Dealing with the global challenges of salinisation

Drivers, challenges and solutions

Judit Snethlage, Marijn Gülpen, Feroz Islam and Catharien Terwisscha van Scheltinga

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'This study/activity was (co-)financed by the Ministry of LNV and supported by NFP and NWP.

Wageningen Environmental Research
Wageningen, June 2023

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Report 3269
ISSN 1566-7197

WAGENINGEN
UNIVERSITY & RESEARCH

Snethlage, Judit, Marijn Gülpen, Feroz Islam, Catharien Terwisscha van Scheltinga, 2023. *Dealing with the global challenges of salinisation; Drivers, challenges and solutions.* Wageningen, Wageningen Environmental Research, Report 3269. 42 pp.; 1 fig.; 1 tab.; 103 ref.

Toenemende verzilting is een grote complexe mondiale uitdaging die om een integrale aanpak vraagt. Om deze uitdaging aan te pakken is het Partnership Saline Water & Food Systems (SW&FS) opgericht door Netherlands Water Partnership en Netherlands Food partnership met als doel stakeholders bij elkaar te brengen. Het partnerschap heeft een globale campagne over verzilting geïnitieerd om het onderwerp beter op de kaart te zetten, een gedeelde agenda te formuleren en acties in de water- en voedselsector te stimuleren. In dit kader is er een infographic en een achtergronddocument gemaakt. Allereerst is er gebruikgemaakt van kennis en ervaringen uit het verleden om een integrale benadering na te streven voor het duurzaam aanpakken van de huidige uitdagingen op het gebied van verzilting. Vervolgens zijn aan de hand van casestudy's de huidige uitdagingen, impacts en oplossingen bestudeerd. Deze casestudies uit diverse regio's (Bangladesh, Argentinië, Bahrein, Egypte, het Aralmeer en Pakistan) benadrukken de veelzijdige impacts van verzilting en stellen regio specifieke oplossingen voor, waaronder alternatieve zoetwaterbronnen, efficiënte irrigatie, ontzilting en drainagebeheer. Het volledige overzicht van de effectiviteit van deze oplossingen moet nog blijken, gezien het feit dat verzilting blijft toenemen als gevolg van, onder andere, klimaatverandering. Het is van cruciaal belang om een integrale en adaptieve aanpak te hanteren die preventie- en aanpassingsstrategieën combineert en tegelijkertijd de complexiteit van de uitdagingen op het gebied van verzilting erkent. Geïntegreerde benaderingen zoals de Food System Approach en Integrated Water Resources Management kunnen kaders bieden voor het beheer van watervoorraden en het waarborgen van duurzame voedselsystemen. Robuust waterbeheer, beleidsinterventies en maatregelen om klimaatverandering tegen te gaan zijn essentieel om de voedselzekerheid, het levensonderhoud en de ecosystemen te behouden in het licht van veranderende zoutgehaltes.

The increasing salinity levels in water and soil have emerged as critical global challenges, needing a context-specific solutions. Salinisation, characterised by salt accumulation, demands an integrated approach that incorporates the causes, sources of salts, the extent of salinisation and socio-economic context. To tackle this problem, the Saline Water & Food Systems (SW&FS) Partnership was established with the aim of bringing stakeholders together. The partnership has initiated a worldwide campaign on salinity, seeking to raise awareness, formulate a shared agenda, and stimulate actions in the water and food sectors. In this context an infographic was created and a background document containing more in-depth information. First, past knowledge was examined to facilitate the development of an integrated approach to address the current salinity challenges. Then, case studies were used to research the current challenges, impacts, and solutions. These case studies from diverse regions (Bangladesh, Argentina, Bahrein, Egypt, Aral Sea, Pakistan,) highlight the multifaceted impacts of salinity and propose region-specific solutions, including alternative freshwater sources, efficient irrigation, desalination, and drainage management. However, full realization of the effectiveness of these solutions in combating salinity remains incomplete, given the increased salinisation resulting from climate change. It is crucial to adopt a comprehensive and balanced approach that integrates prevention and adaptation strategies while acknowledging the complexity of salinity challenges. Integrated approaches such as the Food Systems Approach and Integrated Water Resources Management can provide frameworks for managing water resources and ensuring sustainable food systems. Robust water management, policy interventions, and measures to mitigate climate change are essential for safeguarding food security, livelihoods, and ecosystems from salinity challenges. By drawing upon knowledge and experiences from the past, a holistic approach can be pursued to sustainably address current salinity challenges.

Keywords: Salinity, Global Campaign on Salinisation, Communication, Climate Change, Agriculture

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Wageningen Environmental Research Report 3269 | ISSN 1566-7197

Photo cover: Wageningen University & Research Brand Portal

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Verification

Report: 3269
Project number: 5200047967

Wageningen Environmental Research (WENR) values the quality of our end products greatly. A review of the reports on scientific quality by a reviewer is a standard part of our quality policy.

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Summary

The increasing levels of salinity in water and soils have become critical challenges globally, demanding context-specific solutions. To address these challenges, the Saline Water & Food Systems Partnership (SW&FS) was established by Netherlands Food Partnership and Netherlands Water Partnership, aiming to unite stakeholders.

The partnership initiated the Global Campaign for Salinisation, which seeks to raise awareness, formulate a joint agenda, and drive actions in the water and food sectors. This document serves as a comprehensive resource for the developed infographic, entailing detailed information guided by case studies. First, the past knowledge and experiences were studied to develop an integrated approach in addressing the current salinity challenges. Case studies were used to research the current challenges, impacts, and potential solutions. These case studies, conducted in regions including Bangladesh, Egypt, the Aral Sea, Pakistan, Argentina and Bahrein highlight the impacts of salinity and region-specific solutions. These solutions entail alternative freshwater sources, efficient irrigation, desalination, and drainage management. However, the effectiveness of these solutions in dealing with salinity remains uncertain, given the increased salinisation resulting from climate change.

It is crucial to adopt an integrated and adaptive approach that integrates prevention and adaptation strategies while acknowledging the complexity of salinity challenges. Integrated approaches, such as the Food System Approach and Integrated Water Resources Management, can provide frameworks for managing water resources and ensuring sustainable food systems. Robust water management, policy interventions, and measures to mitigate climate change are essential for safeguarding food security, livelihoods, and ecosystems from the challenges posed by salinity.

Abbreviations and acronyms

FAO	Food and Agriculture Organization of the United Nations
ILRI	International Institute for Land Reclamation and Improvement
ICBA	International Centre for Biosaline Agriculture
IWMI	International Water Management Institute
NFP	Netherlands Food Partnership
NWP	Netherlands Water Partnership
SW&FS	Saline Water & Food Systems partnership
SIDS	Small Island Developing State(s)
NAP	National Adaptation Plan
INSAS	International Network of Salt-affected Soils
WASAG	Water Scarcity in Agriculture

1 Introduction

Salinisation, characterised by the accumulation of salts, presents complex challenges that require integrated approaches. These approaches should also acknowledge the intricate interactions between water and food systems. In response to this need, the Saline Water & Food Systems (SW&FS) Partnership was initiated to bring stakeholders together.

The partnership was formed in 2021 by the Netherlands Food Partnership and the Netherlands Water Partnership, and fully established in 2022. Shortly after, the UN 2023 Water Conference was organised in March 2023 with the objective of mobilising Member States, the UN system, and stakeholders to take action and implement successful solutions on a global scale. The Water Action Agenda was developed as a platform for organisations to declare their voluntary commitments. The SW&FS Partnership made a commitment during the conference to address salinisation challenges. Since then, the partnership has taken a new step with partners in response to the conference's call to action. This new step is the Global Campaign for Salinisation, which aims to boost new ideas and activities, consolidate initiatives, and generate momentum. The primary objective of the campaign is "to increase awareness about salinisation issues among policymakers, researchers, and practitioners in the global water and food sectors, and subsequently formulate and drive a joint agenda of actions" (SW&FS Partnership, 2023).

The agenda of the Global Campaign for Salinisation is defined at three levels. Firstly, at the policy level, integrated strategies are being developed to guide decision-making processes and facilitate the implementation of effective measures to address salinisation. Secondly, the campaign will initiate the development of new knowledge and research programs aimed at deepening our understanding of salinisation processes, challenges, impacts, and solutions. Lastly, innovative implementation projects will serve as demonstration sites for the adoption and evaluation of novel technologies, practices, and interventions to manage salinity challenges.

Through the Global Campaign for Salinisation, a focused global effort will be launched to deal with the challenges of salinisation, promoting collaboration among diverse stakeholders. To establish a common understanding of salinisation this project has been initiated. Two main activities have been undertaken in this project: the development of this background document and the creation of an infographic. The following paragraph will provide an explanation of the aim and context of these two components.

1.1 Aim and context

The two outputs of this project are: the infographic and the background document. The background document supports the Global Campaign on Salinisation by collecting and displaying a variety of drivers, solutions, and impacts around the world. The document consists of a literature review on causes and challenges dealing with salinity. Furthermore, a set of case studies from different regions, that currently face salinity challenges are discussed. The infographic is designed to create an overview of drivers and challenges related to salinisation. The objective of the infographic is to facilitate and showcase the salinisation topic to partners while collaboratively establishing a shared agenda. Both outputs contribute to a better understanding of the diverse nature of salinity challenges and solutions. In the next section we elaborate on the methods that are used to reach both outputs.

1.2 Methods

Different approaches have been followed to develop the infographic and the background document. The background document consists of the literature review, the infographic and case studies. The literature review represents mostly the past challenges of salinisation, and the infographic and case studies mostly represent the current challenges of salinisation. To understand the present challenges of salinisation, it is essential to examine and identify the specific challenges and solutions that were encountered in the past.

1.2.1 Literature review

The approach for the literature review consisted of 2 phases. The first phase of the literature review involved identifying organisations that have actively worked on salinity globally in the past. Several institutions emerged from this process, including Food and Agricultural organisation of the United Nations (FAO), International Water Management Institute (IWMI), International Center for Bio saline Agriculture (ICBA), and International Institute for Land Reclamation and Improvement (ILRI). ILRI was specifically chosen as the focus for this background document. This organisation was selected because it is the oldest organisation that extensively and scientifically reports on salinity-related matters. Additionally, it was observed that the knowledge from the other institutions is well-documented, while ILRI's knowledge appears to be relatively scarce in online documentation, making its recovery more impactful. However, it is important to acknowledge the significant contributions of other institutions such as FAO, IWMI, and ICBA to the field of salinity research. Further overview regarding these contributions is discussed in Chapter 2.

The second phase was an in-depth analysis of the documents from ILRI. The publications from ILRI were retrieved from the library of Wageningen University and Research (WUR). The library has access to many journals, magazines, and several other sources worldwide. The goal for the literature review was to explore whether the causes of salinity and, impacts and solutions regarding salinity have changed over the years. The terms "International Land Reclamation Institute" and "salinity" were used in the search function of the WUR library. Two separate searches were conducted, one without a time delineation and the other up to the year 2003, since ILRI ceased to exist in 2001. 31 publications have been found. The search results are noted in Annex 2.

1.2.2 Infographic

The objective of the design was to ensure that the infographic accurately represents the challenges of salinisation and how impact different contexts. The infographic was designed based on the information collected from the case studies, literature and (in)formal discussions with relevant stakeholders. The first draft design of the infographic was presented on during the annual meeting of International Network of Salt-affected Soils (INSAS). This took place in May 2023, the draft was presented and with the support of interactive tools, feedbacks were collected from the participants (~ 60 people). A summary of the meeting and feedbacks are described in Annex 4.

1.2.3 Case studies

The salinity challenges and solutions of current situation were identified by selecting various cases. The aim of these case studies was to zoom-in and provide concrete examples of how different countries with different contexts are addressing salinity. The selection was achieved through a combination of document analysis and (in)formal conversations. Documents from key-organisations such as the FAO were also used. The case studies were selected by focusing on differences in several characteristics of salinisation such as cause of salinity (natural occurring, climate change induced, irrigation induced etc.) and difference in geography. The difference in activities dealing with salinity (prevention such as use of technology vs adaptation such as using salt tolerant seeds) was also considered.

The case studies explored the variety of circumstances resulting in salinity increase and how the countries are addressing this complex issue. The cases are divided into three categories: i) deltas; ii) (semi)arid regions and iii) Small Island Developing States (SIDS). These categories are chosen because the main drivers and challenges of salinity differ among these three categories. By including case studies from different regions, the campaign can provide a more comprehensive understanding of the challenges of salinisation and how they are addressed in different contexts. The following case studies are described in this document:

1. Bangladesh
2. Nile basin, Egypt
3. Aral Sea basin
4. Indus basin, Pakistan
5. La Plata Basin, Argentina
6. Bahrein

2 Past challenges and solutions

As outlined in the methods section, to comprehend the present (and future) challenges of salinisation, it is essential to examine and identify the specific challenges and solutions that were encountered in the past. This subsection begins by providing a broader overview of important organisations and general publications regarding salinity. Subsequently, a more detailed analysis of the ILRI publications is presented.

ILRI

ILRI was established in 1955 as an independent, non-profit institute under the Netherlands Ministry of Agriculture, Nature Management, and Fisheries (currently Ministry of Agriculture, Nature, and Food Safety). ILRI focused on land drainage and salinisation and conducted applied research on sustainable development of irrigated agriculture. Until today, one of the landmark ILRI documents, Ritzema (1994), with an overview on land drainage, is featured on websites[1] of various organisations. ILRI was a central point for scientific knowledge collection and spreading.

FAO

FAO has been established in 1945 by the United Nations. FAO leads international efforts to defeat hunger. In this respect, salinity is a threat to food security. Therefore, FAO has been involved in various activities regarding salinity. Also in the recent years, several working groups have been established like International Network of Salt-affected Soils (INSAS) and The Global Framework on Water Scarcity in Agriculture (WASAG). FAO has been publishing some key-documents on the topic of salinity. These focus on different aspects of salinity such as salt tolerance threshold levels of plants, drainage management, water quality. A selection of the documents is named in this section:

- FAO IRRIGATION AND DRAINAGE PAPER 61 published in 2002
- Irrigation Water Management: Training Manual No. 1 - Introduction to Irrigation published in 1985
- Salt-Affected Soils and their Management published in 1988
- Water quality for agriculture published in 1994

IWMI

The International Water Management Institute (IWMI) is an important institution that has been contributing extensively to the field of salinity research. Established in 1985, IWMI has recognised the importance of addressing salinity-related challenges (International Water Management Institute, 2021). Table 1 provides an overview of their number of publications throughout the years on salinity. These articles, primarily focus on water management and salinity issues (e.g., irrigation and drainage management. Like ILRI, IWMI has also conducted substantial work in Pakistan. It is noteworthy that the majority of these publications were produced during the period of 2000-2009. These publications primarily focus on developing countries, such as Pakistan, and are largely technical in nature. Examples of these publications include "How to Manage Salinity in Irrigated Lands: A Selective Review with Particular Reference to Irrigation in Developing Countries" (Kijne et al., 1988) and "Root Zone Salinity Management Using Fractional Skimming Wells with Pressurized Irrigation" (Saeed et al., 2002).

Table 1 *Overview number of articles on salinity between 1984-2023 (International Water Management Institute IWMI, 2023).*

Year	Number of articles
2020-2023	28
2010-2019	124
2000-2009	186
1990-1999	128
1984-1985	2

[1] Ritzema-1994-Drainage.pdf (ircwash.org).

ICBA

ICBA was established in 1999 as a result of expert consultations initiated by the Islamic Development Bank (IsDB) in 1992 (ICBA, n.d.). This institute also has contributed a major deal to the development on salinity knowledge. The centre primarily specialises in salinity-related research. Different topics are connected to salinisation such as climate change, agriculture-aquaculture systems, crop improvement and management of natural resources. The institute owns a dedicated land area where experiments on salinity are conducted. Although the publications list is not available on their website, ICBA is known for having a team of experts who regularly produce research papers. Additionally, numerous field experiments are carried out on the ICBA premises itself.

2.1 Overview of salinisation challenges in the past publications ILRI

The initial search in the WUR library resulted in 31 outputs (without year limitations). When the articles were searched until the year 2001 (final year of ILRI), 12 results were left. Also, ILRI had donated many of its papers and publications to the Watersnood Museum in Zeeland (WUR, 2023[2]). At this moment, the total number of articles donated is unclear.

ILRI played a significant role in combining applied agriculture research, training and advisory services related to land drainage and salinity (Ritzema et al*.*, 2008). The work of ILRI particularly focused on countries with large irrigation and drainage systems such as Egypt, Pakistan, India, and Iraq. Most of the research conducted by ILRI originated from these areas. The causes of salinity mentioned in the articles of ILRI predominantly focused on soils, irrigation practices, and waterlogging. Other variables like climate change or policy decisions that may contribute to increased salinisation were not explicitly addressed in that time.

When reviewing the collected articles, it appeared that salinisation was primarily associated with natural occurrences or improper irrigation management, resulting in the salinisation of soils. Climate change was not mentioned. Looking at the wider discussion and time frame, it may be noted that it was not until the 2000s when climate change became a recognised factor in the discussions. Only in the last few years the topic of salinity is considered as connected to climate change. Most of the articles were of a rather technical nature, indicating that the focus of ILRI research had primarily been the measurement and explanation of the level of salinity in soil and water and providing advice on technical water management. Relatively a few information can be found on the impact of salinity on socio-economic factors and vice-versa. The solutions proposed for dealing with salinity were mostly related to soil, water and drainage management.

In conclusion, the studies mentioned in the text highlight the historical and contemporary issues of soil salinisation and the importance of proper drainage in addressing this problem. Salinity has been a concern for centuries, with evidence dating back to 2400 B.C. in the Gharraf area of East Iraq, possibly caused by intensive irrigation and rising water tables. The use of saline water for irrigation was already discussed at the 25th anniversary of ILRI in 1980, where they summarised the main conditions for successful use of saline water: soils of sufficient permeability; crops chosen for their salt tolerance; good irrigation management to ensure sufficient and properly distributed water; good drainage, either natural or artificial; skilled and well-equipped farmers (ILRI, 1980, p.157). More in-depth information on the articles can be found in Annex 3.

[2] Seventy years after the Great Flood of 1953, salinisation is once again a hot topic - WUR.

3 Current challenges and solutions

Salinisation is a context-specific phenomenon driven by various factors and resulting in diverse challenges worldwide. This chapter aims to highlight the current challenges and context-specific solutions for addressing salinisation. The infographic is used as a summary to describe these challenges and different contexts. The six case studies that are presented show concrete examples of how different countries or regions, each with their unique contexts, are dealing with salinity. To show the diversity of salinisation challenges the case studies include salinisation in delta areas (Bangladesh and Egypt), in arid areas, (Aral Sea basin the Indus basin in Pakistan, Argentina) and in Small Island Developing States (Bahrain). By incorporating case studies from diverse contexts, the background report aims to provide a comprehensive understanding of the challenges posed by salinisation and the various solutions implemented in different settings.

3.1 Infographic

The infographic presented in Figure 1 offers a visual representation of the drivers and challenges connected to salinity on a global scale. Its primary objective is to address the broader global challenges related to salinity, while also highlighting the different areas in the world where salinity is a significant problem. The following paragraphs provide examples of these areas through case studies.

In the lower part of the infographic, a brief overview of the main impacts is displayed on different landscapes. This insight demonstrates how salinity can have varying effects on different landscapes. Additionally, the right part of the infographic presents relevant facts and figures, indicating the significance of salinity and the challenges it brings. For detailed references supporting the information presented in the infographic Annex 1 can be used.

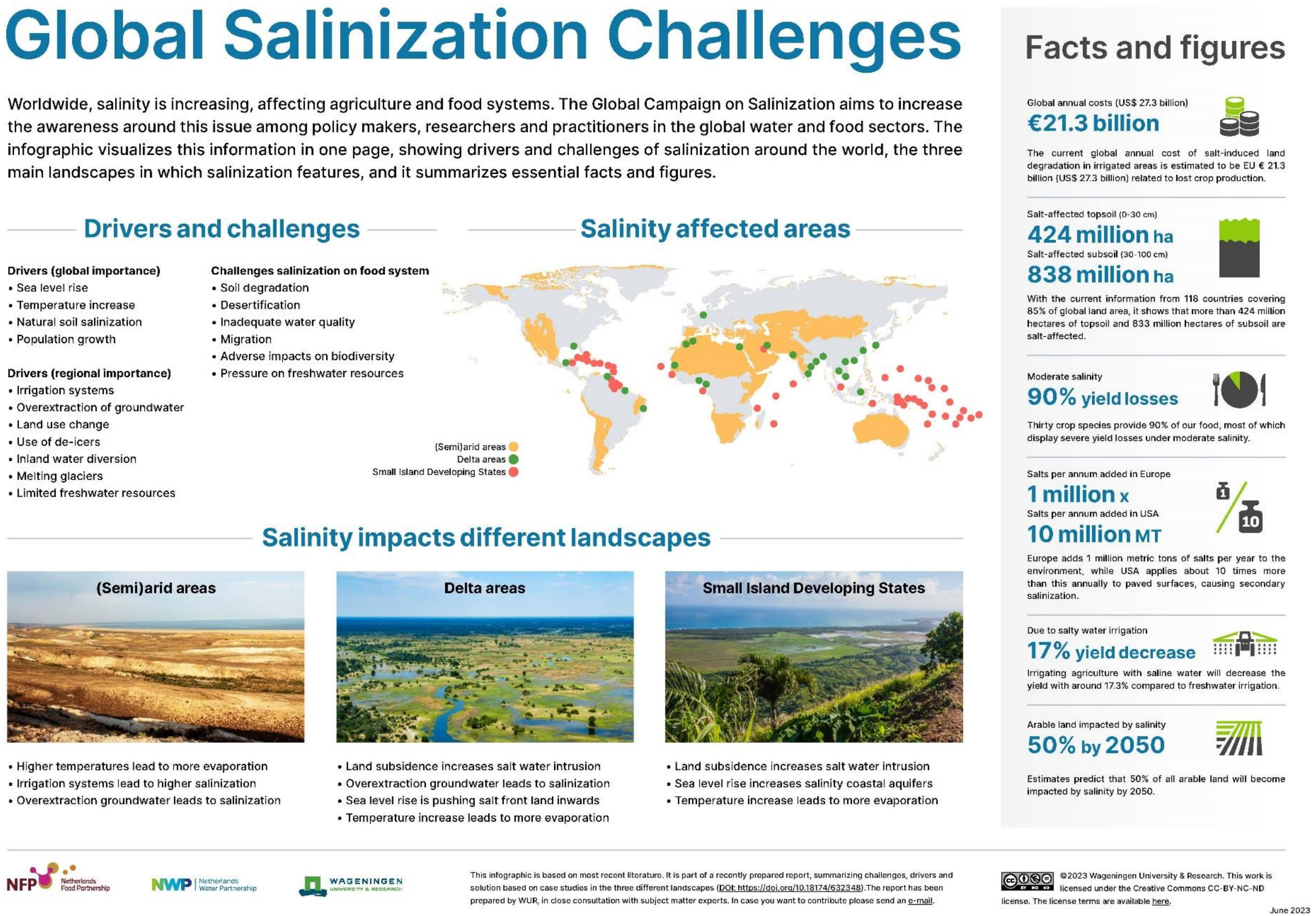

Figure 1 *Infographic global salinisation challenges.*

3.2 Salinisation in deltas

3.2.1 Case study 1: Bangladesh

Bangladesh is one of the largest and most densely populated delta countries in the world. About one third of the country's total population lives in the coastal areas where agriculture is one of the primary economic activities. The agricultural sector employs about half of the labour force and contributes 19.3% of the gross domestic product (GDP) of Bangladesh (Shelley et al., 2016). Rice contributes to 70% of agricultural area and 80 percent of the irrigated land (Sayeed & Yunus, 2018). Bangladesh heavily relies on groundwater for irrigation as about 79% of irrigated area uses groundwater and the rest are irrigated with surface water (Mainuddin et al., 2019). There are three main agricultural seasons in Bangladesh. Most farmers cultivate both local and high yielding variety (HYV) Aman rice in kharif-II season (mid-July to mid-October) and as the salinity during Kharif I (mid-March to mid-July) and Robi (mid- October to mid-March) seasons intensifies, farmers grow vegetables such as tomato, bean, and pumpkin for both domestic consumption during these seasons and to sell in local markets (Chowdhury & Hassan, 2013; Uddin & Nasrin 2013; Hoq et al., 2021). Vegetables are mostly produced during winter. The average annual rice production is 34 million metric tons and for wheat it is 0.88 million metric tons (BBS, 2012). However, salinity intrusion is affecting rice production in the coastal region.

3.2.1.1 Causes of Salinisation

The coastal zone of Bangladesh deals with temporal variation and spatial distribution of salinity. The salinisation in the coastal areas of Bangladesh is influenced by both natural drivers and anthropogenic changes. Bangladesh receives freshwater flow from upstream coming from precipitation and melting of glacier in mountains of Himalayas (Khanom, 2016; Bhuyan et al., 2023). The freshwater is passing mostly through the Meghna estuary. As the rainfall varies seasonally, the freshwater flow and salinity in the rivers varies throughout the year. The south-central and south-eastern part of the coastal areas are adjacent to the Megna estuary and experience low salinity during monsoon and relatively higher salinity during dry season (Salehin et al., 2018). The primary source of freshwater flow in southwestern coastal region is Gorai River which is a tributary of Ganges River and receives most of the freshwater during the monsoon season but limited freshwater rest of the year. This governs the salinity in the southwestern region which is highest during the dry season and lowest during the monsoon season (Salehin et al., 2018). Freshwater discharge in the southwestern region of Bangladesh was dependent on Mathabhanga River and Gorai River. The Mathabhanga River got detached from the Ganges River, the source of freshwater supply due to Farakka Dam upstream. These areas experience high salinity round the year. Due to lack of freshwater in the rivers during dry winter cropping season, groundwater is extracted causing salinity front to move further inland and increasing salinity in the unconfined and semi-confined coastal aquifers (Jamei et al., 2022). Polders were constructed to protect the coastal areas from tidal flooding, but the embankments interrupted the sediment flow in the low elevation areas resulting in subsidence. Lack of freshwater from upstream reduced the flushing of the sediments brought by the flood tides resulting in sediment deposition and rising of the riverbeds (Islam et al., 2020). Lower land elevation in the areas inside the polders and higher water level in the rivers resulted in increased soil salinity. The coastal areas of Bangladesh experience cyclone induced storm surges every year which results in breaching of the earthen embankments causing prolonged flooding of large areas with saline water increasing soil and water salinity of the flooded areas even after the embankment is repaired and the area is dry (Auerbach et al., 2015; Mainuddin & Kirby, 2021). Increased salinity in the areas close to the sea made shrimp culture with saline water lucrative resulting in allowing saline water inside the polders. This increased salinity in the ponds and in the adjacent areas. Relative sea level rise and effective sea level rise will push the salinity front further inland (Salehin et al., 2018).

3.2.1.2 Impacts of salinisation

Salinisation of soil and water impact the food security, health and livelihood of the people especially living in low elevation deltas like Bangladesh (Rahman et al., 2019). During the 15 years between 1995 to 2010, the rice production in the salinity affected southwestern coastal Bangladesh had decreased between 15% to 31% (Rahman et al., 2019). Higher salinity during the dry winter seasons reduced the productivity of winter crops and vegetables which rely heavily on freshwater irrigation (Mirza & Hossain, 2004). Food security of about 60 million small-scaled farmers is threatened due to increase of salts (Rahman et al., 2019). In the areas with soil and water salinity, about 60% of the households faced a food crisis between 2009 and 2013

(Rahman et al., 2019). Complexity and challenges of agricultural production due to salinity swayed the small-scaled farmers to transition to brackish water shrimp farming (Rahman et al., 2019). Salinity also impacts the aquaculture and livestock which are primary source of protein of the coastal region (Chen & Mueller, 2018). The salinity tolerance is less than 5 parts per thousands (ppt) for the freshwater fish species which have large habitat areas. Due to increased salinity these freshwater fish species can lose up to 15% of the habitat by 2050. The habitat of brackish and saline tolerant species with much smaller habitat areas can potentially gain habitat areas by 2050. However, as the habitat area for brackish fish species is much smaller than for freshwater fish at the moment and the increase in habitat area for brackish water fish by 2050 will not be able to compensate for the loss of habitat areas of freshwater fish species. About 70% of the coastal areas can potentially experience loss of habitat for fish and loss of species. As fish is the primary source of protein for 43.2 million poor people who are also unable to afford to purchase alternative source of animal protein such as beef, lamb, poultry and eggs, the loss of habitat for fish will have adverse impact on health and nutrition status of the poor people (Dasgupta et al., 2017a). Salinity will impact livestock production due to lack of availability of feed, forage, straw and drinking water (Miah et al., 2020). The ecosystem will be adversely impacted as well. The mangrove forest can potentially lose large number of species including the species of highest value of timber which will impact the livelihood of the people living adjacent to and depending on the mangrove forest (Dasgupta et al., 2017b). Increased salinity will reduce the availability of drinking water and impact the health of people resulting in hypertension (Rahman et al., 2019). The adverse impact of salinity on livelihood and urbanization of the coastal areas will result in migration to the urban areas and slums (Rahman et al., 2019).

3.2.1.3 Current solutions to address salinisation

The solutions for freshwater availability are currently focused on the use of alternative sources such as ponds and ground water and storing of rainwater (BDP2100, 2018). National Adaptation Plan (NAP) of Bangladesh (2023-2050) emphasizes on management of freshwater resources and monitoring of salinity for reducing vulnerabilities in existing and potential salinity-prone areas and on research to develop stress-tolerant (e.g., salinity, water stagnant, heat, cold, lodging) crop varieties both rice and other crops (MoE, 2022). Some pilot cases to desalinate water using solar energy are initiated by the government but the operation costs for these were deemed too high by the local communities (Saleh, 2015). For agriculture, more salinity tolerant varieties are being explored and suggested through climate smart agriculture innovations (Jamil et al., 2023). Efficient irrigation practices such as drip and pitcher irrigation and managed aquifer recharge are being practiced at pilot scales (Ahmed & Fernando, 2017; Ralf et al., 2019). The added value of combining mangrove forest and shrimp culture was studied and suggested (Rahman et al., 2020). The measurement of salinity and crop suitability table is being used by some farmers (Cordaid, 2021). Some of the silted rivers are being excavated to increase the freshwater flow towards the sea. The freshwater from overland flow during monsoon is being stored in the canals inside the polders and the flow of sea water inside the polders is being controlled using the gates (Hossain et al., 2017 and, Khanom and Salehin, 2012). The use of treated wastewater is being researched to use for agricultural purposes to ease the demand of freshwater for irrigation (Mojid & Wyseure, 2013). Use of cow dung and fertilizers (gypsum) is being experimented on agricultural lands with saline topsoil to recover agricultural productivity (Haque, 2021). There is a knowledge gap and lack of research regarding the effect of such soil treatments on salinity. The freshwater availability, salinity, agricultural practices, and socio-economic structure in coastal region varies spatially which makes the upscaling of the aforementioned solutions complex. To understand the scalability of such interventions regarding water and agricultural system, socio-technical feasibility, nature inclusivity and governance aspects need to be carefully considered.

3.2.2 Case study 2: Nile Delta, Egypt

Egypt is home to the Nile Delta where the Nile River meets the Mediterranean Sea. The catchments of Blue Nile and White Nile are located about 7000 km south of the delta, feed the Nile River which is the longest river in the world (Fielding et al., 2017). The Nile Delta spreads for about 20,000 km^2 and has a coastline of about 250 km with a population of about 40 million people (Zeydan, 2005). The Nile Delta is one of the most fertile areas in the world and it is surrounded by arid areas. The mean annual precipitation is about 664 mm and annual average discharge in the river is about 2778 m^3/s (The World Delta Database, 2004). About 20% of the total GDP of Egypt is contributed by Nile Delta (Eid et al., 2007). Cotton, rice, corn, potatoes, oranges, and wheat are mostly grown (Noaman, 2017). The area depends largely on the water from the Nile River for irrigation and areas further away from the Nile River are unable to produce agricultural products due to lack of irrigation water. The river is the primary source of water for Egypt with 5.5 billion m3 annually which supplies 85% of total irrigated land in Egypt (Abdelhafez et al., 2020). The irrigation system in Egypt is the largest within the Nile River basin and provides irrigation to 3.45 million hectares (Nile water basin atlas, 2023). Surface water is used for irrigation and farmers use sprinkler or drip irrigation. Drainage water is also pumped to the fields by farmers which is regarded as unofficial use of water that accounts for about 2800 million m^3 to 4,000 million m^3 per year (Tanji and Kielen, 2002). Several dams and barrages from Aswan dams to the Mediterranean Sea controls the water flow and feeds the irrigation system which extends to about 1200 km long (Nile water basin atlas, 2023). Irrigation water is the most limited resource of Egypt and therefore, water management strategy has been the central part of Egypt's development strategy. The water availability and salinity in the Nile Delta are not only influenced by natural processes but also by human interventions upstream. This is because the water in the Nile River relies on the flow from upstream catchments.

3.2.2.1 Causes of salinisation

Soil salinity in the Nile Delta has gradually increased in the past few decades due to sea water intrusion, high ground water level, accumulation of salt in the upper soil layers due to unsuitable irrigation management, inadequate drainage, use of improper cropping patterns and rotations, poor land levelling, and dry season fallow practices in the presence of shallow water table (Mohamed, 2017). The alluvial soil deposit which accounts for 95% of all muds and siltation of Nile River is completely leached by freshwater from the Nile River, indicating that the salt affected soils are result of improper management and practices, dry and warm weather of Egypt with high evaporation rate (2000 mm/yr) which is 10 times the precipitation rate and shortage of freshwater to leach out accumulated salts (Mohamed, 2017). Over-extraction of groundwater has also increased salinity in the Nile Delta aquifer in recent years (Mabrouk et al., 2018). The projected sea level rise due to climate change will exacerbate the scenario even more. Abdelaty et al. (2014) projected that by 2100 the salinity front in the Nile Delta can potentially extend 79.5 km in the west and 92.75 km in the east from the shoreline considering 100% increase in ground water extraction rates, 100 cm of sea level rise and 100 cm decrease of surface water level. The water management in the upstream catchments will impact the water availability and soil salinity in the Nile Delta as well. According to Aziz et al. (2019), the Grand Ethiopian Renaissance Dam (GERD) will increase soil salinity and reduce water availability.

3.2.2.2 Impacts of salinisation

Salinity in the Nile Delta impacts agricultural production, water availability and drinking water sources. FAO suggests that salinity is already impacting about 15% of the most arable fertile land in the Nile Delta (FAO, 2021). Mohamed (2017) indicated that the soil of about 30-40% of the Nile Delta is affected by moderate to high salinity ranging from 4 dS/m to 16 dS/m. Egypt by 2050 can potentially lose production of two major crops wheat and maize by 15% and 19% respectively and 50% drop in tomato production. As agriculture sector is the largest employer involving about 31.2% of the total population, salinity intrusion will impact the livelihood of millions. Millions of subsistence farmers of the Nile Delta are already struggling due to water shortages and salinity intrusion. Climate change in the Nile Delta can potentially result in displacement of millions of people (Saleh, 2018). Due to climate change by 2050 the flow in the Nile River will reduce by about 11.8% and salinity in shallow ground water will increase by 27% which will reduce freshwater availability (Omar et al., 2021). Anthropogenic changes such as dam upstream can increase soil salinity, decrease ground water level, and have negative impact on crop production (El-Rawy et al., 2021). The lack of freshwater availability and salinity intrusion will threaten food security as the cropping intensity will reduce and the self-sufficiency for wheat, rice and maize will decrease (Omar et al., 2021).

3.2.2.3 Current solutions to address salinisation

Saline tolerant variables are explored to bridge the gap between actual and potential yield in the last decades (SALAD, 2022). Applying carbon-rich biochar, using different crops such as safflower, quinoa and potatoes, crop rotation and soil and water management are a few of them (Begmuratov, 2019; University of Utah, 2020). To meet the shortage of water, drainage water has been reused mixed with freshwater (Barnes, 2014). However, the quality of drainage water has been deteriorating recently due to rapid urbanization and industrialization (Tanji and Kielen, 2002). To adjust for shortages, two alternative modes of reuse have been tested. One is to use freshwater separately from drainage water and another is to not irrigate during a certain period and let the plant use the water from the shallow groundwater level. The second one saves engineering and energy costs and the first results in a considerably better yield (Tanji and Kielen, 2002). Increasing efficiency of water usage has been applied as well through climate smart agriculture and usage of sensors for measurements at field scale (van Weert et al., 2022). Desalination has also been applied to meet the water deficiency; however, desalination is energy intensive, relatively expensive and can potentially increase greenhouse gas emission depending on the source of energy. Brine produced from desalination can potentially be hazardous if not processed properly (Elsaie et al., 2023). On a national scale, land improvement programs have been initiated by the government by applying chiseling, land leveling by laser beam, mechanical cleaning of water courses, and application of gypsum amendment to control alkalization. In about half of the total cultivated areas in Egypt a network of subsurface drainage has been installed by the Egyptian Public Authority for Drainage Projects (EPADP) of the Ministry of Public Works and Water Resources (MPWWR). The government also suggests utilizing rice cultivation with flood irrigation to reclaim salinized soils but the requirement of adequate quality and large quantity of water lead to challenges. Other crops are recommended when accumulation of salt in the soil is stabilized (Kotb et al., 2000). Numerous projects were initiated after 2014 to address the increasing salinity and water management issues of Egypt which include National Canal Lining covering 398,000 acres, Toshka Barrage, desalination plants, increasing efficiency of water bodies and development of Water Resources Management Strategy till 2050 costing 50 billion dollar. These projects have positive impact on agriculture sector of Egypt which covers 75% of total water demand (WRMS, 2021).

3.3 Arid areas

3.3.1 Case study 3: Aral Sea basin

The Aral Sea basin is located in Central Asia and includes two large rivers: in the North Syr Darya River and in the south Amu Darya River is located. These two rivers are feeding the Aral Sea, a lake that lays between Kazakhstan and Uzbekistan. Moreover, the basin covers next to these two countries, also five other countries: Uzbekistan, Turkmenistan, Kazakhstan, Afghanistan, Tajikistan, and Iran. The total basin covers an area of 154.9 million ha. In the end of the 20th century, 7.9 million hectares of land was irrigated agriculture, while this has been only 3.2 million hectares in 1913, due to improper management. In 2010 the area was expanded to around 8.2 million hectares. (Dukhovny, 2002; Micklin, 2007; Micklin, 2014). The main crops cultivated in the basin are cotton, rice, wheat, maize, and fodder. The water resources are surface- and groundwater and return flows from agricultural drainage and wastewater (Dukhovny, 2002). Due to the large expansion of irrigation the Aral Sea is drying up. Before large-scale irrigation started the annual inflow of water to the Aral Sea was 54.000 million m^3, this declined with more than 90% to 5.000 million m^3 per year (Dukhovny, 2002).

3.3.1.1 Causes of salinisation

The expansion of irrigation and the increase of high demanding crops (e.g., crops) in the Aral Sea basin has led to an increase of evaporation on agricultural land. This has resulting in lower freshwater availability in the two rivers and eventually in the Aral Sea. Moreover, the water that is returning to the two main rivers increased in salinity due to the leaching of salts from irrigated land (Micklin, 2006). Nowadays, around half of the irrigated land is affected by salinity or is waterlogged and the most affected area being the irrigated lowlands in Uzbekistan (Kijne, 2005). Due to inadequate water management, the groundwater tables have been increasing which have led to (secondary) soil salinisation. To deal with these problems a collector drainage has been developed of 4.45 million hectares. However, this has been causing water quality problems downstream, as 92 percent of the total return flow contained agricultural drainage water (Dukhovny, 2002; Micklin, 2006).

Climate change is affecting the temperature and rainfall patterns in the region eventually leading to decreased discharge from the two rivers. This will result in lower water availability for agriculture among other sectors and degraded soil quality. Next to this, the melting of glaciers that feed the two rivers will initially increase the discharge for a few decades. However, gradual disappearance of these glaciers will reduce the flow in the rivers dramatically (Glantz, 2005). In the future, the lack of freshwater will accelerate the problems around salinisation in the region.

3.3.1.2 Impacts of salinisation

A large part of the irrigated area in the basin is suffering from land degradation due to salt affected soils and therefore putting food production at risk (Qadir et al., 2009). The increase of salts in freshwater flowing into the Aral Sea has led to ecological degradation. Aquatic organisms died resulting in losses for fisheries. Moreover, health issues arose with the people living close to the Aral Sea as a result of the increased application of chemicals in agriculture and salinisation which polluted the water supply systems for drinking water (Wang et al, 2020; Saiko & Zonn, 2000).

3.3.1.3 Current solutions to address salinisation

Many solutions to address the problem of salinisation in the Aral Sea basin are related to reducing the water consumption and to increase the flow of freshwater in the two main rivers of the basin. However, agriculture is economically the largest sector of the basin and cutting down the withdrawals will have major effects on societies and especially rural livelihoods. Application of more efficient irrigation systems or changing to crops that require less water would be more beneficial (Micklin, 2014). Next to this, drainage water from irrigated areas should be properly reused (Wang et al, 2020) and irrigation and drainage systems should be maintained (Kijne, 2005). Another solution that is found in literature is the afforestation of native plants (e.g., wild halophytes) that can adapt to the saline soil conditions on abandoned lands that are not suitable for agriculture. These may increase the quality of the soil and reduce the salt concentrations. More research is necessary to prove trends of time (Alikhanova & Bull, 2023). Integrated land use planning by incorporating future challenges related to climate and water resources is therefore of upmost importance. Transboundary cooperation between the countries in the basin is required, since water use upstream influences availability and salinisation as a consequence downstream (Eshchanov et al., 2011).

3.3.2 Case study 4: Indus basin, Pakistan

3.3.2.1 Causes of salinisation

In the Indus basin, the main freshwater source for irrigation is the Indus River with low salt concentrations. The area with the highest irrigated food production takes place are the Indus plains. Besides surface water from the Indus, large areas of Pakistan pump groundwater with varying salt concentrations. The groundwater is used mainly for agriculture; however, it also serves as a source of drinking water for urban areas. Even though not all groundwater is saline, one-third of the irrigated area in Pakistan has groundwater with high salt concentrations. The total area of salt affected soils is 4.5 million hectares, and these are mostly located in the Punjab and the Sind provinces (Badruddin, 2002; Qureshi et al., 2008). After the dry years of 1996-2001, groundwater pumps doubled for agricultural use and in 2007, 2.5 million farmers use these pumps making the country dependent on ground water (Shah, 2007; Qureshi et al., 2008). In the Punjab region salt accumulation is much higher than the Sind region. However, in the latter, reducing soil salinity by desalinizing is much harder as the groundwater tables are high and the quality is poor. Besides this, there is a lack of drainage facilities (Qureshi et al., 2008). Natural processes cause salinisation in the region as well: there is salt deposition from the sea, weathering of parent material and salts that travel inland by the rivers from glaciers (Syed et al., 2021).

3.3.2.2 Impacts of salinisation

The Punjab province has the largest food production, which is 90% of Pakistan’s total food production. Around 30% of the salt affected area is located in this province (Qureshi et al., 2008). Agricultural land is being yearly lost at a rate of 0.02-0.04 million hectares as a result of salinisation (Anjum et al., 2010). This puts a lot of pressure on the food security of the country next to the growing population. Many farmers will not be able to sustain their livelihoods with agriculture, leading to rural migration to cities. Moreover, the agricultural sector contributes for more than 20% to the gross domestic product and the income of two-third of the population depends on the agricultural production (Syed et al., 2021).

Desertification is Pakistan is caused partly by salinisation of the soils leading to reductions of carbon, biodiversity loss and erosion. The latter has socio-economic consequences due to flash floods.

3.3.2.3 Current solutions to address salinisation

Several solutions are undertaken in Pakistan in the last decades. First, drainage systems are important to be present and maintained (Syed et al., 2021). Next to that, for drainage water that has too high salt concentrations to discharge them into the river there is the option to discharge the water via a bypass, so called outfall drains, directly into the Arabian Sea. This solution can only work if the water management and drainage systems are improved. Local water management institutes should cooperate on basin level and decide on what water can or cannot go into the river. Another option is the use of evaporation ponds, but it was found that also these can have negative effects on the people living close to the ponds (Ritzema, 2009).

Reclaiming the land by reducing the soil salinity is another solution by lowering the groundwater tables, leaching the salts from the soils, and restoring the groundwater via aquifers. For the land that cannot be reclaimed salt-tolerant plant species can be beneficially to combat the environmental effects (Syed et al., 2021).

3.3.3 Case study 5: La Plata Basin, Argentina

The largest saline areas are located mostly in Russia, Argentina, China, United States, and Kazakhstan (Negacz et al., 2022). In many plains with sub-humid climates, like the Pampas, the steppes of western Siberia, the Great Plains of western Canada or the Carpathian basin, salinisation is a key issue, affecting the productivity and availability of agricultural lands (Nosetto et al., 2013). Argentina has been selected as a case as it represents also that salinity can occur naturally, however it is also be increased by human influences. The Pampas, a vast plain in central Argentina, is known for its highly fertile and productive agricultural landscapes. However, due to its flat terrain and sub-humid climate, the groundwater table in this region tends to be shallow. This characteristic poses a risk to the local rural economies, as it can lead to periodic flooding and salinisation. Both have negative effects on the agricultural production (Nosetto et al., 2013).

3.3.3.1 Causes of salinisation

Argentina has salt marches occurring naturally in the country. These salt marshes are found in coastal areas worldwide, while mangroves are occurring in tropical regions (Adam, 1990). Salt marshes typically form in estuaries, deltas, lagoons, and along intertidal zones, where the limited water circulation facilitates the accumulation of fine sediments. These marshes are of significant ecological importance and behave like as coastal wetlands due to the valuable ecosystem services they offer. Moreover, the salinisation of soil and groundwater can occur when afforestation is carried out within agricultural landscapes like the Inland Pampas of Argentina. This suggests that native grasslands and croplands may show similar hydrological characteristics and behaviours in terms of water and salinity dynamics (Carol et al., 2019).

Moving from the natural occurrence to human induced salinity because of land use changes. For example, annual agricultural crops have often shallow roots, unlike native species. These agricultural crops are sometimes not able to extract the water when low matric potentials occur. In combination with shorter growing seasons and other differences with the native vegetation, this can lead to a larger amount of moisture that is not used in the soil. Therefore land-use changes from native vegetation to agriculture in semi-arid contexts can lead to the onset of deep soil water drainage, where before this did not occur yet. A consequence of this, is increased salt mobilization and migration, which can lead to deterioration of the water quality through salt leaching to surface and groundwater (Jayawickreme, 2011).

3.3.3.2 Impacts of salinisation

Starting in the late 19th century, the region, which was historically dominated by native grasslands, underwent a gradual transformation. It shifted from mostly consisting of native grasslands, annual crops, and pastures to a landscape predominantly occupied by croplands, with soybean emerging as the most profitable and dominant crop today. This produced soy is used for feed for livestock (Ritchie, 2021).

This significant land-use change, particularly observed since the 1980s and intensifying in the last decade, has resulted in the near-complete conversion of the remaining grasslands and pastures into croplands. The replacement of pastures with annual crops, known for their lower evapotranspiration rates and shallower rooting systems compared to pastures (e.g., Nosetto et al., 2012), has led to various environmental consequences (Nosetto et al.,2013).

Historical water-table records observed land-use patterns, and hydrological modeling studies suggest a correlation between this widespread land-use change and increased water-table levels, more frequent flooding events, and salinisation issues. As the planet's most productive lands are already largely under cultivation (Ramankutty et al., 2002), future expansions of agricultural activities are expected to occur increasingly in risky marginal lands around the world, but also in Argentina (Jayawickreme, 2011).

3.3.3.3 Current solutions to address salinisation

To address the issue of salinisation in Argentina, an effective solution known as bio-drainage, involving the establishment of tree plantations, has been successfully implemented in certain areas of the world. This approach holds promise for the Pampas region. Deep roots of the trees hold the water table stable and less upward movements of salinity can be seen (Singh, 2021). However, it is important to consider potential consequences associated with these plantations, such as salt accumulation within the root zone and increased utilization of groundwater by the trees (Nosetto et al., 2013). Additionally, promoting rainwater harvesting is encouraged to flush out salts and facilitate soil coverage by native species characterized by extensive root systems. This practice serves several beneficial purposes, including reducing soil evaporation which leads to decreased salt rise, enhancing soil porosity which facilitates easier salt removal, and promoting improved infiltration rates (Instituto Nacional de Tecnología Agropecuaria, 2022).

3.4 Small Island Developing States (SIDS)

3.4.1 Case study 6: Bahrein

Small Island Developing States (SIDS) are characterized that they are islands, which could mean that the sea, as a source with high salt concentrations, exerts high pressure on the freshwater resources on the island through groundwater flows or tidal intrusion. Combining this with climate change that increase the sea level table will push the SIDS to new boundaries. The SIDS experience on a smaller scale, faster the effects of climate change. To showcase the salinity effect on one of the SIDS, Bahrein is selected as it shows unique ways of dealing with salinity. Bahrein climate is characterized by high temperatures, rainfall (around 80 mm/yr), and a high evapotranspiration rate (approx. 1800 mm/yr) (Zubari, 1999). Bahrein was more than a hundred years ago mainly depending on agriculture for its economy. However, due to the discovery of oil in 1932 the population of the island increased together with high urbanization rates. This has led to competition on water between different sectors (Bani, 2020).

3.4.1.1 Causes

In Bahrain, four possible sources of salinisation exist: i) seawater intrusion, ii) brackish water up-flow from the underlying zones, iii) migration of sabkha water (a sabkha is a saline mudflat, or playa), iv) and irrigation return flows (irrigation water that gets re-used) (Zubari, 1999). A study concluded that ground water salinisation, soil texture and in-efficient farming practices were among the main reasons for soil salinisation in the studied areas (Abahussain et al.,2014). Next to this climate change is contributing also to the increase of the of the salinzation, mostly focusing on the increased SLR and increased temperatures leading to higher evporation rates (Le Quesne, 2021).

3.4.1.2 Impacts

Historically, Bahrain, being a highly arid country, has been dealing with increasing salinity issues for a considerable period already. The overexploitation of the Dammam aquifer has been contributing to the sitiation, leading to a decline in water levels. Also, the intrusion of saltwater bodies, including seawater and underlying brackish/saline water have infiltrated the aquifer. This has resulted in ongoing salinisation and degradation of groundwater quality. Nowadays, a significant portion of the original groundwater reservoir is lost to salinisation, but for a small area in the north-western part of Bahrain where the salinity of the Dammam aquifer measures below 3,500 mg/L. In this part, the main agriculture products are being produced (mainly date palms, fruit trees and tomatoes). Mostly the groundwater is being used as source for the agriculture (FAO, 2008). The salinisation had great impacts on the agriculture and drinking water provisons (Fanack water, 2021). Agricultural products produced locally cover only 12% of total consumption needs of Bahrein and the rest is imported. This high import rate brings vulnerabilites to food security. The government is promoting to produce more locally. However with increasing salinisation, among others, this is a very challenging task to adhere to (Bani,2020). For the future it is expected that the water demand will rise, the population will rise, leading to even higher pressure on the existing agricultural production (Ansari,2013).

Also for biodiversity it has had signifcant impacts. The arabian gulf, where Bahrein, is located consits of an unique ecosystem and it is crucial to recognize that water temperature and salinity play a critical role in the growth and survival of all aquatic organisms. Changes in these indicators can pose substantial risks to various species, such as corals. Desalination plants, through their operations, contribute to a reduction in plankton biomass, species diversity, and richness within the Persian Gulf. Ultimately it can lead to the depletion of fishery resources and economic activity due to reductions in biomass and reproductive capacities of marine species (Sharifinia, 2019;Le Quesne, 2021).

3.4.1.3 Current Solutions to address salinisation

To address the issue of deteriorating groundwater quality and rising municipal water demand, the municipal water authorities have implemented a policy in the mid-1980s that focussed on reducing reliance on groundwater. This was achieved by increasing the input of desalinated water to meet drinking water standards (Fanack water, 2021). Significant improvements in salinity levels, observed in 1999, 2008, and 2014, correspond to significant expansions in desalination infrastructure. Half of all water used now comes from desalinated water (Le Quesne, 2021). The focus of the solutions are mainly adressed to decrease the groundwater abstraction, such as the use of treated wastewater for irrigation purposes, and treating the saline water into water usable for drinking and agriculture (FAO, 2008). Bahrain has been able to meet till now the rising demand for municipal water by expanding its desalination plant production. These developments has come at a high costs, both financially and environmentally. The depletion of gas reserves and the discharge of elevated temperature brines to the surrounding coastal and marine environment, as well as gaseous emissions to the surrounding air environment, are some of the environmental costs associated with desalination (Fanack, 2021). Furthermore, desalination plants have been shown to reduce biodiversity, and richness in the Persian Gulf, while high levels of brine discharges may have a range of negative impacts (Sharifinia, 2019;Le Quesne, 2021). This shows that also desalinisation comes at a cost.

4 Conclusion and discussion

4.1 Discussion on the main findings

Research conducted by ILRI primarily focused on countries with large irrigation systems like Egypt, Pakistan, India, and Iraq. The research of ILRI considered that salinity was driven by factors such as natural occurrences, improper irrigation management, and waterlogging. The effects of climate change (e.g., higher temperatures and unpredictable rainfall patterns) were not recognized as significant factors impacting salinity until the 2000s. Solutions for dealing with salinity mainly revolved around water and drainage management. Drainage (subsurface) and strip cropping were identified as effective methods. Further research was recommended on effluent disposal from drainage systems. The ILRI research shows a disciplinary approach towards the salinisation challenges and solutions. For example, the use of (modified) salt tolerant seeds is not mentioned within the publications of ILRI. This could be because ILRI was mainly focusing on land reclamation and water management and not on plant studies. Integrated solutions (e.g., conservation agriculture) are not presented as a way of dealing with salinity. Interesting is that the study of Boonstra et al. (2020) includes a section on eco-friendliness of subsurface drainage, showing that there was some increased awareness on the environmental impacts. Previous studies conducted during that period also examined the environment to some degree, however in a less comprehensive manner than currently is done.

Current challenges and solutions on salinisation pose complex challenges worldwide. In Bangladesh, salinity intrusion has impacted rice production, leading to increased shrimp farming. Moreover, the salt concentrations in the soils have increased. In Egypt's Nile Delta, salinisation threatens agricultural productivity due to factors like salinity intrusion from the sea, improper irrigation practices, developments upstream, and over-extraction of groundwater. The Aral Sea basin in Central Asia faces severe salinisation problems caused by large-scale irrigation, resulting in the drying up of the Aral Sea, contamination of rivers with salinity and desertification of agricultural lands. The Indus basin in Pakistan relies heavily on groundwater, leading to high salt concentrations and significant salt-affected soils, which pose challenges for agriculture and food security. The Pampas region in Argentina demonstrates how salinity can occur naturally or be intensified by human activities, impacting agricultural productivity, and needing sustainable solutions. Small Island Developing States, exemplified by Bahrain, experience salinity issues due to seawater intrusion and inefficient farming practices, leading to the implementation of desalination solutions with associated environmental costs.

These case studies highlight the various impacts of salinisation on food security, health, livelihoods, ecosystems, and water availability. To address salinisation, a range of solutions in the cases have been proposed and implemented. Across different regions, solutions for salinisation vary based on the specific environmental and socio-economic conditions. In Bangladesh, the focus is on alternative freshwater sources, salinity-tolerant crop varieties, efficient irrigation, and treated wastewater usage. Egypt tackles salinity through saline-tolerant crops, water management improvements, desalination, land programs, and subsurface drainage. The Aral Sea basin emphasizes water conservation, efficient irrigation, drainage water reuse, afforestation, and transboundary cooperation. Pakistan aims to maintain drainage systems, discharge high-salinity water into the sea, reclaim land, and promote salt-tolerant plants. Argentina employs bio-drainage, rainwater harvesting, and native species to combat salinisation. Bahrain relies on desalination, reducing groundwater abstraction, wastewater treatment for irrigation, and saline water purification for drinking and agriculture. These region-specific solutions entail alternative water sources, efficient agricultural practices, and technology implementation to address salinisation challenges. However, challenges such as energy consumption, cost, environmental consequences, and potential negative impacts on local communities must be carefully considered.

When comparing past challenges and current challenges related to salinisation, it is evident that there has been progress in our understanding and approach to addressing this global issue. Past research primarily focused emphasizing technical measurements and water management advice. Climate change was not recognized as a significant factor for salinisation until 2000. Past solutions centred around water and drainage management, with limited consideration given to integrated approaches. However, the current scientific sources (see chapter 3 for elaboration) show a more comprehensive perspective on salinisation challenges, including diverse case studies from various countries. The effectiveness of these solutions in addressing salinity remains to be seen, as we have only begun to experience the significant impacts of climate change in recent years. Climate change acts as a catalyst for salinity, indicating that the process of increased salinisation is still ongoing. It has become clear from history that focusing solely on technical solutions will not be sufficient to tackle the present salinity challenges as this new salinity challenges are more complicated.

4.2 Key takeaways

Addressing the global challenge of salinisation requires an integrated and balanced approach that includes both prevention and adaptation strategies. The pressure of population growth and the drive to maximize land productivity contribute to salinity risks, underscoring the importance of revaluating our approaches to agricultural systems. As salinisation is a slow-onset process, and while every solution has its drawbacks, it is crucial to implement solutions (e.g., developing desalination techniques and efficient brine management). However, the increased pace of salinisation poses challenges to the adaptation process, especially considering the time required for developing suitable context specific solutions (e.g., developing or using salt-tolerant seeds, or transitions in agricultural production systems). Thus, finding the "sweet spot" between prevention and adaptation is essential to ensure that prevention efforts are in line with the need for adaptation.

Salinisation represents a significant challenge to food security, livelihoods, and ecosystems in various regions worldwide. The drivers of salinity (e.g., climate change) are complex. It is therefore necessary to adopt integrated approaches that extend beyond agriculture alone. Example of an integrated approach is the food systems approach (FSA), which emphasizes the entire food system, from production to consumption, ensuring sustainable and resilient systems. Another example is, Integrated Water Resources Management (IWRM) also provides a holistic framework for managing water resources in a coordinated and sustainable manner, considering the needs of both humans and the environment. WUR has been working since 2020 actively on integrating these two concepts of water and food systems (Terwisscha van Scheltinga and Timmermans, 2020) and recently an initiative on integration in the context of groundwater and salinity was undertaken by WUR, Deltares and Salt Doctors (Ilja America et al., 2023).

Climate change increases the drivers of salinisation in many areas around the world by reducing freshwater resources with low salt concentrations. Unpredictable precipitation patterns, increased evaporation rates, and the accelerated melting of glaciers further increase these issues. To develop long-term solutions, it is needed to mitigate the impacts of climate change. Therefore, drawing on past knowledge and experiences is of vital importance in addressing the current salinity challenges. Furthermore, effective water management, including the implementation of robust drainage systems, plays a pivotal role in preventing and mitigating salinisation in these regions. It is the responsibility of policy makers to implement strategies and measures that address the challenges posed by salinity, incorporating integrated approaches to water and food systems, as well as considering the preservation and restoration of ecosystems. By doing so, it is possible to enhance food security, sustain livelihoods, and safeguard the delicate balance of ecosystems in the context of salinisation challenges. Furthermore.

4.3 Implications for future research and action

To effectively address the global challenges of salinity, the following recommendations are proposed:

- Enhance interdisciplinarity by increasing collaboration: foster collaboration among researchers, policymakers, farmers, and local communities to ensure the effective application of knowledge and the implementation of sustainable solutions through a multistakeholder approach. Encourage the formation of interdisciplinary action and platforms for knowledge exchange to bridge the gap between the different stakeholders (e.g., scientific research and practical implementation). Engage stakeholders at all levels in decision-making processes to enhance the relevance and effectiveness of salinity management strategies.
- Promote integrated approaches and adaptive management: recognise that addressing salinity is not a matter of choosing between different approaches but rather adopting an integrated and adaptive management approaches. Some examples are mentioned in the discussion and conclusion and key-takeaways sections. In the past there has been a technical focus, however now it widely acknowledged that solutions for dealing with salinity are not mainly resulting from only technical focus. Given the complexity of salinity issues, it is crucial to integrate knowledge from various disciplines, including agronomy, hydrology, ecology, and social sciences. Develop decision support tools and models that can assess the impacts of different interventions and facilitate adaptive management strategies. Emphasize the importance of monitoring and evaluation to learn from past experiences and adjust interventions based on changing salinity dynamics and emerging challenges. Next to this mitigation and prevention are needed to deal with climate change, otherwise the SIDS will not survive.
- As this background document only uncovers part of the knowledge from the past, it would be advised to dive further into the literature from other relevant organisations mentioned (FAO, ICBA, IWMI) and other parts of Wageningen Research and University. This would lead to a more complete inventory of knowledge of the past.

Furthermore, substantial investment in research, infrastructure, demonstration or testing sites and capacity-building initiatives is essential. Research funding should be directed towards interdisciplinary studies that increase our understanding of salinity processes, livestock impacts, and socio-economic aspects (e.g., policy). It is also crucial to invest in the development and dissemination of appropriate technologies, including salt-tolerant crop varieties, precision irrigation systems, and sustainable water management practices. Capacity-building programs should focus on equipping stakeholders with the necessary skills and competencies to address salinity challenges effectively. Overall, a multi-faceted approach involving collaboration, adaptive management, and targeted investment is crucial for addressing global salinity challenges and ensuring the long-term sustainability of agriculture, food security, and resilience to climate change in affected regions.

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Annex 1 Infographic references

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Annex 2 Literature search

2 searches entered in WUR library website: https://www.wur.nl/en/library.htm.
Terms entered: International Land Reclamation Institute AND salinity

1. Total without year limitation: 31 publications
2. With year limitation: 12 publications (2003).

X = appears both searches
X = no highlight, showing up in search without time delineation.

1. Symposium on Land Drainage for Salinity Control in Arid and Semi-arid Regions (1990: Cairo, Egypt), Egyptian Public Authority for Drainage Projects, Drainage Research Institute, & International Institute for Land Reclamation and Improvement. (1990). Symposium on land drainage for salinity control in arid and semi-arid regions, February 25th to March 2nd, 1990, Cairo, Egypt. Ministry of Public Works and Water Resources.
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Annex 3 Summary of articles

Going more in-depth into the content, the study of Dieleman et al. (1977), showed that the first salinity records encountered about 2400 B.C. relate to the present area of Gharraf in East Iraq. This salinity may well have been caused by intensive irrigation and a rising water table. In the more recent past, Tanji & Kielen (2002) mention that salinisation affected about 20-30 million ha of the world’s 260 million ha of irrigated land (FAO, 2000). To maintain favorable moisture conditions for optimal crop growth and to control soil salinity, drainage development is indispensable especially in saline groundwater zones. Dieleman et al. (1977) presents that causes of salinity to originate from differences in irrigation practices, differences in soils and occurrence of natural drainage. In this connection it should be noted that until very recently no artificial drainage facilities existed. Also, Oosterbaan et al. (2020) highlights that the artificial causes of salinisation are originating of waterlogging and irrigation. Next to this, the study highlights that salinisation can happen more naturally because of mineral weather or by gradual withdrawal of seawater leaving salts in the soil. When reflecting on solutions, it was mentioned that to reduce salt concentrations in agricultural soils, proper drainage is complement to the irrigation system (Hoorn & Alphen, 1994). El Guindy & Risseeuw (1987) described a case study in Egypt for the rice fields. The main reason for salinisation was not enough water availability so that the soil could not be fully recharged. This led to a change in the capillary rise, became greater than the downward movement of water., causing salty groundwater to move upwards. As a result, the soil became more saline during those months. Subsequently, even with irrigation, there was not enough water to remove sufficient the salts from the soil, resulting in a high salt content at the end of the rice-growing season. Dieleman & De Ridder (1964) show with a technical case study in lake Chad that they predominantly focus on the water applied and water requirements for the salt balance. They acknowledge the fact that the salts need to be removed to maintain a high agriculture production. A lowering of the groundwater table is proposed as a solution for removing salts. However, it is addressed that it may result in the upsetting of the existing balance between inflow and consumption of water. The amount of seepage water will probably increase and the need for an additional water supply will arise if the irrigated acreage expands. Oosterbaan et al. (2020) mention that most effective ways in dealing with salinity is focusing on drainage and strip cropping. According to the authors, drainage is the most effective method of controlling salinity, by leaching 10-20% of the irrigation water to the soil and make sure it is drained through an appropriate drainage system. Strip cropping is highlighted by Oosterbaan et al. (2020) it means that within a piece of land some strips are irrigated while strips in between are left permanently fallow. This causes extra “space” for water and therefore avoids waterlogging. The strips that are unirrigated will become salt, here livestock or salt resilient crops can be held. Boonstra et al. (2002) remarks that design specifications for horizontal subsurface drained can be thought of as measures contributing to solutions. El Guindy & Risseew (1987) are also showing that subsurface drainage supports in dealing with drainage. This helps removing access water from the land. Boonstra et al (2002) also mentions that studies on disposal effluent of drainage systems need to be done for further research.

Annex 4 Feedback from INSAS meeting

In the week of May 22, the second meeting of INSAS took place in live in Uzbekistan[3] and partly online. We had the opportunity on May 23 to present online the Global Campaign on Salinisation and the draft infographic that was designed by that time. We had around 1 hour for this session and the following agenda was discussed:

- Goals of the session
  - Get to know each other
  - Get an understanding of the Global Campaign on Salinisation
  - Reflect and review on infographic by sharing your knowledge on salinisation
- Who are we
- Who are you
- Introduction on the Campaign
- Infographic
- Follow up infographic and closing

To discuss the infographic, we used the MIRO board to collect the feedback and we asked four questions:

1. What content do you like?
2. What content would you like to see improved?
3. What do you like about the style?
4. What would you like to see improved on the style?

To summarize the feedback, the participants were mostly discussing what needed to be improved. In the draft version, the purpose and the authors of the infographic was still missing. However, it was mentioned that this was important. Moreover, it was said that also the success stories should be shown. We explained that this is not the goal of the infographic since the focus is on drivers and challenges. Also, participants said that a zoom in on the countries would be valuable. The background document has this detailed information, and a link can be found now on the latest version, so that people still can have this zoom in on some countries. The three landscapes were seen as a positive point but needed to be improved with new images or a legend to explain the arrows and other symbols. As the language of the infographic is English, the point was raised if it could also be translated into other languages like Spanish. On some of the facts and figures there were comments, which were incorporated, and some drivers and challenges were added or removed after discussing internally.

[3] 2nd Meeting of the International Network on Salt-affected Soils INSAS | Uzbekistan, May 2023 | Global Soil Partnership | Food and Agriculture Organization of the United Nations (fao.org).

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Report 3269
ISSN 1566-7197

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