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Article

The complex system of climate change security and the ripple effect of water–food–socioeconomic nexus

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Abstract: The effects of climate change are recognized globally. This study hypothesizes that climate change impacts are a complex system that creates a ripple effect on water security, food security, and economic security. Ultimately, those domains simultaneously exacerbate climate change effects and produce national security concerns. The study's framework uses a transdisciplinary team's quantitative and qualitative approach to evaluate the challenges and possible solutions to climate change security on the Water–Food–Socioeconomic Nexus. Iraq has been taken as a case study highlighting the deficits in management and governance. The dynamic of the ripple effect shows the interventions for each sector's water-food-socioeconomic and security that collectively impact upon each other over time. The radical shift in the political infrastructure after 2003 from a centralized to a decentralized one without proper preparation is one of the root causes of the governance and management anarchy. About 228 state and non-state actors are involved in decision-making, leaving it fragile and unsustainable. Only 1% of the national budget is allocated to both the Ministry of Water Resources and the Ministry of Agriculture, which leaves no capacity to mitigate the risk of climate change impact.

Keywords: climate change; water security; food security; economic security; national security

1. Introduction

Our understanding of climate change has changed dramatically during the first few decades of the 21st century. Theories and hypotheses concerning climate change are diverse, from those that view it as a complicated system (Schneider and Dickinson, 1974; Schneider and Dickinson, 1974) or a complex system (Manabe, 2019; Rind, 1999) to those that hold that it is a fundamentally complex, self-regulating system (Jones and Ricketts, 2021). Applying complex system principles to natural and social phenomena has changed the paradigm for interpreting both. Complex systems are open systems grounded in the dynamic interaction of a large number of elements, where this interaction is characterized by nonlinearity, a short range, recurrence (loops), disequilibrium, and the independent behavior of each element (Cilliers, 2002). In this context, studying the complex structure of a system is the key to understanding that system, and the interaction between the elements, regardless of their positions, is what defines the system. Millar (2016) demonstrated the importance of analyzing complex systems in the economic and social sciences, where the complex system enables us to understand the whole picture of the world and transcend the reductionism

of these sciences. However, recently, complex systems have also been considered a new paradigm through which to study social relations surrounding solutions to sustainable development challenges. Such an approach is characterized by ten properties: emergence and coevolution, phase transitions and punctuated equilibrium, adaptivity, feedback and recursion, heterogeneity, cooperation and co-intelligence, self-organization, networking, scaling, and nonlinearity (Lock, 2023).

Iraq's economy is based on extracting oil without consideration of the balance between oil production and sustainable development and use (Bamber et al., 2023). The concept of sustainable development refers to balancing present needs with expected future limitations (Ravago et al., 2015). Iraq is expected to increase oil production, which means more greenhouse gas (GHG) emissions to the region; coupled with the current water impoundment by riparian countries and the rapid population growth, the risk of environmental degradation, in the long term, is anticipated (Noon et al., 2022). Accordingly, the water demand will be increased dramatically due to the plans to increase oil production through reservoir development. Since farming activities are the major consuming sector the agricultural sector will dwindle, and food security challenges are expected to emerge soon. Currently, climate change's impact on Iraq still requires more evidence-based, reliable statistics and documentation. However, its symptoms exist, such as an increase in temperature that is two to seven times faster than the global rise (Salman et al., 2017), desertification estimated to exceed 92% of the country's total surface area (Haktanir et al., 2004), a reduction in rainfall of nearly 50% over Iraq and the surrounding region, and a reduction in vegetation of about 62% since 2008 (Al-Faraj and Al-Dabbagh, 2015). Collectively, at the state level, Iraq must manage the following trade-off: mitigating the ripple effect of collateral environmental decline while sustaining the socioeconomic system at the same time.

The Food and Agriculture Organization (FAO) (2012) performed a detailed desk analysis to assess the conditions of the Iraqi agriculture sector and identify relevant performance gaps in state programs, and government policies to better understand the level of support required. The assessment included the following topics: 1) agricultural subsidies, 2) water resource depletion, 3) the widespread use of traditional irrigation methods, 4) the absence of banking sector infrastructure, 5) complex and time-consuming investment requirement processes, 6) poor agricultural planning, 7) landholding systems, and 8) inadequate information systems. The World Food Programme (WFP, 2020) analyzed the current food security of households in Iraq after the triple threat of the COVID-19 pandemic, depression of local currency, and rainfall deficits. The report includes socioeconomic analyses of how the pandemic affected global commodity prices, oil shortages, imports, and exports, and how changes in government policies are affecting agriculture and food security. Kool et al. (2020) conducted a trial analysis of the urgent crisis of water resources in Iraq. The author showed that water crises result from numerous issues, including the decrease in precipitation, groundwater overuse, and extensive use of freshwater by the oil industry. The research included the impacts of war and political instability on the country's water infrastructure, rapid population growth, and inadequate water management in the agricultural and industrial sectors. Adam-Bradford et al. (2020) examined how developing the agricultural sector enhances post-conflict stabilization

and increases the resilience of farmer communities. The author focused on the nexus of shortages in water, water fluctuations, and pollution. The research suggested that conflicts with upstream countries (Turkey, Syria, and Iran) are the key challenges confronting Iraq and affecting its socioeconomic growth. Bekheet (2021) investigated the real economic consequences associated with food security. Water control through massive dams by riparian countries in the absence of strategic agreements reduced the water supply for the Euphrates–Tigris basin, cutting off over 70% of the freshwater used in the agriculture sector. Five main archetypes of socioeconomic growth factors were identified: irrigation, livestock, thermal cooling, industrial water, and municipal water.

Hamdoon (2021) suggested that the new fuel of the third millennium is water, since it will become a scarce commodity. The author investigated water governance around the world and the policies governing the Mekong Delta waters in Vietnam. The results indicate that good water governance directly contributes to sustainable development efforts overseen by governments. Good water policies are characterized by being clear, participatory, communicative, fair, and integrated with national development plans. The study concluded that water security policy in Iraq should consider the following influential factors: climate change and environmental degradation, water management and planning policies, and regional cooperation. Two billion people across the world are predicted to suffer from water scarcity by 2050; this number is expected to double by 2080 (Thắng et al., 2020). Thus, designing and implementing efficient water policy is crucial for any nation.

The term "nexus" in the natural sciences is a concept that enables us to address trade-offs and seek synergies between, for instance, energy, water, food, land, and the climate (Brouwer et al., 2018). Almuqdadi et al. (2020) explored the interlinked water–energy–food nexus in Iraq. The research described this complex system and evaluated the relevant challenges and opportunities from different perspectives, including policy, management, and technology. However, the increasing pressures of different drivers, such as population growth, urbanization, and climate change, have increased the importance of governance and management concepts, especially for complex systems (Cosens et al., 2021). Water, food, and the economy are interconnected in multiple ways, whether through agricultural and farming activities, which are the major drains on water resources or through agribusiness and food production via supply chain management (Regonda and Dornadula, 2021). Hence, the impact of climate change and extreme weather events (droughts and floods) can disrupt water availability and agricultural patterns, affecting food production, causing crop failures, and leading to economic losses.

Several scholars have discussed the domino effect of climate change on different sectors, the present work helps further advance the understanding of the complex interrelations between those sectors to illustrate interlinks through the cascading impacts of a single process spreading and influencing other elements within the system. As an external challenge, climate change might cause ripple effects across the region, leading to water scarcity (water security), agricultural disruptions (food security), and affecting livelihoods that increase poverty (socioeconomic security). That collectively might increase the national and regional security challenges. The current work will use Iraq as a case study; however, the hypothesis and framework are

flexible enough to be implemented in any region or country, depending on their priorities and perspectives.

The current study aims to demonstrate the links within the nexus of four sectors: climate change, water, agri-food, and the socioeconomic of Iraq. Consequently, we illustrate the influence of this nexus on national security, providing a historical background and present perspectives. The investigation will be conducted in two major domains—management and governance—because they form the core of the political system. In addition, stakeholders' maps were created to illustrate the complexities of decision-making in the climate change–water–agri-food–socioeconomic nexus. The research will also reveal the ripple impact of the four sectors at the state level and propose feasible solutions and policies to sustain this complex - dynamic system.

2. Materials and methods

Iraq was used as a case study for the current research and the framework had five stages as follows:

1) The diagnostic stage was represented by secondary data and included a literature review, information collection, initial screenings, and institutional analysis. Through the examination of existing studies, reports, and scholarly articles related to the research topic, this review helped to gather background information, understand previous findings, and identify their limitations. The information collection process involved gathering secondary data from various sources, such as government publications, databases, and research reports. The data included historical records, policy documents, statistics, and other relevant information related to the research problem. An initial screening was conducted to filter and select the most appropriate information for further analysis through different criteria: source credibility, relevance to the current research questions, accuracy, and reliability. This step ensured that only the most pertinent data were considered to effectively address the research objectives. The last component of the diagnostic stage was the institutional analysis, where the focus shifted to understanding the roles, structures, and dynamics of institutions relevant to the research problem. This analysis helped identify the stakeholders involved, their interactions, and the regulatory or policy frameworks shaping the issue.
2) Along with potential stakeholder discussion, the key sectors were identified and analyzed by addressing the indicators and areas of overlap between the targeted sectors, either from the literature or through the diagnosis development. Secondary data were gathered from modern literature, scientific reports, and articles published by academic and non-academic institutions. Google Scholar, government and private sector statistics, industry association webpages, and public portals were used as search sources. A total of 321 articles, supporting documents, reports, books, maps, and official letters or agreements were gathered, reviewed, and evaluated. The references focused on international studies and then zoomed in on regional and local research. All documents were then sorted into the following clusters: A) studies exploring the impacts of climate change; B) studies focused on potential joint sectors, such as water,

agriculture, food security, and the socioeconomic; C) references focusing on integrated environmental management, sustainability, and governance aspects; and D) studies focused on linking climate change with national security concepts. About 30% of the studies were excluded because they were irrelevant to the current work or did not fall into these selection clusters. The data were screened and analyzed in crucial sectors—water resources, agri-food, and socioeconomic development—and the ultimate connection of these three domains with national security. Key indicators were examined, such as water availability, agricultural productivity, and economic growth. The study identified areas of overlap, such as the impact of water scarcity on farming activities and economic development. The state and non-state actors were identified to generate comprehensive stakeholder maps. The stakeholders list included government agencies, academic institutions, the private sector, and civil society. This stage proved vital understanding of the potential challenges, conflict that might exist, and the complexity of interconnections between the stakeholders.

3) Primary data were gathered through fieldwork, group discussion, and personal interviews with state and non-state stakeholders for the research-targeted sectors (climate change, water resources, agri-food, socioeconomic, and national security). The data was analyzed, and integrated from 18 February 2022 to 30 May 2023. Eleven authors orientation internal meetings were held, six rounds of focused group discussions and brainstorming were conducted with state and non-state stakeholders whom identified based on the research sectors, seven personal meetings with specialists from governmental agencies were held, two international conferences were attended—one of which the authors organized—and two international workshops were attended. In total, the research journeys of over 500 specialists from different backgrounds related to the research sectors were involved in adding value to the framework and deliverables. The fieldwork enabled the direct observation of and data collection from the study domains. The personal interviews were conducted with key stakeholders and individuals to gain in-depth insights into the implications of climate change and the potential impact of each targeted sector. The focus group discussions facilitated interactions includes collecting opinions from external experts, allowing for diverse perspectives and collective understanding. These data collection methods ensured rich and comprehensive knowledge of the research through surveys and questionnaires, direct interviews, and workshop conclusions. This combination of fieldwork, and focus group discussions enhanced the validity and depth of the research findings.

The six focus group meetings were designed to gather qualitative data and insights, with each including 13 participants from different backgrounds representing different types of stakeholders. The purpose was to explore their insights and experiences by encouraging open dialogue and constructive engagement. The structure involved a skilled moderator guiding discussions with a small group of participants. The meetings offered valuable qualitative data for research and policy development and provided a better understanding of the participants' points of view and experiences. Two international conferences contributed to the current research. One was the Berlin Climate Change and Security Conference, held on 11–12 October

2022 (climate diplomacy, 2022), where members of the research team participated as speakers to consider research's hypothesis. The second was the Climate Change and Security Conference in Iraq, which was organized at the Iraqi Parliament on May 21, 2023 (Sanad Organization for Economic Development, 2023). This latter conference helped significantly to zoom in on the local context and speak directly with decision-makers formally and informally; more than 200 specialists attended each conference. The first workshop was the Global Workshop on Water, Agriculture, and Climate Change (United Nations Economic Commission for Europe, 2022), held at the United Nations office in Geneva, Switzerland from 17–18 October 2022, where members of the research team participated as speakers and facilitators to determine the key message for Conference of the Parties 27 (COP27), which over 200 specialist participants from around the globe attended. The second workshop in which we participated was hosted by the World Meteorological Organization (World Meteorological Organization, 2022), where over 100 participants convened to discuss the urgent actions required for climate change mitigation and adaptation and to develop awareness of early-warning systems.

4) Comprehensive assessments and interpretations of the findings were conducted to interpret the results, identify challenges to address, and leverage potential opportunities. This included data collection, analysis, and synthesis to understand the complexities of the real-life situation. The complex adaptive system (CAS) and evolving mental model approach, developed by Derek and Laura Cabrera at Cornell University (Cabrera and Cabrera, 2015), was used. The CAS perspective was applied in the data analysis to identify the dynamic interactions between the non-linear relationships and feedback loops; this approach facilitated a deeper understanding of the links and complexities present in the data interpreted. The CAS approach helps illuminate the interrelationships between and interdependence of components within a complex system and recognize feedback loops and their implications. This approach also emphasizes that complex systems are dynamic and constantly evolving; thus, they require a flexible and adaptive approach to problem solving. The CAS approach helps to develop mental models by regularly updating secondary data and revising existing mental models based on new information and feedback from the real-world during communication and discussion with stakeholders. The evolving mental models approach helped reveal secondary data paradoxes where applicable by structuring the primary data collected and revealing the interventions across the climate change security and the water–food–socioeconomic–nexus. This helped to modify the metaphors we encountered and avoid biases that might steer the research in the wrong direction, which could ultimately misguide decision-makers.
5) The implications of the findings were linked with the national security sector to validate the research hypothesis by examining the data in the context of national security dynamics in the past and present to identify their historical and current impacts. This process supported the hypothesis and provided valuable insights into policy- and decision-making. A set of four stakeholder maps (SH maps) was created by integrating discussions described in the primary and secondary data collection and integration, and a list of functions was composed that consolidated

each state and non-state actor along with their numbers and categories (e.g., the federal government or the regional government of Kurdistan, Iraq).

The open-source software Plectica for System Thinkers was used to visualize the conceptual foundations of the stakeholder maps of climate change, water resources, agriculture, and the economy, and to establish the systemic structures of the state and non-state actors while identifying the functions of each (Plectica LLC, 2020). Financial analyses of the Iraqi national budget were conducted for five years (2017–2021) (Ministry of Finance Iraq, 2021) based on public financial statements published on the website of the Ministry of Finance to determine the weight of financial allocations to the Ministry of Water Resources and the Ministry of Agriculture. Carbon emission data were analyzed using Our World in Data, which provides open access to estimations of the CO_2 generated by Iraq and the surrounding region (GitHub, 2022).

The study's framework is enacted by a transdisciplinary team of 10 members (the authors), who contributed to the research based on their expertise within four sectors: climate change, water, agri-food, and the socioeconomic on Iraqi national security; and discussed possible solutions along with the stakeholders. The authors' orientation meetings for the research were crafted to establish the research's direction and objectives. This involved identifying priorities, discussing critical issues, and assembling the necessary expertise. The tasks included setting the agenda and goals, forming action plans, making presentations, and share the resources. Through these meetings, the authors defined their focus areas and ensured that their work was relevant, evidence-based, and impactful in addressing the challenges. This research structure relied on identifying the different sectors' forces and interactions. The dynamics of the ripple effect within the sectors were studied to first reveal the influences of each sector on the others and then present a set of relevant solutions.

The authors were divided into five specialist groups, four of which discussed in depth the following subjects: climate change as an external challenge, shortage in water resources, agriculture and food security, and the socioeconomic. In conjunction with the fifth group, all the four groups examined the national security element, highlighting the deficits in two domains—management and governance—since both are crucial areas that warrant investigation to understand their interplay and collective impact on the complex system of climate change impact. Management practices are vital because they involve planning, leading, and controlling resources and processes to attain organizational goals efficiently. Thus, examining management practices and identifying potential weaknesses would help improve the system's performance and help it adapt to changing circumstances (Den Hartog et al., 2013). Governance is guiding the behavior/actions of the decision-makers through system of rules, procedures, and structures (Carroll and Brown, 2022). An in-depth examination of management and governance is essential, as they directly influence the effectiveness, performance, and sustainability of any institution. These domains are interconnected and reinforce each other to support organizations' overall reliability and accountability (Russo and Perrini, 2010) (**Figure 1**).

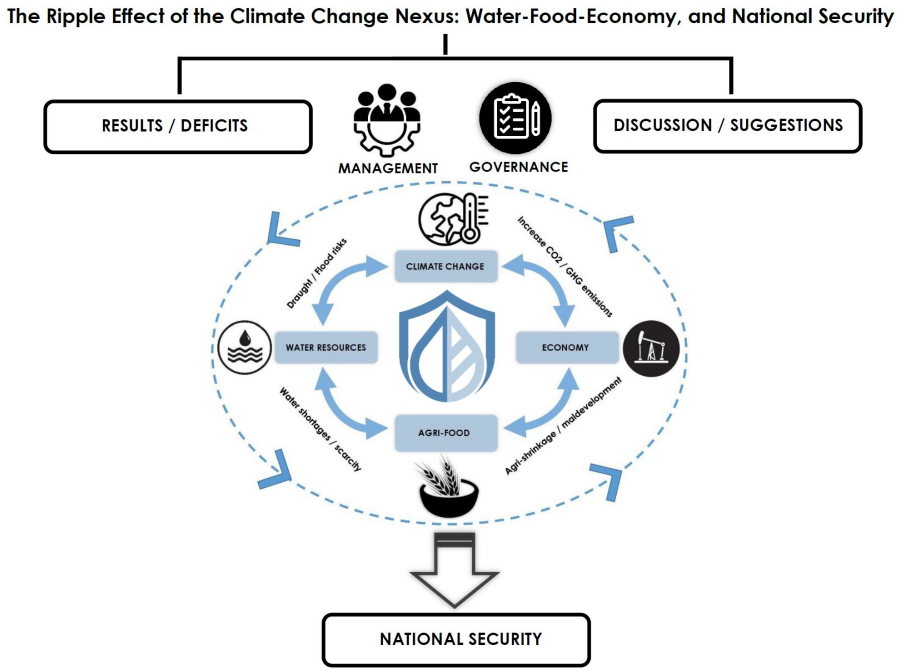

Figure 1. The research framework and hypothesis.

3. Results

The rise in temperature is aggravating water resource challenges. In addition, there are conflicts with riparian countries over shares of water resources in the face of poor management and over-subsidization of these resources, compounded by wasteful consumption in the agricultural sector and in domestic use. Water scarcity, in return, heavily impacts the agricultural sector. Taking a proactive step in any of the four domains studied—climate change, water resources, agriculture, or socioeconomic—will have a domino effect on all others and, more holistically, on the entire region. Therefore, the challenges faced in each area are entangled with other problems and should be examined comprehensively. To do so, the deficits in the management and governance sectors were analyzed for the four domains in reciprocal ways to highlight the complex nexus between them at the state level, and solutions to these deficits are suggested in the same way. **Figures 2–7** summarize both the deficit challenges and the solutions. The involvement of stakeholders in the discussion helped to ensure that findings and solutions were tailored for the actual needs and priorities.

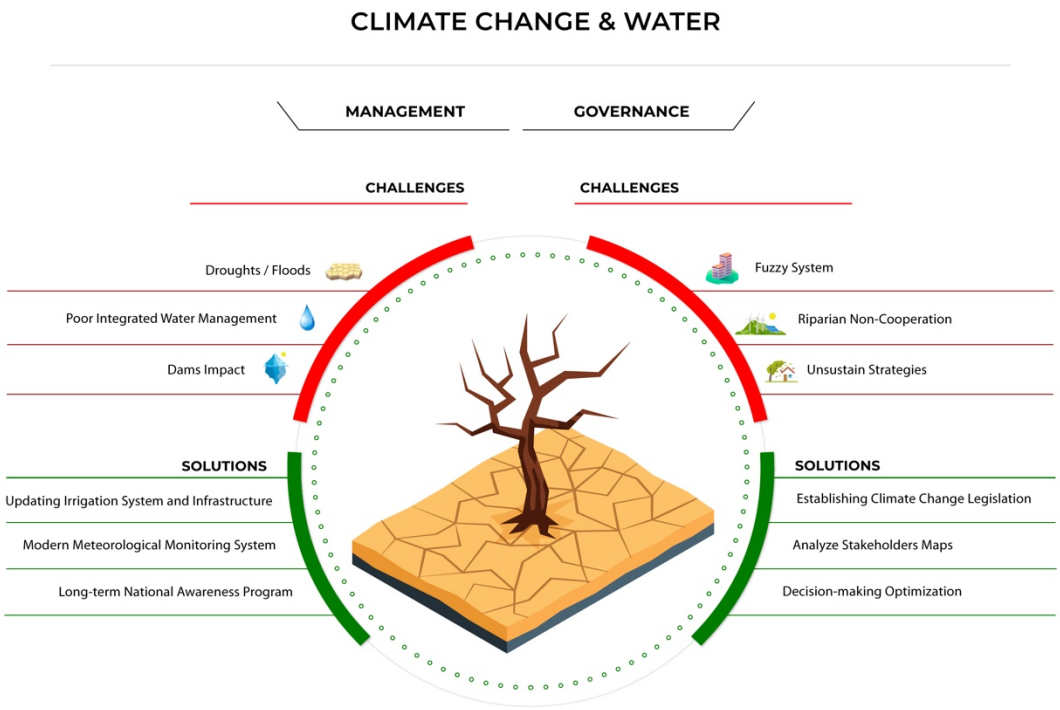

Figure 2. Climate change and water.

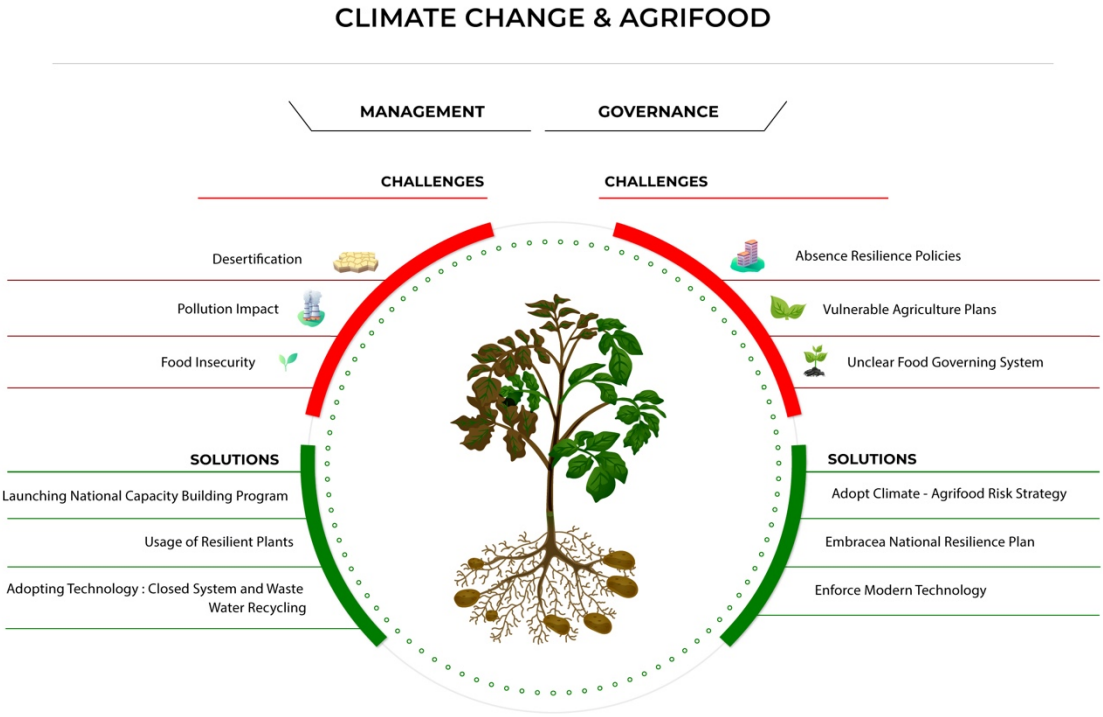

Figure 3. Climate change and Agri-food.

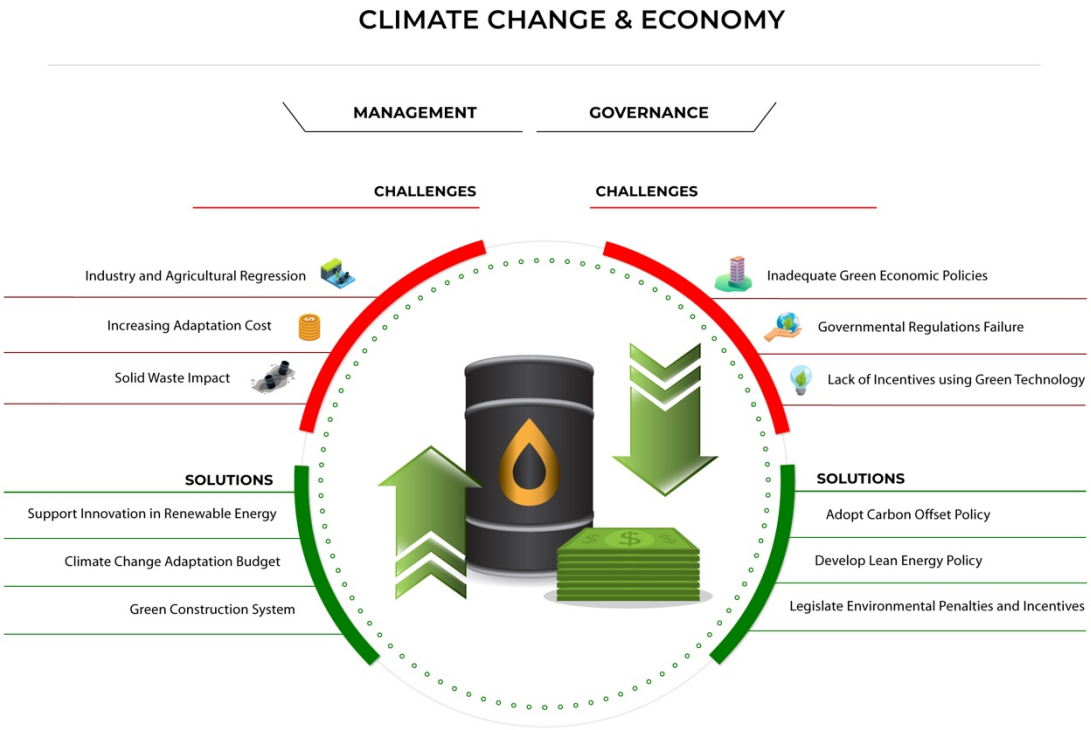

Figure 4. Climate change and economy.

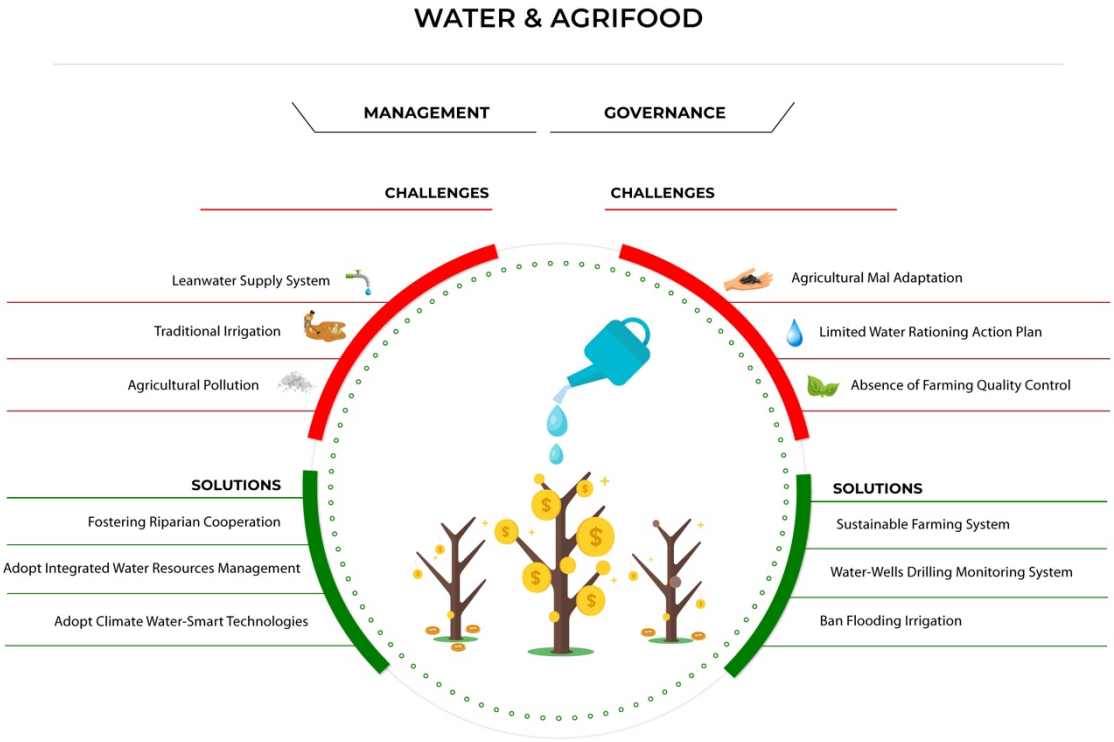

Figure 5. Water and agri-food.

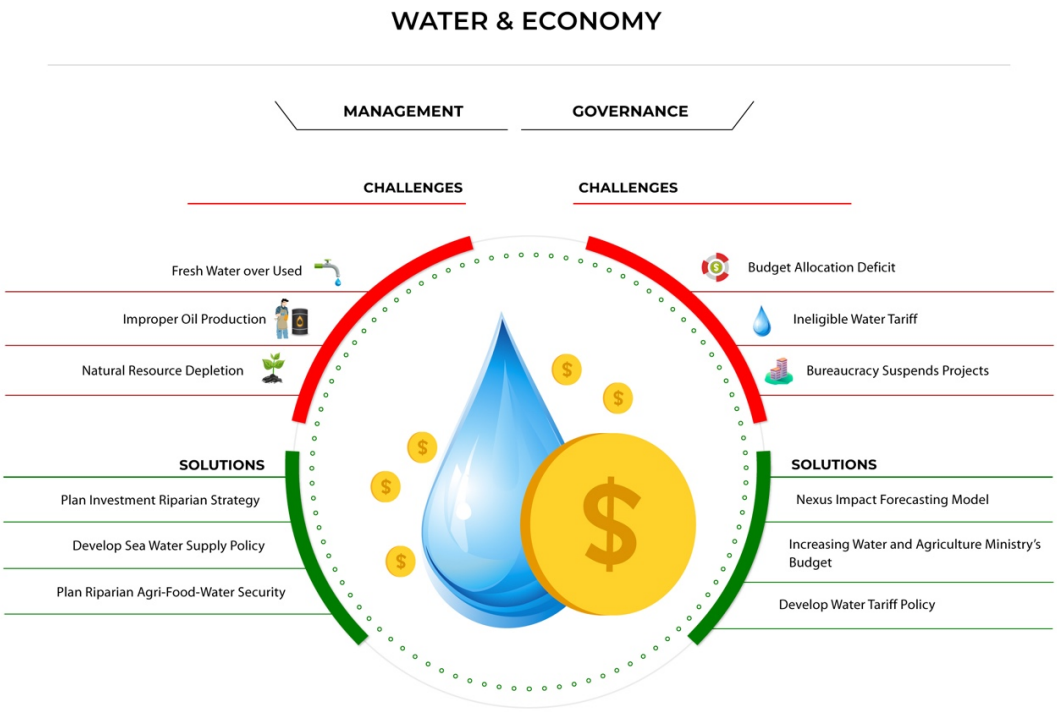

Figure 6. Water and economy.

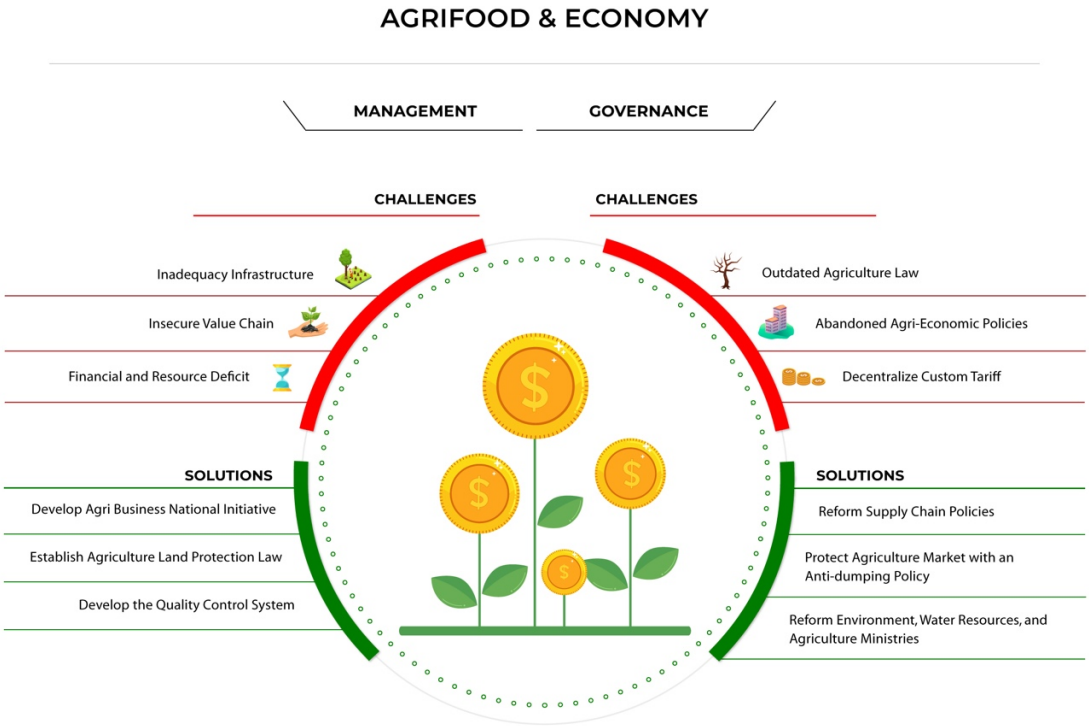

Figure 7. Agri-food and economy.

3.1. Deficit analysis

The following subsections present the results regarding the shortages and challenges within the two domains of management and governance for each sector and subsector.

3.1.1. Management deficit analysis for climate change and water-food-socioeconomic nexus

The long history of conflict and instability in Iraq has likely harmed its management and leadership capacities. Iraq's prominent economic challenges include an unemployment rate as high as 25% (Mahmood, 2020), a large budget deficit (Al-Rubaie and Ahmed, 2021), and a dependence on oil exports that exceeds 90% (Le Billon, 2005). Some potential areas of deficiency in management include a lack of institutional capacity, particularly in the water and agriculture sectors, which is related to investment, education, and training (Jaradat, 2003). There is also a lack of strategic planning (Brown, 2005), with many state-level organizations in Iraq lacking clear goals or plans for achieving them, making it difficult for managers to oversee operations effectively. Political interference and corruption may limit the ability of the state apparatus to effectively lead and manage organizations in Iraq (Le Billon, 2005). Poor communication and collaboration in state-level organizations can hinder governmental agencies' performance (Williams, 2009). Furthermore, there is inefficient resource usage and allocation (Yousif, 2006), especially with financial resources, technology, and personnel. On top of this, environmental and climate challenges may present additional management problems for the country. These challenges may include water scarcity, the threat of desertification, and land degradation during the last two decades, such as soil erosion and soil fertility reduction (Al-Obaidi et al., 2022). Finally, there are different sources and types of pollution, include air pollution (Chaichan et al., 2018), water pollution (Al-Hamdani, 2013), and solid waste management issues (Al-Mohammed et al., 2021).

Climate change and water (Management deficit):

In 2019, floods arose due to heavy rainfall in Iraq (Yadollahie, 2019). Moreover, the temperature increase and rapid population growth will complicate environmental challenges severely; the population is expected to reach 50 million by 2030 (United Nations, 2019), placing great pressure on urban areas in the absence of an integrated water management strategy (Abbas et al., 2019). The rise in temperature, along with changes in precipitation patterns, will shift the ice in the mountains of southern Turkey, which will likely diminish water quality, particularly through sea-level rises and saltwater intrusion into aquifers and rivers (Al-Marashi and Causevic, 2020; Yaseen et al., 2016). Iraq lacks efficient, advanced management systems for storing water during floods and making better use of it during dry periods. The impact of climate change on Iraq's water resources has been attributed to the absence of long-term planning and deteriorating infrastructure (Saab, 2018).

Iraq, as a downstream country, is also suffering from the impact of the massive dam built by the riparian countries of Turkey, Iran, and Syria (Al-Muqdadi, 2019). Dams cause damage to wetlands (Hermoso et al., 2019). About 35% of the world's wetlands were lost between 1970–2015, either because of human actions or the influence of climate change (Bridgewater and Kim, 2021). The estimated marshland area in southern Iraq is between 8000–20,000 km^2, where every 1000 km^2 requires 77 m^3/sec of freshwater (Yasir et al., 2018). This means that Iraq needs to accommodate about 616 m^3/sec of freshwater for marshland water restoration. Maintaining aquifers and managing groundwater is another battle. Drought, as one of the consequences of

climate change, leads farmers to overuse groundwater resources and puts aquifers at risk of depletion. The case of Sawa Lake provides a model. This unique, natural terminal lake in the desert of Southern Iraq relies on groundwater recharge; it works as a natural sensor to indicate the overuse of groundwater. Currently, Sawa Lake has almost disappeared, primarily due to the poor management and overuse of groundwater extraction, with climate change as a secondary cause (Merkel et al., 2021).

Climate Change and Agri-food (Management deficit):

Climate change might have a direct link to the food shortage in Iraq, which was highlighted in 2021 (Al-Faraj and Al-Dabbagh, 2015). Iraq is a water-stressed country; there is a decline in the water share available, which represents a vital risk to the livelihood of the agriculture-reliant population (Salman et al., 2021). Drought in Iraq exacerbates food insecurity and poverty, particularly in rural areas, where farming is the main source of income for most people (Bazza et al., 2018). Between December 2007 and June 2009, 25,578 people, or 4263 families, were displaced by drought (IOM, 2010). During the drought waves that hit the country in 2008 and 2009, 40% of the country's agricultural land was destroyed, particularly in the northern governorates (FAO, 2020). In addition to the major decline in water flow, the agri-food sector is negatively impacted by climate change. The massive dams of Turkey's Southeastern Anatolia Project (Rashidi, Rastegar and Mashhadi, 2021), in addition to the diversion of the Karun and Karkha rivers by Iran (Saab, 2018), have worsened the water situation and have already led to the loss of spawning and nursery habitats for coastal fish and shrimp in the marshes (Mueller et al., 2021).

The season February–April 2021was the second driest in four decades after the worst drought, in 2007–2008, as rainfall was described to be 40% less than average (Organization, 2021). Consequently, the FAO estimated that wheat production in Ninewa decreased by 99%, while whole wheat production decreased by about 70% due to diminished yields; declines in rainfall had a substantial impact on agricultural production, affecting about 75% of the rural population (Mahmud, 2021). Agriculture contributes to climate change through air and water pollution. In 2019, the agriculture, forest, and land use (AFOLU) sector produced 23% of global GHG emissions (Mbow et al., 2017), which means that agriculture is the second-largest contributor to climate change after fossil fuels. Over the last 20 years, agricultural methane emissions in Iraq have increased by the equivalent of 4950 metric tons of CO_2 equivalent (Knoema, 2019). For example, the average concentration of methane (during 2003–2015) is high in Central and Southeastern Iraq compared with the western, southwestern, and northeastern regions (Abed et al., 2018).

Climate Change and the Socioeconomic (Management deficit):

The reliance of Iraq on oil and the lack of private sector participation weaken the national economy. In addition, the rise in temperature will increase evapotranspiration rates accordingly, which will provoke shortages of water resources used by the oil, gas, and cement industries (Lange, 2018). There are also concerns that accelerating extreme weather events will cause greater displacement from rural to urban areas, which will create additional social, economic, and political challenges in overcrowded cities.

Despite the symptoms of climate change impact in Iraq, it is hard to estimate how

deeply climate change has affected the country without solid evidence or periodic statistics given the various interlinks between the influenced sectors. However, the expected extension of these impacts in the future may be significant and create further pressure on the economic sector. Hence, considering the cost of climate change adaptation is essential to sustain the economic system and cope with vulnerability. Conversely, little is known about the actual impact of climate change in Iraq. In the last few years, and relying on the Regional Assessment for West Asia (UNEP, 2017) that has been developed by the United Nations Environment Program (UNEP), a large number of state and non-state institutes along with media channels claiming that "Iraq has been classified as the fifth most affected country by climate change effects". The report has been reviewed by the current authors, and Chapter 2, page 45, mentioned that the reference for that statement is Abdul Hamid, 2009. However, the reference is not cited in the UNEP report. Further investigation to the reference of (Hamid, 2009) on page 46, the author mentions the following statement: "Iraq, fifth most vulnerable, is at high risk for coastal flooding, exposure to extreme temperatures, susceptibility to decreasing food availability, and the negative health problems these create", for the same reference, particularly in page 45, the author seems relay in his estimation on a consultancy firm that developed a global Climate Change Index (CCI) for 30 years (Verisk Maplecroft, 2009). However, the website of the CCI does not tell which methods or frameworks have been used to achieve that ranking system. Moreover, no indicator or information refers to the statement "Iraq, the fifth most vulnerable country in the world to decreased water and food availability, extreme temperatures, and associated health problems".

On the other hand, there are many global ranking systems used from different sources showing that Iraq is not even within the top ten countries affected by climate change (Austa Somvichian-Clausen, 2020; Concern Worldwide, 2022; Rescue, 2023). The comprehensive report Climate Change and International Responses Increasing Challenges to US National Security Through 2040, page 11 (Price et al., 2021), indicates eleven countries at risk of climate change, where Iraq is listed at the very end in the eleventh place. It is hard to approve or find a solid reference and evidence-based to address a clear place for Iraq within the regional or global ranking system. Spreading such statements without solid reference might misguide the decision-makers to make rational economic planning and disordering the list of priorities.

Iraq's solid waste has been recognized as a significant social, economic, and environmental issue. Solid waste accumulates daily, with per capita waste generation exceeding 0.73–1.4 kg per day (Al-Mohammed et al., 2021), more than 70% of which is food waste (Sulaymon et al., 2010). This has serious consequences for the environmental and health sectors. Although local authorities in Iraq, in cooperation with international organizations, took steps to launch the National Solid Waste Management Plan in 2007 (Knowles, 2009), the initiative was rather humble, and investment in this sector is still immature.

Water and Agri-food (Management deficit):

Agriculture is the second-largest contributor to Iraq's GDP, at 5.97%, and the main source of earnings for 20% of the population (The Global Economy, 2021; FAO, 2021). This sector is suffering from a number of challenges that threaten the food security of the country, such as the absence of sophisticated water infrastructure and

government schemes to support farmers, hindering the achievement of the first two fundamental goals of the United Nations sustainable development goals: no poverty and no hunger (Kozicka et al. 2022). The agriculture sector consumes 75% (Al-Maleki and Harry, 2018) to 85% (Oshriyeh et al., 2022) of the water resources in Iraq. Even so, local production is insufficient in Iraq and is mainly dependent on imported goods. In 2021, crop yield production decreased significantly due to the shortage of water and impact of climate change (FAO, 2012). The lack of advanced technology in the agricultural sector and unplanned agricultural activity are causing considerable water loss, specifically in the inadequacy of irrigation networks and the use of ancient traditional approaches (Al-Muqdadi et al., 2020).

The efficiency of the existing water distribution and irrigation systems is estimated to be less than 20% (Al-Faraj et al., 2016). Poorly maintained irrigation systems and overused flooding methods also increase the salinity of the soil, reducing areas of fertile land and harming crops. That lefts about 75% of the irrigated area is saline, and 20%–30% of the area has been abandoned by farmers (Al-Zaidy and Motlak, 2019; Ghandi and Lawell, 2019). The open irrigation channel system increases evaporation rates, and the outdated distribution network loses a significant share—an estimated 25% of water resources (Rasheed and Al-Adili, 2016). However, little is known about the true magnitude of agricultural polluters in Iraq.

Water and the Socioeconomic (Management deficit):

Globally, the estimated amount of water required to produce one barrel of oil varies. Some research suggests that three water barrels are needed to produce one oil barrel; this amount might be increased to between 7–10 water barrels in North America (Gomes et al., 2009). However, other studies posit that Iraq is consuming between 3–5 freshwater barrels (Almahmood, 2019). Poor optimization of water resource consumption has also been identified, particularly in the efficiency of water injections used for oil recovery, which does not exceed 50% (Al-Musawi et al., 2019). It is thought that a substantial amount of water is lost due to leaks and inefficient approaches. Based on the literature cited above, water consumption in the oil industry is an economic concern for several reasons. It consumes a considerable amount of freshwater from the broad estuary and the Tigris River (Al-Zaidy and Motlak, 2019) at a time when Iraq is suffering from water resource shortages. The potential freshwater required to enhance future oil production, taking into consideration that the ultimately recoverable resource rate of Iraqi oil fields has just reached 18%, means that 82% of reservoirs remain unrecovered (International Energy Agency, 2019). Another water-economic cornerstone datum is the cost of water injection into each oil barrel. In their 2010 report, British Petroleum discussed the structure of the total estimated cost for each oil barrel. The breakdown indicated that the cost of water injection forms 31% of the cost of each single oil barrel, which is even higher than the surface infrastructure maintenance cost (26%) (Ghandi and Lawell, 2019).

The oil industry is one of the major freshwater consumption sectors. Iraq is currently producing 4.3 million barrels per day, which means that 12.9–21.5 million barrels of freshwater are needed per day (given that 3–5 freshwater barrels are expected required for each single oil barrel). In the short term, the Iraqi Ministry of Oil plans to increase oil production to 6 million barrels per day (Razzak, 2019), which will increase the quantity of freshwater usage to 18–30 million barrels per day in the

near future. Moreover, the current capacity of the downstream oil sector (refineries) is 800,000 barrels per day. The Ministry of Oil's plan is to increase this capacity up to 1.8 million barrels a day over the next 5 years (Barret, 2020), with each refined barrel needing 1 barrel of freshwater (Nabzar 2011). Collectively, the expected required quantity of freshwater is 20–32 million barrels per day for both the upstream and downstream oil sectors.

Agri-food and the Socioeconomic (Management deficit):

The underdeveloped value chain of the agriculture sector has positioned the Iraqi economy as a major importer and undermined the food security of the country, as 90% of goods consumed in the Kurdistan region of Iraq are imported (Rawa Abdulla, 2015). However, the potential of this sector is undermined by the weak infrastructure and the low-input, low-output value chain. Agricultural activity is characterized by a small scope of farming, with 80% of establishments being smaller than 100 dunums (FAO, 2012). The shabby infrastructure, poor food-processing facilities, inefficient transportation, and the economic system are all hindering the growth of the agriculture sector and preventing it from capitalizing on the added value of the products once they reach the consumer. With the rapid population growth, the development of the agricultural sector is required to secure food. However, with climate change and the shortage of water resources, the agricultural sector is bogged down. The conversion of agricultural land to commercial or residential land is a good example of management and economic orientation failures that directly influence agricultural capacity and urban planning, respectively.

3.1.2. Governance deficit analysis for climate change and water-food-socioeconomic nexus

Iraq witnessed dramatic political changes in the last century, the most recent in 2003. The United States and its allies invaded Iraq and transformed the political system from a centralized to a decentralized system to fit more with the federalism frame. However, that shift was radical, with improper time to transform the political and administrative systems smoothly, leading to several negative impacts on governance (Fleet, 2019). Some of the outcomes of this unprepared shift include a) political instability, which has hindered the country's ability to address critical challenges and implement effective policies (Nore and Ghani, 2009); b) sectarian tensions, in which local conflicts undermine the government's efforts to consolidate the national identity (Shakor, 2020); c) limited economic development, which has led to high unemployment rates, a lack of opportunities for many people, and a high reliance on oil exports (Yousif, 2016); d) escalation of insecurity, which has disrupted regional security and peacebuilding (Jabar, 2007); e) pervasive corruption, leading to a lack of trust in the government (Mahdy, 2016); f) poor public services, as Iraq has struggled to provide essential services, such as healthcare, education, and clean water, to its citizens, partly due to inadequate infrastructure and a lack of investment in these sectors (Ahmad, 2015); and g) conflicts of interest in decision-making between government agencies, in addition to the confusion between old and new policies that have been adopted (AlKafaji and Mahmood, 2019). The impact of climate change as an external challenge, along with all its consequences for water, agri-food, and the socioeconomic, is adding another burden, since particular adaptation policies need to

be considered to cope with the global agenda of the Paris agreement.

Climate change and water (Governance deficit):

Regionally speaking, the increasing temperatures within the Euphrates–Tigris basin have undermined the precipitation rates and surface runoff in the range of 25%–55% (Bozkurt and Sen, 2013). The heatwaves recorded in 2016 in Southern Iraq made it one of the world's three hottest places, as the temperature reached over 53.9 °C (Samenow, 2016). These extreme temperatures severely affect water resource availability. However, building massive dams contributes negatively to water scarcity (King, 2015). This toxic mixture of climate change and a lack of regional water cooperation between Iraq and riparian countries has put millions of Iraqis at imminent risk of water and livelihood insecurity. Internally, the contradiction within the Iraqi constitution between Articles 110 and 114 over regulating water resources (Iraqi Embassy in US, 2020) is an additional, direct water-governance challenge that indirectly leads to a fragile orientation toward adopting overarching national climate change policies. The vagueness of responsibility and the struggle between a centralized and decentralized system impose a risk; it is unclear whether internal water regulation is the federal government's duty or that of the regional government. This might even expose the relations between the federal government and the Kurdistan Regional Government to another political challenge and reinforce the distrust. The initiative of the Ministries of Agriculture and Water Resources to reduce the water used for agriculture by up to 50% due to the water shortage might help in the short term but provides no strategic plan (Basra, 2018). In addition, solid collaboration between government institutes, civil society, and academic associations on explicating the impact of climate change on water resources is still lacking.

An environmental protection law does exist and was developed by number 27 of 2009 (ILO, 2009). However, the law is not enforced. Illegal water-well drilling causes aquifer depletion. The Ministry of Water Resources has adopted a strategy to manage water resources to address the country's water needs in a sustainable manner. The full implementation of this strategy is expected to reduce freshwater consumption by around 24.5% by 2035 (USID, 2006). Nevertheless, serious violations, such as polluting rivers with industrial waste, are estimated to produce around 70% of the industrial waste in Iraq's rivers, in addition to the indiscriminate use of fish farms and digging of groundwater wells (Chatham House, 2020).

Climate Change and Agri-food (Governance deficit):

Food sufficiency is another area affected by climate change. It is very likely that crop production will seriously decrease in the next few years due to the climate breakdown, and thousands of farmers anticipate being displaced to urban cities to seek jobs (Fatli, 2018). Consequently, attempts to develop resilience policies against future environmental and food shocks remain nascent. A total of 39% of the land area has been affected by desertification (Planetary Security Intiative, 2021). Iraq still lacks a national plan to address climate change challenges. The development of such a plan was initiated recently by the government of Iraq in partnership with the United Nations Environment Programme (Zhongming et al., 2020). However, in 2021 Iraq applied a Nationally Determined Contribution with aspires to reduce the greenhouse gasses between 1%–2% by 2030, and up to 15% if global financial and technical support is offered (FAO, 2021). For the time being, policies to mitigate the impact of climate

change on agriculture do not exist. Iraq's food basket in the south-central region of the country has lost about 50% of its production capacity due to salinization over the last two decades (Saab, 2018).

Climate Change and the Socioeconomic (Governance deficit):

Conventional buildings consume about 40% of all energy globally (Cao et al., 2016). There are no environmentally friendly buildings in Iraq to mitigate the impact of global warming, and no local policies are in place to address this concern. The same is true for green energy and renewable resources, which have strong potential to increase the clean and alternative energy available to the country. The concepts of a green economy and green entrepreneurship are other puzzle pieces that are missing in Iraq. Green buildings, solar panel-based energy, and other aspects of green technologies could have a positive impact on climate change and might help the economy thrive (Tawfeeq et al., 2022). Climate change is causing a material decline in water levels, affecting energy production for the main hydropower plants—the expected decrease in hydropower at the Dokan Power Plant, for instance, is 20–40 MW by 2050 (Pilesjo and Al-Juboori, 2016). Salinized water directly threatens the functionality of thermal power stations and is already poisoning livestock and people (Karasik and Spezia Depretto, 2019). The absence of strategies to regulate and prioritize investment in vital sectors, such as the green economy, renewable energy, and developing agribusiness, might lead to a severe collapse in the economic system.

Despite the active environmental laws in Iraq, a proper climate change policy is absent. No obligations or penalties for climate change violations have been applied. Iraq, among other countries, has committed to reducing greenhouse emissions, and an intended nationally determined contribution has been submitted (Saaf et al., 2018). Specifically, the country has committed to reducing GHG emissions (Mock and Díaz, 2021), yet the lack of laws and regulations is hindering climate change mitigation efforts. Thus, Iraq might fail to fulfil its commitments to achieve the carbon credit policy of the Kyoto Protocol; these risks paying penalties worth millions of US dollars (United Nations Climate Change, 1997).

Water and Agri-food (Governance deficit):

There are no specific policies to identify the feasibility of crop cultivation based on the country's water footprint and the lack of a smart national crop map. This is accompanied by a lack of implementation of local laws, abuse of water streams by unauthorized water pumps, and tribal conflicts (Curtin, 2005). The noncompliance of fish farm owners, in addition to a large number of unlicensed farms, is another challenge to water consumption (Salman, 2011). The trade-off is in the water shares allocated to Iraq by the riparian countries and the effects of their food exports to Iraq. Turkey, as an upstream country, provides more than one-third of Iraq's food imports, worth approximately US $3 billion (OEC, 2017).

There is a lack of proper quality control to restrict water pollution due to farm activities. The use of chemical pesticides and fertilizers has led to severe water pollution in agricultural drainage. This can be extremely harmful to the ecosystem, particularly for fish that have been using water drainage to breed over the last few decades (Mohammed, 2019). The irrational use and overexploitation of groundwater have led to a significant drop in the water table, as the average groundwater table's decline is between 25%–42%; the groundwater used in irrigation is considered one of

the key reasons behind this drop (Nanekely et al., 2017).

Water and the Socioeconomic (Governance deficit):

Despite several attempts, Iraq has failed to diversify its national economy. Moreover, the country suffered from a deficit in its national budget from 2005–2021 due to political instability and the COVID-19 pandemic (WFP, 2020). Water projects and infrastructure have been mostly suspended, and the agricultural sector has been damaged by 40%, followed by productivity declining by 67% for agriculture and non-agriculture business (Ismael et al., 2021; Ministry of Finance Iraq, 2021). The shortage in the national budget allocation for both the Ministry of Water Resources and the Ministry of Agriculture hinders executives from implementing strategic projects. A simple analysis of the federal budget in 2017–2021 reveals at least two fundamental shortages: 1) the budget allocation is less than 1% for both combined and 2) these allocations have declined, not increased (Ministry of Finance Iraq, 2021) (**Table 1**). After 2003, Iraq adopted a new political system, embracing the decentralization of the regions and provinces. Nevertheless, this did not apply to budgetary practices (Savage, 2013). AlKafaji and Mahmood (2019) evaluated Iraq's budget for 10 years (2003–2012), reporting that the failure of the budget processes contributed to the mismanagement of the country's resources and promoted a culture of corruption. Although agriculture and food security are essential, the Ministry of Agriculture's share of Iraq's operating budget averaged 0.59% over 10 years.

Table 1. National budget allocation for the Ministry of Water Resources and the Ministry of Agriculture in Iraq for the period 2017–2021 (Ministry of Finance Iraq, 2021).

Year	Financial allocation (IQD.)	Total budget	% of the total budget
Ministry of Water Resources			
2021	547,722,344	93,159,954,484	0.5%
2020	734,053,413	67,425,220,454	1% budget not approved
2019	991,249,732	105,569,686,870	0.9%
2018	406,109,372	91,643,667,236	0.4%
2017	449,075,689	79,011,421,000	0.5%
Ministry of Agriculture			
2021	418,459,999	93,159,954,484	0.4%
2020	807,001,291	67,425,220,454	1.1% budget not approved
2019	781,985,717	105,569,686,870	0.7%
2018	661,221,181	91,643,667,236	0.7%
2017	659,686,929	79,011,421,000	0.8%

Supplying water to different sectors creates a significant cost burden on executive governments. Although Iraq is aware of the risk of water scarcity, no serious efforts have been made to revisit the feasibility of water tariffs. The current, low water tariff covers only 2%–5% of the costs of operation and maintenance (Iraq, 2013), which the local government heavily subsidizes. The water tariff in Iraq is considered the lowest in Arab countries and is about 12 times lower than the tariff applied in Egypt (Al-Obaidy and Al-Khateeb, 2013). Domestic water consumes 4% of Iraq's total water

resources; although meters are installed, most households are not charged for water consumption. In Baghdad, 90% of these meters are out of order (Khudhair and Jung, 2022). This leads to a lack of social awareness, as stakeholders in general may value water resources less and take them for granted.

Agri-food and the socioeconomic (Governance deficit):

Iraq's outdated law of agriculture rehabilitation (LoAR) is one of the fundamental obstacles hindering the development of the agricultural sector and making it economically unproductive. The law's development began in 1958, when Iraq's total population was ~6 million. It was slightly improved in 1970 as Law 117, when Iraq's total population was around 10 million. This law is still valid, but the Iraqi population is four times larger, with fewer water resources. In early 2022, the Legislative Committee for Agriculture, Water, and Marshes released a new version of the LoAR that was still considered a draft waiting to be finalized (Iraq, 2022). State-driven policies have subsidized farm inputs and controlled the price of strategic crops; these policies have distorted markets, with a consequent negative impact on the growth of agriculture, and provided insufficient or perverse incentives for private sector development. Agricultural institutions are unable to provide the required services. There are shortcomings in the institutional capacities of the public agencies in charge of advisory and technical services.

The local production in the agri-food sector is discouraged by unfair competition with imported products, to which no proper taxes are applied. These improper trade policies lead to negative effects on domestic products, and the margin dumping in the local market from neighboring countries, particularly Turkey, Jordan, and Iran, exceeds 2% (Ghadhban and Jbara, 2019). The importation of vegetables is substantial in Iraq, where 60%–70% of the vegetables are supplied by neighboring countries (Lucani and Saade, 2012). Unifying local customary tariffs across national borders is another challenge, as the federal government and the Kurdistan region adopt different custom tariffs (Schnepf, 2004). Collectively, the shortage of water, high cost of agricultural equipment and chemical fertilizers, and shortage of food processing facilities make it difficult for local products to compete with imported goods. The total value of the main food products imported by Iraq in 2015 was US $1.187 billion (WFP, 2018).

4. Discussion

Based on the findings presented above, a discussion of suggestions and opportunities that might improve Iraq's situation is offered below.

4.1. Management suggestions

It is recommended that the relevant authorities implement a long-term water management strategy and action plan. In addition to response emergency plans in cases of droughts and floods, additional suggestions are as follows: a) rehabilitate the infrastructure of water treatment plants and irrigation and drainage pumping stations; b) promote the use of modern irrigation systems that are appropriate for arid regions to avoid water losses; c) increase private sector involvement in the treatment of sewage and agricultural wastewater to rehabilitate Iraq's water management infrastructure;

and d) develop meteorological monitoring systems and early warning centers for weather and storms to reduce disasters deriving from climate change. However, these suggestions are massive undertakings with significant costs that would need to be considered and revisited for further details.

A comprehensive national awareness program covering two decades should be developed to address water shortages and climate change impacts. The national awareness program should address a) the responsible use of natural resources and minimization of human impacts on the environment to avoid groundwater overuse and reduce pollution and contamination; b) the importance of a sustainable ecological system to local communities; c) the negative impact of massive dams on the environment at the local and regional levels; d) the advantage of using modern technology to reduce climate change's possible risks; e) the promotion of dialogue between governmental agencies, academic institutes, and civil society to identify common interests; and f) comprehensive joint research related to climate change by the relevant authorities, academic institutions, and non-governmental organizations (**Figure 2**).

A comprehensive national program for building sustainability capacities is required that targets different stakeholders: decision-makers, executives, academics, farmers, and civil society activists. The program might focus on climate change in different respects, including a) research and development strategies, b) integrated water resource management, c) water diplomacy, d) farming and tailored practices, and e) technology and innovation. Deploying wastewater recycling and using it for farming will enhance vegetation cover, increase the productivity of crops, and mitigate the influence of sandstorms. Agricultural diversity could be developed by using resilient plants, such as palm trees, which consume less water and have a higher tolerance for salinity. Horticulture could be promoted instead of relying mainly on water-thirsty crops, such as wheat and barley, which have low added value. The adoption of new technologies in water resource management could reduce water waste, following the examples of similar arid regions in the Gulf countries. Such technologies include indoor vertical farming, aquaponics, hydroponics, and controlled greenhouses such as Aerofarms and Pure Harvest (Soubrier, 2020). It is crucial to encourage and promote green entrepreneurship by establishing start-up incubators and accelerators to foster the growth of sustainable agribusinesses. Reactivating and developing the country's metrology center based on the five climatic zones of Iraq is necessary (Ajaaj et al., 2016). The center would help determine the climate pattern and its impact on agriculture; the data would enhance the agricultural practices in the precise zones. (**Figure 3**).

There is an acute need to diversify the national economy and reduce the reliance on oil by promoting the private sector to subsidize renewable energy and innovative technologies, such as biogas production and solar/wind energy. Allocating an annual base budget to adapt to climate change's impacts is crucial. Financial allocation might be directed toward supporting projects that can contribute to reducing greenhouse gas emissions. As a close regional exposure and despite the viability of the net zero strategic plan to mitigate climate change impacts has been set to be achieved by 2050 by the Ministry of Climate Change and Environment of the United Arab Emirates (UAE), the concept of that model can be adopted. Around US $40 billion has been

allocated to fund clean energy projects. The goal is to reach 14 GW of clean energy by 2030 (Lim et al., 2018). Furthermore, Iraq should use environmentally sustainable, high-efficiency construction standards while encouraging the modernization of transportation networks connecting all governorates, which would reduce emitted gasses, and the use of natural gas-powered cars. Encouraging alternative fuels can help to reduce CO_2 and other transport-related pollutant emissions quickly and cost-effectively, such as natural gas, which produces 30% less carbon dioxide per end user than oil (Kuo, 2012). Recently, the Iraqi Ministry of Oil adapted a natural gas mobility system. However, the initiative is still limited (NABD, 2022) (**Figure 4**).

A key reason for the water shortages in Iraq is the riparian countries' water practices, which either impound water using massive dams or divert it. It is highly recommended to maintain efforts to negotiate strategic agreements with riparian countries and incorporate economic collaboration, business ventures, and joint projects serving mutual interests. This water–economy link could foster regional development that would reflect positively on the agriculture sector and food security while strengthening regional cooperation in different domains, such as trade, industry, knowledge exchange, and national security. It is also recommended adopting a sophisticated, integrated water resource management system at the national level, given the different challenges and priorities from one region to another. This strategy should include reclaiming land and handling soil salinity to mitigate malpractice in irrigation and the reduction in crop yields. This plan could include a) replacing outdated, traditional irrigation approaches with a smart, modern irrigation system; b) using closed-system pipes for the water drainage network to reduce the evaporation rate; c) installing water-harvesting and artificial recharging technologies to collect and store water for further use in agriculture; and d) encouraging water-saving crop cultivation by adopting smart water technologies, including water harvesting and zero tillage agriculture, to optimize the conservation of soil and water, as this reduces soil erosion and water evaporation rates and increases soil moisture (**Figure 5**).

A responsible investment plan is essential at the regional level for agriculture and food systems. The regional cooperation suggested could be a springboard for blossoming partnerships in clean energy and hydraulic power plants. The rationing of water consumption in oil production is urgently required. The Ministry of Oil, in partnership with the French company Total Energies, is currently establishing the Common Seawater Supply Project to secure water resources for the Iraqi oilfield water injunction. An investment of US $3 billion has been announced, with a capacity of five million barrels per day, to replace the use of surface water supplies. However, the same deal was signed with Hyundai previously, with no progress (Rahi et al., 2021). Implementing this would maintain the economy's sustainability and reduce freshwater resource exhaustion. Refineries might also upgrade their open water systems to closed ones, which would reduce water consumption and enhance economic feasibility accordingly. In addition, installing wastewater units in oil fields and refineries to treat sewage and contaminated water could help provide some of the required water instead of using freshwater (**Figure 6**). Saudi Arabia has an efficient water system that could be adapted, as 60% of its freshwater is produced by desalination projects (Council, 2021).

The economy could be supported via the agriculture sector through a national

initiative for agribusiness. This proposed initiative would replace the discouraging subsidization system with modern incentives by providing international consultancy and easing administrative paperwork to empower local food-processing factories. This would increase production value, for example, by establishing food processing and packaging facilities to make fruit jams or tomato paste, which would generate higher profits for agribusiness than just selling fruits and vegetables. In addition, it would employ a large portion of the labor force, especially non-skilled workers; reduce the dependence on imports; and boost the economy. In addition, improving the quality of seeds and pesticides would be helpful, as would replacing the current emergency recovery actions with strategic development practices. For example, the short-term grants managed by local governments and the support offered by non-governmental organizations to farmers and agribusinesses can only suffice for one season, and a lack of strategic planning leads to an insecure business model. As a result, many agribusinesses have become reliant on such support, which barely keeps them afloat. Reactivating agricultural loans, reducing the barriers to receiving them, making them more accessible and affordable, and conducting comprehensive research to reveal the shortcomings in supply chain management's capacity to bridge the expected challenges are effective strategies (**Figure 7**).

4.2. Governance suggestions

An adaptation plan for dealing with the impacts of climate change requires a clear responsibility structure. the authors created four comprehensive Stakeholders maps (SH maps) by engaging in discussions with decision-makers and focus groups. These maps collect valuable insights and concerns representing the relationships and connections between stakeholders, as well as their respective roles. The SH maps present areas that are interlinked by how they are affected by climate change as an external challenge. These maps could help us understand the shortages, influences, and power dynamics among stakeholders, thereby identifying priorities, revealing conflicts of interest or areas of disagreement, highlighting shortcomings in institutional cooperation between the actors, and developing more effective communication and engagement strategies. Therefore, these SH maps were created after extensive discussions with various stakeholders during the research journey, along with a list that identifies the key function of each stakeholder (Appendices A, B, C, D, and E) in each relevant sector. This was intended to facilitate collaboration and coordination among the stakeholders, improve decision-making by considering the perspectives and needs of all relevant parties, and enhance transparency and accountability in decision-making processes. The SH maps include feedback from 228 state and non-state actors involved in the complex system of ripple effects, with 78% from federal Iraq and 22% from the Kurdistan regional government (KRG). They represent 101 sectors in climate change, 113 in water resources, 87 in agri-food, and 116 in economic areas (**Table 2**).

Table 2. Total stakeholder maps and percentage and ripple effect concept per sector in Iraq (analyzed from Annexes A, B, C, D, E and F).

Location	Total	% of total	Climate change	% of total	Water	% of total	Agri-food	% of total	Economy	% of total
Federal Iraq	177	78%	84	37%	82	36%	62	27%	89	39%
KRG	51	22%	17	7%	31	14%	25	11%	27	12%
SUM	228	100%	101	44%	113	50%	87	38%	116	51%

Adding responsibilities for climate change impacts to the current federal legislation committees governing agriculture, water resources, and marshlands will help regulate codes and policies and monitor the performance and adherence of relevant governmental institutions. Consequently, we recommend ensuring that federal laws are implemented to guarantee cooperation between federal departments and regional governorates. The federal legislation committee might focus on the following areas, though without being limited to them: a) fostering the progress of international collaboration with riparian countries, b) monitoring agricultural investment development, c) coordinating with the international community to guarantee equitable sharing of water from upstream countries, d) developing a national climate change strategy, and e) enacting laws to protect the environment and water from pollution.

The climate change crisis, which threatens food security, requires the adoption of a strategic roadmap to overcome these threats in the short, medium, and long terms. The plans might include (but are not limited to) a) identifying specific crops and vegetables that are more resilient to the effects of climate change and consume fewer resources, b) enforcing the use of new irrigation technology by law, and c) criminalizing environmental violations through tough fines and compelling incentives.

Iraq should adopt a national initiative on climate-resilient agriculture similar to the model provided by India (Singh, 2011), which involves a) strategic research on adaptation and mitigation regarding crops, natural resources, and livestock; this research includes conducting area-specific agricultural vulnerability assessments, understanding and identifying the impacts of the major climate change phenomena, and monitoring the emergence of new pests; b) encouraging the use of technology and smart irrigation systems on farms that can cope with climate change; c) securing financial support for research and development; and d) building the capacity of state and non-state stakeholders at different levels through intensive training, workshops, and awareness campaigns.

Green economy concepts are another key driver of recovering economies. For example, using sustainable construction policies for green buildings could save energy by 40%–50% and water consumption by 20%–30% compared to conventional buildings (Tathagat and Dod, 2015; Umar and Khamidi, 2012). However, fighting the impacts of climate change and promoting a strong economic system requires regulating and applying a set of policies, including (but not limited to) a) enacting a carbon offset policy for the oil and gas industries in response to the effects of global climate change, b) setting up a structure for trading carbon offsets and credits generated, and c) implementing an energy policy with a clear time schedule and long-term incentives for domestic and industrial uses.

Since climate change adaptation is a new challenge for the Iraqi government, it requires new tools and a set of concrete laws. Fees and penalties could be applied to those who impede the laws and thus reduce their impacts. All industries and oil plants could upgrade their equipment to limit GHG emissions. Fees could be charged to private companies that have negative environmental impacts. All charges and fees from these penalties could be collected and used to finance climate change adaptation projects. Conversely, the government might grant credits and other rewards to those who commit to climate change laws and reduce harmful emissions. A good example is the United Kingdom, which applied civil penalties to those who breach climate change regulations dictated by the European Emissions Trading System, the Energy Efficiency Scheme, and the Energy Saving Opportunities Scheme (Dige et al., 2013).

Sustainable urban planning that uses green buildings to combat climate change is essential for a healthy economy. The design and construction of green buildings are environmentally responsible for reducing greenhouse gas emissions, conserving resources, and increasing resilience against the impacts of extreme weather events (Hirokawa and Pohrib, 2013). Granting green financing to green buildings through soft loans would encourage mitigation and adaptation strategies to cope with the long-term impacts of climate change (Debrah et al., 2022).

A package of economic policies might be instituted to rehabilitate the agricultural sector and secure sufficient water shares. This package could include establishing a decent incentive system for farms that use water-recycling systems, encouraging smart irrigation techniques, creating role models for farmers, and establishing a smart national crop map and updating it annually. The map should consider the variable water situations of the different regions. A firm, restrictive monitoring system could be developed for drilling water wells. Introducing a new tariff scheme on water consumption is recommended to reduce water waste, promote efficient water consumption, combat the exhaustion of water resources, reduce soil salinity, and eliminate malpractice in inland irrigation. Banning flooding methods in irrigation and regulating water pumps used on rivers is also crucial.

An action plan is recommended and need to be adopted by the federal legislative committees of agriculture, water resources, and marshlands in cooperation with the federal legislative committee of finance. Current short-listed, high-priority water projects include converting water supply pipes from an open to a closed system in the Sweet Water Open Canal (SWOC) route from the Tigris River (the Garraf Stream), as approximately half the population of Basra (2 million) relies on freshwater from this canal (Wille, 2019). However, the SWOC suffers from failures that cause significant reduction in the canal's capacity and water deterioration due to the high temperature and evaporation rates (Hamdan et al., 2021), and the closed system would lead to a significant decline in evaporation, possibly exceeding 30% (Hu et al., 2021). Improved water infrastructure is needed in the meantime, which could be achieved by investing in infrastructure development to reduce water consumption, particularly for agriculture. About 60% of agricultural water is wasted due to the traditional irrigation methods used by local farmers (Nazarova et al., 2022). Finally, long-term plans could include conducting a forecasting model for water projects. The numerical model would evaluate the impact of the climate change–water–agriculture–socioeconomics nexus along with the population growth while forecasting the worst-case scenarios in

the long term. However, this might require an analysis of the regional forecasting skills and the limitations of model capability which have not been discussed in the present research. It is highly recommended to set aside a sufficient budget so that the Ministry of Water Resources and Ministry of Agriculture can invest in strategic infrastructure. Reconsidering the current annual budget for both ministries is essential. Their allocated budgets require a gradual annual increase to cope with population growth and development plans. New water meters and water tariffs might be applied. The examples of Scotland and the Netherlands, which charge extra for wasting water or contributing to pollution that can affect water quality, could be adapted by the Iraqi government to fit local contexts (Dige et al., 2013). Studies of economic cooperation and development have shown that charging fees for water use can encourage people to ration water use, reduce water pollution, and increase investment in the water sector (Mateus et al., 2020).

The agri-food sector has great potential to relieve the country from the burden of importing crops and secure a margin of independence and self-sufficiency to reach food security. It can also turn the wheels of the economy by serving local markets and their labor forces, as it does not require a high level of skill. Supply chain policies could be reformed to strengthen the value chain in the agri-food sector, facilitate access to the market, and support local production. Encouraging resilient policies and banning monopolies to facilitate agri-business registration processes—for example, biomass production—is key. In addition, possible restructuring of the Ministry of Agriculture, the Ministry of Water Resources, and the Ministry of Environment might be considered. This restructuring would assist in monitoring and executing laws rather than being a market disruptor, and it could help the private farming sector to operate commercially and downsize reliance on governmental subsidies. 2016, Saudi Arabia restructured the Ministry of Agriculture to cover the Environment, Water, and Agriculture. This example could be adapted to fit the Iraqi context. Intelligent solutions for climate resilience are recommended to be endorsed. Iraqi laws have offered specific benefits for industrial projects; the same approach can be applied to climate-smart agricultural and industrial projects.

Anti-dumping policies and costume tariffs need to be considered for all imported goods and food products. Food self-sufficiency requires cooperation between the Ministry of Agriculture and the Ministry of Industrial to establish and expand factories. One successful example comes from the UAE, which conducts a national food security strategy. The Minister of State for Food and Water Security has addressed these goals. The strategy focuses on increasing self-sufficiency based on domestic crops by 5% annually, average income from farms by 10% annually, and the number of workers by 5% annually while reducing the quantity of irrigation water by 15%. They also use an electronic observation system called the "Food Security Dashboard of Dubai," which uses artificial intelligence to analyze the data collected. By applying this strategy, the UAE moved up 10 ranks in the Global Food Security Index within one year (UAE Government, 2022).

4.3. Influence of the climate change and security nexus

The Secretary-General of the United Nations addressed alarming risks regarding

the impact of climate change on peace and security and considered that risk a strategic priority (United Nations Department of Political and Peacebuilding Affairs, 2022). Climate change directly impacts water availability and the increase of evapotranspiration, particularly in arid and semi-arid regions like Iraq and the Middle East region, where the lack of irrigation will reduce the significant crop yield (El-Rawy et al., 2023), which will rise critical concerns on agriculture production and food security nexus (Pickson et al., 2023). However, the burden of climate change's impact on the socioeconomic sector is another debate that would link to water and food insecurity by deteriorating the economic dynamics and creating socio-political and sociocultural challenges hindering development planning (Shapland, 2023; Seyuba et al., 2023). In that sense, several scholars believe climate change is impeding the efforts of peacebuilding and increasing tensions and socio-ecological complexities (Maas and Fritzsche, 2012). The following section will shed light on the strong bond and reveal the complexity of climate change and security nexus, providing a historical overview and describing the present state.

4.3.1. The historical argument concerning climate change impact and security nexus

In the context of climate change impacts, a historical overview can help delineate the links between climate disruption and the hypothesis of the ripple effect in the current work and show how climate change could lead to serious national and regional security concerns. Tracing past climate change impacts will lead to a better understanding of weather events, identifying their patterns and how they have evolved. This will also assist in illustrating the actual effects of climate change-related droughts and floods that have affected different regions in the past, which is helpful to picture the current state, conceptualize possible predictions for the future, and generate a potential framework for practical analysis. Durschmied (2001) examined how weather conditions have played a role in some of the most significant events in history, such as the fall of the Roman Empire, the defeat of the Spanish Armada, and the Normandy landings.

In his book The Life of Reason, Santayana (Corrington, 2017) concluded, "Those who do not learn history are doomed to repeat it," which highlights the value of reviewing the past and learning from it. Let us take an example. Adad, also known as Haddu (Masetti-Rouault, 2013), was an ancient Mesopotamian weather and storm god in the Sumerian and Akkadian eras. As the bringer of rain and fertility, he was one of the most important deities in the pantheon of Mesopotamian gods. He was often depicted as a warrior with a lightning bolt in one hand and a thunderbolt in the other. Adad was associated with the power of nature, and his power was believed to bring both life-giving rain and destructive storms; moreover, he was considered the protector of shepherds, farmers, and all those who relied on rain for their livelihoods. The collapse of the Akkadian Empire is thought to have been caused by a combination of factors, including climate change disruption and the overuse of resources, coupled with long-term drought; the impact of climate change in Mesopotamia and the increasing aridity of the region led to the collapse of the agricultural base, a food crisis, and human displacement from Northern Mesopotamia to the south (Weiss et al., 1993). This also led to institutional and political changes when the landlords granted political

and property rights to the lower classes and laborers by embracing a culture of cooperation to endure the hard times caused by climate shock (Benati and Guerriero, 2021). Recently, solid, scientifically dated evidence of dust activity between 5200 and 3700 years ago supported the conception of the Akkadian Empire's collapse due to climate shock, which was later followed by mass migration from north to south (Carolin et al., 2019). This historical overview indicates the early relationship between humans, national security, and climate events (Marshall, 2022), and provides a dire warning for our own era.

4.3.2. The present state of climate change and security nexus

The concept of climate change and its potential impacts on national security have been recognized for several decades. In the late 1970s, the US Central Intelligence Agency conducted a study to examine the security implications of climate change. In the late 1990s, the Senate Armed Services Committee declared that environmental destruction, including global warming, was "a growing national security threat" (Pumphrey, 2008). Following growing concerns, the Intergovernmental Panel on Climate Change was created in 1995 and addressed the assumption that climate change's impacts would likely lead to increased conflict and instability over natural resources (Agrawala, 1998). In 2003, the Pentagon reported evidence linking climate change to national and global security, laying out a worst-case scenario in which it leads to increased violence, rioting, and disputes (Gleick, 1993). Several studies and reports produced by government agencies, international organizations, and academic institutions have also highlighted the potential national security implications of climate change (Busby and Busby, 2007). Alex Cornell du Houx, an American politician from Maine and an officer in the US Navy deployed to Iraq, believed that he observed early links between climate change and national security when radical groups recruited farmers whose crops had failed due to drought. Climate change turned these farmers into terrorists paid to attack Americans (Alex Cornell du Houx, 2021). In January 2021, the US Department of Defense released a report on the national security implications of climate change (Price et al., 2021). The report outlined how climate change threatens global and national security and addressed possible threats nationwide. Iraq was one of the potential regions in which the risk of tension was increasing due to water scarcity. Following the personal discussion by the authors through the climate change and security conference at the Iraqi Parliament with the member of advisory board of the Iraqi Prime Minister Office (Sanad Organization for Economic Development, 2023), the Iraqi foreign ministry briefed the Prime Minister's office and later gave direction to governmental agencies' concerns to consider this a priority and integrate climate change impacts into any strategic planning. However, the results of adopting the climate change agenda on a national level still need to be determined.

The current research team discussed the impacts of climate change on national security and the implementation of peace-promoting climate action at the local, national, and global levels. Some of the key messages addressed by the decision makers were a) understanding the influence of climate change on regional stability and peacebuilding worldwide, b) taking the climate change nexus more seriously, c) developing technologies and warning systems that will ration resources and mitigate

the risk of climate change impact, d) developing leadership capacity for the future, and e) enhancing global solidarity, partially by sharing the global experience.

The North Atlantic Treaty Organization (NATO) has discussed a net zero emission strategy to reduce gas emissions by at least 45% by 2030 and down to net zero by 2050 (NATO, 2022). Water management and agricultural production under climate change require resilient systems. The priority should be placed on financing and implementing projects and adapting agriculture to transboundary waters. Recently, NATO's headquarters held a Climate Change and Security Roundtable to discuss the latest trends in, ongoing engagements with, and implications of climate change and security in the Euro-Atlantic region, highlighting the best practices and future operating environments of NATO allies and other international bodies with respect to climate adaptation and mitigation (NATO, 2022b).

In Dec. 2023, during the COP28 that was hosted in UAE, the Iraqi delegation led by Iraqi President Abdul Latif Rashid, along with United Nations agencies, focused on Climate Security for Sustainable Development in Iraq; the delegation addressed the importance of the following areas: a) water-food-energy and security nexus to mitigate the climate changes challenge, b) involving youth in climate action, c) negotiating the commitment of gas flaring and emissions reduction and encouraging international collaboration, d) emphasized health resilience and agricultural sustainability, and e) supporting capacity building programs that focus on sustainable development (United Nations, 2023). However, Iraq, along with Saudi Arabia, refused a phasedown or phaseout of fossil fuels, emphasizing that the country still heavily relies on fossil fuel revenue and committed to up to a 2% reduction in emissions to the Paris Agreement from 2020 to 2030 and is already reduced the emissions to 4% (S&P Global, 2023).

4.3.3. The ripple effect of climate change security and the Water-Food-Socioeconomic nexus

The climate change symptoms have become tangible, and the results of the current research show effects at the levels of both management and governance. The climate change and security nexus could be linked in several ways, In addition to the water impoundment by the massive dams from the upstream countries, climate change's impact on the Euphrates–Tigris basin is affecting water availability, particularly for agriculture (water security), leading the Iraqi authorities (the Ministry of Agriculture and Ministry of Water Resources) to reduce the water used for agriculture by up to 50%, leading to reduced crop yields and potential food shortages (food security). In addition to the major reliance on fossil fuel production, the shrinkage of the agricultural sector is straining national economies, affecting livelihoods, and exacerbating poverty, especially in rural areas (socioeconomic security), where the intensive local competition over water resources between tribes and local governments as well as between riparian countries could be one of the critical reasons for the waves of immigration and displacement to Iraq's cities. This has created social unrest and political instability, ultimately posing a national security threat. Tribal disputes over water are also increasing dramatically and make up as much as 10% of all ongoing conflicts. Many studies have assumed that this conflict will increase if more drought is faced in the future (Planetary Security Initiative, 2020), which would trigger conflict between the central government and provincial

authorities (Water and Security, 2022) and escalate the conflicts over water between Iraq and the riparian countries on the Euphrates–Tigris basin (Al-Muqdadi, 2022). Collectively, all these factors comprise serious indicators of how climate change's impact, along with other environmental challenges, is a critical threat to the core national and regional security of countries along the Euphrates–Tigris basin. Iraq and its neighboring countries must respond to and take serious steps to mitigate the far-reaching risks of climate change, which will likely continue to worsen over time. This complex system will hinder any plans for climate change resilience and adaptation, decrease the chances of regional cooperation, and increase transboundary water conflicts. **Figure 8** is a collective figure that visualizes and gathering all the complex system's components, highlights the dynamic of climate change as an external challenge disrupting the water-food-socioeconomic and security nexus, and illustrating the deficits in management and governance domains versus the practical solutions of each sector. The collective figure also addresses the feedback loops between the sectors cascading the interlinks and possible profound implications of water scarcity, livelihood shortages, economic deterioration, and social vulnerability, ultimately posing threats to national/regional security.

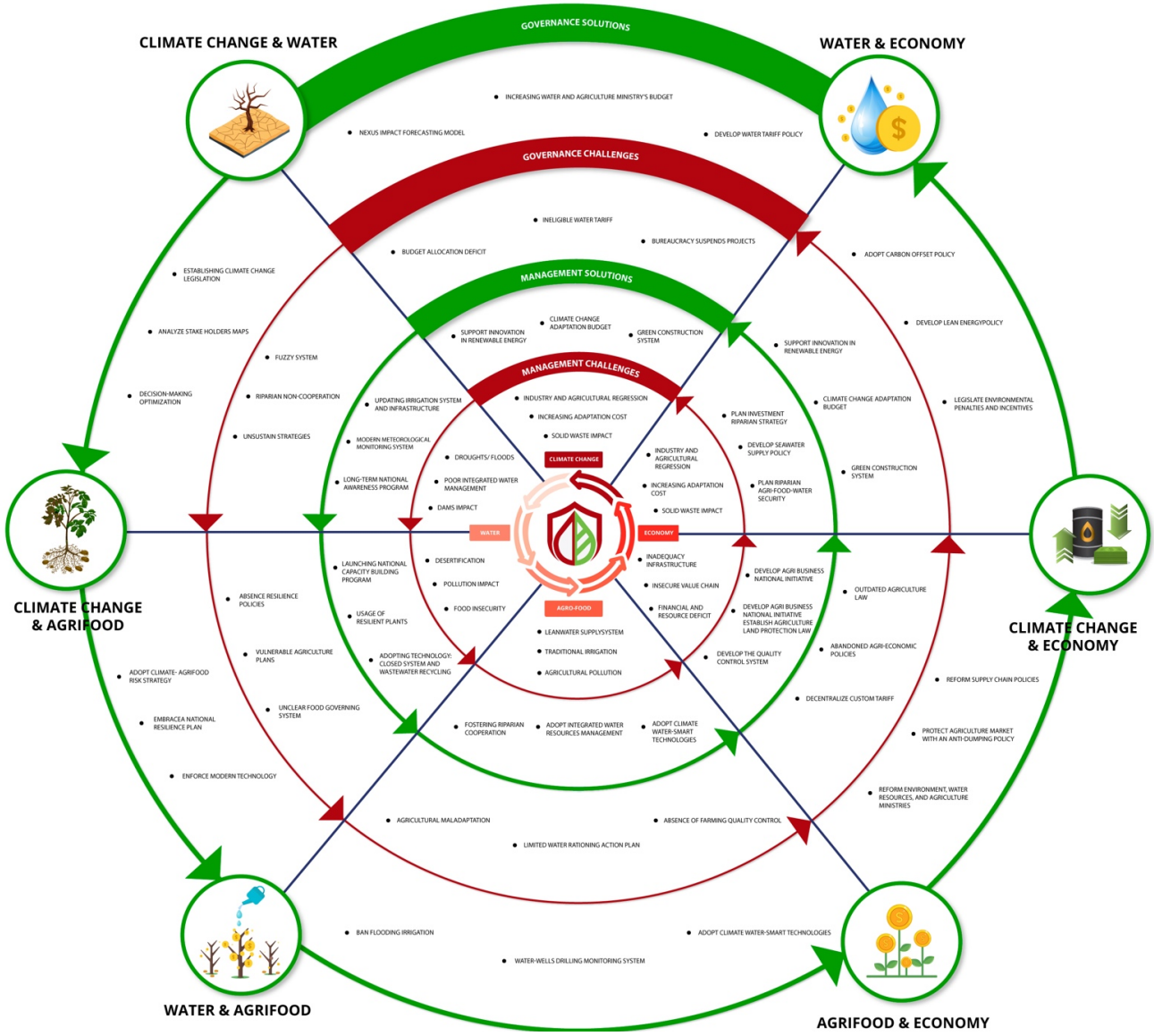

Figure 8. The complex system and the ripple effect of climate change security impact.

5. Conclusion

The authors of this work have proposed that the impact of climate change has a ripple effect on different sectors, with severe consequences beyond a simple rise in temperature, as supported by the findings of this study. Iraq was taken as a case study in which the oil production industry, which is the primary source of national income, could worsen the impact of climate change in the future and threaten local and regional stability. The relationships between climate change and other sectors are reciprocal. The effects of climate change on water resources, agriculture, and the economy are simultaneously exacerbated by those domains themselves and will ultimately produce national security concerns. Symptoms have already been observed, such as the displacement of Iraqi farmers to cities due to a lack of agricultural land, and water scarcity, which fuels desertification, harming the economy. Food demand is increasingly aligned with population growth, social tensions, and local tensions, and local conflicts are thus expected to increase dramatically.

Iraq is turning into a water-stressed region. The long drought seasons and

increased evaporation rates due to the rise in temperature aggravate water resource challenges. In addition, there are conflicts with riparian countries over shares of water resources, poor management and over-subsidization of these resources, and wasteful consumption in agricultural and domestic use. Water scarcity, in return, heavily impacts the agricultural sector, which is a pillar of the economic development of Iraq and the livelihood of the nation and its people. Malpractice and outdated irrigation methods are draining our already scant water resources. Inevitably, the deteriorating state of the agricultural sector will harm the stability and security of the country. A considerable portion of the population, particularly in rural areas, will lose their main source of income, be pushed to the poverty line, and move to urban areas, putting a burden on the economy at the state level so that it will become even more import dependent.

Still, the economy will remain oil-reliant, generating more CO_2 emissions. Reliance on the hydrocarbon economy as a fluctuating source of income is unsustainable, and the value of oil will likely decline since the world is shifting toward renewable energy. At the state level in the near future, Iraq will be unable to provide employment opportunities to its ever-growing population.

This research comprehensively examined the challenges and possible solutions at the management and governance levels in four domains: climate change as an external threat, water resources, agriculture, and the economy, each of which will have a domino effect on all others. It details how Iraq is heading down an unsustainable path that will ultimately threaten national security.

With the impact of climate change and rapid population growth, the country will face profound food insecurity and dumping in the local market from neighboring countries. Using the lion's share of water in outdated irrigation systems is wasting the already scarce water resources and increasing the soil salinity along with the poor control of groundwater overuse, which is leading to aquifer depletion. In the short term, the development of the oil industry is expected to require more fresh water for both the upstream and downstream oil sectors, which will lead to an increased risk of pollution in the water and soil while dramatically expanding the GHG emissions generated by oil field production and flare-gas burning, coupled with the lack of diversification in national revenue. The local economy will be at serious risk of collapse.

The radical shift in the political system after 2003 from a centralized to a decentralized structure without proper preparation is one of the root causes of the governance and management anarchy that led to conflicts between government agencies, with about 228 state and non-state actors involved in decision-making in this complex system. The confusion between old and new regulations and policies contributes to poor governance and hinders development plans. Despite climate change's tremendous implications and tangible impacts, only 1% of the national budget is allocated combined to both the Ministry of Water Resources and the Ministry of Agriculture. This nominal budget, coupled with other challenges, stifles opportunities to invest in strategic infrastructure. Neglecting a holistic approach to the ripple effect of climate change will result in the continued risk of its impact, threatening Iraq and the surrounding region's stability and prosperity.

Supplementary materials: A, B, C, D, E and F: Annex A presents the climate change stakeholders map, Annex B presents the water stakeholders map, Annex C presents the agri-food stakeholders map, Annex D presents the economy stakeholders map, Annex E presents a spreadsheet of key function definition for all stakeholders (state and non-state actors) whom involved in the complex system of ripple effect, Annex F presents the climate change security and the ripple effect matrix.

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