim for about 15 km in Canacona. It meets the sea near Mashem. Poinguinim has been attracting the old traditional occupation of agriculture as it has been a land of agriculturists for ages. Traditionally, farmers carried out paddy cultivation over the rich fertile *khazan* land during *kharif* and *rabi* cultivation (Pradhan, 2016).

Goa has also made its mark on the green states of India. This is possible due to the vast cover of mangroves that have proven to be the most productive, diverse, and biologically important ecosystem, which now have inclined toward the threatened system. This ecosystem is a productive wetland with flora and fauna adapted to fluctuated water levels, salinity, and anoxic conditions. These consist of unique features like aerial breathing roots, extensive supporting roots, buttresses, salt-excreting leaves, and vivipary (Duke, 1992; Shi *et al.,* 2006). Mangroves are mainly observed in the narrow intertidal mudflats along Mandovi, Zuari, Chapora, Sal, Tiracol, Talpona, Galgibagaa, and the Cumbhajua canal. Chorao Island (Dr. Salim Ali Bird Sanctuary) has one of Goa's best mangrove forests and contains most of the species found in Goa. These include *Rhizophora mucronata, Rhizophora apiculata, Bruguiera gymnorrhiza, Bruguiera cylindrica, Ceriops tagal, Kandelia candel, Avicennia afficinalis, Avicennia marina, Avicennia alba, Sonneratia alba, Sonneratia caseolaris, Aegiceras corniculatum, Excoecaria agallocha, Acanthus illicifolius, Lumnitzera racemose, etc*. There are around 16 identified mangrove species in Goa, which have been granted protection under forest law (Kamat, 2018).

Canacona taluka comprises 15 mangrove species, ten genera under seven families, and 85 species of associate mangroves belonging to 30 genera and 18 families. Different species of mangrove are found in other estuaries of Canacona taluka. Several mangrove associates are reported in these regions: Derris heterophylla, Clerodendron inermis, Acrostichum aureum, Cyperus sp, Porteresia coaretata *Caesalpinia crista, Salvadora persica, Halophila beccarii, Lannea grandis, Abrus precatorius,* and *Thespesia populnea* (Mestri, 2021). According to Forest Department of Goa, it is recorded that Galgibaga river has two main important river feeds i.e. Mashem, Loliem: *Avicennia officinalis* and *A. alba* - 30%; *Rhizophora mucronata* and *Rhizophora apiculata* - 60%; *Aegiceras corniculatum* - 10%, and the second is Poinguinim and Galgibaga: *Avicennia officinalis* and *Avicennia alba* - 50%; *Rhizophora mucronata* and *Rhizophora apiculata* - 40%; and *Bruguiera gymnorrhiza* and *Bruguiera cylindrica* - 10% (Mestri, 2021).

Although the mangrove population has an essential role in biodiversity, it can pose a problem if seen in the cultivation sites. When these mangroves grow rapidly in an unwanted area, they are referred to as "invasive species". This condition is now visible in many parts of Goa that have raised concern about the agriculture system and have been an essential reason for the loss of many fertile agricultural lands. Mangrove species intrude on the main cultivation land when the bund system is damaged, caused by cracks or soil erosion, when the river banks are not maintained or when the irrigation system is poor. These circumstances may also create waterlogging conditions in the fields. This then changes the physical structure like the porosity, water holding capacity, and soil bulk density.

Mangroves have unique reproductive strategies by being viviparous. These do not produce dormant resting seeds like common flowering plants. Instead, mangroves disperse propagules *via* water with varying vivipary or embryonic development degrees while the propagule is attached to the parent tree. Once the propagule drops from the parent tree, there is an obligate dispersal period wherein each species' propagule remains in the water. During this period, embryonic development continues. If the propagule stands in a favourable area, there is an obligate stranding period before the primary roots and cotyledons (primary leaves) emerge. So, when the propagules of mangrove fall into the flowing river water along the bank of the river, the propagules may flow towards the inlets caused by breached bunds, and the waterlogging condition would favour its growth. These propagules germinate and gradually grow into new mangrove plantlets on finding suitable substrates. The salinity and waterlogging conditions are two major essential requirements for any mangrove to flourish. These then compete with native plants or crops for space and nutrition. The area will develop dense mangrove population growth. The agricultural practice will have to be either reduced or completely stopped. This problem has gained attention from many social activists and farmers as this issue has been an essential factor in reducing the usage of cultivation land, depriving the farmers of their earnings and making the land unsuitable for any kind of crop cultivation. The land loses its fertility, and due to an increase in the density of the mangrove population, the area may also be marked as Coastal Restricted Zone (Feller, 2018)

Rice Crop

Rice has been traditionally cultivated in three different types of land, the *morod* (upland) crop, the *kherlands* (midlands), and *khazan* lands (saline lands) of Goa. Though the origin of cultivated rice is stated to be in Southeast Asia, India forms a major part of this region. *Oryza sativa* comprises mainly two subspecies i.e., *Japonica sinica* and *Oryza indica.*

Genus *Oryza* belongs to the Poaceae family. The rice plant is semi-aquatic, free tillering annual grass. It consists of a jointed cylindrical stem (culm), fibrous root system, leaves, and spikelet inflorescence. The roots, culm, and leaves form the vegetative part of the plant while the panicle, spikelet, and flowers form the floral part. Though the rice crop cultivation is carried out on different types of soil, soil with good water retention capacity, a good amount of clay, organic matter, and a pH range of 5.5 and 6.5 is considered ideal for rice cultivation.

Among the total cultivated area in the state, rice occupies about 52,191 ha. Traditional rice varieties cultivated included Kendal, Khochro, and Damgo, while Korgut and Assgo were known to be salt-tolerant varieties. Later on, high-yielding varieties such as IR8, Jaya, Jyoti, and Anapurna were introduced. (Krishnan and Bhonsle, 2012).

AIMS AND OBJECTIVES

The present work was carried out with the following objectives:

1. To conduct a primary survey of non-cultivated field area in Poinguinim village along Galgibaga river and interaction with the locals,
2. Basic remote sensing technique and ground-truthing of the study site,
3. Characterization and analysis of physical and chemical parameters of soil in the affected area,
4. To conduct field and polyhouse experiments to check the growth rate in three rice varieties.

REVIEW OF LITERATURE

- Tiwari *et al*., (2021), addresses nanotechnology as a method to overcome environmental stress condition like soil salinity in crop plants. It highlights the role of biosensors and the use of nanoparticles in cultivated land. Green nanoparticles have been discussed as an alternative to the adverse effects and limitations of chemically and physically synthesized nanoparticles.
- Md. Hasibul Hasan *et al.,* (2020), studied the relationship between salinity intrusion and land-use changes in southwest coastal Bangladesh. They observed that agricultural practices were gradually decreasing while aquaculture increased.
- A case study by Phan and Akihiko (2020) in two estuaries in the Red River Delta, Vietnam, concluded that salinity intrusion reduces the grain yield in coastal paddy fields.
- Abbas *et al.,* (2019) have put forward the mechanism of the halotolerant plant growth-promoting rhizobacteria in consideration as a method to overcome the salinity problem of soil. This halo-PGPR supports the plant to withstand saline conditions by producing certain organic and inorganic compounds.
- Elsir and Neama (2019) performed structured interviews with 25 farmers to use farmer's knowledge to understand the important environmental constraints that slow down indigenous riverside farming. It was noted that despite knowing the knowledge of sustainable agricultural practices, it has not been well incorporated into practice.
- Katherine *et al.,* (2019), studied three farm fields affected by saltwater intrusion to determine the changes that occur in soil chemical properties. The increase in EC and concentrations of chloride, sulfate, and forms of P from the center of the field (low) to the ditch banks (high) increased with inundation.

- Kodikara *et al.*, (2018), recorded that seedlings grown in high salinity showed lower performance s compared to seedlings grown in moderate and low salinity.
- Shahnaz *et al.,* (2018) isolated salt-tolerant PGPR - *Bacillus aryabhattai MS3* from the coastal field of Bangladesh. The strain was beneficial in plant growth-promoting activities under *in-vitro* conditions whereas, in salinity stressed fields, it showed a supportive role to the plants by increasing the availability of nutrients, accelerating IAA and chlorophyll production.
- Tareeba and Shabbir (2018), presented a comprehensive scientific details about mangrove soils in Eastern Lagoon National Park. It includes a soil analysis report of 32 mangrove soil samples that includes various parameters, *viz.*, soil texture, pH, salinity, $CaCO_3$, organic matter, total N, P, and K.
- Alam *et al.,* (2017), carried out studies on the susceptibility of soil and water salinities on the crops, fisheries, and livestock production across the Kalapara coastal belt in Bangladesh. To reduce the effect of salinity on crops, they suggested various possible adaptation strategies, practices, and mitigation techniques.
- Grellier *et al.*, (2017) carried out studies to quantify the evolution of soil quantity, carbon (C) stocks, and C fluctuation after mangrove clearance. *Kandelia candel* mangrove forest was compared with a nearby area that had been cleared 2 years before the study. Mangrove clearing impacted the C cycle which was shown by the switch from C sink to a C source. This highlighted the vital role of mangroves in upholding the environmental condition, particularly concerning climate change.
- Mandal (2016), mapped and characterized salt-affected as well as waterlogged soils of the Gangetic plain (Central Haryana) for reclamation and management.

- Chambers *et al.,* (2016) evaluated the consequences of exaggerated salinity, increased inundation, and their combination on soil microbial performance (enzyme activity) and structure (phospholipid carboxylic acid (PLFA) signatures and terminal fragment length polymorphisms (T-RFLP) profiles) in brackish mangrove peat soil using tidal mesocosms (Everglades, Florida, USA).
- Sharma *et al.,* (2015) studied the diversity of salt-tolerant bacilli, isolated from the soil of eastern Indo Gangetic plains of India. Out of the isolated 95 bacterial strains, 55 showed plant growth-promoting characteristics and salt tolerance to more than 4% NaCl.
- Mahmuduzzaman *et al.,* (2014) gave significant reasons that gave rise to salinity intrusion concerning the coastal belt of Bangladesh. The natural system included the critical geographical location, sedimentation, and rise in sea level, tidal flooding, backwater effect, cyclone, and storm surge. Also, the political system involved reasons like weak water governance system at the local level, poor structure, and maintenance, *etc.*
- Plaut *et al.,* (2013) reviewed, analyzed, and discussed the traditional approaches such as improvising plant environment. They concluded that understanding the interactions between plant roots, bacteria, and fungi, as well as treating the plant directly to alleviate the adverse effects of salinity on crops.
- Bui (2012), suggested that salinity even at a low level is an abiotic stress factor that affects the vegetation pattern and its diversification.
- Ashraf *et al.,* (2012), worked on the restoration of salt-affected area for plant cultivation and also developed a technology that would work towards sustainable environment.

- Arora *et al.,* (2011) suggested a mechanism of salt tolerating ability of PGPR that may contribute to plant-microbe interaction for utilizing the saline affected area for cultivation.
- Sonali and Arun (2010), discussed the morphology, physiology, ecology and genetic relationship of *P. coarctata* with *O. sativa*. They also focused on the metabolic pathways and genes/proteins in relation to salt tolerance in *P. coarctata.*
- Raja *et al.,* (2009) confirmed that post effect of a tsunami can lead to increase in soluble salt concentration in the soil making it highly saline. However, the following year due to heavy rainfall, the salinity of the study areas gradually decreased.
- Irfan *et al.,* (2009), studied various physiological and biochemical changes in plants under waterlogging conditions. According to them, waterlogging may arise due to overuse and/or poor management of irrigation water. It also explains how plant cells shift their metabolism towards low-energy yielding anaerobic fermentation pathways in the absence of oxygen. Their study explores the sequential changes of plant responses at different levels with respect to defence strategies.
- Liang *et al.,* (2008) studied the adaptive trait of mangroves at the anatomical, physiological and biochemical levels.
- Elise and Benjamin (2008) studied and analyzed the changes in biotic and abiotic factors that occurred after clearing the red mangroves (*Rhizophora mangle*) from Panamanian Carribbean. Multiple ecosystem-level effects of mangrove disturbance were also examined. Theie study concluded that anthropogenic clearing of mangroves leads to changes in multiple biotic and abiotic processes of mangrove forests.

- Tripathi *et al.*, (2005) examined the microbial biomass and salinity effect on the microbial as well as the biochemical parameters in the affected soil in the Bay of Bengal coastal region.
- Ali and Barlas (2001) proposed a dynamic model of salinization on irrigated lands. Their work revealed the circumstances under which the salinity reaches an alarming level and the appropriate strategies to control it.
- Ravender (2000) examined the diffusivity of highly saline and non-saline soils by showing hydraulic conductivity, penetrability, and weighted mean diffusivity.
- Sharma (1999) discussed the application of regional salt and water balance models.
- Salama (1999) explained two chemical models based on weathering and deposition. The study suggests that the groundwater is an important agent for the transmission, accumulation, and discharge of salts.

MATERIALS AND METHODS

Study site

The study area consists of field areas along the river Galgibaga that flows through Poinguinim village (14.9738° N, 74.0946° E) in Canacona taluka in South Goa district of Goa state, India. The study area covers about 10.3 hectares of *khazan* land which was traditionally used as paddy fields. However, the present condition of the land has made it unfit for cultivation purposes. **(Figure 1)**

Primary data collection and interaction with the locals

The objective of primary data collection *via* conducting a ground-truthing of the study area along the Galgibaga riverside was to examine the current status of the study site in regards to the vegetation cover and the amount of destruction caused by the environmental destruction in the past.

Several locals residing in and around the study site were interviewed to know more about the study site, crops grown previously, traditional methods used, and the changes they have observed during their agricultural practice within the fields.

Remote sensing analysis

The study area was mapped by utilizing basic techniques of remote sensing with the help of Google Earth software. It explains the changes that gradually took place over the past 20 years (2002 to 2022) in a given area. Analyzing the study site with the help of google earth images by going through the past terrain images of the study site and co-relating them with the current evidence can help predict the sequential changes visible through those images. The area and perimeter of the study area can also be calculated through remote sensing.

Ground truthing mainly refers to information collected on the location that allows image data to be related to real features and materials on the ground. A field survey, analysis of aerial photographs, and high spatial resolution data were carried out.

Characterization and analysis of physical and chemical parameters of soil

1. Soil sample collection

Seven soil samples were collected from seven different sites in the study area to understand the variation in the physical and chemical properties of the soil (**Figure 2**). These soil samples were collected in triplicates at a depth of 15-20 cm using a spade. The soil samples were dried at room temperature, crushed using a mortar pestle, mixed thoroughly, and then sieved using a 2mm sieve and preserved in *zip-lock* polyethylene bags for further laboratory analyses.

2. Soil sample analysis

Soil analysis was carried out at the soil testing and analysis laboratory, Ela Farm, Old Goa. The soil was analyzed for various physical and chemical parameters, *viz*., Sand %, Silt%, Clay% were determined by the Soil Texture Triangle method (Davis and Bennett, 1927). Soil particle density, Soil bulk density, and Soil porosity were calculated by the Graduated Cylinder method (Bowen, 2002). Soil pH was measured by using Saturated Soil Paste method (Pansu & Gautheyrou, 2006). Electrical Conductivity (EC) was measured by using a Conductivity meter. Walkley and Black titration method (Walkley and Black, 1934) were utilized to estimate Organic carbon (OC), while available N was measured by using the Aerobic Incubation Method (Keeney and Bremner, 1966). Potassium (K) was determined by the Ammonium Acetate method (Hanway and Heidel, 1945). Bray's P-1 method (Bray and Kurtz, 1945) was employed to estimate the soil P content. Boron estimation was carried out by using Azomethine-H Method (Wolf, 1971; Gupta, 1979), while sulfur (S) content was calculated using the Turbidimetric method (Chesnin and Yien, 1950).

Rice varieties selected for the experiment

Based on soil analysis, three varieties of rice were selected for the experimental purpose. Goa Dhan II and Karjat seeds were obtained from Ela Farm, Old Goa. These rice varieties are as follows:

a. Goa Dhan II - Goa Dhan-2 (KS-17) A high-yielding salinity tolerant rice variety released for cultivation in coastal saline soils of Goa which accounts for 25-30% (12,000-15,000 ha) of the total cultivated area of rice crop in the state. It is a red kernelled tall variety having a long-bold type of grains. It has maturity duration of 125-130 days; EC = 0.6 ds/M - 12.98 ds/M; pH – 6.3-6.9. (ICAR-Central Coastal Agricultural Research Institute, 2016-17)

b. Karjat - the variety of non-aromatic rice that is high-yielding, dwarf stature, short, bold grain, resistant to blast, suitable for rain-fed uplands, and irrigated areas for Kharif and rabi season; harvest duration- 90-125. This hybrid was obtained by crossing IR 36 and Karjat 35-3 (Kumar *et al.*, 2008).

c. *Porteresia coarcata* - The distinct morphology and leaf architecture enabling the plant to exclude salt is a characteristic feature of *Porteresia* in comparison with *Oryza* sp. It shows the high carbohydrate, protein, and lipid content of the species (Sengupta and Majumder, 2010). *Porteresia* not only tolerates high salinity but also displays better growth characteristics at higher salinity. EC = 12-24 dS/M, pH= 5 (Rao *et al.*, 2004).

I. Field experiment

A. Preparation of seeds for Karjat and Goa Dhan II rice variety

- For sowing rice seeds, filled grains of different varieties were selected by immersing them in water.
- Chaffy and half-filled grains that were found floating on the surface of the water were discarded. The filled grains that settled at the bottom were selected and washed in freshwater and air-dried.
- These seeds were then placed in a Petri plate containing moist muslin cloth and incubated for 24-36 hours at room temperature for germination.

B. Preparation of pots for transplantation

- The pre-germinated seeds were sowed in 2 sets of pots containing organic soil. Each set consisted of 5 pots of Goa Dhan II and five pots of Karjat rice. Each pot contained 4-5 seedlings (50-55 plantlets of each variety).
- One set was placed in the polyhouse, while the other set was placed under normal environmental conditions. A thin film of water over the surface of the soil was maintained regularly. After 15 days of sowing, when the plantlets were 25- 30 cm tall, they were transplanted into the field. **(Plate 1)**
- Three smaller sites within the study site were cleared by removing the weeds and other mangrove associates. Out of these, two sites were affected by salinity and waterlogging conditions, while the third site was unaffected and did not have either salinity or waterlogging situation and therefore served as control. Appropriate spacing between the plantlets and waterlogging conditions was maintained.
- Plants of *Porteresia coarctata* were collected a day before transplantation from the Borim site. Small plantlets were uprooted and the wet soil and transplanted to the study site.

II. Polyhouse experiment

- The seeds were selected and pre-germinated using the above protocol.
- The pre-germinated seeds are sown and allowed to grow.
- The seeds were then transplanted in pots containing the soil collected from the affected study area. The pots were maintained in triplicate with regular watering using saline water collected from the waterlogged condition of the study area. Each pot contained 6-8 plantlets.

RESULTS

Primary data collection

Interaction with the locals

Upon interacting with the locals, the following information was gathered which helped in understanding the traditional methods of farming as well as crops grown in the study area **(Table 1)**.

Table 1: Data Collected from local residents.

Sr. No.	Name	Observation	Rice & other crops grown
1.	Kishore Poinguinkar	• 7-8 conventional bandharas were present and Bhata Bandh was the last bandhara. • Bunds were built using surrounding soil. • Olden rice varieties were healthy and were also used for fodder purpose. • Khazan Land Corporation was developed for their maintenance. • Agricultural field related issues were tackled by the community.	Mutalgo, Shitto, Coconut Tree, Areca Palm.
2.	Abel Barretto	• Presently there has been a shift in the interest of locals toward agriculture. • Lack of education and awareness has made the locals unaware of the potential threat posed by the destruction of *khazan* land	Jaya, Korgut

		and changes occurring along the Galgibaga coastline. • Non-maintenance of the riverbank along the field has been the primary cause of the destruction of *khazan* land. • Due to neglecting bandharas within the field, salinity and waterlogging conditions have aggravated.	
3.	Ram Velip	• The sluice gate (Dhatrath) helped in regulating water flow and also provided an initiative for prawn's culture. • Bunds were made of *Caryota urens* (Bhillamaad) and clayey soil extracted from the field itself. • A combination of cow dung,' paalo ', 'saavli ', and leftover dried fish waste was used as manure. • There were 7-8 natural ponds within the study field that were used as a source of water for irrigation.	Jyoti, Jaya.
4.	Chandrakant Velip	• Savli and Cowdung were used as fertilizers (sare) • ' Kamte ' was referred to as the cultivation of crops on hilltops. • ' Porsa ' was referred to the cultivation of	Assago, Jyoti, Shieidi, Coconut Tree &

		crops on low lying land.	finger millets Onions, Chillies, Okra, Radish, Tambdi Bhaji, Muskmelon, Cucumber, Kidney bean,
5.	Pedrao Barretto	• Loss of interest in agriculture due to availability of more opportunities in other commercial sectors. • Government aid on agriculture does not reach the local farmers. • Maintenances of irrigation bunds and channels are a necessity. • When it comes to agricultural development, local farmers are neglected. • Height of a bandharas depends on river depth. • Global warming has also affected the productivity. • Natural manure has been replaced by chemical fertilizers as it is easily available.	Jyoti, Jaya.

Remote sensing analysis

With the help of basic techniques of remote sensing *via* Google earth software, a gradual change has been observed in the study area. The Google earth image of 2002 showed that the study site was covered with vegetation. The presence of bunds indicates that the land was cultivated and maintained. There have been several natural calamities that have been recorded that may have led to the present condition of the study site. Goa had a record of cloud burst in the year 2009 that flooded the Canacona taluka. This has resulted in drastic changes in the cultivated land in Canacona. The bunds within the study area were eroded and there was a large-scale destruction of the river bank.

The 2013 Google earth image recorded that a large patch of mangrove vegetation had occupied the agricultural fields. Again, in June 2019, cyclone Vayu brought in a heavy downpour in several parts of Goa, especially in the coastal region. This resulted in significant rise in the sea level of many rivers.

Further on 16th May 2021, Goa also witnessed a Cyclone named Tauktae, which was closest to Goa's coast. The huge waves have eroded a large mass of sand from the Galgibagh beach. The huge sand bar disintegrated to form small, isolated sand patches. The 2022 image shows a huge mass of invaded mangrove changing the physical and chemical properties of the agricultural soil and making it unfit for cultivation. (**Table 2**); (**Figure 3** & **4**)

Table 2: Growth of mangrove patch over the years.

Month / Year	Mangrove invaded area
December / 2002	6762 m^2
March/ 2011	20177 m^2
December / 2013	24,618 m^2
January / 2022	30,254 m^2

Due to erosion of Galgibaga River banks along the field area, it has caused intrusions. Mangrove seeds from the river bank have found their way into the agricultural fields. Finding the conditions favourable, the seeds have germinated and occupied the saline waterlogged condition within the fields.

Ground truthing

Table 3: Details of survey of the vegetation in the study area.

Group	Sr. No.	Plant species	Family	Local Name
True Mangrove	1	*Avicennia officinalis* L.	Acanthaceae	Indian Mangrove
	2	*Exoecaria agallocha* L.	Euphorbiaceae	Blinding Tree
Mangrove Associate	3	*Acanthus ilicifolius* L.	Acanthaceae	Sea Holly
	4	*Thespesia populnea*	Malvaceae	Portia Tree
	5	*Acrostichum aureum* L.	Pteridaceae	Leather Fern
	6	*Derris trifoliata L.*	Fabaceae	Karanjvel
	7	*Ixora coccinea* L	Rubiaceae	Jungle Flame
Tree	8	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	Indian Ash Tree
	9	*Holigarna arnottiana* Hook. F.	Anacardiaceae	Black Varnish Tree
	10	*Acacia mangium* Wild	Fabaceae	Australian wattle
	11	*Ficus religiosa* (L.)	Moraceae	Pipal Tree
	12	*Ficus hispida* L.fil	Moraceae	Hairy Fig
Shrub	13	*Caesalpinia crista* L.	Caesalpiniaceae	Crested Fever

				Nut
	14	*Justicia glauca* Rottl.	Acanthaceae	Glauca
	15	*Premna serratifolia* L.	Lamiaceae	Creek Premna
	16	*Clerodendrum inerme* L. Gaerth	Lamiaceae	Volkameria
	17	*Urena lobata* L.	Malvaceae	Caesar's weed
	18	*Leea indica* (Burm.f.) Merr.	Vitaceae	Gandhapatri
	19	*Mimosa pudica* L.	Fabaceae	Lajvanti
Herb	20	*Justicia procumbens* L.	Acanthaceae	Karambal
	21	*Colocasia esculenta* (L.)	Araceae	Taro
	22	*Sphagneticola trilobata* L. Pruski	Asteraceae	Wedelia
	23	*Sida rhombifolia* L.	Malvaceae	Bloom weed
	24	*Cayratia trifoliata* (L.) Domin	Vitaceae	Fox grape
	25	*Sphaeranthus indicus* L.	Asteraceae	Gorakhmundi
	26	*Elephantopus scaber* L.	Asteraceae	Elephant foot
	27	*Impatiens minor* (D.C.) Bennet	Balsaminaceae	Lesser Balsam
	28	*Dicliptera paniculate* (Forssk) I.Darbysh	Acanthaceae	Lady Flower
Grass	29	*Fimbristylis ferruginea* (L.)	Cyperaceae	Rusty sedge
	30	*Cyperus rotundus* L.	Cyperaceae	Nutgrass

(Plate 2, 3, 4 & 5)

Characterization and comparison of the two selected areas based on Physical and chemical properties of the soil

I. Physical analysis of soils

The various Physical properties of the soil *viz.*, Sand, Silt, Clay, Soil Particle Density, Soil Bulk Density, Soil Porosity and Water Holding Capacity were analysed using the standard methods as mentioned earlier. The results indicated higher proportion of sand in the affected area as compared to control, while the Soil Particle Density ranged from 1.95 to 2.98 g/cm3. The affected soil shows low soil bulk density (<1.5) and higher porosity level (>40).

Table 4: Physical properties of the soils in the affected areas.

Sr. No.	Parameter	Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Control
1	Sand	%	29	61	50	16	19	86	12
2	Silt	%	63	33	26	75	65	11	78
3	Clay	%	8	6	24	9	16	3	10
4	Soil Particle Density	g/cm3	2.98	2.35	2.5	2.21	1.95	2	2.43
5	Soil Bulk Density	g/cm3	1.19	1.04	1.28	1.1	0.97	1	1.3
6	Soil Porosity	%	60%	56%	48%	45%	41%	39%	72%

II. Chemical analysis of soils

Chemical analysis of the soil samples collected from the affected study site recorded acidic pH. The Electrical Conductivity (EC) at site 3 and site 4 was comparatively higher indicating higher salinity. These sites had dense vegetation cover of *Acanthus sp.* The soils recorded high organic carbon. High N content can be related to organic rich matter developed within the soil over the years (Reef *et al.*, 2010). The potassium (K) content in the soil ranged from 380-660.8. This can be attributed to organic rich mud and decomposed organic matter accumulated over a period by the pneumatophores, which releases K into soil (Alsumaiti and Shahid, 2018). The soil shows higher P content ranging from 22.23-42.11.

The soil shows presence of higher concentration of Boron ranging from 0.922-2.614, indicating the toxicity levels of Boron in the soil. The soils also record higher levels of sulphur (S).

Table 5: Chemical properties of the soils in the affected areas.

Sr. No.	Parameters	Units	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Control
1	pH	unit	7	7	6.4	6.5	6.6	6.1	6.3
2	EC	m.mhos/cm	0.449	1.201	2.34	1.961	1.461	5.65	1.802
3	0rganic Carbon	%	2.1	2.3	2	1.98	1.9	2	1.51
4	Nitrogen	kg/Ha	577	577	550	522	522	550	495
5	Potassium	kg/Ha	414.4	660.8	504	380.8	504	627.2	403.2
6	Phosphorous	kg/Ha	29.64	31.04	22.23	31.04	42.11	36.95	45.83
7	Boron	Ppm	0.924	2.164	1.358	0.922	1.52	2.614	0.706
8	Sulphur	Ppm	24	24	24	20	23	28	26

Field Experiment

After transplantation of all the three varieties of rice, the initial weekly observations indicated that all the varieties showed slow growth in the internodal region and increased leaf length. In the first week after transplantation the plants recorded plant growth, while in the second and third week, Goa Dhan II and Karjat variety did not show any significant increase in plant growth. In the fourth week 70% of the plants of Goa Dhan II and Karjat variety showed wilting. While the third variety, i.e., *Porteresia coarctata* did not show any wilting and showed marginal increase in length **(Table 6) (Plate 6)**. Similar observations were recorded in the two varieties *viz*., Goa Dhan II and Karjat variety grown under polyhouse conditions **(Table 7) (Plate 7)**

Table 6: Plant height (in cm) in three rice varieties after transplantation in the field.

Weeks after transplantation	**Goa Dhan II**	**Karjat**	***Porteresia coarctata***
First	22-24	16- 19	18-22
Second	30-35	23- 28	25-32
Third	32-35	24-29	30-36
Fourth	Wilting (80%)	Wilting (80%)	34-39

Table 7: Plant height (in cm) in two rice varieties grown in polyhouse.

Weeks after transplantation	**Goa Dhan II**	**Karjat**
First	24-28	15- 20
Second	32-35	23- 25
Third	33-36	28-29
Fourth	Wilting (80%)	Wilting (80%)

DISCUSSION

The soil analysis helps to understand the changes that have taken place in the physical and chemical property of soil. The soils analysis recorded high organic carbon content. This may be attributed to carbon rich biomes which are occupied by carbon sequestering mangroves (Alsumaiti and Shahid, 2018).

Nitrogen (N), phosphorus (P), and potassium (K) are the primary nutrients within the group of macro-nutrients. The higher concentration of N and its availability to mangroves keeps the mangroves plantation healthy even under stress conditions (Reef *et al.,* 2010). The pneumatophores release K into soil making the soil rich in K (Alsumaiti and Shahid, 2018). High phosphorus content may be attributed to various reasons such as clay rich particles, pH ranging from 6-7 and high organic matter (Prasad and Debolina, 2019).

The results of the field and polyhouse experiment indicate that the soil does not support the cultivation of the two rice varieties *viz.,* Goa Dhan II and Karjat. This may be attributed to the physical and chemical characteristics of the soil that showed excessive amount of nutrients and organic matter. However, the wild species *Porteresia coarctata* showed positive growth in the field as it grows naturally under such situations. *Porteresia*, a distant wild rice relative, is a monotypic genus exhibiting characteristic features that help it to survive under the saline condition. Besides it occurs as a mangrove associate. The extensive rhizomatous system of the plant helps in absorption even under high salinity. The native habitat of this wild species of rice is along the coastal mud that is flooded twice a day by saline water (Sonali and Arun, 2010). *Porteresia* also shows the presence salt hairs (Flowers *et al., 1990*). Hence, it could survive and grow under stress conditions at the study site.

Key observation of the study site

- The breaching of bunds at the river bank has created narrow channels directing the saline river water into the fields that result in saline waterlogging condition within the fields.
- Along with river water, the mangrove seeds and pods also entered the fields leading to excessive growth of mangrove species in the cultivable fields.
- The soil at the river bank has been eroded and destroyed by pneumatophores of the mangroves increasing the rate of erosion.
- Lack of vegetation on the bunds results in increased erosion.
- The affected area has darker coloured soils indicating that they are poorly drained and have low oxygen concentration with rich in organic matter. Hence, they are also termed anaerobic soils.
- The population of *Acanthus* species has occupied major portion of the field area. This is followed by *Avicinea* species, which is the second dominating mangrove species. It has been observed that the pods of *Avicennia* species have started germinating in large numbers.
- The mangrove root system, i.e., pneumatophores that arise from beneath the soil helping the mangrove to breathe. They are also responsible for the depleted soil structure.
- Effect of saline waterlogged condition was observed on coconut trees growing within the study site. The coconut trees showed stunted growth, reduced leaf surface, leaf discoloration, and reduced leafy crown at the apex indicating poor health which ultimately led to the death of the plants.
- The width of the river flowing alongside the study site is also reduced. It has been observed that the accumulation of sediments and debris, has served as a substratum

for the growth of mangroves. Besides the sediments and debris have deposited at the central portion of the river, thereby reducing its flow. **(Plate 8)**

CONCLUSION

In the present study, the non-cultivable, saline, waterlogged field area of Poinguinim village, in Canacona taluka was undertaken for the study. Primary data was collected by interacting with the local farmers and conducting multiple field survey. With the help of basic remote sensing technique, i.e., Google Earth Software, the gradual growth and succession of mangrove population was traced. Various reasons responsible for the present situation include breaching of Galgibaga river bank, erosion of bunds and the saline-waterlogged conditions in the affected field areas. Soil samples were collected from the study site to analyse the physical and chemical properties of the affected soils. Based on the soil analysis report, three varieties *viz.,* Goa Dhan II, Karjat, and *Porteresia coarctata* were selected for the field experiment and two varieties *viz.*, Goa Dhan II, and Karjat were selected for the polyhouse experiment.

The soil analysis revealed that the various parameters such as pH, EC, Organic Matter, N, P, K, Bo, and S in the field soil were gradually changing to favour mangrove vegetation. The field and polyhouse experiment indicated that the soils were unfavourable for the growth of Goa Dhan II, and Karjat varieties of rice. The study revealed the lone species *P. coarctata* should adaptability to the prevailing saline condition at the study site.

Porteresia coarctata is considered to have great ecological role in the biodiversity towards protection, conservation and restoration of estuarine and creek systems. It is suitable for growing along the bank of Galgibaga River. Being a mangrove associate, it would bind the soil and assist in preventing erosion.

Waterlogging and salinity together greatly reduce the ability of roots to exclude the salt. This causes significant increase in uptake of salt concentration in the shoots. This results in either stunted growth or may kill the plant. This issue can be resolved by the farmers if they take initiative at primary level wherein the Panchayats can help to improve the situation. Still, if the issue is not tackled, then one can approach the state agriculture support team, which would rectify the problem and take necessary action towards improvisation.

Recommendations

- Use of saline tolerant crop species such as grain legumes and canola are seen to be more resistant to waterlogging condition.
- Altering nitrogen (N) management may be one of the steps to adjust to waterlogging conditions.
- Using raised beds would assist as it allows sufficient drainage into the corresponding channels that would help by providing greater soil depth for plant growth.
- Managing weed density is of importance as it affects crop's ability to recover in the waterlogging conditions. Weeds compete for water, space and other nutrients that could be utilised by the crops for better growth.
- The above recommendation would assist in replenishing the fertility and will certain the conditions that otherwise favour the growth of mangrove. This would eventually improve the soil conditions. Thus, the agricultural land can be restored for cultivation purpose.

REFERENCES

- A.K. Mandal and Paolo Paron, (2016) Mapping and characterization of salt-affected and waterlogged soils in the Gangetic plain of central Haryana (India) for reclamation and management, *Cogent Geoscience*, DOI: 10.1080/23312041.2016.1213689.
- A.S. Qureshi, P.G. Mc. Cornick, M. Qadir, and Z. Aslam, (2008) Managing salinity and waterlogging in the Indus Basin of Pakistan, Agricultural Water Management, 95, (1): 1-10. ISSN 0378-3774.
- Alam, M. Z., Carpenter-Boggs, L., Mitra, S., Haque, M., Halsey, J., Rokonuzzaman, M., Saha, B., and Moniruzzaman, M. (2017) Effect of salinity intrusion on food crops, livestock, and fish species at Kalapara Coastal Belt in Bangladesh. *Journal of Food Quality*, Volume 2017, ID 2045157.
- Ali, M. P., Bari, M. N., Haque, S. S., Kabir, M. M. M., Afrin, S., Nowrin, F., Islam M.S., Landis, D. A. (2019). Establishing next-generation pest control services in rice fields: eco-agriculture. *Scientific Reports*, 9(1): 1-9.
- Allbed, A., & Kumar, L. (2013) Soil salinity mapping and monitoring in arid and semi-arid regions using remote sensing technology: a review. *Advances in Remote Sensing*, Vol.2 No.4(2013), id:41262,1-13 pgs.
- Alsumaiti, T. S., and Shahid, S. A. (2018). Comprehensive Analysis of Mangrove Soil in Eastern Lagoon National Park of Abu Dhabi Emirate. *International Journal of Business and Applied Social Science*, 4(5): 39-56.
- Arora, N. K., Tewari, S., Singh, S., Lal, N., and Maheshwari, D. K. (2012) PGPR for protection of plant health under saline conditions. *Bacteria in Agrobiology: Stress Management*. Pp. 239-258.

- Ashraf, M. Y., and Wu, L. (1994) Breeding for salinity tolerance in plants. *Critical Reviews in Plant Sciences*, 13(1): 17-42.
- B.R. Sharma, (1999) Regional salt- and water-balance modelling for sustainable irrigated agriculture. *Agricultural Water Management*, 40 (1):129-134, ISSN 0378-3774,
- Barrett-Lennard, E. G. (2003) The interaction between waterlogging and salinity in higher plants: causes, consequences and implications. *Plant and Soil*, 253(1): 35-54.
- Berg, M. G., and Gardner, E. H. (1978). Methods of soil analysis used in the soil testing laboratory at Oregon State University.
- Brdar-Jokanović, M. (2020) Boron toxicity and deficiency in agricultural plants. *International Journal of Molecular Sciences*, 21(4): 1424.
- Dennis, E. S., Dolferus, R., Ellis, M., Rahman, M., Wu, Y., Hoeren, F. U. Hoeren, A. Grover, K.P. Ismond, A.G. Good and Peacock, W. J. (2000) Molecular strategies for improving waterlogging tolerance in plants. *Journal of Experimental Botany*, 51(342): 89-97.
- E.N. Bui, (2013) Soil salinity: A neglected factor in plant ecology and biogeography. *Journal of Arid Environments,* 92:14-25, ISSN 0140-1963, https://doi.org/10.1016/j.jaridenv.2012.12.014.
- Egamberdieva, D., Wirth, S., Bellingrath-Kimura, S. D., Mishra, J., and Arora, N. K. (2019) Salt-tolerant plant growth promoting rhizobacteria for enhancing crop productivity of saline soils. *Frontiers in Nicrobiology*, 10: 2791.

  Elgabaly, M. M. (1977) Water in arid agriculture: Salinity and waterlogging in the near-east region. *Ambio*, Vol. 6, 36-39.

- Elsir A. Salih and Neama A. Elias. (2019), Assessment of Major Environmental Constraints of Riverside Cultivation in Omdurman (Sudan) by Use of Local Knowledge. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS),* 55(1): 188-203.
- Epstein, E. (1980) Responses of plants to saline environments. In *Genetic Engineering of Osmoregulation.* Pp. 7-21. Springer, Boston, MA.
- Epstein, E. (1985) Salt-tolerant crops: origins, development, and prospects of the concept. *Plant and Soil*, 89(1): 187-198.
- Fallah Shamsi, S. R., Zare, S., and Abtahi, S. A. (2013) Soil salinity characteristics using moderate resolution imaging spectroradiometer (MODIS) images and statistical analysis. *Archives of Agronomy and Soil Science*, 59(4): 471-489.
- Galvani, A. (2006) The challenge of food sufficiency through salt-tolerant crops. In *Life in Extreme Environments*. Pp. 437-450. Springer, Dordrecht.
- Gopalakrishnan, T., and Kumar, L. (2020) Modeling and Mapping of Soil Salinity and its Impact on Paddy Lands in Jaffna Peninsula, Sri Lanka. *Sustainability*, 12(20): 8317.
- Granek, E., and Ruttenberg, B. I. (2008) Changes in biotic and abiotic processes following mangrove clearing. *Estuarine, Coastal and Shelf Science*, 80(4): 555-562.
- Grellier, S., Janeau, J. L., Hoai, N. D., Kim, C. N. T., Phuong, Q. L. T., Thu, T. P. T., Tran-Thi, N.T. and Marchand, C. (2017) Changes in soil characteristics and C dynamics after mangrove clearing (Vietnam). *Science of the Total Environment*, 593: 654-663.
- Hasan, M. H., Hossain, M. J., Chowdhury, M. A., and Billah, M. (2020) Salinity intrusion in southwest coastal Bangladesh: an insight from land use change.

In *Water, Flood Management and Water Security Under a Changing Climate*. Pp. 125-140. Springer, Cham.

- Hossain, M. S. (2019) Present scenario of global salt affected soils, its management and importance of salinity research. *International Research. Journal of Biological Sciences*, 1: 1-3.
- Irfan, M., Hayat, S., Hayat, Q., Afroz, S., and Ahmad, A. (2010) Physiological and biochemical changes in plants under waterlogging. *Protoplasma*, 241(1-4): 3-17.
- Kamat, N. M. (2013). The neglected natural resources of Goa, Published in: *Atharva*. 8(3).
- Kodikara, K. A. S., Jayatissa, L. P., Huxham, M., Dahdouh-Guebas, F., and Koedam, N. (2017) The effects of salinity on growth and survival of mangrove seedlings changes with age. *Acta Botanica Brasilica*, 32:37-46.
- Kumar, V., Shriram, V., Nikam, T. D., Kavi Kishor, P. B., Jawali, N., and Shitole, M. G. (2008) Assessment of tissue culture and antibiotic selection parameters useful for transformation of an important indica rice genotype Karjat-3. *The Asian and Australasian Journal of Plant Science and Biotechnology*, 2: 84-87.
- Latha, R., Srinivas Rao, C., Sr. Subramaniam, H. M., Eganathan, P., and Swaminathan, M. S. (2004) Approaches to breeding for salinity tolerance: a case study on *Porteresia coarctata*. *Annals of Applied Biology*, 144(2): 177-184.
- Manik, S. M., Pengilley, G., Dean, G., Field, B., Shabala, S., & Zhou, M. (2019). Soil and crop management practices to minimize the impact of waterlogging on crop productivity. *Frontiers in plant science*, 140.
- Manjunath, B. L., Verma, R. R., Ramesh, R., and Singh, N. P. (2012) Evaluation of varieties and local manurial sources for organic rice (*Oryza sativa*) production. *Indian Journal of Agronomy*, 57(3): 241-244.

- Manohara, K. K., Morajkar, S., Shanbhag, Y., Phadte, P., and Singh, N. K. (2021) Haplotype analysis of Saltol QTL region in diverse landraces, wild rice and introgression lines of rice (*Oryza sativa* L.). *Plant Genetic Resources*, 19(4): 289-298.
- McLean, E.O. (1982) in Methods of Soil Analysis, Part 2, Agron. 9, A.L. Page, R.H. Miller, and D.R. Keeney (Eds), Am. Soc. Agron., Madison, WI. Pp. 199-224.
- Moayedi, H., Huat, B. B., Moayedi, F., and Asadi, A. (2011) Effect of Embedding Drainage System on Retaining Wall Structure Stability. E*uropean Journal of Government and Economics (EJGE)*, 1-7.
- Munns, R., and Gilliham, M. (2015) Salinity tolerance of crops–what is the cost?. *New Phytologist*, 208(3): 668-673.
- Niu, G., Rodriguez, D. S., and Starman, T. (2010) Response of bedding plants to saline water irrigation. *HortScience*, 45(4):, 628-636.
- Ockenden, M. C., Deasy, C., Quinton, J. N., Surridge, B., and & Stoate, C. (2014) Keeping agricultural soil out of rivers: evidence of sediment and nutrient accumulation within field wetlands in the UK. *Journal of Environmental Management*, 135: 54-62.
- Patil, M. D., Das, B. S., and Bhadoria, P. B. (2011) A simple bund plugging technique for improving water productivity in wetland rice. *Soil and Tillage Research*, 112(1): 66-75.
- Phan, L. T., and Kamoshita, A. (2020) Salinity intrusion reduces grain yield in coastal paddy fields: case study in two estuaries in the Red River Delta, Vietnam. *Paddy and Water Environment*. Pp. 1-18.

- Plaut, Z., Edelstein, M., and Ben-Hur, M. (2013) Overcoming salinity barriers to crop production using traditional methods. *Critical Reviews in Plant Sciences*, 32(4): 250-291.
- Raja, R., Chaudhuri, S. G., Ravisankar, N., Swarnam, T. P., Jayakumar, V., and Srivastava, R. C. (2009) Salinity status of tsunami-affected soil and water resources of South Andaman, India. *Current Science,* Volume 96:152-156.
- Rao, V. P. (2014) Physico-chemical analysis of mangrove soil in the Machilipatnam coastal region, Krishna District, Andhra Pradesh. *International Journal of Engineering Research*, 3(6): 10-12.
- Rashed, A., Khalifa, E., and& Fahmy, H. (2003). Paddy rice cultivation in irrigated water managed saline sodic lands under reclamation, Egypt. In *The 9th ICID International Drainage Workshop, Utrecht, Netherlands* (Vol. 71).
- Ravender S., Kundu, D. K., (2000), A comparative study of water transmission functions in a saline and non-saline soil**.** *Indian Journal of Soil Conservation,* 28 (3):212-215.
- Rishi Prasad and D. Chakraborty, (2019) Phosphorus Basics: Understanding Phosphorus Forms and Their Cycling in the Soil, Crop Production, ANR-2535.
- Ritzema, H. P. (2016) Drain for Gain: Managing salinity in irrigated lands—A review. *Agricultural Water Management*, 176: 18-28.
- S. Liang, RCh Zhou, SS Dong & SH Shi (2008) Chinese Science Bulletin, Adaptation to salinity in mangroves: Implication on the evolution of salt-tolerance, volume 53, Article number: 1708
- S. Negrão, S. M. Schmöckel, M. Tester, (2017) Evaluating physiological responses of plants to salinity stress. *Annals of Botany*, 119(1):1–11, https://doi.org/10.1093/aob/mcw191

- Safdar, H., Amin, A., Shafiq, Y., Ali, A., Yasin, R., Shoukat, A., Hussan, M.U. and Sarwar, M. I. (2019) A review: Impact of salinity on plant growth. *National Science 2019*, 17(1): 34-40.
- Sahab, S., Suhani, I., Srivastava, V., Chauhan, P. S., Singh, R. P., and Prasad, V. (2021) Potential risk assessment of soil salinity to agroecosystem sustainability: Current status and management strategies. *Science of the Total Environment*, 764: 144164.
- Salama, R., Otto, C. and Fitzpatrick, R. (1999) Contributions of groundwater conditions to soil and water salinization. *Hydrogeology Journal,* 7:46–64, https://doi.org/10.1007/s100400050179
- Saviozzi, A., Cardelli, R., and Di Puccio, R. (2011) Impact of salinity on soil biological activities: a laboratory experiment. *Communications in Soil Science and Plant Analysis*, 42(3): 358-367.
- Sengupta, S., and Majumder, A. L. (2010). *Porteresia coarctata* (Roxb.) Tateoka, a wild rice: a potential model for studying salt: stress biology in rice. *Plant, Cell and Environment*, 33(4): 526-542.
- Shahbaz, M., and Ashraf, M. (2013) Improving salinity tolerance in cereals. *Critical Reviews in Plant Sciences*, 32(4): 237-249.
- Shahnaz, S., and Manjurul, K. M. (2018) Salinity intrusion and coastal agriculture: adaptation strategies using salt-tolerant plant-growth promoting rhizobacteria for sustainable food security. *Regional Issue*, *21*(3-1): 58-61.
- Sharma, A., Singh, P., Kumar, S., Kashyap, P. L., Srivastava, A. K., Chakdar, H., Singh, R.N., Kaushik, R., Saxena, A.K. and Sharma, A. K. (2015) Deciphering diversity of salt-tolerant bacilli from saline soils of eastern Indo-gangetic plains of India. *Geomicrobiology Journal*, 32(2): 170-180.

- Shrivastava, P., and Kumar, R. (2015) Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences*, 22(2): 123-131.
- Singh, A. (2018) Alternative management options for irrigation-induced salinization and waterlogging under different climatic conditions. *Ecological Indicators*, 90: 184-192.
- Siscar-Lee, J. J. H., Juliano, B. O., Qureshi, R. H., and Akbar, M. (1990) Effect of saline soil on grain quality of rices differing in salinity tolerance. *Plant Foods for Human Nutrition*, 40(1): 31-36.
- Subardja, V. O., Anas, I., & Widyastuti, R. (2016) Utilization of organic fertilizer to increase paddy growth and productivity using System of Rice Intensification (SRI) method in saline soil. *Journal of Degraded and Mining Lands Management*, 3(2): 543.
- Subardja, V. O., Anas, I., and Widyastuti, R. (2016). Utilization of organic fertilizer to increase paddy growth and productivity using System of Rice Intensification (SRI) method in saline soil. *Journal of Degraded and Mining Lands Management*, 3(2): 543.
- Tavakkoli, E., Rengasamy, P., and McDonald, G. K. (2010) The response of barley to salinity stress differs between hydroponic and soil systems. *Functional Plant Biology*, 37(7): 621-633.
- Tiwari, S., Lata, C., and Prasad, V. (2021) Application of Nanobiotechnology in Overcoming Salinity Stress. In *Nanobiotechnology*. Pp. 375-398. Springer, Cham.
- Tomar, O. S., Minhas, P. S., Sharma, V. K., Singh, Y. P., and Gupta, R. K. (2003) Performance of 31 tree species and soil conditions in a plantation established with saline irrigation. *Forest Ecology and Management*, 177(1-3): 333-346.

- Tripathi, S., Kumari, S., Chakraborty, A., Gupta, A., Chakrabarti, K., and Bandyapadhyay, B. K. (2006) Microbial biomass and its activities in salt-affected coastal soils. *Biology and Fertility of Soils*, 42(3): 273-277.
- Tully, K. L., Danielle W., Wyner W. J., Jarrod M., and Thomas J. (2019) Soils in transition: saltwater intrusion alters soil chemistry in agricultural fields. *Biogeochemistry* 142(3): 339-356.
- Umesha, S., Manukumar, H. M., and Chandrasekhar, B. (2018). Sustainable agriculture and food security. In *Biotechnology for Sustainable Agriculture*. Pp. 67-92. Woodhead Publishing.
- Valipour, M. (2014) Drainage, waterlogging, and salinity. *Archives of Agronomy and Soil Science*, 60(12): 1625-1640.
- Yamaguchi, T., and Blumwald, E. (2005) Developing salt-tolerant crop plants: challenges and opportunities. *Trends in Plant Science*, 10(12): 615-620.
- Ziaul Haider, M., and Zaber Hossain, M. (2013) Impact of salinity on livelihood strategies of farmers. *Journal of Soil Science and Plant Nutrition*, 13(2): 417-431.