Governing Common Pool Resources in Fragile Political Systems: Modelling Behaviour, Institutions, and Social-Ecological Dynamics

Sophie Erfurth

School of Geography and the Environment
University of Oxford

St John's College

In fulfilment of the requirements of the degree of

Doctor of Philosophy

Abstract

This thesis analyses drivers of decision-making in the irrigation water sector in the context of fragile political states and aquifer depletion. The thesis offers insights for theory, evidence, and policy by advancing collective action theory as well Social-Ecological Systems (SES) Thinking and Modelling in the post-Authoritarian and path-dependent context of Tunisia. The three papers of the thesis unpack complex Social-Ecological dynamics in an interdisciplinary mixed-methods approach. The papers investigate decision-making in the water sector across nested governance scales from national-level state-building to self-governing collective action groups and individual behavioural dynamics. By integrating qualitative social historical, and quantitative physical modelling techniques in a longitudinal approach, the thesis traces co-evolving social-ecological feedbacks between and within institutions, water users, and common-pool groundwater resources. The thesis provides nuance to the capacity of institutions to self-govern in the face of chronic water scarcity and inadequate regulatory mechanisms of monitoring and enforcement.

Acknowledging system complexity, this thesis seeks to engage methods that can uncover the emergence of causal relationships and their outcomes within the SES. Drawing on key analytical lenses of historical institutionalism and social psychology, the three papers employ methods of process-tracing, Qualitative Comparative Analysis (QCA), and Agent-Based Modelling (ABM). These methods are purposely chosen to address context-sensitive, non-linear recursive interactions within the Social-Ecological System (SES). The thesis explores the role of the state in water resources management and user perceptions in a fragile political context marked by frequent social unrest. This thesis' contribution comes from understanding how fragility affects the evolution of collective action by

drawing attention to specific variables (state-building, hope) that have largely been ignored, and by specifically working across levels of action/decision-making often treated separately. The thesis traces the evolution of institutions governing water policy-making and resulting practices of water allocation and use - linked to an authoritarian past of repression and control. It identifies empirical causal pathways of local decision-making that mediate contemporary relationships between institutional trust, social trust, hope, and outcomes of collective action (cooperation and conflict) in water user groups. Ultimately, the thesis animates these social-ecological dynamics in a “digital-twin” evolutionary game driven by institutional rules, water availability, and social preferences.

Results indicate limits to top-down policy implementation and bottom-up collective action in the path-dependent SES. Given the systemic erosion of institutional trust, farmers in modern-day Tunisia see social trust-based systems and local coping mechanisms such as illicit groundwater withdrawals as an alternative to formal rules and the coercive power of the state. Results demonstrate how water sector reforms in past authoritarian regimes served as a practical and symbolic vehicle to institutionalise domination, co-optation, and repression of water users. Where aquifers have been degraded and institutional trust eroded, conflict can arise between water users. At the same time, simulations of water user behaviour, hydrogeological dynamics, and agricultural strategies shed light on the erosion of social norms and reveal possible delay mechanisms of system collapse.

Core academic contributions include the application of theories of state legitimisation, repression, and co-optation to the water-agriculture nexus, evidence of collective action dynamics in settings of low hope under varying

social dimensions of trust, and the adaptation of evolutionary games and ABMs to complex contexts of fragility.

Acknowledgements

I know what a privilege it is
to have been able to dedicate three years of my life
to delve into a topic
that I believe deserves our attention.

At times, this has been a lonely journey.
But more importantly
I have so many individuals to thank (more than would fit on this page)
for their love, support, and reality checks.

My family in Vienna,
who believe in me so much
it becomes near-impossible
not to believe in oneself.

My brother Pippo
who always encourages me
to follow my curiosity
for the pure joy of learning.

My fiancé Iqbal
who has become my home
and who gives me strength and hope
to fight for what is right.

My supervisors
who helped me become a better researcher.
My collaborators
who showed me how fun research can be!

My friends in Tunisia,
who gave me a roof over my head,
insisted on feeding me more harissa than was good for me,
and gave me another reason to care so deeply about my work.
Souhaiel, Hind, Arij, Manfred, Nour, Nizar, Kais, Chokri, Rahma, Rihab, Faten
and her family:
This thesis is to a large extent dedicated to them.

To Mohammed BenSakka
who supported my research and provided important leads.
A leader in the Tunisian water sector,
he will be dearly missed.

To my nephew Francesco Joseph
who will grow up in a confusing world
but who will learn to understand
that it is all worth it.

Every day for a year, I passed by these words on my way to work in Tunis. In the beginning, they didn't mean much to me. But with every conversation (often ripe with frustration and disillusion), the meaning behind these words began to grow. This thesis has been an effort to make sense of them.

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List of Acronyms

ABM	Agent-Based Model
AIC	*Association d'Intérêt Collectif* [= former water user group]
ANPDPH	*Agence National de Protection du Domain Publique Hydraulique* [National Agency for the Protection of the Public Hydraulic Domain]
APIA	*Agence de Promotion des Investissements Agricoles* [National Agricultural Investment Agency]
BIRH	*Bureau de l'Inventaire et des Recherches Hydraulique* [Office of Hydraulic Inventory and Research]
BPEH	*Bureau de Planification et des Equilibres Hydrauliques* [Office of Planning and Water Balance]
CA	Collective Action
CPR	Common-Pool Resources
CRDA	*Commissariat Régional de Développement Agricole* [Regional Agricultural Development Commissions]
DGRE	*Direction Générale des Ressources en Eau* [Water Resources Department]
GDA	*Groupement de Développement Agricole* [= water user group]
INAT	*L'Institut National Agronomique de Tunisie* [National Agronomic Institute of Tunisia]
INUS	Insufficient but Necessary part of a factor that is Unnecessary but Sufficient
MARHP	*Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche* [Ministry for Agriculture, Hydraulic Resources, and Fisheries]
MC	Monte Carlo
MENA	Middle East and North Africa
MTI	*Mouvement de Tendance Islamique* [Islamic tendency movement]
OECD	Organisation for Economic Co-operation and Development
OMV-PPI	*Office de Mise en Valeur Périmètres Publics Irrigués* [Development Agency of Public Irrigation Perimeters]
PNEEI	*Programme National d'Economie d'Eau en Irrigation* [National Programme for Water Saving in Irrigation]
QCA	Qualitative Comparative Analysis
SES	Social-Ecological System
SUIN	Sufficient but Unnecessary part of a factor that is Insufficient but Necessary
TND	Tunisian Dinar
UGTT	*Union Générale Tunisienne du Travail* [Tunisian General Labour Union]

UTICA	*Union Tunisienne de l'Industrie, du Commerce et de l'Artisanat* [Tunisian Confederation of Industry, Trade and Handicrafts]

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1. Introduction

This thesis seeks to unpack the interacting social-ecological dynamics that drive decision-making in the irrigation water sector, and the limits to successful collective action (CA) in fragile political systems. Given structural institutional uncertainties in politically fragile Social-Ecological Systems (SES), how are water users making decisions on water use and allocation, and what are the social and ecological impacts of these decisions? The thesis synthesizes and builds on theories from both social and natural science disciplines to unpack these dynamics (table 1). An interdisciplinary approach links the historical exploration of state-building and policy interventions to the study of local patterns of collective action and quantitative behavioural models that simulate interactions with hydrogeological processes. With a focus on context, qualitative methods are informed by theoretical concepts of historical institutionalism, political sociology of water resources management, trust, hope, and collective action. Quantitative methods target groundwater dynamics and are integrated with qualitative outputs using norm-driven behavioural and SES theories.

Human-environment interactions are studied in relation to political agendas, social promises, community-level norms, and ecological outcomes. The thesis seeks to foster the understanding that attitudes and behaviours emerge from these context-specific interactions between Social-Ecological actors. This co-evolution of processes is path-dependent in nature and results in a unique set of outcomes for both humans and the environment. While generalisations across contexts are difficult to assume, the interdisciplinary research conducted as part of this thesis serves as an example for methods of engagements with complex fragile contexts, which require a deeper understanding of action arenas and resulting pathways of policy- and decision-making.

In unpacking complex Social-Ecological dynamics, the thesis highlights the evolution of so-called management syndromes: 'characteristic sets of co-occurring actor and system behaviours, such as overharvesting or social conflict, that negatively impact natural resources and/or the communities that depend on them.' (Cumming, 2018: 2). This thesis studies water user groups in Tunisia that face severe collective action problems: Aquifer depletion leads to empty wells and farmers' unwillingness to pay water fees leads to bankrupt user groups – both disastrous for the many communities that rely on irrigation agriculture for their livelihoods (Frija *et al.*, 2014, Frija *et al.*, 2016, Massuel and Riaux, 2017; Snoussi *et al.*, 2022). Simply blaming these outcomes on mechanisms of a tragedy of the commons, would be a reductive misrepresentation of the complex dynamics at play in the post-Authoritarian context of Tunisia. The research

Table 1 Glossary of key concepts

Key Theoretical Concepts	**Definition and Source**
Collective action	Self-governing institutional arrangements can successfully implement rules that take into account social benefits and costs. Collective action theory seeks to identify the key factors that enhance or limit the capacity of individuals to solve resource problems (Ostrom, 1990; 2005)
Fragility	'The combination of exposure to risk and insufficient coping capacity of the state, systems and/or communities to manage, absorb or mitigate those risks' (OECD, 2020)
Political sociology of water resources management	Day-to-day contestations of water management are inherently political, i.e. the "everyday politics of water" (Mollinga *et al.*, 2007; Mollinga, 2008)
Historical institutionalism	A historical approach to study how institutions structure and shape social and political behaviour and outcomes (Steinmo, 2008)
Path dependence	A recognition that sequence matters and therefore past decisions inform present/future outcomes (Pierson, 2000)
Trust	Trust is relational and can vary from impersonal generalised trust in institutions or government (institutional, political, or vertical trust) to interpersonal trust between individuals (social or horizontal trust) (Fafchamps, 2006, Mayer *et al.*,

	1995): **Impersonal trust**: 'Trust in public institutions manifests itself when citizens assess public institutions as promise-keeping, accountable, efficient, competent, caring, predictable, open, transparent, fair and honest' (Kaasa and Andriani, 2022: 46) **Interpersonal trust**: Individuals are more likely conform to a set of rules if they feel that the collective objective is being achieved and that other members of the community comply with rules (Levi, 1988)
Hope	A cognitive and emotional appraisal that a meaningful goal is achievable, i.e. the perceived possibility of change (Averill *et al.*, 1990; Lazarus, 1991; Cohen-Chen and Van Zomeren, 2018)
Social-Ecological Systems (SES)	'Human-environment systems' that acknowledge the dynamic feedback between the nested, multilevel systems providing essential services to society (Berkes and Folke, 1998; Folke, 2006; Biggs *et al.*, 2021)
Social Psychology in Behavioural Modelling	Norm compliance relies on social preferences that also imply social penalties for non-compliance - these dynamics can be studied in public goods experiments (Fehr and Schurtenberger, 2018; Fischbacher and Gächter, 2010)

conducted as part of this thesis is motivated by practical challenges of water resources management and policy-making in modern-day Tunisia. Despite efforts to address current water crises, the Tunisian administration and international development agencies have been unable to put a halt to decreasing water supplies and increasing demands (MARHP, 2017; WWW). How can a deeper understanding of causal social-ecological relationships and feedbacks, that uncover social and political interdependencies, expectations, and demands, lead to more suitable and realistic policy approaches and resulting development outcomes?

This thesis will unpack the co-evolving role of the state in collective action and individual decision-making. Around the world, governments often fail in their efforts to respond to groundwater depletion by centralised regulation and enforcement measures (Molle and Closas, 2019). While formal frameworks are key in setting regulatory limits to overexploitation, the failure in designing and

coordinating polycentric governance frameworks (where formal rules and regulations work in tandem with collective action) is in part due to the overestimation of the role of the state (Molle *et al.*, 2018). Rather than blaming groundwater governance challenges on a generalised "lack of political will", this thesis seeks to explore the practical limits to both top-down policy-making and implementation as well as bottom-up collective action using the case study of Tunisia. What are the drivers of decision-making beyond a reductive tragedy of the commons and simplified blames on the lack of political will to implement reforms?

The three papers of this thesis will address questions targeting the evolution of institutions and decision-making across governance scales and social-ecological actors: What conditions or combination of conditions drive water user behaviour in a fragile political context with low levels of institutional trust (paper 2)? How have water governance rules and institutions evolved through Tunisia's Authoritarian past (paper 1)? What conditions or governance interventions are effective in avoiding or delaying the collapse of self-governing water user groups (paper 3)? What is the role of social preferences, particularly regarding trust and hope, in overcoming collective action problems (paper 2 and 3)?

Inherently, Tunisia faces physical water scarcity with highly irregular rainfall patterns – natural processes, which are now enhanced by climate change. Resource scarcity poses a deleterious threat to ecosystems and livelihoods of present and future populations. This thesis will come to show, however, that above all, water resource problems in Tunisia are largely social and institutional rather than resource scarcity problems. The thesis stands in contrast to a common sectoral overreliance on technical solutions to social problems: 'groundwater management is fundamentally a governance challenge. The

reticence to prioritize building governance capacity represents a critical ‘blind spot’’ (Schipanski *et al.*, 2023: 30). The transdisciplinary approach of this thesis strives to systematically close these blind spots through longitudinal multi-method analyses of decision-making at various governance scales in the irrigation water sector. Tunisia presents a particularly interesting case for studies of water governance due to dynamic interactions between resource management and its state of political fragility. 12 years after the Jasmine Revolution, the young democracy is grappling with old social and economic grievances as voices of hope gradually become silent around the country (Cohen-Hadria, 2017). Unemployment has surged compared to pre-2011 levels (World Bank Group, WWWa) and ignited discontent with the ineffective consensus government – leading to the dismissal of parliament by President Saied in 2021. In fear of potential political and social unrest (Fautras, 2014), the fragile Tunisian government has seemingly shied away from policy measures that target sustainable water reforms. Existing laws regarding groundwater exploitation lack clarity and are rarely enforced (Friya *et al.*, 2014), so as not to burden farmers that depend on income from low-value crops. This thesis studies the social-ecological factors that drive decision-making regarding water allocation and use in Tunisia and thereby helps to uncover underlying social expectations, norms, and rules.

The social dilemma of irrigation agriculture is a complex problem to address, particularly under ever-growing threats of physical water scarcity and rural livelihoods hat depend on shrinking water supplies (MARHP, 2017; WWW). Collective action theory provides a theoretical recognition that resource users hold the potential of overcoming collective action problems (Ostrom, 2007). In order to explain the factors that help some water users to avoid the worst outcomes (depleted aquifers, bankrupt user groups), this thesis will prioritise an

understanding of context rather than rely on single modes of rational behaviour to explain outcomes of collective action (Orbell et al., 2004). In *Drama of the Commons*, Stern *et al.* (2002) argue that 'the theory of institutions for common-pool resource management has been remarkably ahistorical, considering the important contributions of case study research in the field' (477). While the commons literature has since undergone efforts to incorporate long entrenched power asymmetries into understandings of institutional arrangements (Kashwan, 2016; 2021), historical investigations beyond studies of contemporary functioning and failures of institutions (De Moor, 2015) remain scarce. This thesis will highlight the case-sensitive context in which institutional and social norms have evolved and manifest themselves in contemporary water resources allocation and use.

Despite potentially devastating effects on livelihoods, complex relationships between water, agriculture, and poverty, particularly regarding the overabstraction of groundwater resources, remain largely understudied (Balasubramanya and Stifel, 2020). The practical significance of the project includes insights for policy and planning within Tunisia and across the Middle East and North Africa (MENA) region, where agricultural and economic development projects are designed to enable and support livelihoods and reduce tensions associated with livelihood insecurity and inequalities. The capacity to model the impacts of governance approaches in the context of limited information and trust can provide the basis for participatory decision-making and modelling platforms. The research conducted as part of this thesis hopes to inspire a new outlook on more effective and realistic policy reforms in path-dependent water governance systems. In recent decades, water governance has increasingly sought to integrate institutional aspects to more traditional technocratic approaches to water governance reforms (Balasubramanya *et al.*, 2022). This

shift has revealed a multitude of practical limits of institutional reforms, particularly regarding limits to water extraction under increasing water stress. ‘Instead of looking for ideal reforms, a higher degree of modesty and realism about what can and cannot be achieved within given constraints and circumstances needs to be practised, and on the basis of such assessments, pragmatic and programmatic choices need to be made on where to allocate time and resources’ (Mollinga *et al.*, 2007: 711).

In summary, this doctoral thesis aims to unpack the social-ecological pathways that govern decision-making in the Tunisian water sector. With a focus on the role of groundwater for irrigation, the thesis will explore related socio-political dependencies, local outcomes of collective action, and ecological consequences for groundwater storage and recharge. This necessitates a combination of social and biophysical methods to study the underlying factors that guide decision-making and in consequence the natural resource system. The thesis begins by situating institutional systems of decision-making within their historic context, further analyses how formal and informal rules and relations shape human behaviour and cooperation, and ultimately links these to the state of the resource itself.

To achieve this aim, the following objectives were identified:

i. Trace the evolution of institutions governing water policy-making and resulting practices of water allocation and use - linked to an authoritarian past of repression and control,

ii. Discover the local pathways of decision-making that mediate contemporary relationships between trust, hope, and performance in water user groups, and

iii. Animate social-ecological dynamics in an evolutionary game driven by institutional rules, water availability, and social preferences.

Together, these three contributions advance our understanding of the multi-layered co-evolving dynamics of SES, providing critical insights on the path-dependent role of political fragility and aquifer depletion for processes of collective action.

2. Literature Review

This review of the literature will provide insights on theory and context relevant to the thesis. Key analytical lenses, that serve as a red thread through the three papers, are explored here. The literature review provides the theoretical framing for exploring conceptual questions through empirical analyses and modelling conducted in the research papers. What factors drive individual and collective decision-making on resource use in a fragile political context? What can explain process-driven dynamics and feedbacks in a path-dependent Social-Ecological System (SES)?

a. Theory of the Commons and Collective Action

Under the slogan ‘Freedom in a commons brings ruin to all’ (Hardin, 1968: p. 1244), the Tragedy of the Commons by Garrett Hardin assumes that whenever many individuals use a rivalrous non-excludable Common-Pool Resource (CPR) such as groundwater, they will be compelled to outconsume their competitors and ultimately degrade the resource. Olson (1965) argues that ‘rational, self-interested individuals will not act to achieve their common or group interests’ (2). Hardin’s notion of ‘helpless individuals caught in an inexorable process of destroying their own resources’ (Ostrom, 1990: 8) can lead to potentially deleterious policy recommendations, e.g. promoting Hobbes’ Leviathan as a ‘tragic necessity’ (Ophuls 1973, p. 228) or “iron governments” (Heilbroner, 1974), perhaps in the form of military governments, to solve resource problems with ‘whatever force may be required’ (Hardin, 1978: p. 314). Such ideologies can be particularly harmful in the case of political systems ridden by fragility, e.g. the struggling young democracy of Tunisia, where nostalgic calls to re-establish the authority of past authoritarian regimes are common. This thesis will trace the

evolution of institutions in the Tunisian water sector and analyse the relationship between water sector reforms and patterns of Authoritarian repression (paper 1). On the other hand, fragile contexts may exhibit greater sensitivity towards forms of centrally imposed punishment - with high risks of civil unrest. Attempts to use coercive, and what can be perceived as overly aggressive, force (such as recent plans of the Tunisian government to employ a new “water police”) should therefore be considered with caution. This thesis will shed light on water user perceptions on the role of the state in water resources management and explore the substitutability of social norms regarding cooperation and conflict (paper 2). It will unpack local dimensions of institutional trust in self-governing water user groups and analyse their relationships with outcomes of collective action.

Ostrom (1990, 2005) moves beyond deterministic notions of an ‘inevitable tragedy’ as put forth by Hardin and argues that self-governing institutional arrangements can successfully implement rules that take into account social benefits and costs. Instead of presuming individuals are helplessly trapped in the tragedy of commons, collective action theory seeks to identify the key variables and internal factors that ‘enhance or detract from the capabilities of individuals to solve [resource] problems’ (Ostrom, 1990; National Research Council, 2002). In *Governing the Commons* (1990), Ostrom further disproves a sterile dichotomy of private-public classifications and the notion that the state is necessarily antithetical to local knowledge or community management (Mansbridge, 2014). While institutional rules do not need to be imposed onto resource users by an outside force such as the state or the market (neither of which have historically been uniformly successful in sustaining a productive use of CPR systems), the state plays an important role in solving complex CPR problems in nested polycentric systems (Mansbridge, 2014). Ostrom (1990) argues that central government may lack the contextual knowledge to adequately define local rules

and monitoring, and that decentralised social structures may provide lower transaction costs, which are essential in defining and successfully enforcing rules and agreements (North, 1990). This conceptual understanding resembles that of *Seeing like a State* by Scott (1998), who tracks the evolution of “high modernist” regimes that see their uniformity-promoting planning schemes fail due to their inability to tend to local and ecological conditions. These insights align with Ostrom’s design principle #7 (1990) arguing that ‘rights of appropriators to design their own institutions are not challenged by external government authorities’ (101). Design principle #8 , however, reiterates the role of the state in polycentric governance systems. Here, the state and local resource user groups form a symbiotic relationship ‘organized in multiple layers of nested enterprises’ (101). Ostrom (1990) further recognises that local autonomy is heavily contingent on recognition by external/national jurisdiction, e.g. in Tunisia the legitimacy of local water user groups is facilitated by governmental decree. Central government is further encouraged to support local institutions in cases where threats of local appropriators prove insufficient in enforcing rules. Ideally, enforcement executed by external agents has a sense of local legitimacy and may not to the same degree be perceived as an act of aggression spawned by the central government. This balance between local autonomy and central authority is particularly challenging in the fragile context of a nascent Post-Authoritarian democracy like Tunisia.

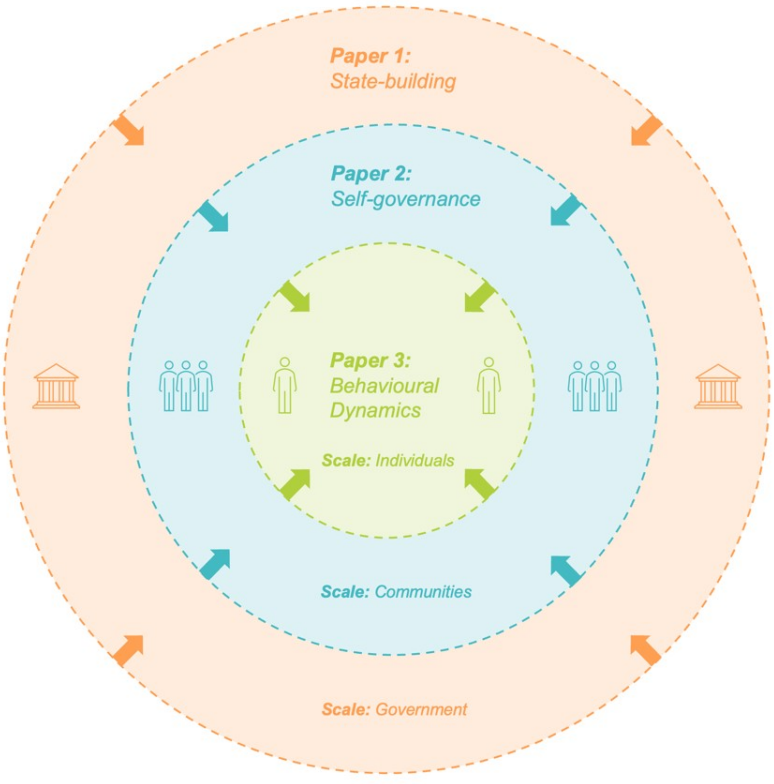
In polycentric settings of governance, tasks and competencies are shared between a complicated set of hierarchical relationships (McGinnis, 2000). A failure in coordination within and between hierarchical level may result in unnecessary fragmentation and duplication of efforts and authority (Huitema *et al.,* 2009). Imperial (2005), however, points out that duplication may also be leveraged as a potential for progressive cooperation and collaboration as trust

between parties can grow over time with decreasing transaction costs. This thesis will highlight the historical interdependence of local, regional, and national institutions by tracing centralisation and decentralisation efforts and their political motivations in Tunisia's past authoritarian regimes. Recent CPR theory increasingly advocates for polycentric approaches to CPR research in a push to recognize the existence of multiple interconnected centres of decision-making and effectively integrating these into robust methodological approaches (Cumming *et al.*, 2020; Meinzen-Dick, 2007). The research conducted as part of this thesis will highlight limits to collective action and policy-making in the fragile political context of Tunisia and highlight inherent challenges in establishing effective polycentric governance systems.

Institutions are 'constructs of the human mind' (North 1990, 107): They 'are the rules of the game in a society or, more formally, are the humanly devised constraints that shape human interaction' (North 1990, 3). Shared internalised norms of behaviour, both formal and informal, influence the subjective mental constructs that resources users use to interpret a specific decision situation and attain individual and collective goals (Siddiki *et al.*, 2019). By defining specified spatial, temporal, and procedural boundaries, institutions serve to reduce complexity and uncertainty in limiting the set of available choices to individuals. Rules are 'prescriptive statements that forbid, require, or permit some action or outcome. One of the three deontic operators - forbid, require, permit - must be contained in the statement for it to be considered a rule' (Ostrom 1990, 139). The institutionalisation of a set of given rules marks a clear differentiation to the status quo of a Hobbesian state of nature, where the only deontic operator is a default 'permit': In an institutionalised setting, all three deontic operators govern decision-making, behaviour, and in turn environmental outcomes. Institutional analysis therefore helps to describe the decision environment and explains how

and why new rules are adopted or rejected by resource users. Since the institutional-choice process is inextricably linked to processes of human judgement, it is also subject to several biases. Individuals generally weigh potential losses over potential gains and are therefore unlikely to adopt new behavioural norms if these are perceived or associated with a large initial payoff (Hardin, 1982; Kahneman and Tversky, 1979). This thesis will trace the evolution of rules and institutions in the water sector to shed light on the complex adaptive decision environment of water resource managers and users. It will assess "arenas of decision-making" at different levels of water governance (figure 1).

The theory of the Commons offers tools to researchers to conduct in-depth analyses of the forces that govern decision-making within a given CPR context. In developing explanations for observed behaviour, researchers can help shed light on the factors that affect the likelihood of resource users to organise and adopt collective water management practices. Collective action theory is therefore 'an effort to understand how rationality on the part of individuals leads to coherence at the level of society' (Bates, 1988: 399). This thesis analyses context-bounded rationality at the scale of the state, collective action groups, and individual



decision-making. Extensive collective action research has shown the capacity for self-governance, including in some settings

Figure 1 Nested decision-making/action arenas and corresponding thesis structure

marked by fragility (e.g. Turkey, Philippines). Little is known, however, about the durability of self-governance in the context of disturbances associated with fragility. This thesis explores the factors that increase the likelihood of collective action in rural water user groups in Tunisia, with a particular focus on the role of history and state-building, the evolution of trust, and their dynamics within social-ecological systems.

Unlike portrayed in traditional game theory, where resource users are coerced into acting independently, resource users in real-world CPR settings are not forced to do so. Therefore, in the same way that individuals will discount the benefits of future use if they feel other resource users are free riding, it is possible that individual will forgo immediate returns in order to leverage increased collective benefits if they are convinced others adhere to the same rules and strategy. “By requiring the participation of a minimal set of individuals, organizations can draw on this frequency dependent behaviour to obtain willing contributions on the part of many others“ (Ostrom 1990, 39). Levi (1988) argues that an individual will conform to a set of rules if they feel that a. the collective objective is being achieved and b. other members of the community comply too. This form of contingent behaviour can be key in achieving quasi-voluntary compliance of resource users. The likelihood of success of CPR institutions is largely enhanced if resource users feel that they “share a common future” (Ostrom, 1990; Baggio *et al.,* 2016). A focus on trust and hope has therefore been

chosen as a meaningful avenue of inquiry to better understand patterns of cooperation and conflict between water users. What factors enhance the capacity of water users to communicate effectively and develop foundations of trust? Since 'rules are not self-formulating, self-determining, or self-enforcing' (V. Ostrom, 1980: p. 312), it is by agency of the resource user that rules are applied and enforced following a consistent implementation standard. Decision-making is therefore inextricably linked to matters of trust, both between resource users (social or horizontal trust) as well as between resource users and higher-level institutions (institutional or vertical trust).

b. Why context matters: Path dependence and historical institutionalism

Theories of path dependence draw our attention to sequence, suggesting that early events or processes are more relevant than those that follow. For example, in the development and persistence of the keyboard layout QUERTY, positive feedback loops have dominated over rational choice (which would suggest replacing the old layout with a more effective layout). 'Institutions and policies may encourage individuals and organizations to invest in specialized skills, deepen relationships with other individuals and organizations, and develop particular political and social identities. These activities increase the attractiveness of existing institutional arrangements relative to hypothetical alternatives. As social actors make commitments based on existing institutions and policies, their cost of exit from established arrangements generally rises dramatically' (Pierson, 2000: p. 259). This can create so-called "lock-in situations" in which co-evolving technologies, rules, and norms mutually reinforce each other making them resistant to change (Pahl-Wostl, 2009). The term institutional "lock-in", however, shall not be confused with historical determinism but rather as a proxy for "context-bounded rationality" (Kay, 2005; Heinmiller, 2009).

The timing and sequence of events should not be viewed as a linear process. Historical processes are often complex, involving a plethora of interwoven causes (Hacker, 1998). Critical junctures help to understand the causal combinations that trigger institutional change at a specific point in time. This combination of conditions, both permissive and productive, ease barriers to change and produce new outcomes (Soifer, 2010). Critical junctures can be internal and external shocks to the system such as policy interventions, coup d'états, or severe droughts. Blatter and Haverland (2014) point out that critical junctures, while a necessary condition for change, are not sufficient to trigger a revision in the status quo. This thesis integrates understandings of path dependence into both qualitative and quantitative analyses of water resources management in Tunisia. The need to bridge methodological approaches stems from the desire to better understand complexity in the SES. This thesis therefore integrates historical analysis on the evolution of institutions into quantitative modelling frameworks that seek to animate inter-dependent social-ecological dynamics. Qualitative data and analyses of state-building and collective action in local water user groups are thereby used for specification and calibration of the behavioural model.

Heinmiller (2009) examines the role of historical-institutional context in collective action in basin-level water management. In the three river basins he studies, the Murray-Darling Basin of Australia, the Colorado Basin of the United States, and the Saskatchewan-Nelson Basin of Canada, he shows how basin institutions in the early stages of development were designed with the sole or main aim of generating water supply. Only as demands grew and supplies decreased, did institutions seek to also address issues regarding the conservation of water stocks. 'The historical fact that apportionment institutions preceded conservation efforts in many semi-arid river basins is important because it means that the actors undertaking conservation efforts did not start with an institutional blank

slate, as is often assumed in analyses of collective action' (Heinmiller, 2009: 133). In summary, the capacity for collective action to conserve water resources was constrained due to the path dependence and preservation of early water apportionment institutions, which enjoyed public support from water users due to early achievements in economic development. While Heinmiller argues that the chosen case studies have been sampled using a "most different" comparative approach, I would argue that the chosen set of case studies is not representative of water management institutions in fragile political settings. Even though the proposed sequential evolution of institutions remains relevant for a variety of contexts, it can be assumed that institutions in fragile political systems are exposed to a plethora of interwoven causes particularly with regards to state-building as well as a heightened importance of the role of economic development for livelihoods. Furthermore, rather than following Heinmiller's (2009) proposal to add path dependence as a separate factor driving collective action (in addition to factors of trust, social capital, etc.), this thesis argues that path dependence is not an isolated independent driver of collective action but rather an underlying phenomenon that interacts and co-evolves with e.g. trust. The thesis will trace the path-dependent evolution of institutions as well as trust relationships between and within institutions.

Research on transaction costs has led to the definition of typologies distinguishing between static transaction costs of operating/maintaining institutions and institutional/lock-in costs of changing them (Garrick *et al.*, 2013a; Marshall, 2013). Rather than measuring the elasticity of transaction and lock-in costs, this thesis seeks to qualitatively unpack the fluid interaction between transaction costs, bounded rationality, and associated norms by drawing on longitudinal studies of behavioural and decision-making patterns. Garrick *et al.* (2013b) reiterate the importance of norms, trust, and social capital in

determining the impact of transaction costs on the likelihood of collective action. Studying path dependence in SES is not only a matter of “understanding context” but also “explaining it”, i.e. causal inference between events and processes. In defining transaction and transformation costs, rules, and norms throughout history, institutions link the past to the present and future of individual and collective decision-making. History can be understood as an ‘incremental story of institutional evolution’, where performances of CPR user groups need to be examined as an element of a sequential process (North, 1990: p.118). Theories of path dependence help to explain why establishing the very same formal rules in different contexts can still lead to divergent patterns of outcomes. Historical analyses provide tools to explore the adaptive capacity and efficiency of institutions.

According to North (1990), it takes a society a number of iterative trials to reach an ‘optimal’ set of rules: ‘The society that permits the maximum generation of trials will be most likely to solve problems through time’ (North, 1990: p. 81). Inspired by Darwin’s evolutionary theory, the theory of social survival of institutions implies that over time maladapted segments of institutions are weeded out, while efficient parts survive, allowing for a gradual evolution towards more efficient and adaptive institutional arrangements. This warrants the question of why, on the flip side, institutions with persistently poor performance would survive and indeed strive? In fragile and uncertain settings, such as Tunisia, the capacity of institutions to explore diverse avenues of decision-making in an organisational trial-and-error approach may be limited. The unpredictable variability of transaction costs within fragile institutions might explain why individuals are reluctant to push for institutional change. Knight (1992) and Bates (1989) argue that institutional change will only occur when specific actors

perceive direct gains from a shift in the status quo. In fragile settings, risk and uncertainty may outweigh these perceived gains.

Analysing institutional rules through a historical lens helps build a coherent, consistent, and logical account of patterns of institutional change and the perceived costs of changing status-quo rules. According to the *Drama of the Commons* (Stern, 2002), 'Researchers have only limited understanding of why self-organized resource institutions emerge where and when they do. We also have limited understanding of the processes that govern adaptation to changes in the institutions' social and biophysical environments' (472). A historically grounded understanding of inter- and intra-group politics and resulting patterns of power and resistance may further address concerns over the absence of systemic examinations of state-locality relations as well as community-level micro-politics in CPR theory (Agrawal, 2003). Recently, the literature on governance of the commons has undergone efforts to incorporating long entrenched power asymmetries into understandings of institutional arrangements (Kashwan, 2016; 2021). Introducing principles of historical institutionalism into the study of the commons pushes the frontier of CPR theory and enhances the crucial focus on mechanisms and causality within nested governance systems (Cumming *et al.,* 2020). Calls for deeper understandings of causal configurations in complex SES will be addressed by the transdisciplinary multi-method approach adopted in this research thesis.

c. Fragility

When defining fragility, researchers often seek to quantify fragility in terms of magnitude and frequency of shocks or disturbances to the system (Baliamoune-Lutz and McGillivray, 2008; Ferreira et al., 2017). Schoon and Cox (2012) establish a typology of disturbances to better understand the interacting effects

of various disturbances on SES. Rather than measuring or categorising shocks, such as social unrest, droughts, etc., this thesis seeks to qualitatively grasp system characteristics and functioning of the SES resulting from these discontinuous interacting disturbances. In line with theories of path dependence, disturbances (whether discrete or prolonged events) will differ in impact irrespective of the quantitative measure of the event. It follows that greater attention should be paid not to quantifying shocks but rather to qualitatively assessing their impact on the system at large. The Organisation for Economic Co-operation and Development (OECD) defines fragility as 'the combination of exposure to risk and insufficient coping capacity of the state, systems and/or communities to manage, absorb or mitigate those risks' (2020). This definition draws focus onto the systems experiencing such "risks" and their ability cope with them.

Rational-choice theory relies on the assumption of stable equilibria. Individuals hold routines in which choices appear repetitive and regular. By institutionalising structures of behaviour, institutions allow for most actions in a day not to require much reflection. Institutions thereby reduce the uncertainty of personal and repetitive decision-making (North, 1990). However, if this equilibrium is disturbed by radical disturbances, uncertainty about actions and outcomes increases. The rules previously applied to the structure of human-human and human-environment interactions can no longer be applied and the information about new circumstances is insufficient to update previously reliable cognitive models of decision-making. Ostrom (1990) underlines the importance of stable populations with low discount rates – environments, where investments made today have a similar value today as in the future. Decision-making in fragile contexts, however, where values and rules are not given or consistent, do not allow for long-term planning nor rational-choice. This thesis explores the ability of

water users to long-term plan under varying social-ecological conditions. It will define social phenomena of trust, hope, leadership, and their relationship with outcomes of collective action under resource scarcity and institutional fragility.

In the Tunisian context, where institutions are unable to monitor and enforce regulatory limits to water extraction, there is a need to identify alternative set of rules driving policy- and decision-making. North (1990) and Ostrom (1990) advocate for soft incremental adjustments to the complex of rules and their enforcement – again, in the scenario of fragile context, institutions may not possess the luxury of time and a stable equilibrium to guarantee slow sequential successes. The events of the Arab Spring in early 2011 as well as a more recent history of social unrest in democratic (or "democratising") Tunisia raise the question of feasibility of water reforms, particularly with regards to potentially unpopular policy action against illicit wells. In addressing challenges of water governance in the fragile political setting of post-Authoritarian and post-Arab Spring Tunisia, attention must be paid to the evolution of social dependencies and expectations within the complex adaptive SES. While discontinuous shocks (such as the ousting of Authoritarian leader Ben Ali in 2011) often trigger a radical change in formal rules, informal constraints (that had gradually developed as extensions of former formal rules) remain largely unchanged. As a consequence, new formal rules and informal constraints are inconsistent leading to ineffectiveness or even tension between rules and resource users (North, 1990). The thesis therefore addresses a knowledge gap in explaining divergent mental models and institutional rules in contemporary Tunisia and seeks to develop a more sensitive means of engagement with conflict between actors.

What are the factors driving institutional design in an environment that has witnessed chronic unrest, where repetition and heuristics is rendered difficult?

Humans are adaptive creatures (Jones, 2001) who develop heuristic strategies to cope with problems (Ostrom, 2004). What influences these strategies (and the social norms that guide them) in politically fragile collective action settings? Standard CA theory seems unfit to explain user behaviour in a fragile political setting that has seen the systemic erosion of trust. This thesis' contribution comes from understanding how fragility affects the evolution of collective action by drawing attention to specific variables (state-building, hope) that have not been addressed, and by specifically working across levels of action/decision-making often treated separately. How can individuals overcome social dilemmas in the absence of institutional trust?

d. Social-Ecological Systems (SES) theory and modelling

SESs are complex adaptive and deeply intertwined systems that are composed of interactions between humans and non-human elements of ecosystems (Berkes and Folke, 1998, Folke *et al.*, 2016). These interactions develop patterns and dynamics that generate feedbacks on the very processes that created them (Levin *et al.*, 2013). Continuously evolving, these system dynamics give rise to phenomena such as social-ecological dilemmas or regime shifts (Cumming, 2018). Researching these phenomena involves the delicate task of unpacking dynamic interactions between actors and recognising emergent system-level outcomes of these interactions (Folke *et al.*, 2003; Olsson *et al.*, 2008; Österblom and Folke, 2013). Further research is necessary to identify and better explain the causal processes underlying interactions between social and ecological entities, resulting patterns, and phenomena (Fischer *et al.*, 2015; Schlüter *et al.*, 2019). The co-evolution of processes dictates the co-constitution of social and ecological process beyond the mere coupling of systems, e.g. "Social-Ecological" rather than "Social and Ecological".

Changes to the SES can be abrupt/'non-marginal' or gradual/marginal (Filatova *et al.*, 2016). Non-marginal changes, or regime shifts, are major structural changes that can be triggered by even small perturbations in explanatory variables around a critical tipping point (Andersen *et al.*, 2009). Take-some dilemmas (e.g. tragedy of the commons) are phenomena where benefits from an ecological outcome are individual (often in the short term) while negative (often long-term) outcomes are collective (Cumming, 2018). These can turn into so-called lose-lose traps over time (e.g. poverty trap and diminishing returns on groundwater extractions, lock-in trap of specialisation), where outcomes are negative for both individuals and the wider community. This thesis animates water user behaviour in the framework of a slow onset lose-lose trap and identifies possible delay mechanisms for system collapse.

SES are context-specific (Biggs *et al.*, 2022). Theories of historical institutionalism and path dependence are therefore well suited for integration with SES as they provide analytical tools to unpack interdependent interactions and their emergence. System-wide patterns such as emergent meso- or macro-level collective action cannot be studied using merely individual system components (Reyers *et al.*, 2018). Tracing interactions between these components including feedback processes can help explain how systems adapt to changing contexts. Research methods fit to address context-sensitive, non-linear recursive interactions remain limited however: 'Despite the growing scientific understanding that nature and humans in the Anthropocene are intertwined, the tools and technologies we have to measure human influence and effects on natural environments fall short when having to deal with uncertainty and the emergent nature of CAS [Complex Adaptive Systems]' (Preiser *et al.*, 2022: 27). Responding to calls to update traditional research frameworks (Wells, 2013; Schoon and Van der Leeuw, 2015), this thesis puts forth a novel methodological

approach to integrate transdisciplinary tools to better understand the complexity inherent to SES, particularly with regards to fragile political contexts.

How can a better understanding of SES processes and their emerging dilemmas interact with practical problem-solving and policy-making? How can researchers distil the complexity inherent to SES into “simple” policy advice? This thesis develops a list of policy recommendations for Tunisian water resources governance based on the empirical and modelling frameworks employed in this thesis.

e. Groundwater governance and modelling

Groundwater is notoriously difficult to govern and model. As the infamous invisible resource (according to *The United Nations World Water Development Report 2022 - Groundwater: Making the Invisible Visible*), collective action problems regarding groundwater management frequently arise due to the non-excludable but rivalrous nature of the resource. “Out of sight, out of mind”, groundwater therefore often serves as a posterchild for Hardin’s tragedy of the commons. Groundwater users are frequently compelled to enter a race to the bottom of the well: The more water is pumped, the higher associated costs due to falling water levels. Therefore, individuals are drawn to harvest more water in the immediate presence rather than wait for costs to rise or indeed for the resource to be depleted by others. Groundwater resources play a particularly crucial role in the agricultural sector supplying irrigation water to farmers - estimated at 43% of global total irrigation water use (Siebert *et al.*, 2010). In semi-arid and arid regions, groundwater is often the predominant, if not the only, source of water for irrigation. Groundwater demands for irrigation are increasing worldwide leading to widespread overextraction beyond natural recharge rates (Siebert *et al.*, 2010; Aeschbach-Hertig and Gleeson, 2012; Dalin *et al.*, 2017; Schipanski *et al.*, 2023).

Resulting trends of aquifer depletion pose deleterious threats to food production systems and associated local livelihoods.

Challenges in groundwater resources management frequently arise with regards to polycentric governance coordination. Since multiple groundwater users and user communities share the same rivalrous resource pool, governments frequently rely on centralised regulatory authorities to set withdrawal limits, monitor, and enforce these limits (Lankford and Hepworth, 2010). However, since groundwater pumping remains a highly localised endeavour serving local interests of water users, local institutions remain a key player in maintaining sustainable withdrawals, at times together with central regulatory agencies, at times super-seeding them (Pahl-Wostl and Knieper, 2014; García *et al.*, 2019; Pahl-Wostl, 2015). Further, in areas where political systems are fragile and institutional trust is lacking, such as Tunisia, local communities may entirely decouple from centralised institutions and establish their own norms and rules independently (or on top) of the ones developed by a central government (van Steenbergen *et al.*, 2015; García *et al.*, 2019).

“We cannot manage what we cannot measure” is a common slogan among groundwater managers and policy-makers. Due to the sheer scope of on-the-ground hydrogeological fieldwork necessary (and associated logistical and financial challenges) to address gaps in groundwater data, groundwater modellers worldwide are increasingly relying on remote-sensed data to model groundwater dynamics - most frequently using gravity measurements from the GRACE satellites (Rodell *et al.*, 2009; Longuevergne *et al.*, 2010; Famiglietti *et al.*, 2011; Richey *et al.*, 2015, Wu *et al.*, 2020; Scanlon *et al.*, 2023). While global synthesis using large remote-sensed data sets serves an important purpose, modelled data need to be ground-truthed with empirical field data to address

valid concerns regarding model uncertainty (Long *et al.*, 2016). Considering the importance of aquifer management on livelihoods and food security, there lies great urgency in addressing these knowledge gaps. At the same time, the lack of groundwater data cannot be an excuse for management and governance inaction (Schipanski *et al.*, 2023). This is particularly relevant for vulnerable small holder farmers, accounting for 84% of global farms and producing around 35% of the world's crops (Lowder *et al.*, 2021). In general, the complex relationship between (ground)water, agriculture, and poverty remains understudied and poorly understood (Balasubramanya and Stifel, 2020).

Recently, increasing attention to context has inspired new research on the importance of fit of groundwater governance systems - with new frameworks assessing their effectiveness in meeting goals, resilience, and adaptability (Marston *et al.*, 2022). However, ignoring the gradual evolution of historically constructed formal and informal constraints, particularly in fragile political systems like Tunisia, risks that noble efforts of policy reforms are nullified. Due to the importance and reliance on recharge rates, groundwater resources reveal path-dependent overexploitation effects - which are frequently difficult or impossible to reverse. This thesis has been motivated by real-world water governance challenges. It has been inspired by farmers and water users in rural Tunisia that are increasingly unable to rely on groundwater resources to secure their livelihoods. Despite adequate data availability on withdrawals patterns and hydrogeological characteristics and dynamics in the given case study area, water resources managers are unable to put a halt to sinking groundwater levels. This reiterates the fact that groundwater management challenges are often governance rather than "lack-of-data" challenges. This thesis will address critical knowledge gaps in understanding decision-making processes in irrigation

management in the context of fragile and (semi-)arid regions as well as those experiencing accelerated aquifer depletion.

f. Research gaps and contributions

This thesis will offer insights for theory, evidence, and policy by advancing collective action theory and common pool resource governance in the context of fragile political systems and complex social-ecological dynamics. Twenty years after the Drama of the Commons, this thesis advances addresses four key variables identified as priorities for complex SES (Stern *et al.*, 2002: 455):

- Institutional forms at other scales or in other regions (e.g., state support for local rules, nesting of institutions, international regimes)
- Adherence of users to shared norms
- Durability of resource management institutions
- Democratic control

The core contribution to theory involves a multi-layered and longitudinal assessment that examines how behaviour and norms evolve in the context of changes in institutions at other scales. Doing so has required careful attention to causal analysis in the context of complexity and the integration of multiple methods (Stern *et al.,* 2002; Poteete *et al.*, 2010). While many studies are primarily qualitative, primarily quantitative, or mixed methods, this study contributes through a balanced approach with studies in each category, including qualitative historical analysis (paper 1), across-case Qualitative Comparative Analysis (QCA) drawing on both qualitative and quantitative datasets (paper 2), and computational Agent-Based Modelling (ABM) integrating social and hydrogeological datasets with model specifications grounded in qualitative interviews (paper 3).

The project also addresses empirical gaps by linking data from hydrogeology and social sciences to understand how governance affects environmental and development outcomes. While the coupling of social and ecological systems has represented the major advance in the field of large-scale collective action in the past 15 years, the capacity to analyse complex social-ecological dynamics is still limited in the context of fragile political systems and sparse data. The academic significance stems from this project's insights for the theory and evidence of collective action, particularly the role of trust, hope, and leadership in the context of state fragility. While patterns of conflict and cooperation are commonly studied in the context of transboundary water governance, there is an academic as well as practical need to further explore intranational power relations (Moore, 2018) and the pathways through which tensions arise and subside in the context of local and regional fragility.

Core academic contributions include the application of theories of state legitimisation, repression, and co-optation to the water-agriculture nexus (paper 1), evidence of collective action dynamics in settings of low hope under varying social dimensions of trust (paper 2), and the adaptation of evolutionary games and ABM to complex contexts of fragility and aquifer depletion (paper 3).

3. Methods

Epistemologically, the research design of this thesis is grounded in the theory and literature of the Commons, Collective Action (CA), and Social-Ecological Systems (SES). A mixed-methods approach sees the integration of qualitative and quantitative data and tools. In the Drama of the Commons, Stern *et al.* (2002) argue that 'the theory of institutions for common-pool resource management has been remarkably ahistorical, considering the important contributions of case study research in the field' (477). According to Agrawal (2002), researchers that study CPR institutions have largely prioritised characteristics and function of these institutions over understanding the contextual forces that shape these functions in their image. The need to acknowledge the important relationship between context and methodological approaches is particularly relevant in the context of fragile systems. Studying SES in fragile political systems requires transdisciplinary methodological approaches to capture the complexity of these systems (Preiser *et al.*, 2022).

This thesis bridges the disciplines of sociology, hydrogeology, history, agriculture, political science, computational modelling, and environmental management. Transdisciplinarity is not achieved through the integration of qualitative and quantitative data alone, nor that of qualitative and quantitative methods, but furthermore through the resulting multitudes of perspectives and frames on given social-ecological dilemmas. The thesis builds on the philosophical understanding that water resources management is conducted in complex adaptive Social-Ecological Systems (SES). The ontology of complex adaptive SES allows for a more appropriate picture of the lived realities water users face on a day-to-day basis. A versatile set of tools and methods, whether historical or hydrogeological, is purposefully chosen to build on each other's strengths and

close respective blind spots. To put it bluntly, academic distinctions between (and sometimes within) disciplines are irrelevant for farmers and water users that face practical resource and livelihood challenges. This thesis is therefore an attempt to explore more appropriate transdisciplinary methodologies to unpack these challenges.

The thesis follows the “three paper-route” using a step-wise methodology, where each paper is informed by evidence from the previous paper (table 2). First, paper 1 adopts a political sociology lens to water resources management tracing how water reforms in Tunisia’s authoritarian regimes came to shape mechanisms of domination, repression, and co-optation anchored in the everyday politics of water allocation and use. Second, insights on the erosion of institutional trust inform analyses of paper 2, zooming into local spaces of decision-making and evaluating the influence (and limits) of social norms, including dynamics of trust and hope, on outcomes of collective action. Third and finally, paper 3 animates these dynamics through an evolutionary agent-based model allowing for strategic simulations of collective action scenarios. Individual papers will provide detailed methods (data collection, analysis, etc.). The role of this methods chapters is to provide an overview over the range of methods applied as part of this thesis and highlight complementarities of nested research methods.

Table 2 Research matrix

	Question	Theoretical Framework	Data	Methods	Evidence
Paper 1	How have water institutions evolved in Authoritarian Tunisia (1950-2011)?	Historical institutionalism	• Key informant interviews • Archival material (National Library of Tunisia) • Legal codes and byelaws • Literature and global datasets	Process tracing	Institutional chronologies and timelines
Paper 2	What is the role of trust, hope and leadership on outcomes of collective action in water user groups?	Collective action	• Legal and institutional timelines • Interviews • Administrative records • Groundwater data	Qualitative Comparative Analysis (QCA)	Empiric pathways between trust, hope, leadership and performance
Paper 3	What social-ecological conditions influence the convergence of asynchronous individual decision-making?	Collective action, Social-Ecological Systems (SES)	• Interviews • Administrative records • Empiric evidence of observed individual and collective behaviour • Groundwater data	Agent-based modelling (ABM)	Modelled relationships between individual preferences and behaviour, institutional norms, and the natural system

a. Site selection

Tunisia presents a particularly interesting case for studies of the commons due to dynamic interactions between resource management and its state of political fragility. 12 years after the Jasmine Revolution, the young democracy is grappling with old social and economic grievances as water resources, key for agricultural production and rural development, are on a steady decline. The case of Tunisian water governance is compelling because inherent physical water scarcity is met with inadequate regulatory instruments and weak institutional capacities, which are mediated by political fragility. Chapter 4 will further outline the biophysical, legal, and social-political factors that make Tunisia a suitable case study for the chosen research questions.

For its analyses of local spaces of decision-making, this thesis chooses to zoom on the Tunisian governorate of Kairouan. The governorate, Kairouan, covers an area of 6 712 km² and has a population of 599,560 inhabitants as of 2021, making it

the eighth-most populous out of the 24 Tunisian governorates (Statistiques Tunisie, WWW). The choice of geographic region stems on the one hand from the critical importance of (ground)water for irrigation and livelihoods in the area and on the other hand from its relationship with social unrest (Kairouan's neighbouring governorate of Sidi Bouzid was the very birthplace of the Arab Spring). Kairouan has witnessed severe groundwater exploitation in the past decades (Snoussi *et al.*, 2022). Due to its hydrogeological diversity and a range of groundwater use and management approaches, depletion outcomes vary across aquifers in Kairouan - with some water user groups sitting on empty wells, while others continue to harvest artesian flows. Failures in collective action have led to low fee recovery, empty wells, and water user groups running bankrupt. The resulting threats to farming livelihoods have inspired long-standing efforts to effectively model hydrogeological dynamics in the region. The variability of social-ecological dilemmas in combination with the availability of existing groundwater data and models, and established research connections led to the choice of Kairouan as a study site. This thesis will help uncover the path-dependent processes that shape water governance challenges in the governorate of Kairouan (info-box 1).

Info-box 1: Evolution of water resources management in Kairouan governorate, Tunisia

From a historical perspective, public intervention in irrigated agriculture has a century-long tradition in the semi-arid governorate that receives around 300 mm of rain a year (MARHP, 2017). Following ancient practices of spate irrigation (Penet, 1908), irrigated areas were extensively developed in the 1920s (Massuel and Riaux, 2017). At the time, water for irrigation on colonial farms was sourced from the Merguellil river. As demand increased and conflict between farmers rose, groundwater resources were discovered as an apt tool to increase supply and meet growing irrigation demands (Belaïd and Riaux, 2013). After independence, colonial farms became state-owned and transformed into cooperatives in the 1960s (Zghal, 1967). In the 1970s, the administration financed wide-spread irrigation intensification with new public irrigation schemes and communal boreholes. When small boreholes started to fail to meet ever-growing demands by the 1980s, farmers started to drill private boreholes using public subsidies (Jouili *et al.*, 2013). Soon, intensive

irrigation of croplands dominated over the originally planned intention to promote a mix of rainfed and irrigated agriculture for subsistence. Despite recent efforts to curb aquifer overexploitation (and wide-spread illicit groundwater withdrawals), associated benefits of groundwater use for irrigation seem to be path-dependent and difficult if not impossible to reverse (Massuel and Riaux, 2017).

b. Data collection

Data (table 3) were collected in two field seasons (see annex 1 and 2 for impressions from the two field seasons). The first set of fieldwork involved archival data collection (National Archives of Tunisia) and 17 key informant interviews conducted in the capital Tunis in November and December 2021. Semi-structured interviews with 15 rural water user groups were conducted during the second field season in the governorate of Kairouan in May 2022. Both sets of interviews employed purposive sampling, i.e. snowballing, in order to identify individuals who can share their own perspective but also account for the broader experiences within the Tunisian water sector.

Quantitative data were collected from official government records, global economic and climatological datasets, and local administrative records. Collaborations with the National Agronomic Institute of Tunisia (INAT) were facilitated by established professional connections and granted access to existing agricultural and hydro(geo)logical datasets and models. Further information on academic collaborations, methods training, funding, and conferences can be found in appendix 3.

Table 3 Overview of data collected

Data Type	Description	Source	Time Range
Social-Qualitative	Oral histories and **key informant interviews** on evolution of rules and	Key informant interviews in Tunis	Interviews conducted in

	institutions in Tunisia	(n = 17)	2021
Social-Qualitative	**Interviews on water user behaviour** and perceptions (contextual questions on cooperation and conflict)	Semi-structured interviews in Kairouan (n = 15)	Interviews conducted in 2022
Social-Qualitative	**Archival material**, water resources planning documents, testimonies, legal codes and byelaws, Tunisian academic and non-academic publications	Archives of Tunisia; official government records	1950-2021
Biophysical-Quantitative	3D **hydrogeological model** of Sisseb, AinJloula, AinBoumorra, and Chougafia aquifers in Kairouan	MODFLOW model (INAT collaboration)	1971-2016
Social-Quantitative	Agricultural data from **hydrological model** (cultivation costs, crop price, extraction, and maintenance costs)	Water Evaluation And Planning (WEAP) model (INAT collaboration)	2003-2017
Social-Quantitative	**Inventory of illicit wells** in Kairouan	INAT collaboration	Field campaign conducted in 2016
Social-Quantitative	**Administrative records** on GDA management	CRDA collaboration	2021
Biophysical-Quantitative	**Climatological data**	Global Precipitation Climatology Centre (Schneider *et al.,* 2011)	1950-2017
Biophysical-Quantitative	**Data on surface and groundwater** availability and management	Official government records (MARHP, 2017; WWW)	1950-2021
Social-Quantitative	**Economic data**	World Bank national accounts data and OECD national accounts data (WWWb)	1965-2021

c. Data analysis

SES research is increasingly embracing methodological pluralism in order to understand systemic interactions and “social-ecological intertwinedness” (Preiser *et al.*, 2021). Methods employed as part of this thesis are chosen with the aim to fit the given research objectives - objectives that have been identified based on empirical on-the-ground knowledge on key challenges (figure 2). The methodological framework of the thesis further addresses issues of scale inherent to SES research by integrating a variety of spatial, temporal, thematic and organisational dimensions using transdisciplinary tools (Wang *et* al., 2023). The chosen methods address causal complexity in adaptive social-ecological settings, where challenges of availability and accessibility of data are common (Poteete *et al.,* 2010). Acknowledging system complexity, this thesis seeks to engage methods that can uncover the emergence of causal relationships and their unexpected outcomes within the SES.

The multi-method step-wise approach of this thesis begins with a deep-dive into the context of the chosen SES (table 2). Grounded in the framework of historical institutionalism, within-case analyses of national- level institutions and norms in paper 1 employ process tracing to explore historic forces guiding decision-making processes in the water sector. Building on evidence of the evolution of rules and institutions, across-case analyses of local institutions in paper 2 employ

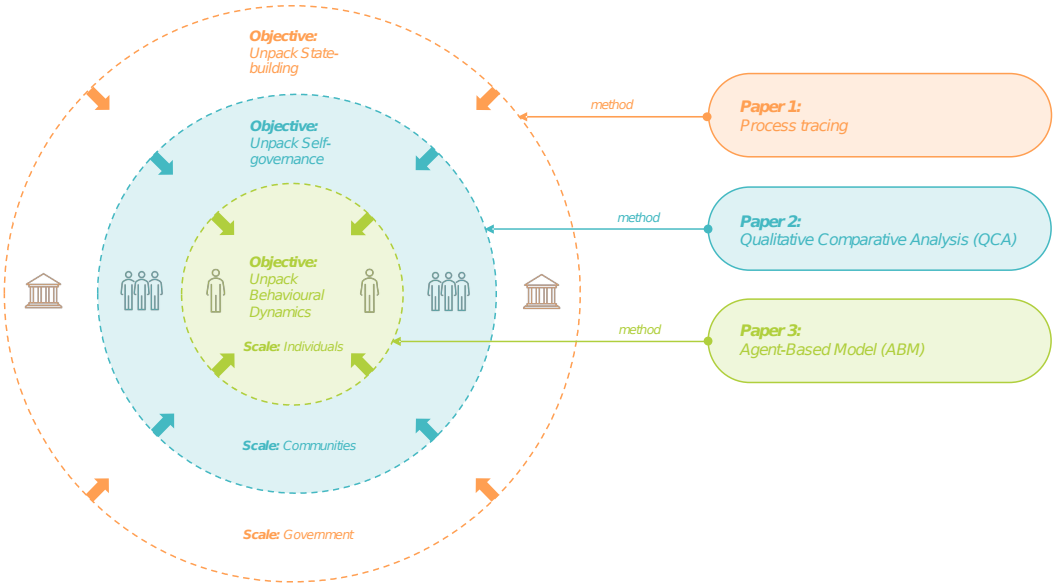


Figure 2 Methodological framework

Qualitative Comparative Analysis (QCA) to shed light on the influence of social norms, and related dynamics of trust and hope, on outcomes of collective action. Finally, building on QCA evidence of qualitative pathways of collective action, social and institutional norms are modelled in an evolutionary game in paper 3 that ties water user behaviour to ecological conditions, i.e. aquifer dynamics. The model thereby animates complex human-environment interactions and emergent outcomes (Schlüter *et al.*, 2022) without ignoring the historic legacy of social norms and resulting learned behaviours. The model allows us to analyse the effects of specific governance interventions as well as uncontrollable system drivers such as exogenous groundwater withdrawal dynamics (Wang *et al.*, 2023).

SES research holds a process-relational worldview that underlines the key role of co-evolving relationships between properties and their functions (Hertz *et al.*, 2020). Since processes will reveal patterns of change over time, a central question to SES research is that of causality. Where effects are dynamic and non-linear, complex causality needs to be explored beyond descriptive analyses of individual property functions. The complementary set methods employed here seek to address causal complexity in the SES of post-Authoritarian Tunisia by building on each other's strengths and addressing respective limitations. Qualitative research conducted in papers 1 and 2 build on empirical data, unpacking both historical and contemporary pathways of policy- and decision-making. Process tracing in paper 1 serves the construction of chronologies and timelines, where assumptions of causality can merely arise through careful descriptive inference using available empirical evidence. Similarly, QCA in paper 2 establishes empirical pathways of causality using set theoretic methods. These pathways do not serve as proof of causality but rather help discern recurring patterns of variation that help to explain different clusters of cases, i.e. which factors are most commonly associated with a given outcome. QCA results are then triangulated with qualitative and quantitative case study data, e.g. from interviews with water users, which help in identifying diverse causal mechanisms across case studies. Balancing empirical explorations with modelled relationships can further approximate our understanding of causal processes. In the Agent-Based Model (ABM) of paper 3, causal chains and their complex drivers can be tested in a "digital-twin" of the SES. The potential short-comings of overly complex ABMs (Schlüter *et al.*, 2022) are vetted through in-depth empirical evidence produced in paper 1 and 2, e.g. qualitative interviews with water users provide the empirical basis for social psychology theories of the modelling framework.

d. Challenges and limitations

As for many, the Covid-19 pandemic created practical barriers for the success of this research project. Fieldwork originally planned for summer 2021 had to be postponed, and the effects of starting my DPhil in isolation of the lockdowns of 2020 meant that iterative improvements through collaborative support and inspiration beyond online supervisory meetings were rendered difficult.

Given general logistical challenges of conducting fieldwork in rural Tunisia, access to local communities was limited to established professional networks. While logistical and financial means were limited, our small research team (local translator and sectorial expert, driver, and I) benefitted from an intimate understanding of the fieldwork setting, which facilitated an open, trustworthy, and respectful environment to conduct interviews with rural farmers. .

e. Ethics

Research in water resources management and SES is frequently 'solutions-oriented' leaning itself to blueprint methodological approaches that neglect complex adaptive qualities of the systems studied (Meinzen-Dick, 2007; Preiser *et al.*, 2022). This thesis puts emphasis on a more context-specific understanding of the complex SES of Tunisian water governance. Further, the thesis employs a transdisciplinary approach that links theoretical, empirical, and practical knowledge to limit potentially harmful simplifications of water governance challenges. By bridging qualitative and quantitative approaches, building on respective strengths and addressing their individual limitations, the thesis hopes to more accurately illuminate practical real-world problems faced by water users. Open debates on these real-world problems and participatory multi-stakeholder knowledge co-production, as advocated for by Hammond (2005), can prove a

challenge in fragile political contexts such as Tunisia. This challenge demands sensitive calibration of engagement with local stakeholders alongside political limits of post-Authoritarian rules. Social and political processes in Tunisia are often nebulous and anchored in rigid hierarchical and hyper-bureaucratic norms. Procedural ethics, for example, had to therefore be safeguarded beyond ethics protocols of UK-based institutions [University of Oxford ethics approval number: SOGE 1A2020-183]. Administrative permission from the regional representation of the Agricultural Ministry was required in order to conduct interviews with rural farmers (on potentially aggravating themes of trust and hope), which could only be facilitated by sensitive mediation from established local connections.

Co-production of knowledge in fragile political systems requires a mutual historical understanding of how the research problem has evolved over time, its practical consequences, as well as desired outcomes (de Vos *et al.*, 2022). This thesis emphasises the need for a broad societal framing of water resources challenges, e.g. paper 2 highlights divergent mental models of actors within the SES in particular regarding appropriate policy solutions for illicit groundwater withdrawals. Building trust with interviewees is crucial in ensuring that data collection is both effective and ethical, and can potentially lay bare underlying expectations and tensions between actors. In terms of personal ethics, it is the responsibility of the researcher to ensure respect for and the dignity of the interviewees. This includes transparency around research goals, integrity, and academic professionalism (Cockburn and Cundill, 2018). As part of this research, it was particularly important to explain and ensure anonymity of research participants given the politically sensitive nature of conversations.

Challenges around communicating research results, e.g. on the erosion of institutional trust and legacies of a repressive administrative apparatus, have

spurred reflections regarding my own role as a “foreign-body” researcher and the limits of engagement in a fragile post-Authoritarian context given local sensitivities and social dependencies. Shared definitions of common goals and challenges (and their evolution) among stakeholders can help guide new forms of collaborations with aligned, or at least partly aligned, mental models (Woermann, 2016). De Vos *et al.* (2022) argue that ‘the leaders of a co-production process face the task of assembling an appropriately broad or inclusive set of relevant actors, while keeping the process manageable within practical and strategic limits’ (58). This thesis holds practical policy ambitions and develops a modest list of policy recommendations based on insights from the three papers. Key stakeholders that can support their knowledge transfer include local academics, development agencies, and policy officers in the water planning department. The three research papers of this thesis entail different approaches to actively engaging with these stakeholders. Generally speaking, the ABM of paper 3 is the most relevant research paper for stakeholders due a stronger technical focus and practical outcomes for local water management institutions.

Figure 3 Farhad, a water user and one of my interviewees in the Tunisian governorate of Kairouan

‘*Water user:* I have to fight.
Interviewer: Against whom?
Water user: The state, against those who took my water! They took our water without giving us anything in return! No development, no help for the farmers, nothing at all. Nothing. I am the victim! I shudder to think about it, I can’t help it. I shudder because I remember my former oasis and how my children, who were in love with it, left it. Nowadays, our rights have become dreams! We beg for our rights.’

(Documentary Om Layoun, 2021)

‘Civitas Africae in mediis harenis petentibus Syrtis Leptimque Magnam vocatur Tacape, felici super omne miraculum riguo solo’
[There is in Africa, in the middle of the desert, on the route of the Syrtes and Leptis Magna, a city named Tacape (Gabes), whose territory, well irrigated, is of a miraculous fertility]
In *Natural History* by Roman author, Pliny the Elder (23 - 79 AD) (XVIII, 188)

Water resources management has a long tradition in Tunisia - spanning not just centuries but millennia. Many civilisations have risen and fallen in the land that was made fertile and productive due to modern advances in water technology. For example, the chronicles of the first expedition of Agathocles at Cap Bon in 311-308 BC describe the hydraulic structures built by the Carthaginians: ‘A territory divided all along into small gardens and various plantations, numerous streams irrigating the whole place and canals watering the smallest plots’ (Diodorus of Sicily, 2006). In the centuries to follow, Romans constructed aqueducts (figure 4) that established an elaborate network of water supply for

urban centres, thermal baths, and agricultural production (Hilali, 2012). Notable in the history of water infrastructure developments are also the technological

modernisations of the Arab-Muslim Aghlabid dynasty (800-909), such as the hydraulic basins in the dynasty's

Figure 4 The Zaghouan Aqueduct was built in the 2nd century AD in Roman-era Tunisia. With a total length of 132 km, it transported water from the city of Zaghouan to Carthage (now Tunis) - making it among the longest aqueducts in the Roman Empire

capital, Kairouan, widely considered the largest hydraulic installation of the Middle Ages. Water resources governance (and governance challenges) in Tunisia must therefore be understood in relation to its historic legacy and emotive link to agriculture – beyond its essential contribution to economic development. Tunisia's panoply of soils and geopolitical position has brought great agricultural fame to the quasi-peninsula that separates the Mediterranean in two, serving as a bridge between the East and West (Mediterranean), and North (Europe) and South (Africa). The legend of Tunisia's agricultural sector as a geopolitical powerhouse remains relevant to this day. Nearly two millennia after the end of Roman-era Tunisia, several key informants continue to refer to Tunisia as *Matmoura Roma*: the "breadbasket to Rome".

This chapter will outline the biophysical, legal, and socio-political context of water governance and resources management in Tunisia. It will explain why Tunisia makes a particularly suitable case study for this research endeavour. This thesis argues that an in-depth contextual diagnostic is instrumental in grounding subsequent analyses within the context of complex adaptive SES. Tunisia's biophysical context of water availability, for example, notably co-evolved alongside social and political dynamics (figure 5). This thesis will analyse interaction effects between resources allocation and use, institutions, and social-ecological disturbances and explore emergent phenomena.

a. Biophysical context

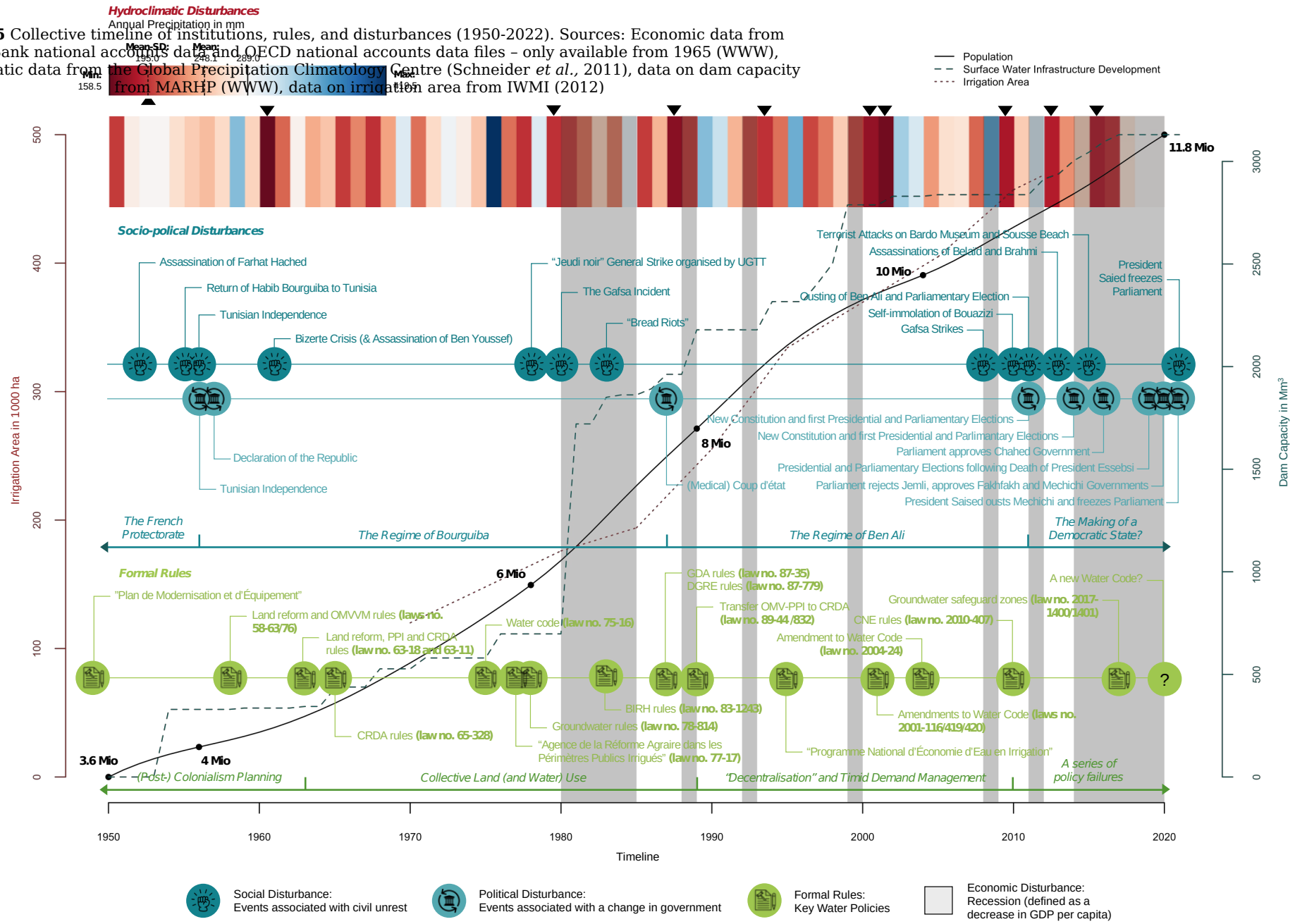
Tunisia faces inherent physical water scarcity with highly irregular rainfall patterns (MARHP, 2017). Recurring droughts, aggravated by climate change, pose a deleterious threat to agricultural systems and the communities that depend on these systems for their livelihoods. To support farmers and the local economy, agricultural policies in the past have subsidised irrigation intensification and the production of staple crops at low economic water productivity. In short, to counteract the natural phenomenon of water scarcity and to raise revenues from agricultural production, farmers increased overall production (rather than value). As a consequence, 87% of Tunisia's water footprint is used for crop production (followed by 11% for grazing and 2% for domestic water supply, livestock production, and industrial activity combined) (Chouchane *et al.*, 2015). Surface water has been fully exploited (figure 5) and is now on a steady decline: In December 2021, potential of dam water was reduced from the theoretical total capacity of 3130.1 Mio m^3 (cumulative initial capacities of all dams in Tunisia) to an actual capacity of 2313.22 Mio m^3 (due to silting and moribund infrastructure) and a usable volume of 594.272 Mio m^3 (due to minimal rainfall) (MARHP, WWW). Since water resources from surface sources are subject to considerable uncertainty, irrigation agriculture largely comes at the cost of reliable groundwater resources. With 80.8% of groundwater use designated for irrigation purposes, Tunisia's groundwater resources are severely degraded (133% overexploitation in 2016) and will therefore serve as the centrepiece of this analysis of water governance (MARHP, 2017).

Regulation aimed at tackling groundwater overexploitation lacks appropriate instruments of implementation and enforcement (Friya *et al.*, 2014): Only 26.8% of total water fees are currently recovered from water users and the government

estimates 48% of total wells to be illegal (MARHP, 2017). As the only way to quantify groundwater allocation and use, licensing, i.e. legalisation, of groundwater abstractions is generally held as the gold standard in groundwater resources management (Molle and Closas, 2020). Molle and Closas (2020) synthesise global evidence for the widespread failure of such licensing efforts. In the specific case of post-Authoritarian Tunisia, there is a need to explore the context-specific barriers to well licensing. Efforts to combat groundwater depletion uncover a new social dimension of the decade-long reliance on irrigation intensification. In the given semi-arid context, rural communities are predominantly agricultural relying on decreasing groundwater supplies for irrigation. The social-ecological dilemma at hand sees two unfavourable solutions to the problem of aquifer depletion: continued over-extraction in favour of local livelihoods but at the cost of accelerated groundwater depletion or limiting extractions in favour of water conservation but at the cost of local livelihoods.

Recurring droughts, threatening agricultural production and livelihoods, are the main hydroclimatic disturbance in Tunisia. Droughts in the context of this analysis are defined as one standard deviation from average precipitation (Schoon and Cox, 2011). Between 1950 and 2018, annual precipitation in Tunisia varied between 158.5 and 419.5 mm with a mean of 248.1 mm per year (figure 5). In this timeframe, nine drought years (annual precipitation below one standard deviation from mean precipitation) are identified with annual precipitation levels below 195.0 mm: 1960, 1979, 1987, 1993, 2000, 2001, 2009, 2012, and 2015. More than half of the drought years identified in this analysis have occurred in the 21st century. These trends correspond well to the literature on drought phenomena in Tunisia (Hénia, 2003; Abdemalek and Nouiri. 2020; Safouene and Lotfi, 2014; Louati *et al.*, 2007).

Figure 5 Collective timeline of institutions, rules, and disturbances (1950-2022). Sources: Economic data from World Bank national accounts data and OECD national accounts data files – only available from 1965 (WWW), hydroclimatic data from the Global Precipitation Climatology Centre (Schneider *et al.*, 2011), data on dam capacity from MARHP (WWW), data on irrigation area from IWMI (2012)



b. Legal context

The following paragraphs will outline the regulatory framework of water allocation and use in Tunisia as well as respective institutional arrangements. It will highlight legal challenges regarding the enforcement of regulatory limits to extraction, a nebulous division of administrative responsibilities, and limited financial and institutional capacity at the local level of governance. The evolution of water laws mirrors shifting political priorities throughout the decades (figure 5). Recent efforts to conduct a sectorial reform are discussed with regards to socio-political trends and public expectations.

The principal backbone for Tunisian water policy is the Water Code of 1975, enacted by law no. 75-16. A progressive piece of legislature, the Water Code integrated principles of common law, Islamic law, and rights-based approaches (Hamdane, 2019). The Water Code defines water resources as a public good and restricts individual freedoms to exploit the resource in favour of the imperative of the public utility of water. It positions the Tunisian government at the centre stage of planning, management, and monitoring of water resources. Rules for groundwater abstractions were defined in 1978 (law no. 78-814) demanding water users to require regional authorisations for withdrawals from shallow wells and national authorisations for wells deeper than 50 m. While the Water Code of 1975 reserves the right to limit or withdraw concessions in the public interest, e.g. if the allowed volume stated in the authorisation is surpassed, neither the code nor the decree of 1978 stipulates mechanisms of volumetric measurement or enforcement. This poses a severe groundwater governance challenge: Regulatory institutions have no means of proving when groundwater withdrawals exceed defined limits, since even big consumers are not legally obligated to install water metres. A simile to this phenomenon of

implementation failure would be allowing cars to drive without tachometer on a highway that has a defined speed limit but no speed cameras – even if accused of law breaking, in dubio pro reo [in doubt, in favour of the accused].

In 1987, the Water Code was amended by law no. 87-35 to endorse established collective interest groups, Associations of Collective Interest (AICs), today called *Groupements de Développement Agricole* (GDAs), and define practical responsibilities regarding operation and maintenance of hydraulic structures (Hamdane, 2019). Law no. 2004-24 completed the amendment of law no. 87-35 regarding GDAs and further extended their role in managing water allocation and use. While responsibilities for GDAs grew continuously, their capacity for financial and administrative management remained limited, frequently resulting in account deficits and ultimately bankruptcy.

The 1980s saw a range of amendments to institutional arrangements within the Ministry of Agriculture (figure 6) specifically regarding the *Bureau de l'Inventaire et des Recherches Hydraulique* (BIRH) and the *Direction Générale des Ressources en Eau* (DGRE). Policies during this decade sought to define roles and increased practical responsibilities for both institutions, law no. 83-1243 for the BIRH in 1983 and law no. 87-779 for the DGRE in 1987. Tasks included among others the establishment and publication of a national inventory of surface and groundwater resources data, installation and

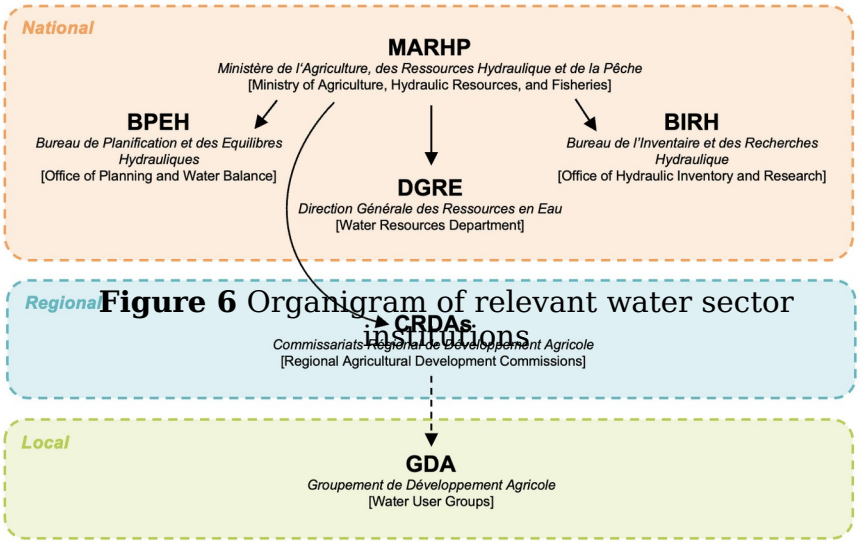


Figure 6 Organigram of relevant water sector institutions

maintenance of monitoring equipment, and hydrogeological exploratory studies (Ministère de l'Agriculture, 1990). Instead of a clear division of responsibilities, these tasks were handed to both institutions: 'It emerges from what precedes that the texts currently in force created a double employment between the attributions of the DGRE and the BIRH on the one hand and omitted, on the other hand, to foresee in the organization chart of these two organizations the structure in charge of the management of the Public Hydraulic Domain' (Ministère de l'Agriculture, 1990: 20). This represents but one of the power struggles between institutions internal to the apparatus of the Agricultural Ministry.

The 1990s also represented a tilt in the nation's water resource management philosophy. Whereas the pre-1990s were focused on grey infrastructure-supply management, the post-1990s see a timid (and often merely on-paper) shift towards demand management: 'Water is likely to constitute a major obstacle to the socio-economic development of the country (…). During the *8th National Development Plan*, particular attention will be granted to the management of water resources so as to define with the maximum of precision the available water potential, to release nonconventional resources (desalination, reuse of wastewater, recycling, etc.) and to develop the techniques of saving water' (Ministère de l'Agriculture, 1990: Preface). Hand in hand with the continued expansion of irrigation areas and groundwater extraction, the Tunisian administration increasingly advertises measures to rationalise water use – within limits. Measures to rationalise water use in politically sensitive sectors such as agriculture are framed as "carrots"/soft incentives rather than "sticks"/sanctions (Closas *et al.*, 2017). 'These measures concern: Agriculture (granting of special credit, institution of subsidies, etc.), and drinking water

(saving water and fighting against waste in industrial units, schools and public communities)' (Ministère de l'Agriculture, 1991 : 44).

Along the same rationale of "carrots", the *Programme National d'Economie d'Eau en Irrigation* (PNEEI) of 1995 advocated for water efficiency in the irrigation sector and created investment incentives (subsidies of up to 60%) to modernise irrigation equipment (MARHP, 2017; M'kadmi, 2005). Other modernisation projects included among others *Amélioration des Périmètres Irrigués dans les Oasis du Sud* (APIOS) and the modernisation of the public irrigated areas of the Lower Medjerda Valley (Hamdane, 2019). Building on the experience and climatic records of previous droughts, Tunisia published its first guideline on drought management, *Guide pratique de la gestion de la sècheresse en Tunisie*, launching a national drought management system in 1999 (Louati *et al.*, 1999). The year 2001 saw three amendments to the Water Code: Law no. 2001-116 expanding the law on water conservation and private sector participation in non-conventional water management (Hamdane, 2019), no. 2001-419 reiterating all ministerial water resource allocation responsibilities to the agricultural Ministry (*Ministère de l'Agriculture des Ressources Hydrauliques et de la Pêche*, MARHP), and no. 2001-420 specifying structure of its subdivisions (Louati et al., 2007).

Most economic and regulatory instruments target local levels of governance: Local water user groups, namely *Groupements de Développement Agricole* (GDAs). The success (or non-success) of policies thus hinges on the implementation capacity and performance of said user groups. GDAs are free membership associations with an elected board of directors that serve potable water to nearby residents and agricultural water to farmers offering an effective low-cost alternative to those who cannot cover the investment cost of a private

borehole. In numbers: 2754 GDAs serve 1.6 Mio Tunisians with drinking water and 200 000 ha with agricultural water (MARHP, 2017). GDAs are generally placed under the tutelage of regional representations of the Ministry of Agriculture (MARHP), called *Commissariats Régional de Développement Agricole* (CRDAs), which fulfil support and control functions by contractual arrangement (figure 6). While GDAs have on-paper administrative and financial autonomy, their lack of technical and financial resources often forges a strong dependence on their respective CRDA, which themselves are heavily underfunded (Frija *et al.*, 2014). Low supply-reliability and service quality harms the legitimacy of GDAs towards their users and forges perceptions of empty administrative apparatus (Marlet, 2013). Law no. 2004-24 extended their role in managing water resources: GDAs are thereby tasked to provide water infrastructure and equipment and are encouraged to engage in income-generating activities to facilitate these services. GDAs further carry responsibilities to supervise water users and advise them on appropriate and efficient agriculture techniques. However, the capacity for financial and administrative management remained limited. Where management contracts between stakeholders (farmers, GDA, CRDA, DGRE, BIRH, BPEH, and MARHP) are juridically unclear, roles and responsibilities are inadequately defined and a blame game ensues (Al Atiri, 2007; Ben Salem *et al.*, 2007; Frija *et al.*, 2014). Initiatives to effectively empower self-regulation often remain political slogans disconnected from the reality of water user organisations (Frija *et al.*, 2016). On the other hand, state intervention at the local level is often met with resistance from local water users: ‘“Political interventions” regarding pricing, bypassing regulatory bodies, (…) has often had a negative impact on the sector’ (Hamdane, 2019: 30). This thesis will further explore the fraught relationship, historical and present, between central government and local water users.

The 1990s also spurred first reflections on the need to revise regulatory tools to allow for more effective enforcement of limits to extraction: 'It is planned, in this context, to update the water code to meet a rational management of the Public Hydraulic Domain and to ensure the establishment of a *Water Police* that will ensure the protection of this Domain. This protection becomes all the more necessary with regards to the preservation of the resource against the abusive overexploitations which unfortunately tend to become generalised considering the inadequacy between the needs and the resources in several regions' (Ministère de l'Agriculture, 1990: Preface). Efforts to update the Water Code of 1975 officially began in 2010, when a consulting firm was hired by the government to elaborate a Water Code 2.0. The Water Code 2.0 outlines new strategies for enforcement – including among others the creation of a new "superior" water council

Info-box 2: Social-political dynamics in Tunisia post-Arab Spring

The ousting of Ben Ali in early 2011 left a political and social void. For the first time in recent history, the Tunisian public was able to voice their concerns, their wishes and raise questions. Hope becomes a new element in this national discourse – and many Tunisians feel uncertain how to manage these novel expectations and the manifold opportunities they hold. The years following the Arab spring are turbulent. At the end of the country's first electoral campaign more than 100 political parties have nominated themselves for the upcoming election. The election results see the prominent Islamic party *Ennahda* with the most votes, but without a majority. Forced to build coalitions where possible, secularist and Islamic parties soon regain awareness of their deeply divergent perspectives on a range of constitutional issues. While *Ennahda* makes concessions on several constitutional issues (e.g. on women's rights), the political situation is complicated by the emergence of new forces of Islamic extremism. The assassination of Chokri Belaid, a prominent human rights activist, in February 2013 presents a serious threat to the fragile limbo of transition politics. The resulting cabinet reshuffle was a concession given to secularists who had critiqued Ennahda's lax handling of extreme Islamists and saw *Ennahda* ceding power of the interior, defense, and foreign ministries to independent technocrats.

Long arguing that Islamist repression would trigger increasing radicalization, *Ennahda* only tentatively started to harden their approach towards Salafi forces. After leftist MP and outspoken opponent of *Ennahda*, Mohamed Brahmi, is assassinated in July 2013, public protests rage - threatening to topple not just the coalition government but indeed the constitution-writing process in its entirety. With a lack of alternatives, the government eventually hands responsibilities to a technocrat government. The so-called Tunisian National Dialogue Quartet consisting of representatives from UGTT, UTICA (*Union Tunisienne de l'Industrie, du Commerce et de l'Artisanat*), Tunisian Human Rights League, and the Tunisian Order of Lawyers. For their ultimate success in guiding the *Ennahda*-led government to a new constitution, the *Quartet Tunisien* receives a Nobel Peace Prize in 2015. The constitution, without discussion a milestone in Tunisian politics, was met with public criticism regarding its general air of consensus: 'We expected a revolutionary constitution, equal to the torture, the threats, the censorship, the oppression, the deaths for freedom. In the end, we end up with a very consensual text, and therefore full of contradictions' (Khiari, 2020: 92).

The first elections after the new constitution on 26th October 2014 see Béja Caid Essebsi as the winner of the election and next president of Tunisia (Habib Essid is appointed as PM). With the simplistic slogan "*vote utile*" ("useful vote"), Essebsi's party *Nidaa Tounes* mobilized voters under the premise of being the only alternative to the Islamic parties who are seen as having failed to prevent the political terror and resulting killing of Belaid and Brahmi (Antonakis, 2019). Revisiting tactics of so-called Bourguibism, Essebsi portrays himself as the father figure of "modern" Tunisia: 'liberator of women and architect of post-colonial state-feminism' (Antonakis, 2019: 147). Disappointingly for many of his voters, Essebsi, as soon as elected, forms a coalition with just those parties (incl. *Ennahda*) he sought to delegitimize during his

campaign in the name of national unification. In March and June 2015, Tunisia is hit by two major terrorist attacks on Tunis' famous Bardo museum and the beach in Sousse. The subsequent freezing of the tourism industry, a key economic sector in Tunisia, has repercussions for the entire country. Rising unemployment, the devaluation of the Tunisian Dinar, and crippling public debt, leads to a vote of no-confidence in Parliament in 2016 relieving Essid of his duties as PM. Instead, Essebsi appoints Youssef Chahed, reportedly the nephew of his son-in-law. Chahed had previously spearheaded the country's anti-corruption taskforce, which strongly implicated Hafedh Essebsi (Essebsi's son), who had earlier that year been appointed head of the political party *Nidaa Tounes* by his father.

Political instability continues to strain social tensions in the following years. In 2017, the government passes the *Loi de Reconciliation Economique et Financiere* [Economic and Financial Reconciliation Law], granting amnesty to functionaries accused of administrative corruption. In response, wide-spread protests sweep the country under the slogan *Manich Msemeh* ("I Will Not Forgive"). Between 2013 and 2018, the cost-of-living increases by 31.97% (*Institut National de la Statistique*, 2018) and austerity laws passed in 2018 trigger a new wave of protests. Tunisia's first local and regional elections in 2018, reveal profound gaps in democratic support and a general dissatisfaction with the ruling government: 64.4% voter abstention according to the Congress of Local and Regional Authorities (2018). Following the death of Essebsi, Tunisia sees turbulent parliamentary and presidential election in 2019. Out of the 26 candidates running for president, Kais Saied (a conservative lawyer) and Nabil Karoui (Tunisia's prominent media mogul – frequently referred to as "Tunisia's Trump") proceed to the second round, which Saied wins with 72,53% of the votes. The parliamentary election produces no majority but a plethora of small parties eager to have a say in the forming of a new government. The first attempt at forming a government under the feather of Habib Jemli fails to pass parliament creating fear of possible new elections in the current fragile democratic climate. Although the second attempt by Elyes Fakhfakh successfully passes parliament, Fakhfakh eventually retires from his post a couple of months later due to conflicts of interest, soon to be replaced by Hichem Mechichi.

The process of democratic transition is endangered by continued economic recession and unemployment. Vice-versa urgent structural and economic reforms are postponed due to the priority of the political and institutional transition, the frequency at which administrations are replaced by the next, and the fear of passing unpopular reforms (Schäfer, 2017). Indeed, in July 2021 President Saied ousts the latest Mechichi government in a controversial move during the country's largest Covid outbreak (as of late 2021). This political escalation followed a number of violent anti-government protests that had previously swept Tunisia. Drawing on Article 80 of the Tunisian constitution, Saied justified the suspension of parliament as protecting the country from "imminent danger". While Saied's move gained widespread public support and triggered multiple celebratory manifestations on the streets of Tunis, former Parliamentary Speaker and co-founder of *Ennahda*, Rached Ghannouchi, also calls upon Tunisians to take the streets in protest against the 'unconstitutional coup'. The international community joined Ghannouchi to utter great concern with Saied's apparent power seizure and pleads for a speedy return to 'democratic order'.

(Conseil Supérieur de l'eau, CSE, presided by the head of government) and a new executive agency, *Agence*

National de Protection du Domain Publique Hydraulique (ANPDPH), or short "water police", which seeks to streamline the groundwater authorisation process. Approved internally by the Ministry, the code was sent for debate and approval in parliament in 2021. After many months of parliamentary discussion, the process was halted by the political turmoil of the summer of 2021, when President Saied froze parliament until further notice (info-box 2). The future of (water) policy-making in Tunisia and that of the new code remains uncertain. Meanwhile, unclear institutional and individual responsibilities make for a lack of coherent vision and planning.

If one takes the mass manifestations in favour of President Saied's power seizure in 2021 as evidence, the democratic mode of governance, associated with great uncertainty, seems to have become widely unpopular. Info-box 2 provides insights on the political turmoil in Tunisia since the Arab Spring. The challenge of passing and implement new water reforms need to be viewed in light of these socio-political disturbances. Where promises of democracy remain unfulfilled – and with every unsuccessful government that resigns, every additional year of economic depression (World Bank Group, WWWb) and rising unemployment (World Bank Group, WWWa) – hope is gradually being replaced by bleak discontent. The social promise of technological advances and continued irrigation intensification is still the dominant rhetoric in the Tunisian water sector and overshadows necessary public debates on water scarcity issues. According to key informants, personal interests of decision-makers (or of those they are associated with) often come in the way of meaningful change (e.g. passing of the new *code des eaux*). The popularity of President Saied (or what is left of it) stems to a large extent from his public campaigns against corruption. Saied's anti-corruption efforts have amongst others led to the dismissal or imprisonment of high-level administrators in the public water sector. While anti-corruption campaigns are a popular tool for keeping public approval ratings high, policies that limit water demand and regulate illegal wells are not. The fact that the government is well aware of the contested nature of water debates (and regularly sends presidential messages to towns affected by water shortages) gives an indication that the administration may be extra cautious to pass new and unpopular water reforms.

c. Social-political context

Why is it important to discuss politics when analysing water resources management in Tunisia? Entering the premises of a water user group in rural Kairouan gives a first indication in this regard. First, the walls of the building usually carry numbered squares - each of them used to hold the campaign poster of a political candidate during the last democratic elections (figure 7). After the dissolution of parliament in 2021, these empty rectangles are but bleak reminders of what was a brief moment of hope for a stable democratic future. Inside the premises, an empty frame used to bear the portrait of authoritarian leader, Zine El Abidine Ben Ali (figure 8). After the Jasmine Revolution of 2011, the frame was emptied and never refilled.

This section seeks to give insights on social and political norms within the overlapping Post-Colonial, Post-Authoritarian, and Post-Arab Spring context of the Tunisian water sector. It outlines co-occurring normative processes of consensus, personality cult, and the centralisation of power. It introduces the complex dilemma of curbing water extraction under existing resource constraints. Given the dire need for regulatory reforms to respond to aquifer depletion, this section poses the following question: Is there a right time for “controversial water politics” in an environment of political fragility and social unrest?

Informality and incoherence of rules have historically favoured the concentration of executive power in Tunisia. According to key informants in the water sector, oral discussions frequently take precedence over physical documents making it easier to not challenge centralised rules and decision-making. While political intermediaries can forward information, they are unable

to make decisions without the personal approval of the “superior”. This mechanism poses a challenge for the enforcement of regulatory limits of extraction. In the case of illicit wells, for example, regional administrators (at the level of the CRDA) are mostly unable to act on known cases of illegal groundwater withdrawals due to a lack of *de facto* authority. The Agricultural Ministry of Tunisia is commonly referred to by key informants as “*l’état dans l’état*” [the state within the state]. The historicity of this mode of governance, the centralisation of power around one strong superior leader, whether Bourguiba, Ben Ali, etc., carries great importance to this day. The myth of consensus that was created during these two authoritarian regimes, was carried by the idolisation of one man, “the superior

Figures 7 and 8 Images of water user groups in the governorate of Kairouan

protector of the Tunisian nation". Similar associations are made today and can be found in the public approval of the dissolution of parliament and seizure of power by President Kais Saied.

A few recurring themes carry themselves through key informant interviews as a red thread: Notions of '*l'état fort*' [a strong state], untouchable leadership, and pride. The concept of '*l'état a toujours raison*' [the state is always right] has

been produced as a result of decades of co-optation under an omnipresent administrative apparatus. An apparatus that enclosed all public procedures in a discourse that denied open debate or diversity of opinions. While the Arab spring of 2011 leveraged freedom of speech, the remnants of a 'world in which

failures do not exist, and where only successes are recorded' are still visible today (Hibou, 2011: 15). Interviewees refer to a social norm where one is forbidden to admit mistakes, where pointing out someone's mistakes can be interpreted as an act of aggression. Amrani (1979) argues that a general sense of pride and outlawing of public failure may have historic roots in the struggle for independence from the colonial aggressor: 'During the 75 years of colonial presence, the country had been deprived of any representation and any participation in the active political and administrative life. The incapacity of the Nation to govern itself had been the major argument justifying the establishment of the Protectorate. The assertion, developed for a long time by the colonial power, of the inaptitude of the Tunisian people had aroused in him [Bourguiba] a complex where the national pride was mixed with the desire to show that the Tunisian people was capable' (131).

In a setting of political fragility and high turn-over of high-level decision makers, water policy reforms are chronically unfinished. '*Ce phénomène nous a laissé avec la même vieille politique de l'eau [inadéquate] alors que l'histoire est passée sous nos yeux*' [This phenomenon has left us with the same old [inadequate] water policy as history has passed in front of our eyes] (interviews with key informants). Political uncertainty within and beyond the water sector are paired with public perceptions of social injustice. Key informant interviewees are often aggravated by discussions of potential policy measures that target water conservation in the agricultural sector: 'Why are we only talking about agriculture and the poor farmer? Why are we not talking about the 50% of water losses and illicit wells of hotels, industry, and private homes?' or 'why take away from the poor farmer while the millionaire is still sitting on his illegal well?'. Based on mere extraction rates, the answer is unequivocal: Because agriculture accounts for 80% of water extractions. On an emotional

level, however, proactive measures targeted at curbing groundwater overextraction are much more difficult to communicate to farmers (and their allies), who are stuck in a poverty trap of irrigation agriculture.

The Tunisian challenge of groundwater overexploitation created divergent mental models in dealing with the social-ecological dilemma. On the one hand, informal tolerance of local authorities vis-à-vis illegal wells and over-exploitation goes hand in hand with an unspoken tolerance from high-level decision-makers in the capital Tunis (Brochier-Puig, 2012). *If* there is mention of illegal wells, government information is often focused on technical information rather than social (and economic) considerations of the problem (Brochier-Puig, 2012). According to key informants, this informal consensus is also carried by private interests of decision-makers and the safeguarding of their social networks. Economic arguments for over-exploitation are commonplace and deeply rooted in the historic rhetoric of “water for development”. In addition to a politically fragile environment, where decision-makers fear social unrest in response to policy reforms, regulating illicit water abstractions does not pose itself as a political priority. ‘The restrictions on access to water, and more specifically the ban on drilling, if they were to be respected, would cause an explosive situation’ (Brochier-Puig, 2012: 63). Key informant interviewees argue that ‘now is not the time for controversial politics’. Others argue that even if new water reforms were passed, the inherent social dilemma would prevent any meaningful action: ‘Who can stop a smallholder farmer to withdraw water illegally? No-one’.

On the other hand, there are those that call for drastic coercive measures to combat illicit wells and groundwater overexploitation. Some key informant interviewees lament that the ‘presence of the state is not adequately felt. People

don’t have fear’. The solution according to these key informants would be the creation of an omnipresent *water police* (by means of the new water code) to ‘rid people of the doubt of being punished’. This proposal of state surveillance, in the style of a Foucauldian panopticon (Foucault, 1975), holds potentially deleterious implications given Tunisia’s recent past of repression and human rights violations. Given current struggles in the democratisation process, where is the line drawn between authority and authoritarianism?

5. Three papers

This section will provide a first introduction to the three papers of the thesis and will iteratively guide the reader from a historical exploration of the evolution of institutions managing water resources use in Tunisia, to local examinations of collective action in water user groups in the Tunisian governorate of Kairouan, to animations of individual farmer decision-making within said SES. Collectively, the three papers illustrate the path-dependence of Tunisian water governance within the context of an Authoritarian past, which builds on irrigation expansion and a reliance on groundwater resources to leverage rural livelihoods and social security. The erosion of institutional trust in a fragile post-Authoritarian-post-Arab Spring governance system co-evolved alongside local dynamics of social trust and cohesion resulting in a unique set of outcomes for collective action and the underlying CPR.

Paper 1
Quote: '*Resources are not, they become*' (Erich Zimmermann)
Title: How water sector reforms institutionalised domination and repression in Tunisia's authoritarian regimes

The first paper traces water reforms in Tunisia's authoritarian regimes and how they came to shape mechanisms of domination, repression, and co-optation anchored in the everyday politics of water allocation and use. This historical study of the water-agriculture nexus in Tunisia (1950-2011) argues that water resources and associated reforms served as a practical and symbolic vehicle to legitimise, produce, and reinforce authoritarian practices and regimes. Using process tracing, this analysis showcases the links between agricultural water governance and practices of state building. Water policy and decision-making are put in the context of past political agendas and social unrest, explaining underlying societal perceptions and motivations. Giddens (1979) argues that

'there simply are not logical or even methodological distinctions between the social sciences and history – appropriately conceived' (230). This paper lays the contextual foundation for the two following paper that seek to unpack local dynamics within the path-dependent setting of post-Authoritarian Tunisia.

Paper 2
Quote: '*Trust is built in drops and lost in buckets*' (Kevin Plank)
Title: Trust, Hope, and Collective Action in Fragile Political Settings: A Qualitative Comparative Analysis of Water User Groups in Tunisia

Following from the analysis of national policy-making in the first paper, the second paper zooms into local spaces of decision-making in collective action groups. Similar to the erosion of institutional trust, groundwater resources have been widely degraded - with low rates of replenishment. The paper studies the pathways that mediate the relationship between trust, hope, collective action, and resource scarcity in the fragile context. It examines whether and how collective action can serve as a substitute to state intervention with regards to cooperation and conflict among water users, and sheds light on the substitutability of shared norms under given ecological conditions. The paper seeks to contribute to the literature on trust by highlighting interactions between varying social dimensions of trust (institutional and social trust) in the context of institutional fragility. Further, the paper contributes to collective action research in settings of low hope, with a focus on how hope interacts with other social-ecological conditions that influence local decision-making processes.

Paper 3
Quote: '*The farmer has to be an optimist, else he wouldn't still be a farmer*' (Will Rogers)

Ultimately, the third paper takes the perspective of the water user by simulating the evolution of water user behaviour and norms under varying institutional, ecological, and agricultural scenarios. Driven by both agricultural profits and social preferences, the utility of the farmer determines water withdrawal rates, livelihoods, and the financial sustainability of the water user group. The model builds on the preceding papers by integrating social dynamics of the SES (institutional trust, and the reliance on informal mechanisms above formal mechanism of compliance and enforcement) into physical dynamics modelled by surrogate hydrogeological models that highlight path-dependent groundwater abstractions. Animating the Social-Ecological dilemma of irrigation agriculture in water-scarce croplands sheds light on coping strategies for farmers, who seek to maintain livelihoods in the absence of formal regulatory mechanisms. The paper highlights the limits and opportunities of collective action within the stressed SES of groundwater depletion and political fragility.

Paper 1: How water sector reforms institutionalised domination and repression in Tunisia's authoritarian regimes

Author: Sophie Erfurth[a,b]

[a]Environmental Change Institute, University of Oxford, Oxford, UK
[b]Smith School of Enterprise and the Environment, University of Oxford, Oxford, UK

Abstract

This paper analyses how water reforms in Tunisia's authoritarian regimes came to shape mechanisms of domination, repression, and co-optation anchored in the everyday politics of water allocation and use. The historical study of the water-agriculture nexus in Tunisia (1950-2011) argues that the sector served as a practical and symbolic vehicle to legitimise, produce, and reinforce authoritarian practices and regimes. Drawing on the dialectic of the state and society, this analysis showcases the links between agricultural water governance and practices of state-building. Water policy and decision-making are put in the context of past political agendas and social unrest, explaining underlying societal perceptions and motivations. On the basis of this analysis, this paper hopes to inspire modest and realistic policy reforms that can address modern-day water governance challenges.

Under review at the
Journal of Environment and Planning C: Politics and Space
(submitted on 14 December 2023)

a. Introduction

As water crises are increasing globally (Schlosser et al., 2014), societies are stepping up efforts in trying to solve them. In order to address present-day water challenges, it is crucial to unpack the historical forces that forged social rules and norms in the water sector. This paper explores the relationship between historical political processes and water resources management in authoritarian Tunisia (1950-2011). The contemporary Tunisian water crisis is driven by an irrigation-intensive agricultural sector that consumes 87% of the country's water footprint (Chouchane, et al., 2015). It is characterised by a failure to implement regulatory limits to water exploitation (Frija et al., 2014; MARHP, 2017) and lays its scene in the post-authoritarian context of an unstable democracy birthed during the Arab Spring. After French colonial rule, Tunisia was governed by authoritarian leaders Bourguiba (1957-1987) and Ben Ali (1987-2011), ultimately culminating in the Arab Spring of 2011. A note of caution is necessary for those that seek to address present governance challenges with panacea "good governance" tools that obscure the country's political past: 'For it is not in itself the departure of Ben Ali and the "clans" that has radically altered the modes of government and the exercise of power in Tunisia. Nothing has been definitively decided' (Hibou, 2011: xiii).

A growing understanding that water resources management is inherently political has led researchers to apply a political sociology lens to water resources management (Mollinga et al., 2007; Mollinga, 2008). Political decisions on water allocation create social patterns of haves and have nots among water users, inextricably linking water management to questions of power and justice (Tilt, 2015). Historical analyses of water governance systems help shed light on how political regimes have shaped these systems in their

image (McCarthy, 2019) and which processes contribute to sustaining or undermining them (Swyngedouw, 2015). Little research has been conducted on authoritarian environmental governance from a historical perspective (Wilson, 2019; Josephson, 2002), particularly with regards to water resources management. Concepts of political control and state-building have frequently been studied in relation to water infrastructures (Engels and Schenk, 2015). Deterministic notions such as Wittfogel's "hydraulic society" (1957) are not well placed to answer questions on dynamic power relations in water systems (Worster, 1985) but have inspired a more critical literature on socio-technical infrastructures, which studies infrastructure, such as irrigation systems, beyond their mere material functions (Obertreis et al., 2016). Expanding on the literature of socio-technical infrastructures, this historical analysis seeks to explore the dialectic of the state and society as they relate to day-to-day contestations of water management (Mollinga, 2008) using key informant interviews and archival data.

In order to untangle interactions between authoritarian control and water resources management and their continued relevance for modern-day water policy and planning, it is crucial to first define the authoritarian process. Authoritarianism is not necessarily the antithesis of democracy (Koch, 2019). Rather than a concrete unit associated with the state, authoritarianism should be understood as practices inherent to a variety of organisational units (Eckstein and Gurr, 1975; Adler and Pouliot, 2011). Indeed, democracies can provide fertile grounds for authoritarianism, e.g. corporate authoritarian practices in worker-employer relations. Within any particular organised context, authoritarianism can be defined 'as patterns of action that sabotage accountability to people over whom a political actor exerts control, or their representatives, by means of secrecy, disinformation and disabling voice'

(Glasius, 2018: 517). In contrast to obsolete conceptions of “oriental despotism” (Wittfogel, 1957), in which the ruler has perfect control over access to water, authoritarian practices go beyond the linear hierarchy between ruled and ruler and frequently involve endogenous self-reinforcement processes that trigger path-dependence (Gerschewski, 2013). The paper studies the relationship between state and society using the case-study of the water sector reforms in Authoritarian Tunisia (1950-2011).

Grounded in the theoretical framework of historical institutionalism (Blatter and Haverland, 2014), this paper mobilises the concept of the security pact as theorised by Hibou (2011). Legitimacy in the precedent authoritarian regimes in Tunisia, first during the colonial order, later in the Bourguiba and Ben Ali administrations, was derived from an image of economic and social security (Hibou, 2011). Inseparable from state-building and ideals of social unity, the so-called “security pact” between the government and those governed lies in the assurance of order and tranquillity. Against the backdrop of imminent danger of poverty and inequality, Hibou argues, the government receives a hall pass to do whatever is required to ensure social security. Where no clear legal status exists, the police is allowed to intervene, to repress individuals and their private affairs, in order to ensure public order. This phenomenon of the security pact can also be applied to the irrigation agricultural sector, where bureaucratic and practical supervision by so-called “social agents” allowed for the co-optation and repression of water users in the name of agricultural development and prosperity. As a complementary mode of governance, political mechanisms of laissez-faire (the systematic, and indeed often tolerated, by-passing of laws) paradoxically works in tandem with strict laws and repressive surveillance. According to key informant interviewees in the Tunisian water sector, the “disorganised” and unregulated landscape of illicit wells is highly regulated

through social means (Ostrom, 1990). The extent to which political authorities are aware of these illicit activities and acknowledge their effectiveness, indicates that they are tolerated (Brocher-Piug, 2012). Acting as a safety valve, regimes would tolerate illicit water extraction to create a public myth of self-determination.

This paper will test the hypothesis that water reforms served as a practical and symbolic vehicle to construct a security pact between Tunisia's Authoritarian regimes and their water users. On the flip side, policy failures in the water-agricultural sector are placed in the context of weakened security pacts, social unrest and ultimately regime change.

The academic contribution of this paper lies in the application of theories of state legitimisation, repression, and co-optation to the water-agriculture nexus. This paper provides an evolutionary perspective on water governance illustrating how (irrigation) water reforms in Authoritarian regimes created standard operating practices to structure interdependencies between individuals, which in turn contributed to the institutionalisation of legitimisation, repression, and co-optation of water users. Co-optation is defined as 'the capacity to tie strategically-relevant actors (or a group of actors) to the regime elite' (Gerschewski, 2013: 22), or in the words of Bueno de Mesquita et al. (2003), the "selectorate". A resulting "with or against us" dichotomy is commonly upheld by instruments of clientelism and corruption. This study builds on the conception of space-time, i.e. that 'space is not static, nor time spaceless' (Massey, 1992: 80), and hopes to untangle the spatio-temporal interactions between institutions and individuals (Koch, 2022).

The practical significance of this paper lies in a deeper contextual understanding of the limits and opportunities in planning for uncertain futures of water resources governance (Mollinga et al., 2007). Empiric research exploring the role of water resources management in nation-building, with respect to the politically contested arena of irrigation management, is necessary to uncover the context-specific power relations at stake in agricultural water allocation and use today (Molle et al., 2009). Causal processes will be studied in the comparative historical tradition: An effort to derive meaningful lessons from the past to address today's challenges. Mahoney and Rueschemeyer (2003) argue that 'even though their insights remain grounded in the histories examined and cannot be transposed literally to other contexts, comparative historical studies can yield more meaningful advice concerning contemporary choices and possibilities than studies that aim for universal truths but cannot grasp critical historical details' (9). Studying history uncovers social-political patterns embedded within every-day decision-making processes - at the level of the public and that of the state. The water sector is not immune to society-level dependencies and expectations. The paper will therefore be generous in its level of historic detail on Tunisia's leadership, hierarchies, and power dynamics, which are considered to shape the foundation of formal and informal rules in the water sector.

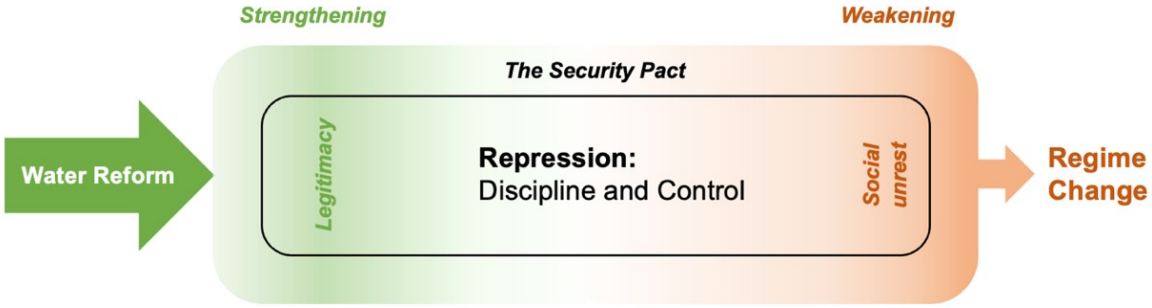
Following this introduction, the paper will summarise its methodological approach. The subsequent analysis will be structured chronologically and phased drawing on the three governance regimes in Tunisia 1950-2011 (the French Protectorate, the regimes of Bourguiba and Ben Ali) and their respective water management agendas. For each regime, the paper will trace the construction of the security pact (by means of water sector reforms), resulting authoritarian control, and the weakening of the security pact as eventually

policy measures fail. The paper will conclude by summarising emerging themes of the analysis and highlighting the relevance for contemporary water governance efforts.

b. Methods

Process tracing is a within-case method to identify possible causal mechanisms from empirical evidence to theorise about links between causes and outcomes (Kay and Baker, 2015; Trampusch and Palier, 2016). With a focus on timing, sequence, and interaction effects, process tracing can help produce causal inferences between historic events and rulemaking - thereby shedding light on key processes of path dependence (Blatter and Haverland, 2014). The unfolding of situations or events over time starts with careful descriptive inference of a series of snapshots at specific moments in time. Once a timeline is created (figure 10), narratives and there-embedded causal ideas can be evaluated within the limits of available empirical evidence (Bennett, 2010). The theoretical pluralism inherent to process tracing is particularly apt to address the problem of complexity in studies of policy change (Lyall, 2015). Causal complexity can be studied using INUS (Insufficient but Necessary part of Unnecessary but Sufficient) conditions, or in simple terms: Conditions that can cause an outcome in combination with other conditions (individually necessary but jointly sufficient) but are not the only pathway by which the outcome can be caused (Blatter and Haverland, 2012).

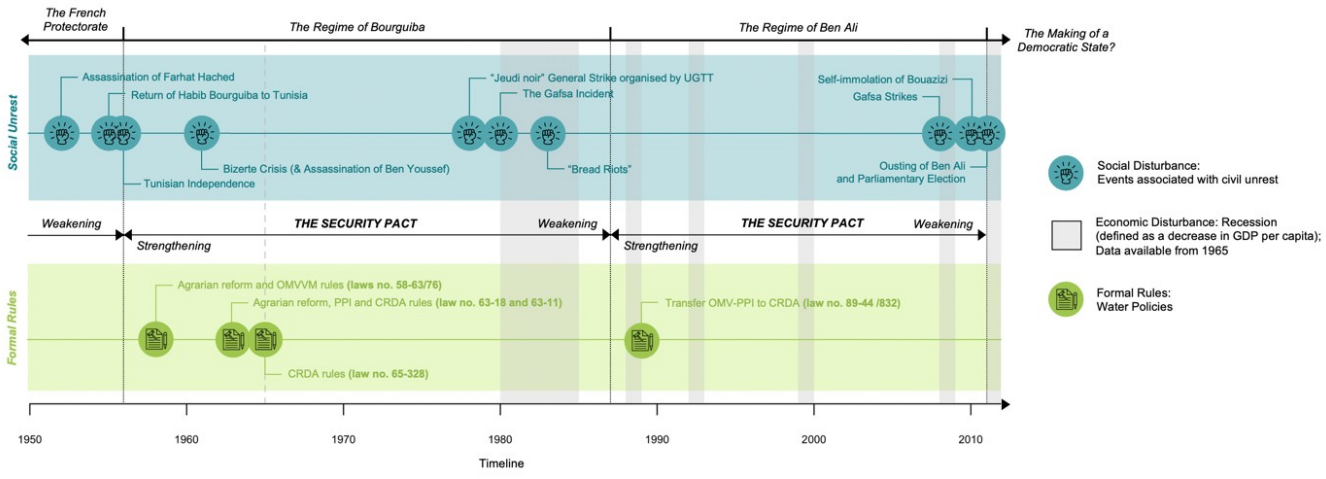
The process tracing approach is based on configurational thinking as conceptualized by Ragin (1987, 2008). Mechanisms inherent to process



dynamics may be immaterial and seemingly invisible to the observer such as social norms and informal contracts. Near immeasurable, these phenomena are often associated with low levels of explanatory certainty (Richards, 2011). Generally speaking, it is important to nuance the causal power that causal explanations, such as INUS conditions, can hold in real-world case studies. Given that this research is not conducted in a model-world where causal experiments yield perfect explanatory power, any methodological tools targeting causal inference are but best efforts in understanding how and why events and social patterns unfold. More importantly, these tools can help researchers explore hypotheses - in this case whether/how authoritarian regimes used water sector reforms as vehicles for authoritarian repression and control. This methodology generates a descriptive evolutionary narrative of the causal process, which is directly tied to historical facts from archival sources and individual testimonies. This ensures that even in research settings of fragmented and incommensurable data, process tracing can deliver meaningful results (Checkel, 2006). Results are not meant to generalise a proof of theory but rather serve as an example of evolutionary pathways of water policy-making and implementation in an Authoritarian context (figure 9).

Figure 9 Expanded framework of the Security Pact (as theorised by Hibou, 2011) with water sector reform as a vehicle for processes of regime legitimacy, discipline, and control

Historical evidence (planning documents, testimonies, etc.) for the analysis of water rules and institutions in Tunisia was collected in November-December



2021. Data was collected from archival sources (National Library of Tunisia), the academic literature, global datasets, and expert interviews. In total, 17 key informant interviews were conducted in Tunis with representatives from government, civil society and NGOs, trade unions, development organisations, and academia. Interview quotes will be referenced using interviewee codes representing the respective expert groups (e.g. GOV1, NGO2, UNO3, DEV4, ACA5). Following standards of good practice, the paper triangulated and cross-referenced data from documentary sources and interview data to limit biases and shifting baselines syndrome (Berkes and Folke, 1998; Folke, 2006; Gergel and Thurstan, 2021).

Figure 10 Timeline of events: Social disturbances and water policies (1950-2011) (economic data from World Bank Group, WWWb)

c. Analysis

'La Tunisie c'est l'Agriculture!' **[Tunisia is agriculture!] [UNO1]**

Regime 1: The French Protectorate

The paper begins its analysis in 1950, six years before the end of the French Protectorate. In unpacking its legacy, however, it is necessary to summarise previous policy efforts and associated pollical agendas. Established in 1881 by the Bardo treaty, the French Protectorate had two priorities regarding the use of land and water in Tunisia: Constructing water infrastructures and changing the juridical status of land collectives. The Plan de Modernisation et d'Équipement was initiated in 1947 and represented an ambitious programme of infrastructure development of Tunisia's agricultural heartlands. Notably, the plan established the Lower Medjerda Valley irrigation scheme, which led to the irrigation of 35,000-40,000 ha of agricultural land (Chevalier, 1950). The

colonial regime struggled to control collective land use systems in the centre and south of Tunisia (such as the Islamic collectives “habous”) and began to abolish traditional agricultural systems under the slogan modernisation du paysanat [modernisation of peasantry] as early as 1938 (Charbonnier, 1964). The colonial administration pushed for the development of Tunisian land and its people through the surveillance of farmers by agents of the Protectorate and the redistribution of resources. Although overt violence was rare (in contrast to French colonialism in Sub-Saharan Africa), violence in Tunisia was exercised by juridical normalisation, e.g. vast operations of resource seizure on the basis of administrative laws (Hibou, 2011). The colonial experience played an essential role in normalising coercion as a regular exercise of power, weaving recurrent violence into the very fabric of contemporary Tunisian political history.

Three key political leaders paved the road to Tunisian independence: Habib Bourguiba, Farhad Hached (leader of the Tunisian General Labour Union, UGTT, founded in 1946), and Salah Ben Youssef (Neo-Destour leader while Bourguiba was in a self-imposed exile between 1945 and 1949). In the 1930s, Bourguiba started challenging traditional power structures within the country’s first opposition party, the Destour Party (founded in 1920), and called for independence in 1933, which lead to his expulsion from les Destouriens and the creation of the ‘Neo-Destour’ party (Partie Socialiste Destourien). In 1952, Bourguiba was arrested by the French administration and handed the baton of leading the nation’s independence struggle to his right-hand man, Hached. In the same year, Hached was assassinated by French intelligence agents of ‘La Main Rouge’ [Red Hand] (Lebourg, 2021). Hached’s murder served as a sufficient condition for public outcry (figure 11), a three-day general strike, and manifestations across the nation, which were countered with unprecedented violence by French forces (Mestiri, 2011). The already frail position of the

French protectorate was weakened by the social unrest and eventually pushed them to open negotiations over possible Tunisian autonomy with the Neo-Destour party. Viewing Bourguiba as a 'lesser evil' over pro-Arab Ben Youssef (Wolf, 2017), the French Protectorate allowed the anew exiled Bourguiba to return to Tunisia in 1955 triggering never-seen-before national euphoria (sufficient condition in figure 11). Following these events of social unrest, French colonial forces put an end to the Protectorate and handed over governing responsibilities to Tunisia's reigning monarch, Lamine Bey. Public expectations and associated political responsibilities of state-building, particularly in association with the "hero's grand retour", set the stage for subsequent land and water reforms in newly-independent Tunisia.

Regime 2: The Regime of Bourguiba

In 1957, Lamine Bey resigns and Habib Bourguiba becomes the Tunisia's first president. In the new "neo-patrimonial republic", the Neo-Destour party has a monopoly of political power without effective constitutional opposition (Moore, 1962). Bourguiba frequently legitimises the authority of the regime as a necessary means to build a common national purpose: 'As the party that gave birth to the state, the Neo-destour will work to resaturate the authority of the state and its prestige' (Bourguiba in 1958 in Amrani, 1979: 74). Patterned upon metropolitan parties of "the West", the Neo-Destour largely assimilated political procedures and culture of the old colonial power (Poncet, 1956). At the time of Tunisian independence, 918,350 out of 1,327,520 active Tunisian workers are employed in the agricultural sector (Amrani, 1979). A first tentative land and water reform was passed in 1958 (law no. 58-63) to set a maximum of 50 ha and a minimum of 5 ha for private irrigated properties in the agricultural heartland of Tunisia, the Medjerda Valley. To contextualise: At the time, three quarters of

Tunisia’s irrigated lands were owned by private landowners holding more than 50 ha, and indeed those that owned more than 200 ha covered almost a third. This land reform of 1958 also foresaw landowners to contribute to irrigation infrastructure investments, either by relinquishing part of their land or paying their share directly (Charbonnier, 1964).

While theoretically revolutionary, these policies (targeted at the subdivision of communal lands) were not rigorously implemented and failed to effect the desired increase in productivity: ‘The titleholders needed credit and technical staff to help develop the land. In addition, the area allocated to each family was insufficient and did not allow the beneficiaries to obtain the minimum income, estimated at the equivalent of 250 Dinars per year per family. This is why they were quick to sell their plots to their neighbours or to third parties and to go work in underdeveloped sites’ (UGTT, 1967: 171). A second policy (law no. 58-76)

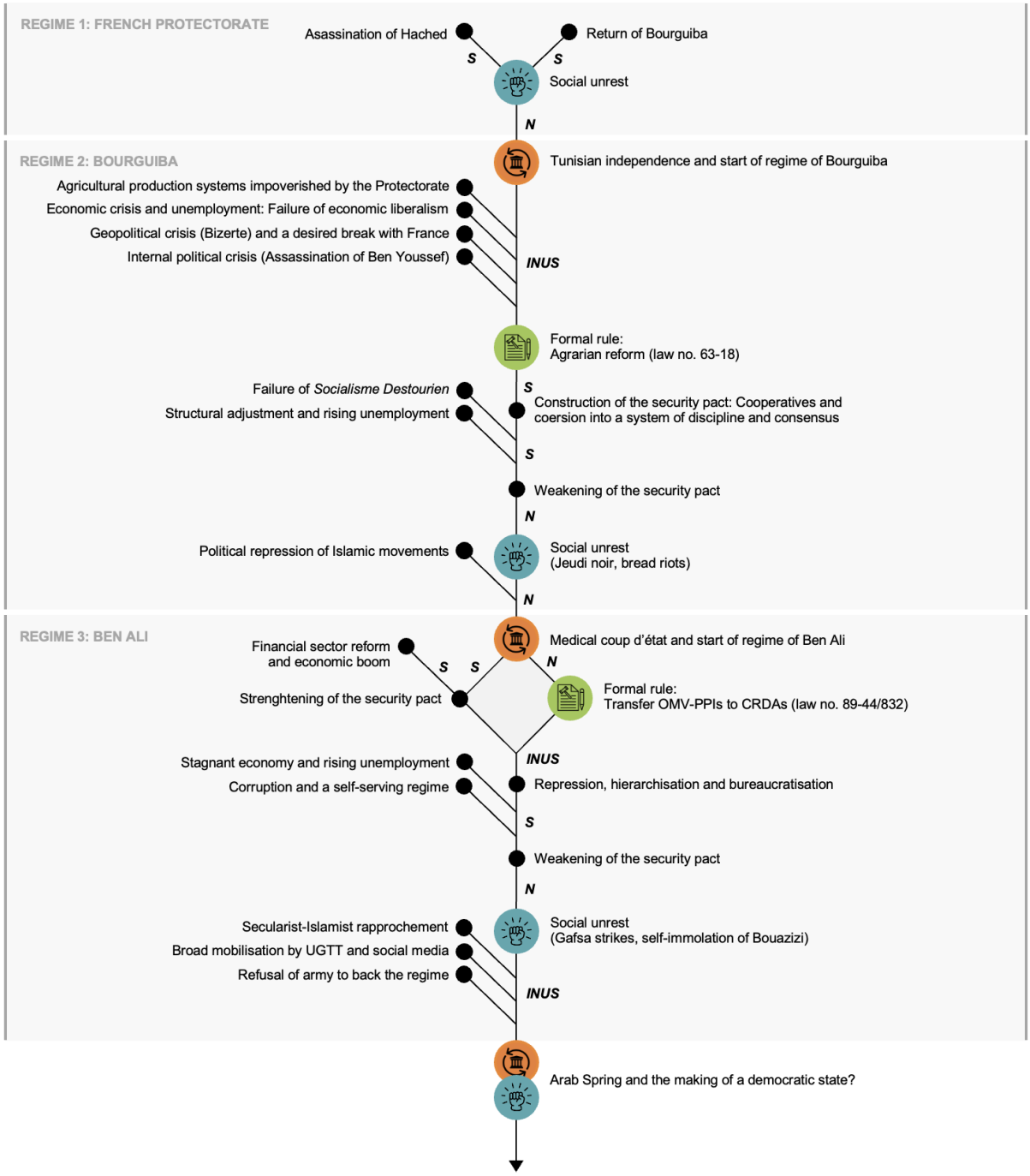


Figure 11 Causal relationship between events tested using empirical evidence (N = necessary, S = sufficient, INUS = individually necessary but jointly sufficient conditions)

was passed in 1959 creating the Medjerda Valley Development Agency (OMVVM), reporting directly to the presidential administration (Hamdane, 2019) (reiterating the high level of national importance of the irrigation water sector). The OMVVM replaced the Commissariat of the Medjerda Valley

(established during colonial rule) and extended responsibilities beyond coordination and research tasks to the development and maintenance of hydraulic structures, technical support to farmers, and managing (where applicable) the land ceded by landowner with more than 50 ha (Charbonnier, 1964).

Construction of the security pact: Cooperatives and coercion into a system of discipline and consensus

In 1963, a second agrarian reform (law no. 63-18) presents a break from the past: Extending limits to property rights, previously only relevant to the Medjerda valley, to the whole of Tunisia and defining clear obligations for farmers to develop and work irrigable lands in the form of cooperatives (Charbonnier, 1964). The creation of these “public irrigation perimeters” (Office de Mise en Valeur Périmètres Publics Irrigués, OMV-PPIs) and respective agricultural cooperatives, so-called unités de production [production units], are often considered one of the major achievement of the Bourguiba era (Charbonnier, 1964). To this day, PPIs cover more than half of Tunisia’s irrigated land (242000 of 435000 ha total irrigated area) (MARHP, 2017). The year 1963 also saw the establishment of four regional representations of the Agricultural Ministry (law no. 63-11), so-called Commissariats Régional de Développement Agricole (CRDAs) (Canesse, 2014), extended to 24 CRDAs, one for each Tunisian governorate, two years later (law no. 65-328) (Amrani, 1979). The land reform of 1963 set Tunisia on a path of continuous irrigation expansion that to this day dominates policy- and decision-making in the water sector.

In the words of Charbonnier (1964), ‘reforms of this kind are only carried out under the pressure of events because their realisation clashes with too many

interests to be undertaken cold' (5). What are the conditions that culminated in the passing of the land reform of 1963 (figure 11)? The sequence of events sets its scene in newly-independent Tunisia, where marketisation and speculations of the French Protectorate had left agricultural production systems impoverished keeping farmers below the profitability threshold (Amrani, 1979). Further, in a brief period of economic liberalism (1956-1960), a series of incoherent and often contradictory policy efforts had been unsuccessful in putting a halt to rising rural unemployment as large-scale farmers resisted the government's call for self-investments in agricultural intensification (Amrani, 1979). The economic crisis of 1959-1960 and the political crises of 1961 (described below) would serve as a trigger for a change in the party's ideology which marks a first (although incomplete) rupture with the colonial past.

During the economic crisis (1959-1960), inflation of the Tunisian Dinar (TND) is paired with economic dependence on France. Not only is TND still tied to the Franc, but an uneven import-export balance fosters structural dependence on the previous coloniser: 'As long as France has the means to constrain us, our political independence will be perfectly illusory' (Bourguiba in 1957 in Amrani, 1979). This debate culminates in the Bizerte crisis of 1961, which can be linked to the resulting path for land reform: 'The Bizerte crisis and its consequences fit quite easily into the political and economic dynamics that led to the (…) adoption of socialism in November 1964 in Bizerte. We must then see how the 700,000 ha of colonial land were integrated into the first part of the experiment of reforming agricultural structures, and especially in what political, ideological and economic framework it took place' (Amrani, 1979: 155-156). Simultaneously to the geopolitical crisis of Bizerte, the Neo-Destourien party is fighting an internal crisis of political domination and control. The assassination of Bourguiba's political opponent Ben Youssef in 1961, drowned out by the success

of the Bizerte crisis (ousting of French military presence on Tunisian soil), is considered the first blatant step on the path towards authoritarian repression.

The land reform was the centrepiece of the period of so-called Destourien socialism (1960-1969) (UGTT, 1967). It sought a. the equitable distribution of land (and water), and b. increases in agricultural productivity (although this paper will go on to show that the regime prioritised the latter over the former). The ‘land reform was in its core a social project’ [ACA4] in favour of agricultural production, which at the time sustained three quarters of the Tunisian population (Charbonnier, 1964). The land reform hoped to achieve these goals via two main avenues: a. limiting land ownership (limiting maximum and minimum area held by one landowner), and b. introducing irrigation cooperatives (raising water volumes available to individual farmers) [ACA4]. At the 7th Party Congress, President Bourguiba ties Destourien motivations of state-building to a new social agenda: ‘Property must therefore be considered a social function. It follows from this that no negligence is tolerated and that the land belongs to those who work it’ (UGTT, 1967: 16). In return for working the land as productive members of their agricultural cooperatives (so-called “production units”), new landowners are granted rights and livelihoods. Membership to cooperatives is mandatory and property rights are shared between its members, after a probationary period of a few years (Charbonnier, 1964). This new formula of collective farming, and water allocation, was designed to raise productivity by shifting the financial burden of rural development from the backs of isolated individuals to structured social groups. This transformation of the rural space was also a means for Tunisia to present itself as a nation that upholds international values of modernisation (Karem, 1989).

Pushing the notion of productivity at all costs, the regime unveils a range of ulterior motives during what can only be called an incomplete implementation of the equity-oriented ambitions of land reform. These motives see the prioritisation of agricultural productivity over promised social justice efforts at the expense of disadvantaged communities and political opponents of the regime. First, while the expropriation of colonial lands represented an initially useful political tool, high returns from colonial farms were regarded as even more useful: 'What is most important is not to put a Tunisian in the place of the French colonist; it is still necessary to maintain, and if possible increase, the level of production', Bourguiba states in front of his party's National Council in 1963 (Bourguiba in Charbonnier, 1964: 15). Second, Bourguiba pushes back against partisans of "Arab socialism" who are fighting for a more egalitarian allocation of resources: 'What exactly do they want?', he argues. 'Is it a question of enacting a law under which the lands would be confiscated, distributed, their owners thrown into prison? Such a spectacle would naturally excite the disinherited masses, who are always sensitive to the spectacle of the downfall of the great or the rich. If this is so, I will tell you frankly that I am not ready to make such a revolution. We know the resentments that have resulted in the countries that have chosen this path and the fall in production that has followed' (Bourguiba in Charbonnier, 1964: 20). Third, the land reform sought the abolition of traditional forms of production (and thought) deemed incompatible with the economic development of the country (Karem, 1989). The reform conveniently reshuffled rural order against the traditionalist agrarian opposition that were angered by the abandonment of Youssefist pan-Arabism. Traditional systems of land tenure and agriculture particularly those associated with religious institutions such as the habous were strategically outlawed (UGTT, 1967) - similar to previous efforts by the colonial oppressor.

The shift towards a productive irrigation society built on the notion of state-building and serves as a sufficient condition for the construction of the security pact (figure 11). Bourguiba infuses Tunisia with a new sense of “Tunisian-ness”, a communitarian nationalism that seeks to put a halt to conflict, divisions, and tribalism (Hibou, 2011). It is in this notion of civic patriotism and the identification of Bourguiba as its “creator” that the choice of a single unifying party is sought to be justified. In its decadal development plan (1962-71), the government directly links its vision of agricultural production to a social promise: 250 TND per year for families of five - 50 TND as the minimum individual income for a decent life (République of Tunisia, 1961). Presented as the only limiting physical factor to this promise, the question of water exploitation thereby becomes inextricably linked to social security. Agriculture is chosen as the key driver of the Tunisian economy - one that regulates and harmonises all other sectors by allowing for an equitable income distribution through agricultural cooperatives (UGTT, 1967). Two notions keep repeating themselves during interviews with key informants: ‘l’agriculture doit gérer tout’ [agriculture must manage everything] and ‘l’eau peut gérer tout’ [water can manage everything] [GOV2].

A leading political force since independence, the UGTT and its unionists make “water for agriculture” its key political priority in the 1960s. Having co-developed the land reform, the UGTT promotes the spirit of cooperatives as a tool to capture the public support of Tunisian citizens and integrate them in productive social communities: ‘The Tunisian experience is essentially based on the cooperative system. This system which can vary in form always tends to the same goal, to acknowledge the promotion of the peasants, to prepare them for community life and (…) for higher productivity. Another principle that emerges from all this is also a method: persuasion. This is one of the best means that we

have always used in our militant life before and after Independence' (UGTT, 1967: 17-18). Being a productive member of a cooperative (and therefore society), individuals would be coerced into a system of discipline and consensus which is safeguarded by the social promise of development. This exemplifies the construction of a security pact between the regime and rural farmers. Appealing to popular unity and social cohesion, the regime creates an undeniable "truth": 'Here is our program. From now on, no one has the right to hesitate, whatever his function, whatever his position (...). It is up to each of us, in each of our fields to help the realisation of this popular program' (UGTT in Amrani, 1979: 41). 35 years earlier in the Soviet Union, in an effort to join the ranks of the world's modern industrial nations, Stalin inaugurated a similar collectivisation programme, which sought to increase agricultural productivity and consolidate power (Wilson, 2019; Josephson et al., 2013; Wemheuer, 2014a; Wemheuer, 2014b). The UGTT (1967) acknowledges taking inspiration from the Kolkhozes and Sovkhozes farming systems of the USSR.

The road from discipline to repression is a slippery one. As a necessary means to protecting the security pact and the myth of public consensus, Bourguiba soon introduces an apparatus of social agents, which he justifies on the basis of the necessity of ensuring social order (République Tunisienne, 1965). The process of political domination is fostered by the populist rhetoric of state-building and the initial successes experienced by farmers, recently being able to afford investments collectively. Political control over "units of production" produces a fine-tuned apparatus of domination and repression onto the working class: 'The Neo-Destour supervises the population. Without this supervision, the success of the cooperative experience would be incomprehensible. In the boards of directors of most of the units there are leaders of local party cells - elected naturally like other administrators by the assembly of cooperators, but whose

presence reinforces the control of the Neo-Destour' (Charbonnier, 1964: 18). Despite the return to economic liberalism in 1969, the rhetoric of social development continued to prove useful in legitimising increasingly repressive means of control going forward. As one of the interviewees puts it: 'La notion du développement agricole, ça soulage l'état!' [the idea of agricultural development relieves the state] [GOV2].

In the following decades, direct involvement of the state becomes a necessity in all matters of water sector decision-making (Ministère de l'Agriculture, 1976). 'The state has taken charge of setting up and financing the basic infrastructure, from the construction of the dam to the installation of the irrigation terminal in the farmer's plot of land' (Elloumi and Gara, 1995: 99). The patrimonial political system of Bourguiba morphs into a 'modern administrative dictatorship' (Moore, 1970: 108). What the regime called 'a temporary and inevitable tutelage' practically equates to a monopolisation of all facets of political and social life in Tunisia, where the party 'insisted on loyalty from a passive population while maintaining a populist, participatory ideology' (Vandewalle, 1988: 605).

The weakening of the security pact: Economic decline and social unrest

By 1969, Tunisian socialism had suffered from rigid hierarchies, growing inefficiencies (Karem, 1989), and corruption, and was largely dismantled having encountered significant opposition from Tunisia's political elite. The break with socialist traditions was accompanied with 'the alignment of Tunisia with the model of a liberal Western economy and the strengthening of an authoritarian and repressive state' (Dakhli, 2021: 64). To counteract a lingering political and economic malaise, mounting debts owed to French banks, the decline of the

agrarian sector, the new system put in place in the second half of the 1970s intended to free up private investment and implement new public infrastructure programmes (Wright, 1982). The regime bowed to new wisdoms of liberalisation by drawing on inspiration from the success of the export-oriented industrialization of the East Asian tigers (Murphy, 1999). With financial support from the World Bank and IMF, structural adjustment and stringent austerity programs forced the closure of unproductive unités de production leading to a rise in unemployment accentuating regional disparities (Dakhli, 2021).

On January 26th 1978, often referred to as Jeudi Noir [Black Thursday], the country witnessed its 'biggest working class upheaval since Tunisia won independence in 1956' (Disney, 1978: 12). The, at that point half a million members strong, UGTT had called for a general strike, which was met with violence by the government, leaving more than 200 dead, thousands injured, and around 1600 arrested. The strike represented a sharp break from the previous co-dependency between UGTT and the government. Having acted as a transmission belt for the regime and its policies, the labour union's role had 'been as much to control the workers as to defend their interests' (Disney, 1978: 13). Evidence from police communications of the strike later reveal planned escalations of violence and that clashes between protesters and police/military forces were purposely provoked in order to justify a campaign of repression. After the events of Jeudi Noir, the government took control of the UGTT leadership but sources of discontent within the organisation and its workers continued to grow. Two years later, on January 27th 1980, a group of around 60 guerrilla fighters opened fire on a military base and police station in Gafsa, a mining town in the South of Tunisia (Wright, 1982). The uprising, which sought to rally Gafsa's citizen against the Bourguiba regime, was halted by Tunisian security forces after some days and several dozens of casualties.

In 1982, nearly two-thirds of unemployed are under 24 years old, representing a considerable and potentially hostile social force (Murphy, 1999). On December 28th, 1983, the so-called “Bread Riots” ignite. Lasting barely ten days and costing the lives of more than one hundred people, the riots fit into a chronology of the civil struggle against neoliberalism. The destabilisation of the Tunisian economy had been accompanied by price hikes and the withdrawal of redistribution policies. Beyond the sudden doubling of the price of bread, the Bread Riots of 1983 was a testament to an inherent social struggle: ‘More than hunger or poverty, what the demonstrators pointed to was the violation of a tacit social contract’ (Dakhli, 2021: 42-43). The strong symbolic value of the riots turned a seemingly unorganised and apolitical group of people into political insurgents. The events served as a natural extension of a confrontation with power, a theme that can be revisited as part of the Arab Spring protests. The strength of the campaign in 1983 lay in the appearance of hope and the imagining of a new open and progressive society. ‘The value of bread is less measured by hunger than by the gap, transformed into a divide within a few days, between those who can “be part of it” and those who remain on the sidelines’ (Dakhli, 2021: 67).

Despite this never-before-seen civil unrest, both in nature and extent, the regime of Habib Bourguiba showed little to no inclination to initiate or implement political reform. In the meantime, Islamic movements, most notably the Islamic Tendency Movement (MTI), had started to receive considerable public attention since the 1970s. Initially, the movement’s stance had not been to seek a monopoly on political expression but rather to add a contemporary Islamic meaning to the political debate (Vandewalle, 1988). When the entire MTI leadership had been imprisoned or exiled, after having asked the government for recognition as a political party, the movement gradually

politicised creating new splinter groups prone to violence. When Bourguiba insisted on a retrial and harsher sentences for Islamists arrested in early 1987, his prime minister, Zine el-Abidine Ben Ali, grew wary of a potential breakdown of the country's social order and took it into his own hands to effect a change in political leadership (Vandewalle, 1988). During the night of 6-7th November, a medical evaluation signed by seven doctors deemed Bourguiba incapacitated and silently removed him from office. What was thought to necessarily end in violence as an 'inevitable result of the polarization of Tunisian politics' (Wright, 1982: 134) instead took the form of a peaceful "medical coup d'état".

Regime 3: The Regime of Ben Ali

Construction of the security pact: A new era of discipline and coercion

The political events leading up to the decline of the regime of Bourguiba represent the boundary conditions for the subsequent regime of Ben Ali and illuminate political motivations for water sector reforms going forward. Ben Ali had near unanimous internal support and public appraisal for the so-called constitutional coup (referring to Article 57 of the Tunisian constitution stating that the president of the republic may be replaced in case of "death, resignation, or permanent inability"). The new five-year plan (1987-1991) foresees a great push for irrigation and water infrastructure development (Murphy, 1999) as well as the liberalisation of the Tunisian market: A near impossible task in a political system that had practiced clientelism and state control over pricing and planning even when and where private enterprise was allowed and encouraged. Ben Ali's liberalisation reforms showed promise in the 1990s, when the country received substantial external funds to implement

financial sector reforms, improve the competitiveness of Tunisian businesses, and privatize public sector enterprises (Angrist, 2013; Radwan et al., 1991). His increasingly autocratic rule was for a long time legitimized by his rational stewardship of the Tunisian economy.

In 1989, OMV-PPIs, locally managing public irrigation perimeters, were dismantled and absorbed by regional CRDAs (law no. 89-44/832). This tactic served the centralisation of water management by means of decentralisation or in other words a relay of power from technical institutions quasi-independent from the government to bureaucratic institutions representing the state itself [ACA4]. The new law charged the 24 regional CRDAs with the responsibility to implement agricultural policies at the regional scale including the maintenance and control of hydraulic structures, etc. (M'kadmi, 2005). Two years earlier, the Water Code had been amended by law no. 87-35 to endorse established collective interest groups, Associations of Collective Interest (AICs), today called Groupements de Développement Agricole (GDAs), and define practical responsibilities regarding operation and maintenance of hydraulic structures (Hamdane, 2019).

With law no. 89-44/832, authoritarian repression receives a new coat by the new regime. Quasi-decentralisation meant that from then on, every decision must pass through the regional representation of the agricultural ministry. With this integration of the state in the operationalisation of agricultural production (local monitoring of resources, creation of boreholes, installation of hydraulic equipment for drinking and irrigation water, etc.), the government directly involves itself in the everyday lives of farmers (M'kadmi, 2005). This shift also

triggers a loss of technical expertise: ‘dans les CRDAs on ne gère plus l’eau’ [in the CRDAs, we no longer manage water] [GOV2]. While OMVs were specialized, managed by water technicians, water management is only one of many divisions in CRDAs, managed largely by generalists [GOV2]. More promising efforts to decentralise agriculture, e.g. structuring water users into groups (GDAs), were overshadowed by theses centralisation effects. By creating a single instance for everything water-related, ‘le service à proximité est perdu’ [accessible service is lost] [GOV2]. Instead, technical proximity is replaced by spatial proximity of the state creating a new social dimension of water resources allocation and use. The power of the regime creates, coexists with, and mutual reinforces the omnipresent power of the administrative apparatus. ‘In the words of the jurist Mustapha Ben Letaïef, “governorate councils and municipal councils are structures that appear to be more like emanations of the central power, consecrating its territorial penetration and its hold on the local field”’ (Brochier-Puig, 2012: 59).

Power, in the regime of Ben Ali, was systematically exercised through a dynamic interplay of social and economic arrangements, negotiations, and informal contracts. Hibou (2011) draws on Foucault’s political anatomy of the detail (1975) to unpack mechanisms of instrumentalization by police institutions and practices, that shape domination beyond physical coercion. Diffuse supervision transcends “obvious” coercive repression, commonly associated with repressive regimes, and enters the realm of moral, administrative, and social policing. Daily life in Tunisia during authoritarian rule is shaped by the conjunction of apparent normality and perpetual obtrusive surveillance. Beyond what common analyses of repressive regimes suggest, it is seemingly banal practices that render constraint almost “invisible” and subsequently render conformity “voluntary”. Complementing standard forms of punishment, e.g.

detainment, political opponents would for example be coerced to present themselves at the police station multiple times a day, be subject to systematic police surveillance, and could expect unwarranted confiscation of important documents such as their social security cards. These disciplinary functions 'whose purpose it is to intimidate, to make an example of someone, to shape people's minds and define the outlines of the social norm' (Hibou, 2011: 6) are part of the so-called fringe strategy. It is through this exemplarity of exclusion that concealed procedures of domination are engrained in the social and economic reality, and personal interest, of Tunisian citizens. The interdependency of reciprocal relations between individuals results in the normalisation, and indeed often the acceptance and support, of disciplinary functions of the regime.

This institutionalisation of political and economic roles within the water sector can be linked to the rise of two phenomena: Hierarchisation and bureaucratisation. The power of administrative control holds a strong disciplinary grip on water users with seemingly banal bureaucratic requirements. The government assumes the role of 'supreme planning authority' (Omar, 2012: 135) and coerces Tunisian farmers into a strict regime as laid out in their plan economy: 'planners set constraints for the farmers, so for example, for a farmer with so many hectares, so many cattle (...), the planners take the liberty of forecasting the production of such and such quantities at such and such prices and the acquisition of such and such an income allowing the implementation of such and such an investment with such and such a grant and such and such a loan and the consolidation of such and such a debt at such and such a date' (Karem, 1989: 2). Prior to law no. 89-44/832, receiving well authorisations or assistance from specialised OMVs (e.g. for a new borehole) was a straight-forward process. Now that approval from

central government is required for well authorisations, the authorisation process is slowed down substantially (Kassah, 1995). Water resources management by the Tunisian government is handicapped by the bureaucratic heaviness and randomness of its administrative processes. The centralisation of power decision-making divides and isolates local production units and its stakeholders: 'Integrated in an extremely hierarchical circuit, the cooperative is isolated, in the sense that there are no possibilities of direct exchanges between the different cooperative production units of the same delegation or the same governorate' (Amrani, 1979: 231). In 1992, the structure for agricultural subsidies, e.g. funding for irrigation equipment, becomes centralised and channelled through one single national agency (Agence de Promotion des Investissements Agricoles, APIA). Previously, subsidy payments had been processed by regional CRDAs, who could hand out cheques directly on the spot [GOV2].

The weakening of the security pact: Unemployment and social unrest

New roles and responsibilities resulting from the shift from OMVs to CRDAs lack overall coherence and remain unclear to water users (Brochier-Puig, 2012). According to interviewees, the resulting uncertainty spurs "creative solutions" (such as illicit wells) as a response mechanism. Meanwhile local water management is delegated to GDAs, who unaccompanied by the government lack the capacity to work the new system or indeed implement laws (e.g. code des eaux of 1975). The uncertainty of rules and responsibility means that individual civil servants are unable to take initiative to ensure policies are implemented. Even if policies were clear and coherent, local decision-makers always require

unlocking of bureaucratic barriers, e.g. an official authorisation from a higher level of hierarchy (Hibou, 2011). Consequently, the institutional framework is a construct of social interdependencies, favoured by the extensive use of oral over written media. It follows, that 'a law, in its real effects, is much more closely linked to attitudes, to schemas of behaviour than to legal formulations' (Foucault, 1975: 308). Individuals who violate laws (e.g. drilling or taking water from an illicit well) will rarely think of their by-passing of the law as a politicised activity but rather a commonplace activity as any other.

Ben Ali's reforms continuously turn more superficial than fundamental and his stewardship more rapacious than rational. The consequent stifling of new investment and gradual dismantling of tariffs during and after the 1990s, notably pushed by the European Union and liberal trade agreements, delivered poor economic performance and growing unemployment, e.g. among university-educated Tunisians, an estimated 40-45% were unemployed (Angrist, 2013). These processes served as a sufficient condition for the weakening of the security pact (figure 11). As the negative aspects of a stagnant economy and the arbitrariness of a bureaucratic surveillance system outweighed the positive aspects of social promises, anger and disappointment grows within the Tunisian public. Bureaucracy is increasingly associated with lack of information and transparency: In the irrigation sector, a farmer who is denied their livelihood-sustaining authorisation would often not be given an explanation for this decision. As the security pact is weakening, the potential for frustration grows: "If my neighbour got his well authorised, why didn't I get an authorisation? How am I to make a living?" [UNO1].

The calm façade of the police state begins to crumble in 2008 when the country's biggest protest movement since the Bread Revolt (and the first

protests against Ben Ali) hit the city of Gafsa. The revolt started after a public phosphate company in Gafsa, a region ridden by unemployment and general economic distress, did not keep their promise of hiring marginalized local workers but instead individuals with proven connections to the regime. Although the strikes mobilized a wide range of social fractions from mine workers to unemployed graduates and internet activists, they were unable to withstand the coercive policies of the regime and remained regionally constrained due to limited national support (Marzouki, 2011).

On 17 December 2010 in the town of Sidi Bouzid, fruit vendor Mohamed Bouazizi is stopped, interrogated, and harassed by the police. For the lack of official papers, he sees his stand confiscated. In an act of complete despair, he sets himself on fire in the centre of the town and dies hospitalized a couple of days later. It was in the humiliation that this incident produced, that the Arab spring started. 'As with bread [during the Bread Riots of 1983], it was not simply a confrontation, or a discussion about a corrupt system (although this was also a central issue), but a political statement, from the working classes, on the meaning of social justice' (Dakhli, 2021: 68). Nationwide protests, populated by citizens from all socio-economic classes and across political divisions with shared aspirations for political liberties, trigger Ben Ali to step down on 14 January 2011. The link between social unrest and perceived violations of promises of social security holds relevant for modern-day debates on water sector reforms.

d. Conclusion

This Following a political sociology lens to water resources management, this analysis has traced historical processes that causally link (agricultural) water

sector reforms in Tunisia to the creation of a security pact - and in its maintenance authoritarian repression and self-reproducing social norms. Bundled land and water reforms transformed rural spaces and created standard operating practices to re-structure land and water use and there-embedded social interdependencies between water users and the state. This in turn contributed to the institutionalisation of legitimisation, repression, and co-optation of water users. The above case-study of water governance systems served to expand theories of authoritarian control and the “selectorate” to trace the evolution of irrigation systems as materialisation of non-democratic politics, and vice-versa how non-democratic procedures can be facilitated by water sector reforms.

The analysis set its stage during the French protectorate, a regime that saw the systematic redistribution of land and water resources by juridical normalisation (a foreshadow of the repressive tactics employed in Tunisia’s later regimes). The steps that led to Tunisian independence in 1956 also lay the foundation of the symbolic vehicles of state-building used to legitimise policy shifts in the water sector in the decades to follow. In the name of social security, the regimes of Bourguiba and Ben Ali consolidated political power by reshuffling rural order and associated irrigation systems (laws no. 63-18 and 89-44/832 respectively). Irrigation intensification served as the social promise justifying the centralized presence and increasingly repressive force of the administrative apparatus and its bureaucratic co-optation tactics over farmers.

In the contemporary history of Tunisia, social unrest was born when individuals or groups of individuals felt the security pact was violated. In other words, the “force of obedience” (Hibou, 2011) weakened when positive elements of the pact, no longer outweighed the violent and humiliating dimensions of the

repressive regime. For example, threats to a decent standard of living incited the bread riots of 1983, the Gafsa strikes of 2008, or the self-immolation of Bouazizi in 2010. The role and value of water for livelihoods and job security is relevant to this very day: In the public discourse, threatening farmers their access to water, whether in the form of raising water prices or closing illicit wells, essentially means taking their livelihood, their very means of existence. Decades of forging an apparatus of repressive surveillance gave rise to widespread distrust in formal rules and to informal contracts between water users and communities, which developed in part as coping mechanisms and in part as reinforcements to existing hierarchical structures. On the other hand, as a consequence of the decadal erosion of decentralised institutional and technical capacity, there remains a continued dependence on centralised government in water resources management: 'La locomotive c'est l'état' [the government is the engine] [NGO1]. In this sense, the state is simultaneously distrusted and made responsible for solving contemporary water issues.

The paper was able to link resource management policies to mechanisms of state-building by authoritarian regimes. The study of the evolution of water rules and institutions highlights the importance of social interdependencies governing water use and allocation in present-day Tunisia. The historical analysis of policy outcomes marks the erosion of institutional trust and regional capacities, the perversion of social promises for repressive ends, and the coercive construct of informal, hierarchical, and bureaucratic interdependencies that are still alive today. The author believes that it is important to understand the past, more precisely the pathways of decision-making in space and time, to understand what avenues for policy-making and practical institutional support are available and meaningful in the present. The past can serve as a tool for precaution, e.g. in relation to recent calls for a new

water-police to combat illegal wells, and as an indicator for policy potential e.g. collective action in water user groups. As Tunisia enters an uncertain political future as well as a growing (ground)water crisis, grounding policy interventions in empirical evidence is pertinent not only to reach sustainable resource use but moreover to ensure the protection of current and future livelihoods.

Paper 2: Trust, Hope, and Collective Action in Fragile Political Settings: A Qualitative Comparative Analysis of Water User Groups in Tunisia

Authors: Sophie Erfurth[a,b], Dustin Garrick[c], Constance McDermott[a]

[a]Environmental Change Institute, University of Oxford, Oxford, UK
[b]Smith School of Enterprise and the Environment, University of Oxford, Oxford, UK
[c]School of Environment, Resources and Sustainability, University of Waterloo, Waterloo, Canada

Abstract

Collective action theory acknowledges that self-governing institutional arrangements, such as water user groups, can successfully develop strategies to address natural resource problems. However, studies of collective action have largely neglected the role of social, political and/or ecological fragility, where institutional trust and hope may have been eroded over time, and where natural resources are severely depleted. Building on an in-depth background diagnostic of contextual factors and theoretical conceptions of trust and hope, this paper studies the pathways that mediate the relationship between trust, hope, collective action, and resource scarcity in water user groups in post-authoritarian Tunisia. The analyses are based on data from archival sources, key informant interviews, hydrogeological models, local inventories, and semi-structured interviews with 15 local water user groups in the governorate of Kairouan. Results from Qualitative Comparative Analyses shed light on dynamics of trust and hope as well as the substitutability of shared norms under given ecological conditions. Results demonstrate that water users see social trust-based systems as an alternative to the coercive power of the state. Social cohesion and the expectation that other water users stick to local, often informal, rules were found to increase collective action, i.e. fee recovery, under systemic fragility. While depleted aquifers, as measured by low levels of hydraulic head, are often associated with higher levels of fee recovery,

they are also linked to more frequent conflicts among water users. This paper furthermore tested hypotheses related to hopelessness, finding that conflict is more frequently associated with low-hope environments, where users are unable to perceive the possibility of positive system change. These results seek to inform more realistic policy reforms tailored to path-dependent water governance systems.

Under consideration at the journal of
World Development
(submitted on 28 August 2023)

a. Introduction: Research aim and objective

Collective action theory serves as a useful tool in studying the varied forces that govern water resources management in Social-Ecological Systems. However, collective action research rarely focuses explicitly on the role of fragility in the emergence and endurance of collective action. North (1990) and Ostrom (1990) emphasise the importance of stable institutionalised structures of behaviour – structures in which rules draw up a set of standard routines for individuals and thereby reduce the uncertainty of personal decision-making. Yet this raises critical questions about whether and how collective action may also occur in social-ecological systems subject to chronic socio-political disturbances, institutional fragility, and/or severe levels of ecological degradation.

This research paper studies water resources management and associated collective action dynamics in water user groups in post-Authoritarian Tunisia. Using empirical evidence from interviews, archives, and secondary data about contextual factors, the paper outlines systemic collective action challenges in the context of institutional, social, and ecological fragility contributing to research on the role of disturbances in Social-Ecological Systems (Schoon and

Cox, 2012). It examines whether and how collective action can serve as a substitute to state intervention and seeks to identify the pathways most frequently associated with cooperation or conflict in water user groups. The paper will further explore where social-ecological conditions, such as low levels of hope or groundwater levels, present practical limits to successful community management of water resources. We compare case studies of local water governance using Qualitative Comparative Analysis (QCA), a method that combines qualitative and quantitative inquiry to identify diverse causal mechanisms across case studies. QCA draws on case study data to understand the conditions that lead to an outcome, i.e. co-operation or conflict, in situations where there are multiple possible causal paths.

This paper's analysis is grounded in theories of historical institutionalism (Steinmo, 2008), which place a strong emphasis on understanding context. We focus on two particular issues – trust and hope – that have been identified as critical factors in the context of fragile states. Fafchamps (2006) identifies trust as a key success factor for achieving collective action in the absence of state rules. Analysing dynamics of trust, both within communities as well as between individuals and the state, is therefore key to understanding the social and political relations that govern water resources management in fragile settings (Dunn, 1984). Research on collective action and social change commonly targets high-hope environments, settings where individuals are generally hopeful about their shared future (Cohen-Chen and Van Zomeren, 2018). Limiting collective action research to high-hope environments, however, disregards settings where individuals may not even conceive of the possibility of positive system change.

In order to strike a useful balance between ‘depth and breadth’ (Ragin, 2000: 22 in Levi-Faur, 2004: 178) in water resources management research, Mollinga and Gondhalekar (2014) suggest as a stepwise small-N/ medium-N methodological approach to qualitative comparative analyses. In line with this approach, this paper is structured in three parts: A contextual diagnostic of the Tunisian water sector, a literature review on theorisations of trust and hope, and an analysis on causal pathways of collective decision-making in local water user groups (using QCA), with respect to fee recovery and conflict among users. The diagnostic serves to provide substantive insights on social-ecological phenomena, processes, and events in the specific context of political fragility. The literature review on trust and hope defines formal concepts and is used to unpack the multidimensionality of key social-ecological phenomena that are studied in the subsequent comparative analysis. QCA draws on both qualitative and quantitative data to explore which combinations of local characteristics, varying degrees of trust, hope, leadership, and hydrogeology, are commonly associated with success or failure of irrigation water user groups. Using geospatial analysis of existing hydrogeological models and well inventories, we can identify behavioural patterns across diverse resource settings. QCA results are further interpreted using empirical qualitative insights from interview data.

b. Contextual Analysis

Orbell *et al.* (2004) argue that the context within which resource users face social-ecological dilemmas is more relevant in explaining outcomes of collective action than conceptualisations of a-contextualised models of rational behaviour. A diagnostic of contextual factors, in line with Mollinga and Gondhalekar (2014), therefore serves as the backbone for the identification of key social norms and subsequent case-specific analyses of local decision-making. Since

trust and hope are subjective phenomena based on judgements or perceptions (Rose and Mishler, 2011), a detailed account of water users' practical challenges, social expectations and dependencies is crucial in order to understand possible emotional responses to these sets of challenges and their relationship with the state of political fragility they are embedded in.

The following diagnostic grounds itself in an in-depth literature review of peer-reviewed and archival sources (National Archives of Tunisia) as well as 17 key informant interviews, which are discussed in greater detail in the methods section below. Key informants include representatives from the government of Tunisia (both past and present), Tunisian civil society and NGOs, trade unions, Tunisian experts at international development organisations, and local academia. Interview quotes will be referenced using unique interviewee codes representing the respective groups (e.g. GOV1, NGO2, UNO3, DEV4, ACA5).

Water resource availability and the role of irrigation

Water resources management in Tunisia is inherently linked to questions of agricultural development and social security. To support farmers and the local economy during recurring droughts, agricultural policies over the past four decades have subsidised irrigation agriculture with low economic water productivity. In short, to counteract the natural phenomenon of water scarcity and to raise revenues from agricultural production, farmers were encouraged to increase overall production of low-value crops (rather than the value of individual crops) in a paradoxical shift towards irrigation intensification under increasing water scarcity. Existing laws targeting water rationalisation are not enforced so as not to burden farmers that existentially rely on income from low-value crops. As a consequence, 80% of water withdrawals are dedicated for

irrigation purposes (Guissouma, 2009). According to Chouchane *et al*. (2015), 87% of Tunisia's water footprint is used for crop production.

In the absence of enforceable regulatory limits to extraction (Friya *et al*., 2014), the search for increasing water supplies for an increasing population has reached physical limits to extraction. The gradual but intensive push for groundwater exploitation has left aquifers overexploited (133% exploitation according to MARHP, 2017) with an estimate of 48% illicit wells (of total wells). Meanwhile, the capacity to store surface water resources is on a gradual decline due to ageing dam infrastructure and recurring droughts (MARHP, WWW). Struggling to satisfy ever-rising demands with ever-shrinking water supplies, the Tunisian government puts hope into non-conventional sources of water – with desalination, aquifer recharge, and wastewater recycling high on the political agenda (MARHP, 2020). This represents a continuation of the administration's efforts to solve social (i.e. water demand) problems, particularly with regards to rural development, with technological solutions (i.e. water supply).

A growing sense of injustice

Political activist Nadia Khiari (2020) puts it best when describing the popular disenchantment with post-Arab Spring politics in Tunisia: '*La revolution, c'est bon mais c'est long*' [revolution is good but it's long]. The state of political pluralism, which was introduced after the Arab Spring of 2011, is one that Tunisians had practically never known. The making of a democratic state seems to have been stalled while urgent structural and economic reforms are being postponed due to the priority of an institutional transition, and the fear of passing unpopular reforms (Schäfer, 2017). In a global review of local and

national politics of groundwater overexploitation, Molle *et al*. (2018) argue that 'groundwater policy making is frequently premised on an overestimation of the power of the state, which is often seen as incapable or unwilling to act and constrained by a myriad of logistical, political and legal issues' (445). In the case of Tunisian groundwater governance, it is important to analyse the capacity of the state within its context of political fragility. According to a Tunisian key informant from the development sector, institutional arrangements and relationships between those who govern and those that are governed are littered with fear: 'The institutions are afraid of the citizens. They are afraid to implement the laws' [DEV4].

The present environment for policy- and decision-making in the water sector is underpinned by a history of repression, the struggle against repression, and modern challenges of democratisation. According to key informants, the failure of water institutions to address pressing water challenges and the dissolution of individual agency in a democratic Tunisia is conditioned by decades of a repressive administrative apparatus: 'The state has done everything to ensure that there is no democracy in its institutions' [ACA2]. Having blossomed throughout the Ben Ali-era (Arouri *et al.*, 2019), clientelism and corruption are 'still very much alive today. It is now that we see the consequences' [ACA4]. At the local water user level, unequal access to water resources is a source of tension between farmers, and between farmers and local authorities (Fautras, 2014). The variable nature of conflicts is driven by institutional arrangements that were designed during authoritarian regimes (Fautras, 2014). Pessimists among key informants predict an acceleration of the race to the bottom of the well and the exacerbation of inequalities due to ever-increasing costs associated with drilling deeper wells: 'The challenge of access to water is the reorganisation of space and segregation. It is a story where the rich get richer,

and the poor get poorer' [ACA3]. Protests and manifestations against inadequate water supply are common (Morin, 2014) and while they largely target drinking water issues, they frame public discourse on water resources and thereby influence policy debates on irrigation management.

Water security is inherently linked to social promises of agricultural productivity. Central to that promise is the understanding that water provision is plentiful and cheap (or even free). 'Agriculture is a large consumer of water in quantity and cannot pay for its water at a high price, if the agricultural activity is to remain profitable' (Ministère de l'Agriculture, 1976: 13). Prices for agricultural water notoriously do not cover extraction costs – let alone externalities (Sghaier, 1995; Kassah, 1995). Recent efforts by the administration to implement existing water laws and raise water prices are met with resistance. Opponents of these efforts argue on the basis of social justice: 'An illicit well is not a choice', says one of the interviewees, 'for many farmers, the question of drilling, of access to water, has become a question of live or die' [UNO1]. The rigid bureaucracy associated with well authorisations often lack transparency. Farmers who are denied an authorisation do not receive an explanation and frequently feel humiliated [UNO1]. Experiences of farmers who are denied a livelihood because of a missing authorisation reignite public memories of Mohamed Bouazizi, the Tunisian street vendor who, without an authorisation and humiliated by the police, triggered the Arab Spring in 2010.

Where historically central authorities have encouraged irrigation intensification at low/no cost, and have failed to accompany farmers through water regulation reforms, farmers who are now asked to pay for water and prove their authorisation status feel betrayed. Without trust in government institutions, farmers may feel it wiser to not engage with water authorities in 'fear

something could be confiscated' [NGO2]. There is little public understanding of the source of the current groundwater crisis (i.e. irrigation intensity). With an overwhelming sentiment of injustice thrown upon them, farmers frequently see the state as the enemy to blame for the growing water crisis [NGO2].

The role of local water user groups (GDAs)

In 1987, the Tunisian Water Code of 1975 (law no. 75-16) was amended by law no. 87-35 to endorse established collective interest groups, Associations of Collective Interest (AICs), today called *Groupements de Développement Agricole* (GDAs), and define practical responsibilities regarding operation and maintenance of hydraulic structures (Hamdane, 2019). Law no. 2004-24 completed the amendment of law no. 87-35 regarding GDAs and further extended their role in managing and rationalising water use. GDAs are thereby tasked to locally manage water infrastructure and equipment and are encouraged to engage in income-generating activities to facilitate these services. GDAs further carry responsibilities to supervise water users and advise them on appropriate and efficient agriculture techniques.

While responsibilities for GDAs grew continuously, their capacity for financial and administrative management remained limited resulting in chronic account deficits, and frequently bankruptcy (Frija et al., 2014). In addition, and as a result, low supply-reliability and service disruptions have severely harmed the reputation of these institutions (Marlet, 2013). GDAs serve as intermediaries between regional administrations (CRDAs) and water users. While the on-paper institutional framework for local water user groups is relatively advanced, their capacity for financial and administrative management is often limited due to the lack of state funding (Frija et al., 2016). Where roles and responsibilities

between stakeholders are inadequately defined or responsibilities exceed practical capacities, blame games ensue (Al Atiri, 2007; Ben Salem *et al.*, 2007; Frija *et al.*, 2014). Collective action problems include illegal water abstractions, inadequate fee recovery, and conflict among users, all of which regularly lead to the collapse of GDAs and associated Social-Ecological Systems (e.g. in the chosen geographic focus of the study, around half of the GDAs have collapsed). Despite the adoption of new public policies, initiatives to effectively empower self-regulation often remain political slogans disconnected from the reality of water user organisations (Frija *et al.*, 2016).

c. Literature review of key variables of interest

Mollinga and Gondhalekar (2014) argue that comparative analyses and subsequent theorisations of complex configurations are handicapped without appropriate formal concepts and frameworks. Based on the above diagnostic, two key core analytical lenses were identified: Trust and hope. These themes present key drivers as well as limiting factors for collective action in the given context of political fragility and give crucial insights into mechanisms of decision-making in water user groups. Following a literature review of each theme, variables pertaining to the subsequent analysis will be introduced, and research questions defined.

Trust

Gambetta (1988) and Mayer *et al.* (1995) argue that the concept of trust in the broader literature is widely treated as a non-descript phenomenon that eases social transactions. This paper hopes to apply a more nuanced look into the different relational dimensions of trust. The following paragraphs will first analyse the historical role of trust in Tunisian society, and ultimately

differentiate between trust relationships across scales, e.g. institutional versus social trust.

In settings of strong impersonal trust, e.g. generalised trust in institutions, an over-reliance on procedural norms, social policing, and insurance-like arrangements can give rise to opportunities for the abuse of trust relations (Shapiro, 1987). Everyday mechanisms of control and co-optation, such as were common during Tunisia's authoritarian regimes (Hibou, 2011), have the ability to conceal abuses of trust under a cloak of discretion, where interdependencies between actors render lower levels of trustee performance socially acceptable (Kneier *et al.*, 1976). Given that it takes time to build trust, how is the evolution of trust affected by system shocks, such as the Arab Spring? Sapsford and Abbot (2006) argue that trust and confidence suffer under sudden negatively perceived change. The Arab Spring and its consequences bore a series of negatively perceived events for Tunisians: The coming-to-terms of the abuse of trust by former Authoritarian governments, social unrest, vandalism, a series of government failures post-2011, etc. How do trust and fragility interact with each other? Shapiro (1987) argues that trust is 'a social relationship in which principals – for whatever reason or state of mind – invest resources, authority, or responsibility in another to act on their behalf for some uncertain future return' (626). It follows that arguably, trust is only necessary if individuals are taking part in an interaction involving risk (Deutsch, 1958; Sitkin and Pablo, 1992). On the flip side, interactions are most dependent on trust during times of turmoil, where the resource of trust may be limited. Kee and Knox (1970) argue that phenomena of trust can only be appropriately studied where meaningful incentives are at stake.

In fragile settings, 'collective action can serve as a substitute to the state. However, because it cannot rely on the coercive action of the state (e.g., the ability to tax and enforce contracts), collective action is much harder to set in motion. Two essential ingredients are then required: leadership and trust' (Fafchamps, 2006: 1185). It is important to note, however, that trust is not only a necessary condition in the absence of an external control mechanism but at the same time an extension of the historic legacies of said control mechanism. Trust has frequently been studied following a disenchantment with traditional organisational theories of "command and control" (Kramer and Cook, 2004). This paper does not regard trust as an antithesis of command and control, but rather explores concepts of trust within a post-authoritarian context of learnt behaviours and social interdependencies such as are relevant in contemporary Tunisia. Research has shown that individuals turn to their insurance policies and clientele networks when national institutions fail or stagnate (Roniger, 2004; Yasun, 2022). Such networks of dependency established during authoritarian rule continue to play a central role in post-Arab spring settings (Elvira *et al.*, 2018).

Trust is relational (Levi and Stoker, 2000) and multi-level, involving both individuals as well as groups or aggregates such as governments (Weatherford, 1992). Trust relations can therefore vary greatly, from interpersonal trust between individuals (social trust) to impersonal generalized trust in institutions or government (institutional or political trust) (Fafchamps, 2006). The relationship between institutional and social trust has been given much attention in the literature (Hakhverdian and Mayne, 2012; Zmerli, 2012; Mishler and Rose, 2001) – without conclusive consensus. Putnam (1993), for example, argues that institutional trust is a mere extension of social trust. Their "social trust approach" envisages spill-over effects from a general propensity of

trust for institutional trust and compliance (Kaasa and Andriani, 2022). There also has been evidence supporting a reversal of the causal ordering put forward by Putnam arguing that a trustworthy government can generate higher levels of social trust on a community level (Fukuyama 1995; Levi and Stoker, 2000). In general, 'it is conceivable that social trust and political trust are unrelated to each other, or related only spuriously' (Levi and Stoker, 2000: 493).

'Trust in public institutions [institutional trust] manifests itself when citizens assess public institutions as promise-keeping, accountable, efficient, competent, caring, predictable, open, transparent, fair and honest' (Kaasa and Andriani, 2022: 46). In understanding generalised trust in government (Lubell, 2007) in Tunisia, it is useful to unpack concepts of trustworthiness and trustees' propensity of trust and track them onto the historic legacy of trustor-trustee relationships. According to Mayer *et al.* (1995), perceived trustworthiness is based on three characteristics of the trustee: ability, benevolence, and integrity. Or in the words of Peters *et al.* (1996), perceptions of knowledge and expertise, concern and care, and openness and honesty. Experiences of the past will shape trustworthiness perceptions: 'The higher the trustor's propensity to trust, the higher the trust for a trustee prior to availability of information about the trustee.' (Mayer *et al.*, 1995: 716). In Tunisia, historic overreliance on the benevolence of authoritarian regimes and consequent disillusionment of government's ability and expertise to respond to pressing water issues has led to an updating of prior perceptions of the government's trustworthiness. The 'expression of trust in government (…) is a summary judgement that the system is responsive and will do what is right even in the absence of constant scrutiny' (Miller and Listhaug, 1990: 358). This personal judgement or perception of the government's output is in many regards more revealing than objective measures of outputs (Rose and Mishler, 2010). Even when governments

objectively achieve the attributes of trustworthiness, e.g. efforts of democratisation in post-Arab Spring Tunisia, individuals may still not have adequate propensity to trust the government to act in their interest (Levi and Stoker, 2000).

Social trust, on the other hand, relies on a slightly different set of mechanisms. Levi (1988) argues that an individual will conform to a set of rules if they feel that the collective objective is being achieved and that other members of the community comply with rules. In community-based settings, compliance should further be linked to prestige, where the protectors of rules gain while the offenders lose status and prestige: 'Individuals have shared a past and expect to share a future. It is important for individuals to maintain their reputations as reliable members of the community' (Ostrom 1990, 88). How is social cohesion and reputation affected by chronic unrest as witnessed in (post-)Arab Spring Tunisia? Seabright (1993) and Ostrom (2007) argue that heuristic repetition is key in allowing reputation to evolve as a community value that strengthens social trust. Further, Gambetta (1988) defines trust as the subjective judgement of one individual assessing another individual's probability of performing a given task. Systemic risk and fragility may render decision-making more erratic and thereby challenge the ability of community members to predict individual behaviours of other members. Leadership is also positively associated with community levels of trust, where leaders are 'capable of convincing community members that they should voluntarily contribute to the public good' (Fafchamps, 2006: 1185; Tooby *et al.*, 2006). This paper seeks to contribute to the literature on trust by highlighting interactions between varying social dimensions of trust (institutional and social trust), hope, and ecological degradation (groundwater depletion) in the context of fragility in Tunisia.

Hope

The possibility, or rather the perceived possibility, of change is explored by the discrete emotion of hope defined as a cognitive and emotional appraisal that a meaningful goal is achievable (Averill *et al.*, 1990; Lazarus, 1991; Cohen-Chen and Van Zomeren, 2018). Hope hereby reflects a particular mentality about the future and associated goals. Goals are not solely individual pursuits but comprise communal or shared future goals (Snyder and Feldman, 2000). People in "high-hope" contexts are able to reflect on shared goals and develop pathways and agency thoughts about said goals. The concept of hope is largely understudied in collective action research, and the few studies on hope generally target environments of high-hope (Cohen-Chen and Van Zomeren, 2018). Group efficacy beliefs, the shared understanding that the so-called ingroup is able to unify and attain social change (Van Van Zomeren *et al.*, 2012), have been found to only predict collective action in settings where hope is high: 'Without hope, there can be no basis for agency, which informs goal-directed action' (Cohen-Chen and Van Zomeren, 2018: 50). Hope thereby serves as a necessary condition for group efficacy beliefs, i.e. the belief that a group can achieve social change necessitates that this change is perceived as possible in the first place. It follows that arguments on the interaction of political trust and efficacy (Gamson, 1968) are likely not to hold in a low-hope context where individuals may find the group's ability to drive change irrelevant. While hope, e.g. independent of group efficacy, may be a weak indicator of the practical collective agency of the group, research has indicated positive relationships between hope and cognitive flexibility, creativity, and conciliatory attitudes (Lazarus, 1991; Clore *et al.*, 1994; Cohen-Chen *et al.*, 2014; Halperin and Gross, 2011; Moeschberger *et al.*, 2005). Hope, serving as a psychological resource that makes collective action desired and realisable, can further enhance

attitudinal changes in conflict resolution (Cohen-Chen *et al.*, 2017; Leshem *et al.*, 2016).

Hope, or lack thereof, can be structural and does not necessarily have to be tied to whether individuals or groups have agency over a situation (Bruininks & Malle, 2005). Systemic lack of hope, and as a consequence low agentic thought, can arise through frustration in government: 'In short, if government does not create an environment in which it is possible to rise on merit and effort expended, whole groups of people will simply stop trying. Such a government encourages its citizens to feel hopeless in the face of impending environmental and collective social disasters' (Snyder and Feldman, 2000: 406). Exposure to such "unsolvable" problems critically reduces individuals' motivation to take on new challenges and diminishes creative problem-solving capacity (Mikulincer, 1986; Scherer, 2022). The stressful feeling of helplessness associated with repeated experiences of negative events is linked to social identity theory, which suggests that collective action can likely only occur when groups and individuals can imagine the possibility of a different future (Ellemers, 1993; Tajfel, 1978).

A troubled past of political (and social) fragility can be reconstructed in the collective memory of communities (Misztal, 1996). Perceptions of hope and trust can be constructed and sustained as a collective habitus in the memories of group members. The ability to long-term plan, for example, will be influenced by the memories of past failures and visions of a distant future. Research has shown that individuals in high-hope environments are more likely to develop long-term goals and pathways to reach these goals (Snyder, 1994; Snyder *et al.*, 1991). If we understand future goals as targets of mental action sequences (Snyder, 2002), under which circumstances are individuals able to construct

collective goals in low-hope environments? In this paper, we hope to contribute to collective action research in settings of low hope using the example of Tunisia, with a focus on how hope interacts with other social-ecological conditions that influence local decision-making processes, such as trust and groundwater decline.

Research questions

A review of the above literature leads to the following general hypothesis: Trust in government, social (community-level) trust, and hope for the future increase collective action in fragile political settings. A more context-specific nuancing of these themes is necessary to unpack these dynamics across scales. Under the thematic groups of trust and hope, six conditions were refined (table 4). Under the general theme of trust, we focus on conditions of generalised trust in government, social cohesion, perceptions of equitable distribution of resources, and the expectation of rule-following within the water user group. Hope is analysed in terms of visions of individual and collective futures: The likelihood of foregoing present benefits for future benefits, and the imagined possibility of a "positive sustainable water future". In addition to trust and hope, we added leadership as a so-called conjunctural condition in order to examine combined interaction-effects between trust, hope, and leadership. Independent of contextual fragility, leadership is widely referenced in the literature as a key driver for local collective action (Meinzen-Dick, 2007; Rueden *et al.*, 2014; Glowacki and Rueden, 2015). By adding leadership as another condition, we can explore complex interactions of trust and hope under varying levels of leadership (and vice versa interactions of leadership under varying levels of trust and hope). Leadership is examined based on leaders' characteristics, motivation, and outcomes such as effective maintenance or conflict resolution

(Fafchamps, 2006; Meinzen-Dick, 2007). We also analysed two ecological conditions, groundwater levels and surrounding density of illegal wells to explore resource availability as a potential driver or limiting factor to collective action within given settings of trust and hope (Uphoff *et al.*, 1990). Outcomes capture two collective action processes: Fee recovery as a proxy of cooperation, and conflicts among users (table 5).

Using the example of Tunisia to understand the complex interactions between social-ecological conditions and individual outcomes of collective action in a fragile political setting, the following research questions have been developed. Overarching research question: How do trust and hope shape the likelihood of collective action under systemic fragility? Sub-questions: How do trust and hope influence fee recovery and conflict among water users? How do ecological conditions mediate these relationships? What pathways, i.e. causal combinations of these social-ecological conditions, drive dynamics of collective action?

Table 4 Table of QCA conditions

Type	Theme	Condition	Definition*	Data source
Social	Trust	Trust in government	Perceived expertise, benevolence, and integrity of the government	Interviews
Social	Trust	Social cohesion/reputation	Importance of social peace/opinion of others	Interviews
Social	Trust	Equity	Perception of fairness	Interviews
Social	Trust	Expectation of rule-following	Expectation that members follow rules without monitoring	Interviews
Social	Hope	Hope	Possibility of a positive future of sustainable water management	Interviews
Social	Hope	Discounting/Ability to long-term plan	Likelihood of forgoing present for future benefits	Interviews
Social	Leadership	Leadership	Capacity to motivate members, engage in conflict resolution	Interviews
Ecological	-	Groundwater level	Hydraulic head in 2016	MODFLOW groundwater model built by National Agronomic Institute of Tunisia (INAT) in 2018
Ecological	-	Density of illegal wells	Density of illegal wells in 5km radius	Field campaign conducted by National INAT in 2016

*see annex 1 for respective interview questions

Table 5 Table of QCA outcomes

Outcome	Definition*	Data source
Fee recovery	Percentage of fees recovered from farmers	Interviews
Conflict	Frequency and severity of tensions and conflicts between users	Interviews

*see annex 1 for respective interview questions

d. Methods

Background Diagnostics

Qualitative background data stem from peer-reviewed and archival sources (National Archives of Tunisia) as well as a set of 17 key informant interviews conducted in the capital Tunis in November and December 2021. Key informants from government, civil society and NGOs, trade unions, development

organisations, and academia were sampled based on established professional networks, online investigation, and snowballing techniques. All interviews followed ethics protocol of the School of Geography and the Environment, University of Oxford [approval number: SOGE 1A2020-183].

QCA Analysis

Qualitative data for QCA analysis were collected using another set of interviews with 15 local water user groups in the governorate of Kairouan in May 2022 (guiding questions and corresponding variables in annex 1). The governorate, Kairouan, covers an area of 6 712 km² and has a population of 599,560 inhabitants as of 2021, making it the eighth-most populous out of the 24 Tunisian governorates (Statistiques Tunisie, WWW). The choice of geographic region stems on the one hand from the critical importance of (ground)water for irrigation and livelihoods in the area and on the other from its relationship with social unrest (Kairouan's neighbouring governorate of Sidi Bouzid was the very birthplace of the Arab Spring). Kairouan has witnessed severe groundwater exploitation in the past decades (Snoussi *et al.*, 2022). Due to hydrogeological diversity and differences in groundwater use and management, depletion outcomes vary across the aquifers – with some water user groups sitting on empty wells, while others continue to harvest artesian flows. Failures in collective action have led to low fee recovery and water user groups running bankrupt. The resulting threats to farming livelihoods have inspired longstanding efforts to effectively model hydrogeological dynamics in the region. The variability of social-ecological dilemmas in combination with the

availability of existing groundwater data and models, and established research connections led to the choice of Kairouan as a study site.

Water user groups were chosen based on the geographic extent of an established groundwater model, a MODFLOW model of the aquifers Sisseb, AinJloula, AinBoumorra, and Chougafia elaborated by the National Agronomic Institute of Tunisia (INAT) (Hamdi *et al.,* 2018). Hydrogeological data were extracted from the model using the Python package FloPy and analysed with the geospatial software QGIS. A local inventory of illicit wells, based on a field campaign conducted by INAT in 2016, was also analysed using QGIS. All agricultural water user groups covered by the model and inventory were investigated in the study (in total 15 water user groups distributed across 15 villages). Semi-structured interviews were conducted in Tunisian Arabic and translated to French by a local expert. We employed purposive sampling, i.e. snowballing, in order to identify individuals who can share their own perspective but also account for the broader experiences within the GDA (1-7 interviewees per water user group). All interviews followed ethics protocol of the School of Geography and the Environment, University of Oxford [approval number: SOGE 1A2020-183]. Interviews will be referenced using unique codes for each water user group: G-GDA stands for groundwater user groups (10 in total), S-GDA stands for surface water user groups. Information was further triangulated from multiple data sources (administrative records, inventories and models by local research groups, etc.) to i) corroborate for contradicting statements from interviews, and ii) calibrate measures for subsequent analysis to create a spectrum of variation along which GDAs can be ranked relative to one another.

This paper draws on Qualitative Comparative Analysis (QCA) in order to unpack causal complexity in Socio-Ecological Systems. QCA follows principles of combined causation and equifinality. Combined causation highlights that multiple factors interact to produce an outcome, rather than independent variables operating independently to produce net effects. In quantitative research, combined causation is captured through interaction variables. Yet QCA also differs from quantitative studies through its recognition of equifinality, the notion that there are multiple paths to an outcome. In this sense, a given combination of factors, often described as a causal recipe, will only explain a subset of the cases. In our case, we describe causal recipes as “pathways” (following Svensson *et al.*, 2021) to capture different explanations for outcomes of collective action and account for the dynamic nature of groundwater levels and institutional change. The process of developing and testing models becomes an iterative process of conceptualisation and measurement of contextual factors, potential causal conditions, and outcomes to discern recurring patterns of variation that help to explain different clusters of cases, helping to identify a set of necessary conditions (if a causal condition applies across all cases) and different sets of conditions that are sufficient to produce an outcome or explain its absence. This process offers a structured dialogue between theory and evidence and helps to explore the differential effects of fragility across different contexts.

QCA results are complemented by qualitative interpretations drawing on the interviews, archives, and the wider literature. The coupling of QCA with case study development helps to identify recurring patterns across water user groups (GDAs), allowing for non-universal generalisations about key interlinkages that may apply to different subsets of the cases (Sietz *et al.*, 2019). As a set theoretic method, QCA uses Boolean algebra to reduce causal

complexities into a limited set of outcome-relevant conditions and group cases into sets with similar causal factor configurations (Ragin, 1987). Boolean operators “AND” and “OR” denote configurations of the presence or absence of relevant conditions for a given outcome. Set memberships are used to test for necessity (condition x is a superset of outcome y, i.e. whenever y is present, x is present) and sufficiency (condition x is a subset of outcome y, i.e. whenever x is present, y is present). Using QCA, this paper seeks to identify combinations of local social-ecological conditions that are consistently associated with the outcomes of collective action (Ragin, 2008; Schneider & Wagemann, 2012) and hence trace pathways linking given conditions to single outcomes of cooperation and conflict. Cases are coded in terms of gradients of archetypal conditions and outcomes using “fuzzy-set” QCA (fsQCA) (see Pahl-Wostl and Knieper, 2014; 2023). Fuzzy set QCA evolved from earlier “crisp set” QCA approaches which treated conditions and outcomes as binaries that could be coded 0 or 1, which missed finer grained variation. Conversely, fuzzy sets allow for a spectrum from 0 to 1 with intervals, continuous (ratio-scale), or expert judgements about where the cases lie along the spectrum from 0 to 1 (see annex 4). Data generation, i.e. the translation of qualitative interview data into gradients of archetypal conditions, requires thoughtful and transparent calibration based on theoretical and empirical evidence. Following protocol rules developed by Basurto and Speer (2012), anchor points were iteratively developed based on theoretical knowledge, i.e. what are the key characteristics of a given condition, and expert knowledge, i.e. which characteristics are relevant for the chosen cases/what are appropriate ranges and anchor points for given conditions across cases (annex 4). Quantitative data were transformed to fit a 0-1 scale representing variations in the respective condition.

Analyses of necessity and sufficiency are run for the presence and absence of all conditions and tested against the presence and absence of a single outcome, i.e. cooperation or conflict. QCA tests of necessity and sufficiency follow Theory-guided Enhanced Standard Analysis (TESA) protocol, aimed at including good counterfactuals while excluding untenable assumptions and non-simplifying good counterfactual, i.e. remainders that do not aid the logical minimisation of the solution (Oana and Schneider, 2018). QCA generates so-called SUIN and INUS conditions to identify causal conjuncts, combinations of multiple conditions, where the effect of a single condition unfolds in combination with other conditions (Ragin, 2008). Tests of necessity generate SUIN conditions: Sufficient but Unnecessary parts of a factor that is Insufficient but Necessary (SUIN) for the result. In the analysis, these Boolean OR-combined conditions can be functional equivalents of a higher order necessary condition, where neither condition is indispensable, but they alternatively fulfil the requirements of necessity. Tests of sufficiency are at the core of causal explanations and generate INUS conditions: Insufficient but Necessary parts of a condition which is itself Unnecessary but Sufficient (INUS) for the result. Constructed using the Boolean operator AND, INUS conditions exert their effect in combination with other conditions thereby creating pathways of causal interactions.

Models developed in QCA are evaluated through parameters of fit, consistency and coverage, which are broadly analogous to the reliability and validity of the causal explanations across cases. A consistent model will find the outcome *consistently* associated with a condition or set of conditions. Consistency scores reveal the percentage of causal explanations with similar composition associated with a specific outcome, i.e. fee recovery or conflict among users (we assume best-practice values of 0.9 for tests of necessity and 0.8 for tests of

sufficiency according to Oana *et al.*, 2021). Low consistency scores indicate that configurations are not supported by empirical evidence.

A model with high coverage will explain a large subset of the cases. Coverage scores refer to the percentage of cases for which the given causal explanation holds true. In contrast to consistency, low coverage scores do not necessarily imply low relevance. For example, if multiple causal explanations are associated with an outcome, a single explanation may nonetheless explain a relevant subset of said outcome (Ragin, 2000). The modelling process generates a range of potential solutions and offers options that considered parsimonious, complex, or intermediate solutions. Intermediate solutions (between complex and most parsimonious solutions) were chosen for both outcomes and include counterfactuals guided by directional expectations based on theory and empirical evidence. Furthermore, cluster diagnostics were performed to differentiate between analytically meaningful subgroups, i.e. operational and non-operational GDAs. Consistency scores help assess the fit of individual pathways with given clusters of operational status. QCA analyses are conducted in the open-source software R using the packages *SetMethods* (Dusa, 2019) and *QCA* (Oana and Schneider, 2018).

QCA can address the call for more nuanced attention to the interaction between structural variables in collective action theory (Ostrom, 2007), e.g. one condition might only influence the outcome in conjunction with another condition. '*Reflecting on knowledge and questions after 15 years of research*', Stern *et al.* emphasise the importance of case study research in *The Drama of the Commons* (2002). Since QCA does not directly establish relationships of causality but rather necessity and sufficiency, this paper ascribes particular importance to case-based qualitative explanations of set membership relations.

Here, a limited number of cases allow for a more intimate understanding and exploration of individual cases. QCA results are qualitatively examined based on oral histories of water user communities. Empirical evidence from interviews can help uncover specific pathways that cause relations identified by the QCA.

e. QCA Results

The analysis of results follows rules of commutativity and associativity meaning that the order of factors and sequence of combining factors is irrelevant. A descriptive analysis of the data reveals substantial variations associated with each of the conditions and outcomes, which lends itself to set-theoretic analyses that uncover varying pathways of combined conditions leading to a given outcome (figure 12). Results of tests on the absence of outcomes can be found in annex 5.

Table 6 Results of necessity tests

	inclN*	RoN*	covN*
Cooperation: Fee recovery rate			
Groundwater level + social cohesion	0.93	0.55	0.66
~ Illegal well density + rule-following	0.95	0.51	0.64
~ Illegal well density + leadership	0.95	0.50	0.64
Conflict: Conflict among users			
~ Hope	0.91	0.73	0.88
~ Groundwater level + ~ rule-following	0.93	0.67	0.86
~ Rule-following + ~ leadership	0.92	0.55	0.81
~ Rule-following + leadership	0.91	0.65	0.85
~ Rule-following + ~ equity	0.95	0.85	0.94

*Inclusion/consistency (inclN), relevance (RoN), and coverage (covN) cut-off values have been set to 0.9, 0.5, and 0.6 respectively for fee recovery and to 0.85, 0.5, and 0.6 for conflict.

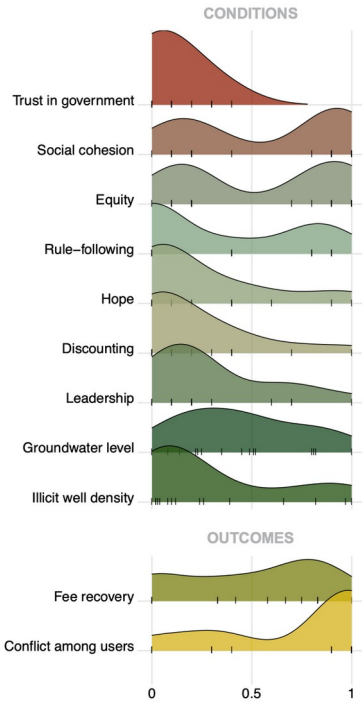
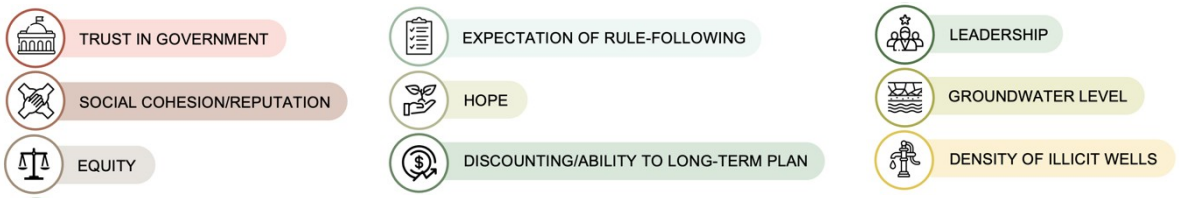


Figure 12 Variation across QCA conditions and outcomes

Cooperation: Fee recovery

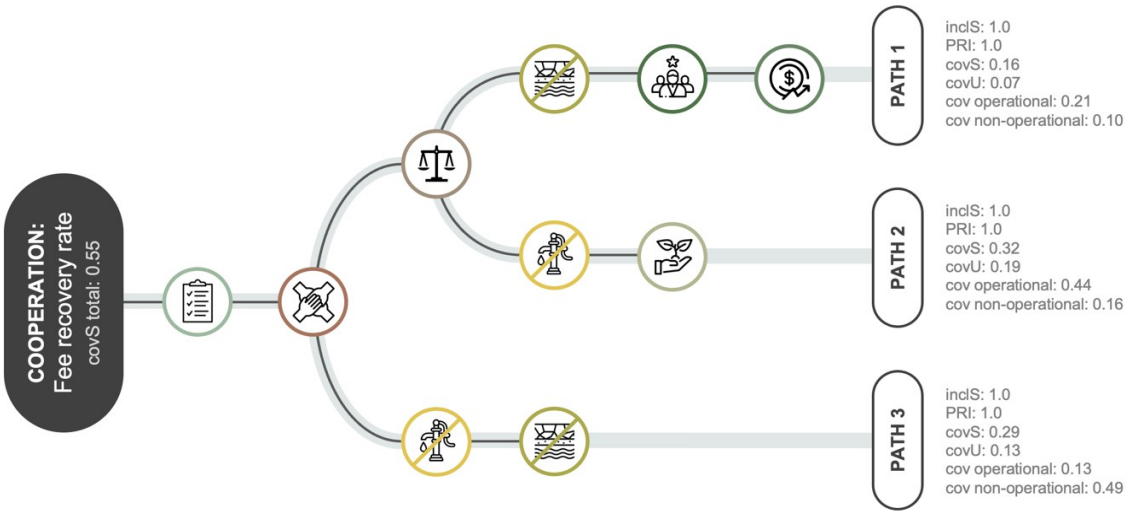
SUIN conditions of necessity for fee recovery (table 6) reveal high groundwater levels OR social cohesion as necessary conditions for fee recovery. The absence of surrounding illegal wells paired (using the Boolean operator OR) with leadership or the expectation of rule-following further reveal high consistency values as necessary conditions for the outcome.

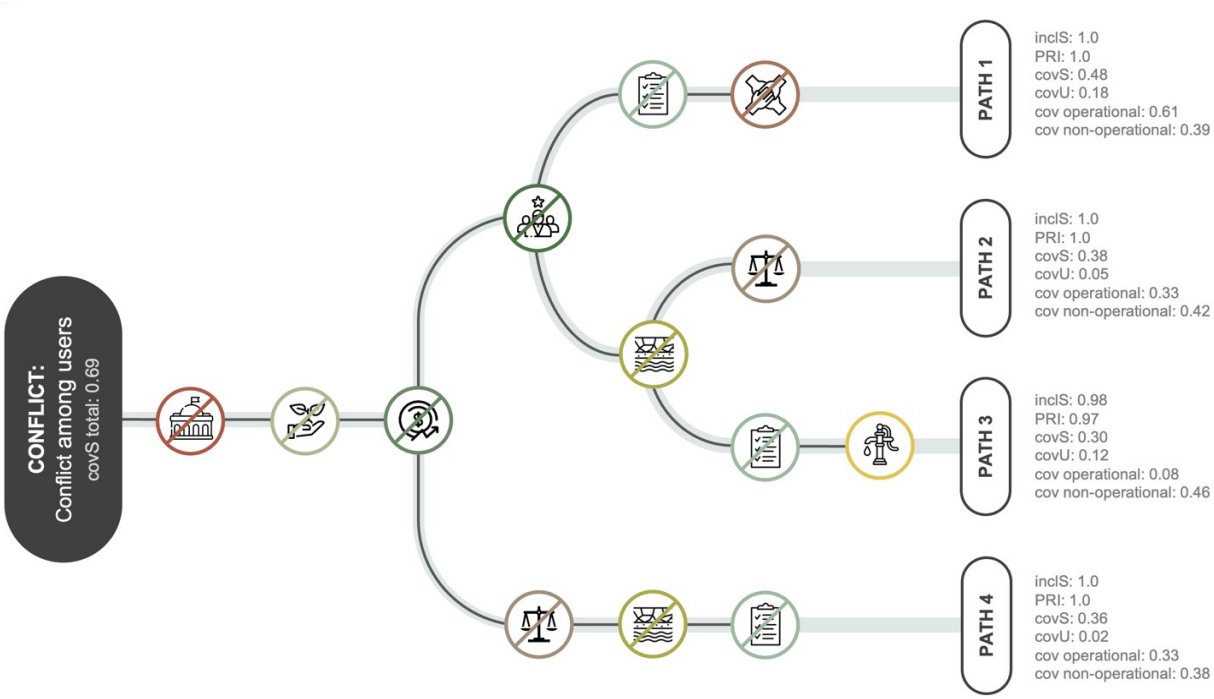
Sufficiency analyses reveal three pathways leading to fee recovery, causally explaining the outcome for 55% of total cases (figure 13). Among INUS conditions, the expectation of rule-following and social cohesion are necessary parts of causal combinations in all three pathways. Low density of surrounding illicit wells is part of two INUS pathways as well as low groundwater levels, and equity. Pathway 1 is named “bad luck – good effort” and represents GDAs that collect fees with good leadership and forward-looking planning despite unfavourable resource constraints. For example in G-GDA-5, fee recovery was 90% despite low groundwater levels. Pathway 2 has the highest unique coverage (0.19) with causal combinations that include rule-following, social cohesion, equity, low density of illicit wells, and uniquely hope. This pathway is named “resource abundance”: GDAs in this pathway are based in favourable aquifers with high hydraulic heads and recharge rates – for example, G-GDA1 and G-GDA2 who enjoy favourable hydrogeological conditions with higher hydraulic heads than their counterparts in pathway 1. Cluster diagnostics demonstrate that this pathway is particularly common for operational GDAs (coverage of 0.44). Pathway 3 is named “bad luck – bad management” because it includes GDAs based in unfavourable aquifers that charge fees that do not cover costs. Cluster diagnostics further reveal high coverage of pathway 3 for non-operational GDAs (coverage of 0.49), where the SUIN condition of low groundwater levels and low fees likely contributed to the eventual shut-down of GDAs, despite high levels of fee recovery such as was the case for G-GDA 9.



Conflict: Conflict among users

Necessary conditions for conflicts among users are dominated by perceptions of lack of rule-following. Lack of hope has a single explanatory consistency of 0.91 and coverage of 0.88. Regarding statements of





Figures 13 Pathways of sufficiency for cooperation (fee recovery rate) and conflict (among users)

sufficiency, the four pathways associated with causing conflict among users collectively have high explanatory power, with a coverage of 0.69 over all cases. Conditions of vertical trust in government and hope (hope itself and the ability to long-term plan) are necessary parts of all four pathways of sufficiency. Pathway 1, including lack of trust in government, lack of hope and long-term planning, lack of leadership, low perceptions of rule-following, and lack of social cohesion, alone explains around half (0.48) of the outcome across cases. This pathway is named “surface water” because it includes all GDAs that draw their supply from surface water sources (plus G-GDA3). This is the only pathway, where the lack of social cohesion directly contributes to conflict. All four pathways include elements of social associations with injustice (perceived absence of rule-following and equity). Pathway 2 is named “no equity – no leadership” and includes GDAs that lack leadership where members perceive they are treated unfairly. G-GDA3, G-GDA6, G-GDA9, and S-GDA5 belong to this pathway. Pathway 3, named “desperation”, reflects GDAs (e.g. G-GDA5 and G-GDA6) that are in unfavourable ecological settings (high density of illicit wells and low groundwater levels) paired with chaotic institutional arrangements. Cluster analysis confirms that these GDAs are frequently non-operational. Pathway 4, named “low institutional capacity”, has low unique coverage (0.02) and largely resembles pathway 2 in terms of cases attributed to the pathway (e.g. G-GDA3, G-GDA6, G-GDA7, S-GDA5).

Case-specific evidence from qualitative interviews with water users

This section uses further empirical evidence from qualitative interview data to interpret QCA results. Our analysis finds that conflict among water users is often associated with lack of trust in government and hopelessness. This can be tied to chronic uncertainty regarding roles and responsibilities in the water

governance system. On the one hand, there are high expectations associated with the role of government in ensuring water systems are successful: ‘It is the responsibility of the state to solve availability issues and ensure system functioning’ [S-GDA3], or ‘farmers are not ready to use less water because it is the government’s responsibility to ensure that there is enough water’ [G-GDA5]. On the other hand, there is overt distrust in the administration: ‘The government does nothing for farmers’ [G-GDA8], or even going as far as ‘there are no laws’ [G-GDA5] and ‘there is no more government’ [G-GDA8].

‘Laws don’t matter if we don’t implement them’ [G-GDA10], says one GDA council administrator – a valid statement in the absence of regulatory enforcement mechanisms. Many water users reminisce about the authoritarian past and effective patterns of coercion and repression: ‘Ben Ali was better. He was with the poor!’ [G-GDA7]. Many water users blame the Arab Spring for present-day water crises: ‘It is because of their [other farmers’] mentality and the revolution that GDAs have failed’ [G-GDA7]. Water users feel misunderstood and rejected by the government: ‘We aren’t interested in “them”. We can only gain a living as farmers, and we expect the government to understand that without agriculture many would have left by now’ [G-GDA2]. Anger against the government often translates to overt acknowledgement of unlawful behaviour: ‘Laws are for the profit of the state, not for us’ [G-GDA7].

In line with the above quotes on trust in government, the QCA analysis also found that intra- and inter-community levels of trust, expectation of rule-following in GDAs, and surrounding illicit wells are consistently important SUIN and INUS conditions. INUS conditions, in particular, are strongly tied to mechanisms of social trust and reputational pressures, e.g. I will only pay my fees if others do the same and if I am not surrounded by illicit wells. The blame

game is an important deflection mechanism used by farmers. Whether it is the government to blame, the “mentality of other farmers”, or the “revolution”: ‘There is no more respect. The young generation doesn’t care’ [S-GDA2], ‘farmers are fearless now [after 2011], they misbehave and vandalise’ [G-GDA3]. When water users in a post-authoritarian context argue that the problem is that ‘people don’t have fear anymore’ [S-GDA3], it may be worth carefully re-examining the potential impacts of new policies aimed at installing a new executive water police with renewed reliance on fear tactics. Water users see social trust as an alternative to the coercive power of the state. To the question whether they generally trust farmers to follow GDA rules, one GDA president answers: ‘Yes, because there are no [formal] rules’ [G-GDA1]. Where strong community cohesion often correlates with local family ties, however, it may be difficult to develop meaningful policy recommendations aimed at increasing levels of social trust when such ties are absent.

Furthermore, social cohesion has been found to have causally complex interactions with resource availability. SUIN combinations for fee recovery, for example, reveal that low hydraulic heads paired with social cohesion are more conducive to fee recovery. GDAs in favourable hydrogeological settings frequently allocate water for free to its users. In G-GDA1, representative of pathway 2 of fee recovery, where groundwater water flows from artesian sources, water is unmetered and costs are annual (50 DT per year) rather than hourly. According to the president, sustainability questions do not pose themselves because the GDA ‘has to use the run-off from artesian flow’ [G-GDA1]. While fee recovery is consistently high in the GDA (90%), prices do not adequately cover costs during recurring droughts that disrupt artesian flow and have required the GDA to pump for groundwater. In other settings with high groundwater levels, farmers frequently received more water from the GDA than

officially allocated, surpassing real irrigation demands (G-GDA10). Based on the perception that more water automatically equates to higher yields and profits, overirrigation is common for farmers in areas with high groundwater levels. Even if low groundwater levels often lead to higher fee payments, cluster diagnostics show that this trend is largely associated with GDAs that eventually fail – likely due to the drying up of wells. Low levels of hydraulic head are also causally linked to higher levels of conflict among users. In unfavourable ecological settings, water users responded to questions around social cohesion with ‘everyone has to fend for themselves’ [S-GDA2]: ‘Social peace is important when there is water. When there is no water, social peace goes out the window’ [S-GDA3].

Leadership features as a necessary condition for both outcomes but is less prevalent in causing cooperative outcomes than for example social cohesion. In other words, there is only so much a good leader can do. For example, in G-GDA5 (INUS pathway 1 for fee recovery including leadership and long-term planning) the administrative council calculated a new cost-covering price with reference to the GDA budget and raised the price for water from 0.150 to 0.339 DT per m^3. Despite their best efforts and ambitions to long-term plan, the administrative council was unsuccessful in leveraging the support from the community and explaining to water users the need for higher fees to cover basic pumping and maintenance costs. There is a pervasive lack of motivation for community members to assume leadership roles in their GDAs. The position of GDA president, for example, is an unpaid role, relying on the benevolence of a given community member. Unsurprisingly therefore, community members often only take on such responsibilities in their short-term self-interest as a farmer, rather than as a water manager. ‘The CA [administrative council] works for their own benefit as farmers’ [G-GDA9], says one local water user, reflecting

perceptions of inequity as portrayed in pathway 2 for conflict among users. The systemic nature of volunteerism causes anger in members of the administrative council: ‘We are only ever compensated with insults’ [G-GDA10].

Hope plays an important role particularly for operational GDAs (as INUS for fee recovery). One GDA administrator argues: ‘There is absolutely no trust that farmers will follow rules but really it is the system that is broken’ [S-GDA2]. This argument ties well to a quote from a key informant interview conducted in the capital Tunis: ‘How can we ask the little farmer to pay his bills if the police, surrounding institutions, … the entire system is corrupt?’ [ACA4]. Farmers in the chosen case area often see little hope in a future of sustainable resource use: ‘We are optimists but our perspectives are zero’ [S-GDA2], ‘You need to save your plants before you can save your future’ [S-GDA5].

f. Conclusion

This paper examined how trust and hope influence outcomes of collective action in water resources management in the fragile setting of Tunisia. In line with theories of Sapsford and Abbot (2006) regarding negatively perceived shocks and their impacts on local levels of trust, many water users in the governorate of Kairouan blame social disturbances triggered by the Arab Spring for present-day water crises. Disappointed by the government and in the absence of formal rules, many farmers build on their communities for livelihood-sustaining water service provisions. In line with Fafchamps (2006), water users see social trust as an alternative to the coercive power of the state. Social cohesion and the expectation that other water users stick to, mostly informal, rules have been found to increase the likelihood of collective action, i.e. fee recovery, under systemic fragility.

The analysis was also able to shed light on social-ecological dynamics in low-hope environments. The paper found that the ability to envision a positive future contributes to collective behaviour. More specifically, QCA illustrated conjoint interactions of social dynamics with ecological limits. Under scenarios of resource abundance, water user groups were more likely to collect water fees in communities where there were higher levels of hope. Where groundwater resources were depleted, on the other hand, hope did not influence fee recovery. In such cases of resource scarcity, however, INUS combinations reveal that social cohesion and the expectation of rule-following can lead to fee recovery. These findings are in line with the theory by Uphoff *et al.* (1990) that argues that some limits to resource availability encourage collective action and incentivise rational water use.

The analysis also confirmed hypotheses on hopelessness – "unsolvable problems" that reduce the motivation and creative problem-solving capacity of individuals (Mikulincer, 1986; Snyder and Feldman, 2000; Scherer, 2022). The lack of hope, combined with the lack of trust in government, was a "necessary sufficient" (INUS) condition for all pathways leading to conflicts among water users. These findings are in support of social identity theories (Ellemers, 1993; Tajfel, 1978), that claim that collective action can only occur when there is hope. This paper was able to demonstrate that conflict arises in the absence of hope.

Further set-theoretic multi-method research should look into within-case analyses to trace the causal mechanisms that are formed between conditions and their outcomes, i.e. what are the underlying processes that forge the pathways of decision-making identified by the preceding QCA? This could include ethnographic research such as situational process observation and

process tracing on the individual causal conjuncts (INUS and SUIN conditions) identified in the analysis of this paper.

CrediT author statement

Sophie Erfurth: Conceptualisation, Methodology, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Visualisation. **Dustin Garrick**: Conceptualisation, Writing – Review & Editing, Supervision. **Constance McDermott**: Conceptualisation, Writing – Review & Editing, Supervision.

Acknowledgements

This research was supported by the Dudley Stamp Memorial Research Grant of the Royal Geographical Society (RGS).

Paper 3: The Role of Interacting Social and Institutional Norms in Stressed Groundwater Systems

Authors: Sophie Erfurth[a,b,c], Jacopo A. Baggio[d,e], Reetik-Kumar Sahu[c], Taher Kahil[c], Jamila Tarhouni[f], Rahma Brini[f], Matthias Wildemeersch[a,c]

[a]Environmental Change Institute, University of Oxford, Oxford, UK
[b]Smith School of Enterprise and the Environment, University of Oxford, Oxford, UK
[c]International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
[d]School of Politics, Security and International Affairs, University of Central Florida, USA
[e]National Center for Integrated Coastal Research, University of Central Florida, USA
[f]National Agronomic Institute of Tunisia (INAT), Tunisia

Abstract

Groundwater resources play a critical role for irrigation, particularly in arid and semi-arid regions, where depletion poses threats to agriculture and associated local livelihoods. However, the relationship between groundwater withdrawals, farming, and poverty remains poorly understood in stressed groundwater systems. Here we assess this relationship by developing a behavioural model of a water user group, empirically grounded in the Tunisian context. The Socio-Ecological System model captures biophysical aquifer dynamics, the governance of groundwater use, and farmer decision-making, all of which is occurring under conditions of aquifer depletion and illicit groundwater extraction. The model provides distributional outcomes depending on individual decisions. We specifically examine community-level norms driving collective outcomes and explore how varying levels of trust and leadership, ecological conditions, and agricultural strategies can avoid or delay local system collapse. The findings highlight the erosion of social norms and limitations of self-governing institutions in the face of chronic water scarcity and institutional fragility. Leadership serves as a key driver of collective action, while social trust is mostly insufficient to prevent financial collapse of water user groups. The results

suggest the need for income diversification beyond agriculture to sustain local livelihoods, as well as underlines the role of illicit groundwater sources as social buffers for farmers in the absence of alternative irrigation sources.

Under consideration at the journal of
Environmental Modelling & Software
(submitted on 28 August 2023)

a. Introduction

Globally, around 70% of freshwater withdrawals and 90% of freshwater consumption (water with- drawals excluding return flows) are designated for irrigation use (Shiklomanov, 2000; Döll *et al.*, 2009). Groundwater resources supply an estimated 43% of global total irrigation water use (Siebert *et al.*, 2010). In semi-arid and arid regions, however, groundwater is often the predominant, if not the only, source of water for irrigation. Groundwater use in agriculture is increasing worldwide leading to widespread aquifer depletion (Siebert *et al.*, 2010; Aeschbach-Hertig and Gleeson, 2012; Dalin *et al.*, 2017; Schipanski *et al.*, 2023), posing threats to food production systems and associated local livelihoods. Notably, small holder farmers, accounting for 84% of global farms and producing around 35% of the world's crops (Lowder *et al.*, 2021) are at risk of losing their livelihoods. Despite these concerns, the complex relationship between (ground)water, agriculture, and poverty remains understudied and poorly understood (Balasubramanya and Stifel, 2020). Further research is particularly needed to better understand irrigation management and decision-making processes in the context of arid regions as well as those experiencing rapid groundwater decline, impacts of climate, and socio-economic changes.

Groundwater, by its nature, is a non-excludable but rivalrous resource. Hence, individual decisions affect entire communities of water users. In fact, the same groundwater source is often used by multiple user groups/communities, which has often led to the centralisation of regulatory agencies in charge of monitoring and setting withdrawal limits for respective water user groups (Lankford and Hepworth, 2010). However, due to the complexity of groundwater, local institutions are often key to maintaining sustainable withdrawals, at times together with central regulatory authorities, at times super-seeding them (Pahl-Wostl and Knieper, 2014; García *et al.*, 2019; Pahl-Wostl, 2015). Further, in areas where political systems are fragile and institutional trust is lacking, local communities may decouple from centralized institutions and assume a prominent role by promoting their own norms and rules independently (or on top) of the ones developed by a central government (van Steenbergen *et al.*, 2015; García *et al.*, 2019). This implies that communities are able and willing to self-regulate, and thus monitor, sanction and mediate potential conflicts. At the same time, this poses a Collective Action (CA) problem whereby individuals are faced with both inter-temporal and social dilemmas, by which increasing withdrawals today can lead to a future system collapse, and by which increasing withdrawals for one individual can be detrimental for the entire system.

This paper models decision-making in a small-holder farming community in rural Tunisia. Groundwater users in the semi-arid context of Central Tunisia depend on underlying aquifer systems to irrigate livelihood-sustaining crops. The social and political context of Post-Authoritarian and Post-Arab Spring Tunisia is marked by the erosion of institutional trust and the reliance on local informal mechanisms above formal rules or institutions. We explore dynamics of water user decision-making within this fragile political setting, defined broadly

as an environment that is exposed to frequent or chronic disturbances or stressors to social-ecological resilience and institutional robustness (Schoon and Cox, 2012). The reliance on dwindling groundwater resources for irrigation can be characterised as a “take-some dilemma”, where benefits from an ecological outcome are individual (often in the short term) while negative (often long-term) outcomes are collective (Cumming, 2018). In the case of groundwater over-exploitation, this dilemma can turn into a “lose-lose trap” over time (e.g. when groundwater-dependent farmers have depleted their aquifers), where outcomes are negative both for individuals and the wider community. These traps are reinforced by social-ecological feedbacks (e.g. lower groundwater levels lead to higher extraction costs, which farmers are increasingly unable to cover, which leads to decreasing revenues from irrigation agriculture, which further impacts the ability to cover rising costs) and may be difficult if not impossible to reverse (Cinner, 2011).

The coupling of Social-Ecological Systems (SES) (Folke, 2006) has represented the major advance in collective action research in the past 15 years (Filatova *et al.*, 2016; McGinnis and Ostrom, 2014). SES represent complex adaptive systems composed of interactions between humans and the environment (Berkes *et al.*, 1998; Folke *et al.*, 2016). Modelling these interactions sheds light on inherent dynamics, patterns, and feedbacks within the coupled SES (Levin *et al.*, 2013). SES research acknowledges the need to include governance, behavioural social and psychological processes to assess management adaptability in SES (Peng *et al.*, 2021; Kimmich *et al.*, 2023; Mathias *et al.*, 2020; Baggio *et al.*, 2022; Freeman *et al.*, 2020). While some advances have been made in this regard, e.g. in the developments of methods for polycentric governance (Oberlack *et al.*, 2018; Kimmich and Tomas, 2019), and experimental studies aimed at understanding the interaction between

individuals and collective behaviours (Baggio *et al.*, 2019; Janssen *et al.*, 2010; Ostrom, 2009), methods to operationalise individual and collective structures of decision-making in complex Common-Pool Resources (CPR) settings remain limited (Kimmich *et al.*, 2023). Collective action theory underlines the importance of stable institutions – a reliable set of rules that streamline decisions on resource allocation and use (North, 1990; Ostrom, 1990). Studying collective action dynamics in the context of political fragility, this study contributes to the CA literature by considering bottom-up decision-making in the absence of stable institutions and formal mechanisms of water governance.

In addition to these formal characteristics, SES research on groundwater systems has largely been limited to settings where informal local monitoring and enforcement of rules are in place and assumed-functioning (e.g. Castilla-Rho *et al.*, 2017). In fragile political settings, however, where formal as well as informal rules are subject to considerable uncertainty, water users are likely to make decisions on water withdrawals based on alternative sets of rules. In contrast to rational-choice theory, which sees resource users as proactive maximisers of private preferences and beliefs (Shepsle, 1989), theories of institutionalism in CPR theory portray resource users as fallible learners of bounded rationality (Ostrom, 2011). Choices are made based on incomplete information and imperfect information-processing capabilities and are affected by shared norms, rules, and incentives. Shared internalised norms of behaviour, both formal and informal, influence the subjective mental constructs that resources users use to interpret a specific decision situation and attain individual and collective goals (Siddiki *et al.*, 2019). This paper explores the role of leadership (Von Rueden *et al.*, 2014; Glowacki and Von Rueden, 2015; Meinzen-Dick, 2007) and trust (Levi and Stoker, 2000; Fafchamps, 2006) within the path-dependent context of fragile political systems. We bear on notions of

social psychology to integrate social and institutional norms into the SES, which reflect commonly shared standards of behaviour within the community. Compliance with norms depends on existing social preferences, the ability to generate shared understanding and visions, and the desire to retain a prosocial self-image and avoid judgement or disapproval from peers (Fehr and Schurtenberger, 2018). Resource users attach a positive or negative internal valuation to given action situations, e.g. groundwater withdrawal, fee payment, etc. (Ostrom, 2009; Boix and Stokes, 2007).

Given the particular characteristics of stationarity and storage of groundwater resources as compared to other CPR systems (Baggio et al., 2016), SES models of groundwater systems need to pay specific attention to the biophysical characteristics of the underlying aquifer (Schlager *et al.*, 1994). This paper will explore ecological drivers and limits to collective action within the chosen aquifer system. Previous research suggests that collective action is highest under relative resource scarcity, where water users see the value of participating in allocation and management activities (Uphoff *et al.*, 1990; Ostrom, 2002.; Rutte *et al.*, 1987). In contrast to coupled social-ecological groundwater systems that model closed-loop feedbacks between water user behaviour and the aquifer, this SES simulates groundwater levels as a largely exogenous process with weak feedback links between local withdrawals and groundwater levels. By shifting the boundary of endogenous water withdrawals from the aquifer scale to individual water user groups, we believe it is possible to construct a more realistic model-world that represents the CPR context from the perspective of water users. Most commonly, local collective action of water withdrawals will hold weak feedback links with the state of the aquifer. Resource users will be bounded by their biophysical environment, where neighbouring withdrawals are outside of their own control.

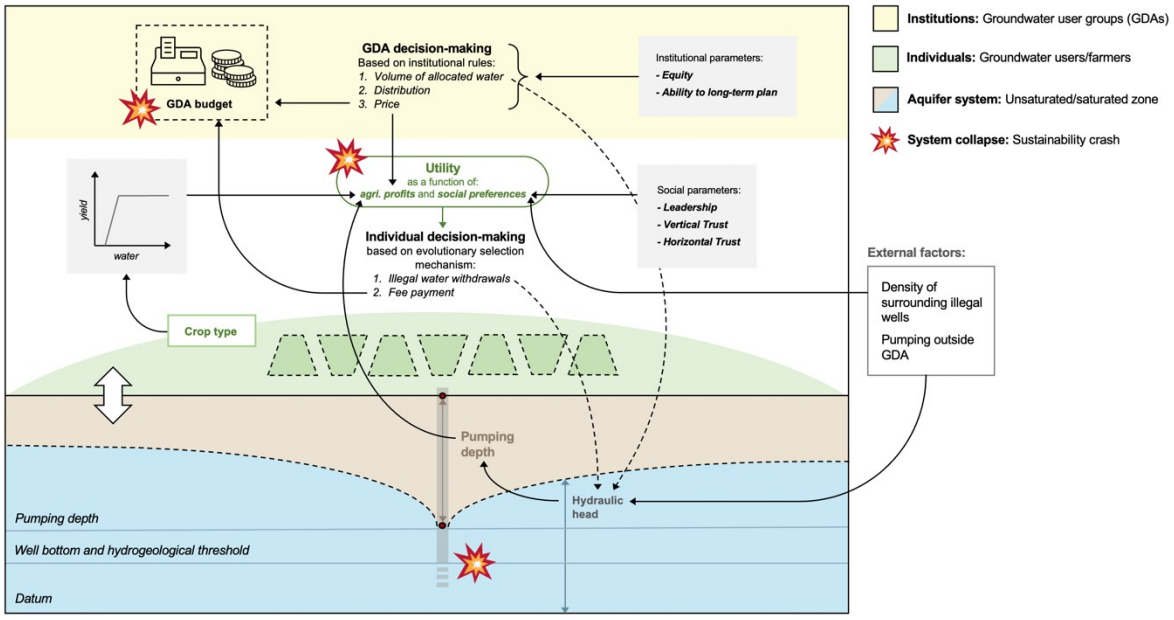
While CA theory hypothesises that self-governing resource users have the ability to successfully overcome resource problems, here we provide nuance to this capacity to self-govern in the face of chronic water scarcity and institutional fragility. We aim to study the role of overlapping social and institutional norms in highly stressed CPR settings, and to shed light on social-ecological complexity of the coupled groundwater system based on both quantitative and qualitative data collected on the ground. We link groundwater user behaviour, aquifer dynamics, and governance together in an SES framework (figure 14), consisting of a social decision-making module for water use, a hydrogeological module, and an institutional governance module, as well as feedback loops between and within these modules. We track the erosion of social norms and the resulting impact on system sustainability or collapse (Richter *et al.*, 2013) and identify scenarios that can delay system collapse. The SES model captures the behaviour of individual farmers, and integrates the interactions with their peers and the water user group by means of social and institutional norms. The model provides distributional outcomes depending on individual decisions. Further, we contextualise our model by leveraging qualitative data for the decision-making and institutional modules based on interviews performed in the governorate of Kairouan, Tunisia in May 2022, and on simulated groundwater data for the hydrogeological module related to the same area. The paper thereby addresses critical knowledge gaps on the causal processes that transform local decision-making and ecological process to emergent SES phenomena (Schlüter *et al.*, 2019). With this SES, we investigate the following research questions: (i) In the absence of formal legal frameworks and informal structures of monitoring and compliance, which community-level norms drive collective outcomes under conditions of aquifer decline? (ii) Which system dynamics can explain the erosion of social norms? (iii) Under what ecological

and institutional scenarios can groundwater user groups avoid or delay system collapse?

b. Methods

Social-Ecological System (SES) model

We present here a modelling framework to analyse the viability of sustainable water governance in the absence of a centralised regulatory framework, formal monitoring, and compliance mechanisms. Instead, the governance of the common-pool resource emerges only through local leadership and informal peer monitoring. The model simulates distributional outcomes of individual farmer behaviour with collective effects on the success or failure of the water user



group as well as individual effects on livelihoods. The model will simulate two types of system collapses: (i) a hydrogeological collapse, where hydraulic heads go

Figure 14 SES model schematic with interacting, co-evolving resource, social, and institutional modules

below critical threshold levels, and (ii) a financial collapse, where the water user group (also referred to as *Groupements de Développement Agricole* (GDAs) in the Tunisian context) is unable to cover pumping costs and has to terminate its service of water provision. In the latter case, the GDA is blocked by the central electricity provider. These two types of crashes represent two collective action problems, i.e., the overexploitation of groundwater resources and the unwillingness of farmers to pay groundwater fees. The model considers thresholds levels for groundwater hydraulic heads and financial debt, and the groundwater user group collapses if one of these thresholds is exceeded. Similarly to these thresholds, the model establishes a poverty threshold to the user profit function to understand livelihood dynamics. While exceeding this threshold will not crash the system of groundwater extraction, it is an indicator of social sustainability within the system. Linked to these thresholds, the model observes three types of sustainability: ”Social sustainability” defined as the percentage of farmers living below the poverty threshold, ”financial sustainability” as a measure of the financial budget of water user groups, and ”ecological sustainability” as a function of groundwater withdrawals. Note that in this work local decisions only have a minimal impact on groundwater depletion, which is mostly driven by the combined groundwater use by the other water users in the aquifer. We identify scenarios that delay surpassing the poverty and financial threshold, i.e. social and financial sustainability. The model was constructed using Python software and will simulate 20 years of water user behaviour.

Dynamic resource model

Hydrogeological dynamics of the aquifer are represented by a surrogate of an established MODFLOW model. Based on 45 years (1971-2016) of observed and modelled data (see SES calibration section for more detail), regional responses of hydraulic heads are linked to the volume of water pumped from the aquifer using an auto-regressive approach (coefficient of determination: 0.96). The change in hydraulic head, Δhh(t), is predicted using previous changes in hydraulic head and groundwater withdrawals at time t.

$$\Delta hh(t) = \alpha + \beta_1 \Delta hh(t-1) + \beta_2 V^{\mathrm{p}}(t) + \epsilon\,. \tag{1}$$

V^{p}(t) refers to the total volume of groundwater pumped within a given aquifer, and can be expressed as follows

$$V^{\mathrm{p}}(t) = V^{\mathrm{ext}}(t) + W^{\mathrm{alloc}}(t) + W^{\mathrm{ill}}(t)\,, \tag{2}$$

where W^{alloc} is the total allocated water in the GDA, and W^{ill} the total amount of illicitly extracted groundwater by the GDA. The water extracted outside the GDA is represented by V^{ext}(t) and stands for the fraction of pumped water outside the GDA at t_0, calculated based on rescaled pumping rates. The variable values of V^{ext}(t) are outside the control of the GDA and are predicted based on the pumping trend of the last twenty years of the MODFLOW simulation (1996-2016) yielding a growth rate of 4.2% per year. It follows, that groundwater depletion is a largely exogenous model process, where water users only contribute marginally to overall withdrawal rates.

Governance module

Water user groups (GDAs) are managed by a leadership council that decides how much water will be pumped in a given year, and consequently how much water will be allocated to each farmer in the GDA. Groundwater is made available to water users as determined by institutional decision rules. These decisions are a function of GDA decision-making: a. how much water to extract, b. how to distribute it among users, and c. at what price. Volume and price are determined by the ability of leaders to long-term plan (binary parameter *sust*) and distribution is based on equity (binary parameter *equ*), both derived from qualitative interview data. Under high *sust*, price is calculated each year based on extraction and operation costs and the expectation of fee recovery, while total withdrawals by the GDA stay static. Under low *sust*, price is static (based on an initial (low) price-setting of 0.15 TND per m^3 based on interview data), while withdrawals increase at the same rate as withdrawals outside the GDA (based on MODFLOW data). Under high *equ*, water will be allocated equitably among all water users. Under low *equ*, one-fifth of GDA members receive twice as much water than they would have, had the water been allocated equitably. The price and allocated volume will influence whether farmers choose to withdraw additional water from illicit sources or settle for official allocations.

The financial state of the GDA is determined by

$$S(t) = S(t-1) - W^{\text{alloc}}(t-1) \cdot c_{\text{E}} - c_{\text{op}} + \sum_i D_i(t-1) \cdot c_{\text{w}}(t-1) \cdot w_i^{\text{alloc}}(t-1)\,, \qquad (3)$$

where S stands for the financial budget of the GDA at a given time, c_{E} stands for the GDA's groundwater extraction cost, c_{op} for additional operational costs (e.g. maintenance, labour, etc.), D_{i} for the decision of individual farmers to pay their fees, c_{w} for the price at which groundwater is sold to farmers, and w_{alloc} is the water allocated to user i. Once the GDA surpasses its debt threshold, the user

group is frozen by the local electricity provider and can no longer supply GDA members with water. In this case, farmers can only resume agricultural activities by drawing on water from illicit sources. Extraction costs are calculated using a linear regression approach based on collected well data on extraction costs and associated hydraulic heads from the year 2012. Based on the regression results, we determine an increase in extraction cost of 0.050 TND for every meter of groundwater decline. This includes electricity prices, which for the purpose of this model are assumed to be constant.

Famer decision-making module

We model the strategic decisions that individual farmers make, the collective outcomes that result from these decisions, and the distributional effects on their livelihoods. Farmers create agricultural profits by cultivating crops and using the CPR to irrigate. The utility of farmers is however affected by vertical and horizontal institutional arrangements. We consider farmers within a water user group (GDA) that can observe the irrigation practices within as well as outside of the GDA (both private farmers and farmers belonging to other GDAs). Farmers get water allocated by the GDA, and make decisions to pay their fees for allocated water, and to extract groundwater illicitly. Agricultural land is assumed to be uniformly distributed among farmers (23500 m^2 per farming household based on administrative datasets). Based on the presence of vertical and horizontal trust, households make decisions about additional, illicit water extractions. Under strong leadership, farmers are more likely to be encouraged to pay fees for allocated water.

Utilities of farmers are driven by individual household profit functions. The output (kg/ha) generated for a representative hectare is given by

$$y_i(t) = \begin{cases} 0 & \text{if } w_i(t) < ET_{\min} \\ y_{\max} - \left(y_{\max} \cdot K_y \cdot \left(1 - \frac{ET_i(t)}{ET_{\max}} \right) \right) & \text{if } w_i(t) \in [ET_{\min}, ET_{\max}] \\ y_{\max} & \text{if } w_i(t) > ET_{\max}, \end{cases} \quad (4)$$

where w_i is the total water used by household I for irrigation, y_{max} and y_i are the maximum and actual yields, ET_{max}, ET_{min} and ET_i are the maximum, minimum, and actual evapotranspiration ($ET = (p + w_i) \cdot k_c$, where p is precipitation and k_c is the crop coefficient), and K_y is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses. These water-yield relationships are defined by the FAO water production function (Steduto *et al.*, 2012).

The total amount of water used by farmer I is given by

$$w_i(t) = w_i^{\text{alloc}}(t) + w_i^{\text{ill}}(t)\,, \quad (5)$$

while total allocated water and total illicit extraction are given by $W^{alloc}(t) = \sum w^{alloc}(t)$ and $W^{ill}(t) = \sum w^{ill}(t)$, respectively. The profit of household I in the GDA at time t is given by

$$\pi_i(t_s) = \sum_{t=t_s}^{t_s+h} \left(p^c \cdot y_i(t) \cdot a_i - c_i^{\text{alloc}}(t) - c_i^{\text{ill}}(t) - c_i^c(t) \right), \quad (6)$$

with p^c the price the crop is sold at (TND/kg), a_i the average size of agricultural land per farmer, $c^{alloc}(t)$ the cost for the allocated water, $c^{ill}(t)$ the cost for illicit water extraction, and $c^c(t)$ stands for the cultivation costs. The cost for the allocated water is given by

$$c_i^{\text{alloc}}(t) = D_i(t) \cdot c_{\text{w}}(t) \cdot w_i^{\text{alloc}}(t)\,, \tag{7}$$

where $D_i(t) \in \{0,1\}$ is the decision of household i to pay the water fee at time t and $c_{\text{w}}(t)$ is the cost per unit of allocated water. If farmers don't manage to make sufficient profits, they cannot pay for water resources.

Utilities are not solely driven by profits but also by norm-based dynamics in the water user group community. Internal valuations of actions are subtracted from the individual profit of a given action, which translate to collective outcomes for the groundwater user group (Ostrom, 2009; Fehr and Schurtenberger, 2018). Vertical and horizontal mechanisms generate these penalties (r^{V} and r^{H} respectively) of not adhering to rules and norms. The vertical mechanism is driven by social parameters of trust in government rules and GDA leadership, and the psychological cost of deviating from vertical norms is given by

$$\begin{aligned} r_i^{\text{V}}(t) &= \alpha^{\text{V}_\text{T}} \cdot V_\text{T} \cdot (w_i(t) - w_i^{\text{alloc}}(t)) + \alpha^{\text{V}_\text{L}} \cdot V_\text{L} \cdot (1 - D_i(t)) \\ &= \alpha^{\text{V}_\text{T}} \cdot V_\text{T} \cdot w_i^{\text{ill}}(t) + \alpha^{\text{V}_\text{L}} \cdot V_\text{L} \cdot (1 - D_i(t))\,, \end{aligned} \tag{8}$$

where $\alpha^{\text{V}_\text{T}}$ and $\alpha^{\text{V}_\text{L}}$ represent penalty weights for observed levels of vertical trust (V_T) and leadership (V_L). These weights, as opposed to the parameters of trust and leadership themselves, indicate how receptive water users are to the specific social characteristic. For example, even high leadership efforts can be nullified by unresponsive water users (i.e. low leadership weight). Vertical trust refers to trust in government rules and institutions (Kaasa and Andriani, 2022; Lubell, 2007). Based on interview data, we assume that higher levels of trust in government rules reduce the likelihood of farmers to withdraw water illicitly. Leadership refers to the ability of the GDA administrative council to long-term

plan (with regards to the financial budget of the GDA and the volume of groundwater withdrawals) and in part to motivate users to support these plans (Meinzen-Dick, 2007; Fafchamps, 2006; Von Rueden *et al.*, 2014; Glowacki and Von Rueden, 2015). In our model, this is captured by the norm to pay for allocated water. The horizontal mechanism is driven by social trust within the GDA and social pressures from outside the GDA related to the surrounding density of illicit wells, and the psychological cost of deviating from horizontal norms is given by

$$r_i^{\mathrm{H}}(t) = \alpha^{\mathrm{H,int}} \cdot H_{\mathrm{T}} \cdot |(w_i(t) - \bar{w}^{\mathrm{int}}(t))| + \alpha^{\mathrm{H,ext}} \cdot \left(c^{\lambda_0} - c^{\mathrm{den}} \cdot \lambda\right) \cdot w_i^{\mathrm{ill}}(t)\,, \tag{9}$$

where $\alpha^{\mathrm{H,\ int}}$ and $\alpha^{\mathrm{H,\ ext}}$ represent penalty weights for observed levels of horizontal/social trust (H_{T}) and the tolerance for illicit extractions determined by the density of surrounding illicit wells. The variable $w^{\text{-}\ int}$(t) stands for the average water use within the GDA. Ostrom (1990) argues that 'individuals have shared a past and expect to share a future. It is important for individuals to maintain their reputations as reliable members of the community' (88). It follows that social trust, the expectation that other members of the GDA comply with rules, influences individual judgements of performing an action (Levi, 1988; Gambetta *et al.*, 2000). In the first term, deviations from the average use, both positive and negative, are penalised and reflect the pressure towards conformism. The second term captures how illegal wells in the neighbourhood of the GDA shape the norm of illegal extraction. The penalty incurred per unit of illegally extracted water depends on the density λ of the illegal wells in a range of 3 km from the GDA, assumed to represent the most commonly frequented radius by GDA water users. The cost is proportional to the extracted volume

from illicit wells. Values of trust and leadership stem from qualitative interview data (more detail can be found in the parameter calibration section).

The utility of a household *i* in the GDA at time *t* is therefore given by

$$u_i(t) = \pi_i(t) - r_i^{\mathrm{V}}(t) - r_i^{\mathrm{H}}(t)\,, \tag{10}$$

as we assume that households are myopic in the context of stressed groundwater systems.

An evolutionary selection mechanism is established to simulate the ability of water users to switch to utility-enhancing strategies. In each year, all households have on average a chance to change their strategy on illicit withdrawals and fee payment. They do so by comparing their own utility with the utility of one of the best performing members of the GDA. This selection mechanism represents the asynchronous decision-making of farmers. Specifically, one of the five best performing households is selected uniformally, reflecting the influence of high-status GDA members. Strong horizontal mechanisms can lead to the erosion of norms – a new normal is defined as water user compare themselves to others, while strong vertical mechanisms reinforce the norms. At each time *t*, the probability of household *k* changing strategy to the strategy of household *l* (both for payment decision and illicit water withdrawals) is a function of the relative utility differential between the matching partners, according to the logistic function:

$$p_{kl}(t) = \frac{1}{1 + \exp\left(-\zeta \cdot \frac{u_l(t) - u_k(t)}{u_k(t)}\right)}\,, \tag{11}$$

where ζ represents the responsiveness to relative utility differentials. Since illicit water extraction is not perfectly observable, there is an imitation error captured as follows

$$w_i(t) \rightarrow w_k(t) + \varepsilon\,, \tag{12}$$

where ε ~ U[0.8 w_k(t), 1.2 w_k(t)] and U[·,·] represents the uniform distribution over the specified interval. When the water allocation is uniform over the GDA members, this imitation mechanism means that only illicit water withdrawals are imitated. In case of unequal water allocation, the illicit water extraction can compensate for lower levels of allocated water.

SES calibration

The governorate of Kairouan presents a particularly interesting case study to investigate social- ecological dynamics in a complex groundwater dilemma. First, groundwater plays a critical role for irrigation and associated livelihoods in Kairouan and has witnessed severe depletion in the last decades (Snoussi *et al.*, 2022). Second, the hydrogeological diversity of the area enables us to study farmer behaviour under varying aquifer conditions. Third, with close proximity to Sidi Bouzid, the birthplace of the Arab Spring, the region holds a fraught relationship with social unrest and institutional fragility.

The SES is calibrated using empirical evidence from qualitative interviews with water user groups (GDA), hydrogeological models, local inventories, and the wider literature. Semi-structured interviews with farmers and water user group officials from 15 GDAs were conducted in the Tunisian governorate of Kairouan in May 2022. Guiding questions concerned variables of generalised trust in government, social trust, perceptions of equity, discounting and the ability to

long-term plan, leadership, etc. Interviews followed ethics protocol of the School of Geography and the Environment, University of Oxford [approval number: SOGE 1A2020-183]. Semi-structured interviews were conducted in Tunisian Arabic and translated to French by a local expert. These informal interviews ranged from 1-7 interviewees depending on respondents' availability and interest in joining the study. Qualitative interview data were translated into gradients of 0-1 based on protocol rules developed by Basurto and Speer (2012). Anchor points were iteratively developed based on empirical and theoretical knowledge of the case setting (see annex for question and corresponding variables). Specific parameter value ranges (for Monte Carlo simulations), variable values, and their data sources can be found in the annex.

The MODFLOW groundwater model of the aquifers Sisseb, AinJloula, AinBoumorra, and Chougafia was elaborated by the National Agronomic Institute of Tunisia (INAT) (Hamdi *et al.*, 2018). Hydrogeological data were extracted from the model using the Python package FloPy and analysed with the geospatial software QGIS. Hydrogeological thresholds were defined based on empirical accounts of water users and GDA officials in water user groups, where wells have run dry. We assume that if groundwater levels fall below a given change in depth, GDAs are unable to continue pumping and farmers can no longer rely on official GDA groundwater (only illicit sources). For the purpose of this model, illicit water is assumed to be 50% more expensive than water from legal sources (average measure based on literature and interviews) and continuously available to water user independent of the pumping depth of the GDA (e.g. illicit water can be purchased from deeper wells beyond the perimeter of the GDA). Initial pumping rates, hydraulic heads, pumping depths, and extraction costs are calibrated based on observed and modelled data from the year 2012. Hydrogeological processes largely serve as input to the model –

with limited feedback of simulated water user behaviour on the underlying aquifer due to the chosen model boundary.

The inventory of illicit wells used in this analysis stems from a field campaign conducted by INAT in 2016 and was analysed using QGIS. All agricultural water user groups covered by the model and inventory were investigated in the study (in total 15 water user groups distributed across 15 villages). Agricultural data from Water Evaluation And Planning (WEAP) models include information on cultivation costs, crop price, extraction and maintenance costs based on data collected between 2003 and 2017.

Definition of scenarios

Four scenarios are defined to model decision-making under different hydrogeological conditions and agricultural strategies. Given the hydrogeological diversity in the chosen study area, two representative GDAs, one for “unfavourable” and one for “favourable resource settings”, were chosen to represent the breadth of aquifer dynamics. In “unfavourable” resource settings, hydraulic heads are considerably lower than in the “favourable” counterpart. Lower hydraulic heads translate to higher extraction costs that will influence farmers’ utilities. GDAs in unfavourable resource settings are subject to higher aquifer extraction rates and higher densities of surrounding illicit wells. Lower hydraulic heads also translate to higher risks of hydrogeological collapse, i.e. the well running dry. Based on empirical evidence from water user interviews, we assume hydrogeological thresholds are lower under unfavourable conditions. Regarding agricultural strategies, we model two types of crops: a low-value/low-water crop and a high-value/high-water crop. Crop

types are stylised to represent crops with different water inputs/requirements and cash outputs. Water-yield relationships are calibrated based on data on representative crops in the region (olive and tomato for low-value/low-water and high-value/high-water crop respectively). In the SES, all farmers cultivate the same crop within a given simulation. We assume that farmers cannot switch to the other crop type within a single simulation (reflecting the difficulties farmers face when switching between crops in the real world, e.g. sunk investment, social rules). Further information on the calibration of resource settings and crop types can be found in the annex. To summarise, four scenarios emerge:

1. FAV+LOW: Favourable resource setting combined with low-value/low-water crop
2. FAV+HIGH: Favourable resource setting combined with high-value/high-water crop
3. UNFAV+LOW: Unfavourable resource setting combined with low-value/low-water crop
4. UNFAV+HIGH: Unfavourable resource setting combined with high-value/high-water crop

Feature importance analysis

After model construction and calibration, we employ Monte Carlo (MC) simulations of key social parameters for each scenario. Social parameter ranges (consistent across all four scenarios) represent the range of social and institutional characteristics under fixed ecological resource conditions and agricultural strategies (see parameter ranges in the annex). Social parameter values are sampled from a random uniform distribution (10,000 MC simulations for each of the four scenarios). The results represent the range of possible

collective action outcomes given variable social characteristics of water user groups. We have employed boosted decision trees to examine the relative impact of social characteristics on the likelihood of collective action outcomes (i.e. fee recovery, illicit withdrawals, poverty etc.). In order to identify key drivers of these outcomes, individual feature importance of these parameters is assessed by XGBoost, which stands for Extreme Gradient Boosting, a scalable, distributed gradient-boosted decision trees machine learning library (Chen and Guestrin, 2016). These iterative decision tree algorithms are trained on multiple iterations to find patterns within features of a dataset. XGBoost hyperparameters were optimised using k-fold cross-validation in combination with randomized grid search. Machine learning tools such as XGBoost hold several advantages over more traditional statistical approaches such as identifying complex non-linear relationships in large modelled datasets. Subsequently, we employed Shapley values (Lundberg and Lee, 2017; Shapley, 1953; Dubey, 1975; Cohen *et al.*, 2005) to assess the contribution of specific features to the outcomes predicted via XGBoost. Shapley values are rooted in cooperative game theory (Shapley, 1953) and represent the average marginal contribution of a feature across all possible feature combinations. By computing the Shapley values for each feature, one can assess their relative importance in the model's predictions. Features with higher Shapley values have a larger impact on the model outcome predictions, while features with lower values have lesser influence. Results of the feature importance analyses serve the identification of specific scenarios that illustrate system dynamics and there-embedded causal chains.

c. Results

User group collapse and declining agricultural revenues are unavoidable in the long-term

Two pathways lead to system collapse of water user groups: Hydrogeological collapse and financial collapse (figure 15). Independent of scenarios, pathway 2 of financial collapse most often precedes pathway 1 of hydrogeological collapse (figure 16.A). Water user groups in unfavourable conditions (UNFAV) experience hydrogeological collapse after 8 years and FAV user groups after 17 years (figure 16.B and 16.C). Results from the model, however, reveal a common trend of early bankruptcy within the first five years of the simulation across all four scenarios (figure 16.A). Under the scenario FAV+LOW, groundwater user groups are most likely to avoid bankruptcy. Under the same ecological scenario but combined with the high-value/high-water crop choice (FAV+HIGH), all water user group, independent of social and institutional characteristics, run bankrupt after 4 years. This is tied to the rapid erosion of the norm of fee payments. Under unfavourable conditions, 87.6% of user groups run bankrupt independent of agricultural strategies: GDAs with high rates of fee recovery can delay system collapse until their wells run dry in year 8. After 9 years, GDAs under FAV+LOW face the erosion of fee payment norms due to the increasing financial pressure on farmers under decreasing aquifer levels and increasing withdrawal costs.

In terms of individual livelihoods, we compare the average percentage of farmers living below the poverty threshold across the four scenarios (figure 17). Overall, income-poverty from agricultural activity cannot be avoided in the long term. Notably, water users under unfavourable resource settings are generally

better capable to delay a lose-lose poverty trap. Among the four scenarios, the scenario UNFAV+LOW is the best performing scenario. Choosing to cultivate low-value/low-water crops leads to consistently better outcomes than the high-value/high-water equivalent likely due to early adaptation to water scarcity. This means that user groups that employ water-efficient agricultural strategies (LOW) under unfavourable water availability (UNFAV) are better equipped to buffer the effects of path-dependent aquifer depletion. Under

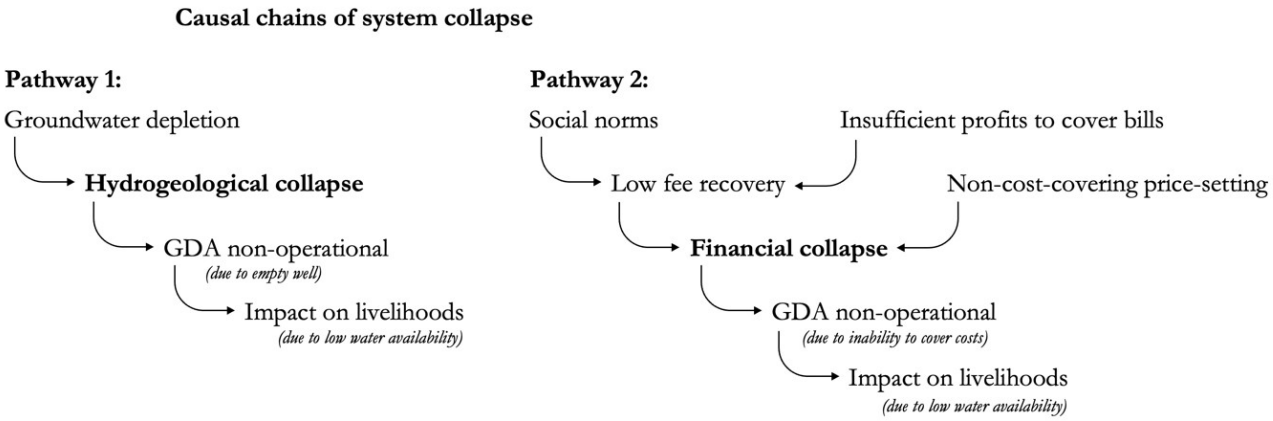


Figure 15 Causal chains for system collapse: Pathways of hydrogeological or financial collapse

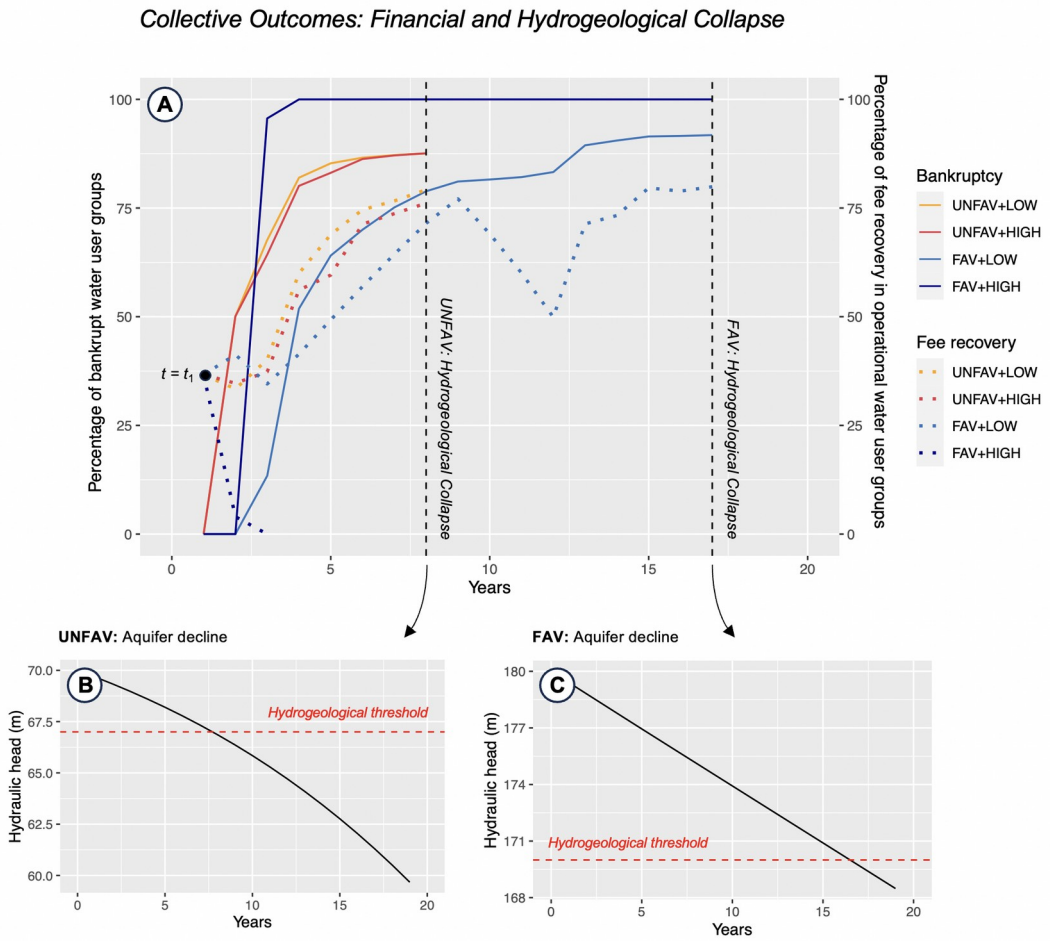


Figure 16 Sustainability of the user group: Monte Carlo simulations of bankruptcy among user groups (10,000 simulations) under four key scenarios including hydrogeological thresholds for system collapse

diminishing water supply, lower water demands enable more sustained agricultural profits. When high-value crops are cultivated, 100% of farmers live below the poverty threshold after 12 years independent of social and institutional rules. For FAV+HIGH, poverty levels increase drastically within the first year of simulation. Low-value crops can postpone the point in time when the poverty threshold is surpassed by several years. We also observe that although GDAs stop functioning after hydrogeological collapse, farmers are able to sustain their livelihoods for several years by means of illicit water extraction. The social and institutional parameters that explain these outcomes will be further explored in the subsequent section, where we unpack the social and

institutional dynamics that can prevent or delay bankruptcy and poverty outcomes.

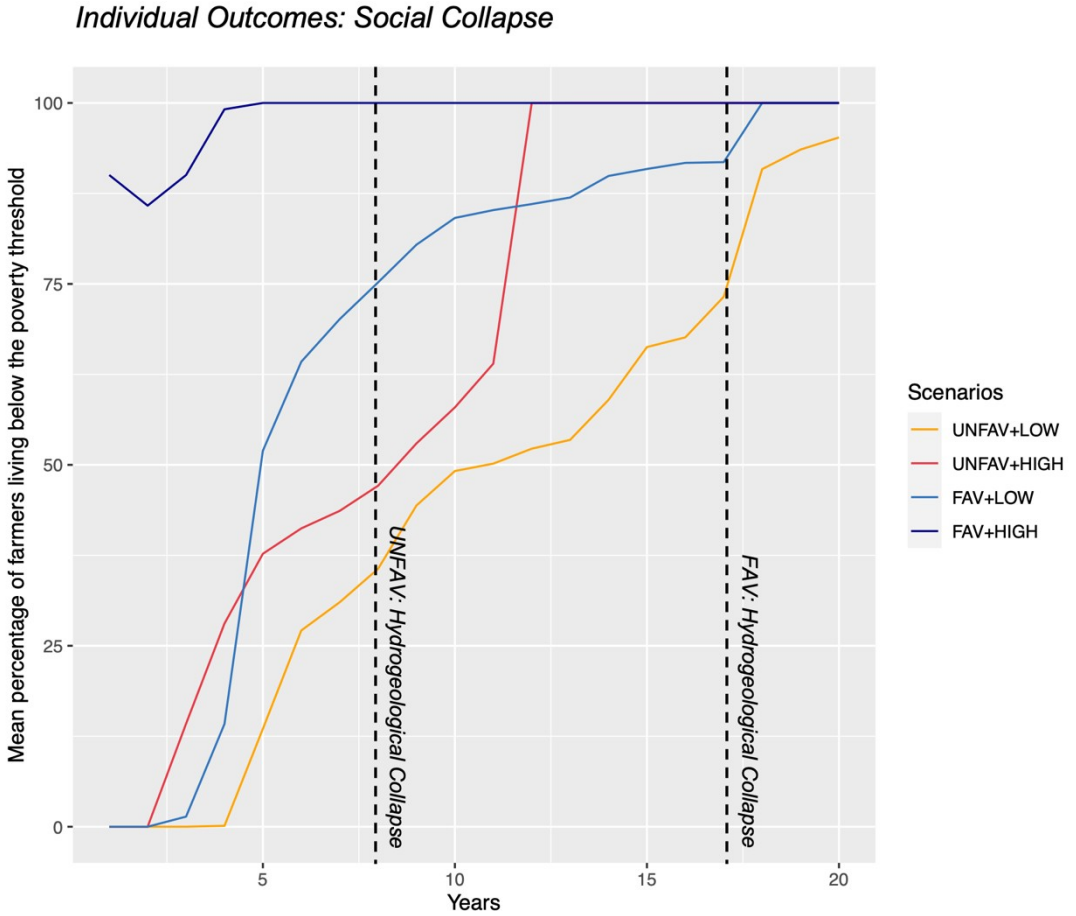


Figure 17 Social Sustainability: Percentage of water users living under the poverty threshold (World Bank Group, 2019) averaged across Monte Carlo simulations (10,000 per scenario)

Strong leadership, sustainable water pricing, and low levels of vertical trust serve as delay mechanisms for system collapse

Feature importance analyses reveal which social and institutional parameters (sampled from a random uniform distribution, appendix 7) have the greatest influence on farmer behaviour and collective outcomes (Table 7). Under the scenario FAV+LOW, leadership is consistently ranked the most important feature for all independent variables, followed by price setting and equity. Contrarily, under unfavourable resource settings, the importance of parameters

varies across outcomes. Choosing low-value/low-water crops, the key parameters for fee recovery and the budget of the user group (in order of importance) are price setting, leadership, and equity. Regarding poverty and illicit withdrawals, the key parameters are vertical trust, horizontal trust, and price setting. Choosing high-water/high-value crops, fee recovery and GDA budget were most influenced by price setting, leadership, and vertical trust.

Table 7 Results of feature importance analyses

	Sustainability of price-setting and allocation	Equity	Leadership (absolute)	Leadership (alpha)	Vertical Trust (absolute)	Vertical Trust (alpha)	Horizontal Trust (absolute)	Horizontal Trust (alpha)	External pressure (alpha)
FAV+LOW									
Fee recovery	1.19	0.45	1.81	1.76	0.12	0.10	0.05	0.03	0.24
Poverty	0.99	0.37	2.02	1.95	0.16	0.14	0.05	0.04	0.28
Illicit withdrawals	0.98	0.37	2.01	1.95	0.15	0.14	0.06	0.05	0.27
GDA budget	1.27	0.69	2.28	2.20	0.18	0.17	0.07	0.05	0.33
UNFAV+LOW									
Fee recovery	1.3	0.12	0.55	0.54	0.08	0.08	0.03	0.03	0.02
Poverty	0.00	0.00	0.00	0.00	0.03	0.03	0.01	0.01	0.00
Illicit withdrawals	711.70	387.37	247.17	503.82	8525.51	7539.02	815.95	712.67	90.83
GDA budget	2.81	0.39	1.89	1.88	0.32	0.34	0.06	0.09	0.04
UNFAV+HIGH*									
Fee recovery	1.30	0.12	0.55	0.54	0.08	0.08	0.03	0.03	0.02
GDA budget	2.85	0.17	1.94	1.90	0.25	0.31	0.13	0.11	0.03

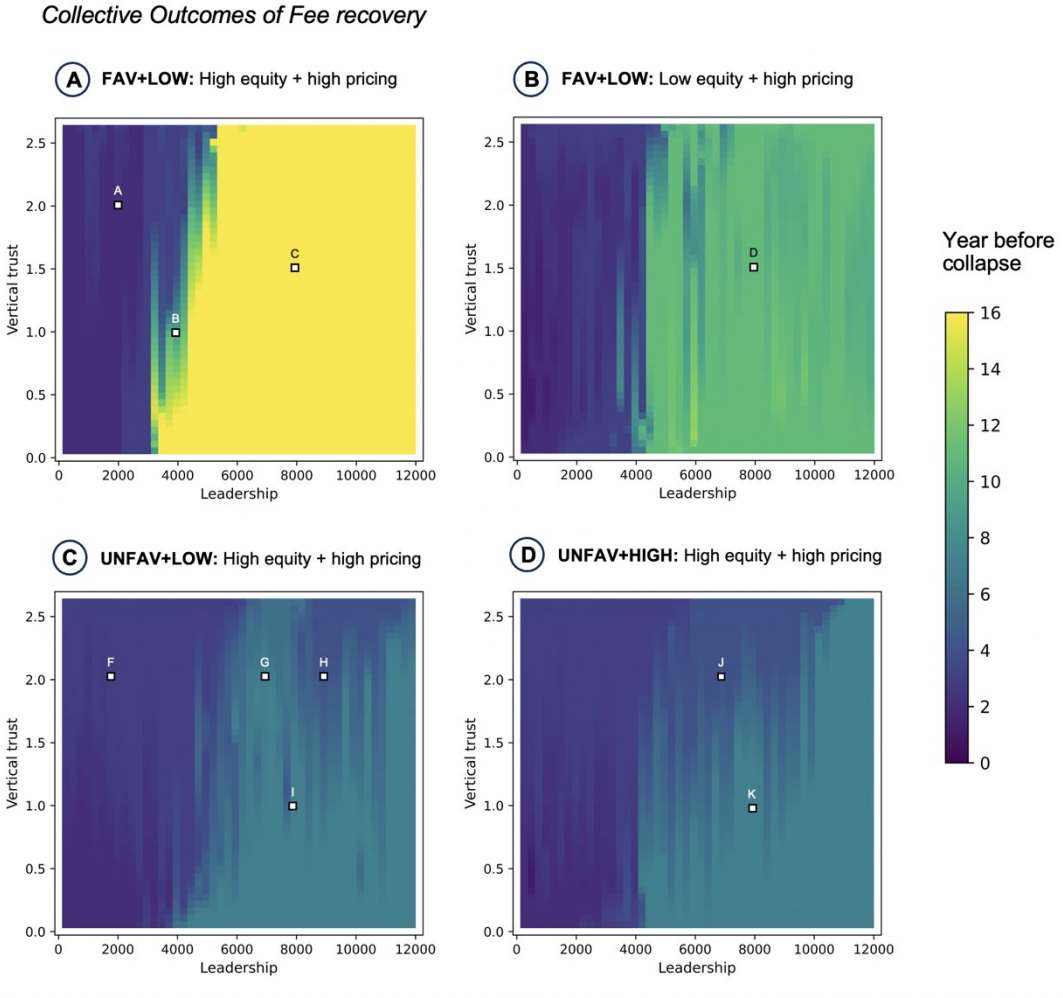
* Feature importance for poverty and illicit withdrawals could not be tested since there was no variation between values at terminal time *t* or times of system collapse (after 11 years). Feature importance was also not analysed for the scenario FAV+HIGH due to the lack of variability in outcomes (i.e. systems collapse independent of social and institutional conditions).

First, second, and third most important feature

Since water user groups most often collapse due to bankruptcy (pathway 2), we explore which conditions motivate farmers to pay their fees using heatmaps (figure 18). To better understand individual and combined effects of social and institutional parameters, we simulated a set of scenarios that illustrate the impact of the ecological, social and institutional context on fee recovery. To this purpose, we show the combined effects of leadership and vertical trust on the time of collapse for fee recovery (i.e. fee recovery = 0%). Year 17 is the latest

possible year up to which water user group collapse can be delayed by measures of good governance, since this is the latest point of hydrogeological collapse (FAV). Scenario FAV+LOW combined with high equity and sustainable price setting (figure 18.A) yields the best results for fee recovery, particularly under high leadership and low vertical trust.

The results reported in figure 18 help us identify key areas to further explore in single-simulation scenarios, indicated by capital letters in figures 19 and 20. Leadership, as the parameter determining penalties regarding fee payments, is a key driver of farmer behaviour with cascading effects across all collective action (CA) outcomes. Under high leadership, price-setting, and equity, water user groups are most likely to avoid financial collapse and high poverty outcomes (figure 19 - scenario C). Lower leadership scores reduce the ability of the water user group to prevent collective outcomes of user group bankruptcy and individual outcomes of poverty (scenarios A and B). Equity only has a



positive effect on outcomes under conditions of sustainable pricing. Under low equity conditions and sustainable pricing the time of collapse occurs several years earlier than under high-equity conditions (scenario C versus D). Sustainable pricing, the ability of water user groups to recover their costs, is a conditio sine qua non for the GDA to avoid bankruptcy.

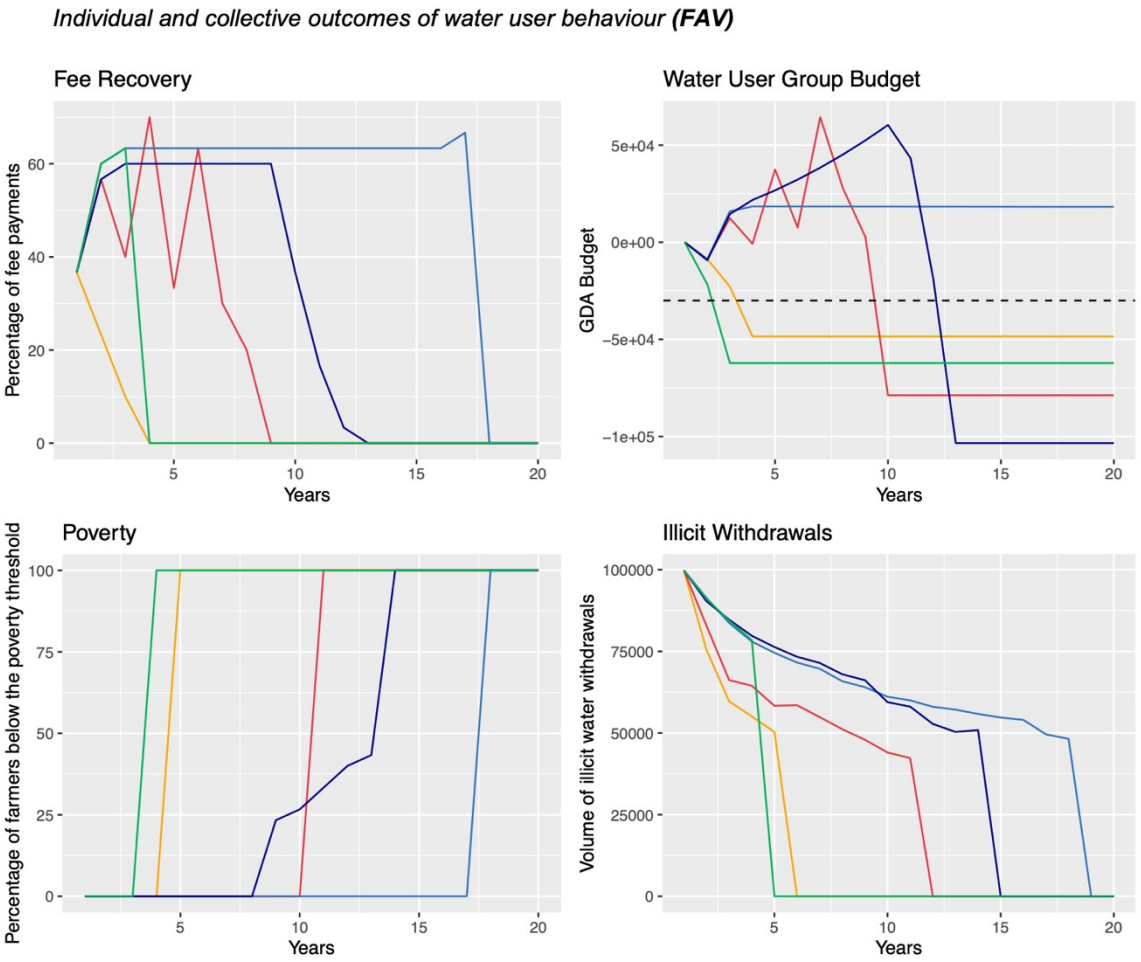
Figure 18 Heatmaps of fee recovery: Drivers of individual fee payments under varying scenarios. The time of crash corresponds to a fee recovery of 0%

Even under high leadership and equity scores, setting a non-cost-covering price leads to the financial crash of the user group (scenario E). In each scenario, farmers cannot avoid poverty outcomes when user groups have collapsed and the cost of illicit withdrawals becomes too expensive to cover.

Under UNFAV conditions (in figure 18.C and 18.D), leadership also serves as a key driver of fee recovery among water users (figure 20 - scenario F versus G). Increasing leadership, however, does not consistently lead to better outcomes for water user group. Systemic feedbacks can trigger negative consequences for generally positive predictors of CA. For example, under resource and income scarce conditions increasing penalties for users failing to pay their fees can push communities into collapse under already stressed social-ecological conditions earlier (scenario H versus G). Lower levels of vertical trust, associated with lower penalties regarding illicit water withdrawals, lead to positive outcomes for water users particularly in unfavourable resource settings, where farmers rely more heavily on illicit water sources (scenario G versus I for UNFAV+LOW, and scenario J versus K for UNFAV+HIGH). While under unfavourable resource settings (as opposed to FAV), high-value/high-water crops can achieve positive individual and collective outcomes under favourable leadership and trust conditions (scenario K), poverty rates will

always reach 100% sooner than in scenarios where lower water demands can continue to generate yields and incomes for farmers (scenario I).

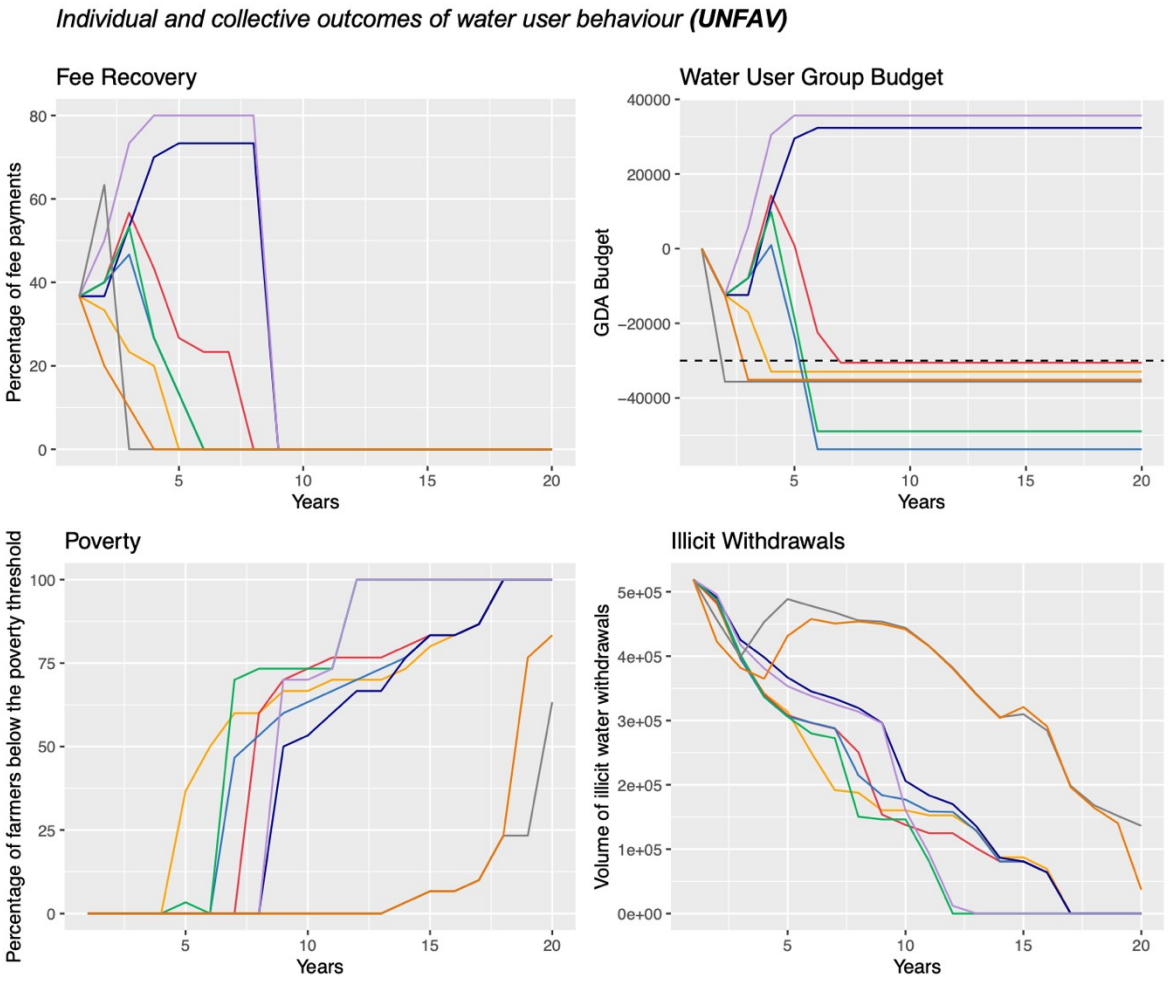
High leadership, low vertical trust, sustainable pricing, and high equity lead to the best possible collective outcomes for the water user group in terms of fee recovery and financial sustainability. The results suggest, however, that the best outcomes in terms of individual livelihoods can be achieved under low leadership and trust (scenarios L and M in poverty panel of figure 20). We can track the erosion of norms both in terms of a rapid decline in fee payments (in years 1-4) as well as an increase of illicit withdrawals (in years 3-6). The model thereby suggests that water user groups that disregard formal government rules perform better in terms of poverty outcomes due to higher cash flows from illicit withdrawals. Generally, illicit withdrawals serve as a meaningful buffer and coping strategy for water users under increasing water scarcity. In contrast to previous simulations, cost-covering price-setting by the GDA in these scenarios is not an advantage for farmers with respect to poverty outcomes as the ability to easily access groundwater from illicit sources is more relevant for farmers than a functioning GDA. Under these two scenarios that see low penalties for illicit withdrawal (low vertical trust and external pressure), levels of poverty remain low despite early financial collapse of the water user group. The decline of illicit withdrawals (due to rising extraction cost) and the sharp increase of poverty levels in the last years of simulations indicate, however, that this serves only as a temporary coping strategy for water users.



Scenario	Resource Setting	Crop	Sustainability of price-setting and allocation	Equity	Leadership	Vertical Trust	Horizontal trust	External pressure
A	Favourable	Low-water/ low-value	High	High	2000	2.0	0.27*	1.34*
B			High	High	4000	1.0	0.27*	1.34*
C			High	High	8000	1.5	0.27*	1.34*
D			High	Low	8000	1.5	0.27*	1.34*
E			Low	High	8000	1.5	0.27*	1.34*

*representing median values for the respective parameter

Figure 19 Single simulations of user behaviour: Outcomes of fee recovery, user group budget, poverty, and illicit withdrawals under favourable conditions.



Scenario	Resource Setting	Crop	Sustainability of price-setting and allocation	Equity	Leadership	Vertical Trust	Horizontal trust	External pressure
F	Unfavourable	Low-water/ low-value	High	High	2000	2.0	0.27*	1.34*
G			High	High	7000	2.0	0.27*	1.34*
H			High	High	9000	2.0	0.27*	1.34*
I			High	High	8000	1.0	0.27*	1.34*
J		High-water/ high-value	High	High	7000	2.0	0.27*	1.34*
K			High	High	8000	1.0	0.27*	1.34*
L		Low-water/ low-value	Low	High	2000	0.01	0.15	0
M			High	High	2000	0.01	0.15	0

*representing median values for the respective parameter

Figure 20 Single simulations of user behaviour: Outcomes of fee recovery, user group budget, poverty, and illicit withdrawals under unfavourable conditions.

d. Discussion and Conclusion

This study explored the impact of aquifer depletion on agricultural systems and associated local livelihoods using the fragile political system of Tunisia as a case study. We assessed the influence of interacting social and institutional norms on decision-making of small-holder farmers in the absence of formal monitoring and enforcement rules. Results revealed practical limits of self-governing institutional arrangements under given social-ecological conditions and provide critical insights into collective action dynamics in stressed CPR/groundwater SES. With a focus on vertical and horizontal mechanisms of trust and leadership and associated norm-driven behaviour, we developed a digital twin that captures the behaviour of individual farmers, and integrates the interactions with their peers and the water user group by means of social and institutional norms. The SES model thereby contributes to the Commons and SES literature and addresses critical knowledge gaps in the water-agriculture-poverty nexus.

The SES model was able to show that under the simulated scenarios of groundwater decline, low-value/low-water crops lead to better long-term livelihood outcomes for farmers than high-value/high-water crops. Vertical mechanisms of leadership served as key drivers for collective action in water user groups (particularly under favourable conditions) with cascading effects across all CA outcomes. Horizontal mechanisms on the other hand were found inadequate to overcome practical hurdles that prevent financial collapse of water user groups. In other words, social trust is useful but if the user group goes bankrupt, there is little trust can do to avoid or mitigate effects. Most commonly, financial collapse (pathway 2 in figure15) precedes hydrogeological collapse (pathway 1 respectively). It follows that farmers and their water user groups are not able to prevent the type of collapse that is directly caused by

their own collective action (as an endogenous process of the simulation). Financial collapse is triggered either by inadequate price-setting (by the GDA administrative council) or user behaviour (inadequate fee recovery due to inherent payment preferences or insufficient profits to cover water costs) (figure 15). We find that water user groups can only avoid bankruptcy by setting cost-covering prices but even that may not be sufficient under insufficient water availability or norms that favour non-payment.

Generally, water user groups are more likely to delay rather than avoid system collapse. Scenarios where the system has not fully collapsed after 20 years (see for instance the poverty rate in scenario L and M with low levels of vertical trust), reveal a trend towards looming collapse in the last years of the simulation. Decreasing groundwater supplies and high levels of poverty at terminal time indicate that agriculture alone struggles to provide long-term livelihoods for farmers in the case region. Water economising measures such as switching to low-water crops or improving water use efficiency could provide relief but only if these measures are implemented in a well-concerted manner at the aquifer scale and are supported by regulatory limits to extraction. Institutional challenges at the local level suggest further issues regarding the scaling of solutions across polycentric governance levels, including the basin scale. Shall polycentric coordination fail, farmers will be faced with the collapse of agricultural production system and the need to diversify their income sources beyond agriculture.

Our model has taken the perspective of the farmer and has thereby outlined the limits of individual or even community-level action (in the face of extensive aquifer-level groundwater depletion) as well as practical consideration of livelihood-generating agricultural strategies. Against common policy advice that

seeks the rapid closing of illicit wells, the model highlights that under unfavourable resource conditions, water users may find it advantageous to turn to illicit groundwater sources that are independent of the collective action risks associated with legal withdrawals in official water user groups. By drawing from reliable (albeit more expensive) illicit groundwater sources, farmers can generate stable incomes from cultivating crops. Groundwater from illicit wells thereby serves as an important buffer for farmers to avoid the poverty trap and could help with the transition away from agriculture in a region set on a path of long-term aquifer depletion. Due to the key importance of reliable groundwater sources, lower levels of trust in governments that discourage illicit extraction thereby lead to better outcomes for farmers and their water user groups as social penalties for illicit withdrawals decline. Given the historic context of political fragility and the general lack of trust in government and government rules, illicit welling turns into a coping strategy for water users. In a regulatory framework that offers no formal means of enforcement of rules, and under given conditions of water scarcity and associated risks for agricultural livelihoods, communities that disregard formal rules perform better than rule-conforming GDAs.

It is important to reiterate, however, that illicit withdrawals accelerate the process of aquifer depletion and do not serve as a long-term coping strategies for farmers. The system simulated here has taken a realistic stance on the low probability of rapid concerted action on the scale of the aquifer that would put a halt to decade-long groundwater depletion. In the absence of a functioning regulatory system and formal support for local water user groups, farmers are likely to be left to their own devises to generate livelihoods from agricultural activities for as long as they can do so. The gradual depletion of aquifers exemplifies the context of slow onset events. The social- ecological take-some

dilemma of continued or even accelerated groundwater overextraction from largely illicit sources translates to higher likelihoods for poverty traps, i.e. the higher the overextraction levels, the earlier farmers will be unable to withdraw sufficient water to irrigate their crops.

Finally, our simulations reveal strong patterns of path dependence. Farmers generally rely on known ”tried-and-tested” cultivation and water withdrawal strategies and will only change their own strategies if they see an opportunity to improve their utilities by imitating a well-performing peer. While this phenomenon has been observed in the study area, the simple social network chosen for the model neglects the possibility of external interventions e.g. policy implementation or individual ingenuity. There are multiple opportunities to expand the current version of the model. They range from more complex social networks, forward-looking discount rates for farmers, more diverse and dynamic crop choices, to aquifer-level (rather than GDA-level) agent-based groundwater withdrawals (to make groundwater decline an endogenous process of the model), incorporating market volatility affecting both the price of illicit water and crops sold, as well as climate change scenarios for precipitation inputs.

The paper has demonstrated that in settings of gradual aquifer decline, a continuation of the status quo results in the eventual collapse of agricultural production systems with deleterious effects on associated livelihoods. Policy efforts should strengthen the institutional capacity of collective action groups including practical guidance regarding a transition to less water-intensive crops. A reconsideration of the feasibility of irrigation agriculture under given water constraints is necessary and should be accompanied by providing farmers with the opportunity to diversify incomes beyond agriculture. Regardless of

policy interventions, irrigation agriculture will decrease due to falling groundwater tables and limited water supplies - either accompanied by appropriated policy measures or unaccompanied (with potentially devastating effects on farmers' livelihoods). Results thereby reiterate the necessity of basin-wide collective action in stressed groundwater systems while acknowledging associated implementation challenges, particularly in the fragile political contexts.

CRediT author statement

Sophie Erfurth: Conceptualisation, Methodology, Software, Formal Analysis, Investigation, Data Curation, Writing - Original Draft, Visualisation. **Jacopo A. Baggio**: Conceptualisation, Methodology, Software, Writing - Review & Editing. **Reetik-Kumar Sahu**: Data curation, Software, Methodology, Writing - Review & Editing. **Taher Kahil**: Writing - Review & Editing, Project Administration. **Jamila Tarhouni**: Investigation, Validation, Resources. **Rahma Brini**: Investigation, Resources, Project Administration. **Matthias Wildemeersch**: Conceptualisation, Methodology, Formal Analysis, Writing - Review & Editing, Supervision.

Acknowledgements

Part of the research was developed while I was participating in the Young Scientists Summer Programme at the International Institute for Applied Systems Analysis, Laxenburg.

6. Discussion and Conclusion of the Thesis

a. Contribution to Theory

This thesis examined common pool resources (CPR) governance in the context of fragile political systems. What factors enhance or detract from the capability of resource users to self-govern? Established theories of collective action (CA) were deemed unfit to answer this question in environments, where hope and trust in institutions have been systemically eroded. CA and CPR research rarely focuses explicitly on the role of fragility in the emergence and endurance of collective action. The strength of this thesis lies in capturing the evolution of institutions, rules, norms, and emergent patterns of collective action in a complex adaptive SES mediated by political fragility. The thesis provides a theoretical underpinning to the understanding of the role of fragility in water governance across temporal and spatial scales. It examines path-dependent causal drivers in centralised policy-making, local self-governing institutions, and individual user decision-making. This thesis gives new empirical and theoretical insights on how policy- and decision-making in the water sector is contextually bounded within the SES. It expands theories of collective action and CPR theory for fragile settings of low-hope, where resource users feel unable to rely on formal institutional rules: If water users have “nothing to lose”, as they state, what mechanisms remain to motivate the pursuit of collective goals, i.e. sustainable groundwater management? In the absence of formal frameworks of monitoring and enforcement, and in the absence of institutional trust and hope, this thesis highlights alternative modes of decision-making on water resources use across governance scales.

Two decades after the Drama of the Commons, this thesis has addressed critical knowledge gaps regarding the durability of resource management institutions (Stern *et al.*, 2002). It has applied a multi-layered and longitudinal assessment to unpack how individual and collective behaviour and norms evolve in the context of political fragility at a variety of institutional scales. It has placed local rules in the context of post-Authoritarian state control thereby shedding light on the nesting of institutions in a complex SES setting. Paying careful attention to causal analyses, this thesis was able to analyse the role of fragility in collective action problems of groundwater management, particularly with regards to the erosion of trust and hopelessness among water users. In bridging social science theories (such as historical institutionalism) and theories prevalent in computational behavioural modelling (such as social preferences as theorised by Fehr and Schurtenberger, 2018), the thesis has been able to generate crucial insights on asynchronous water user behaviour and decision-making in a fragile context. Complexity inherent to the SES was captured using transdisciplinary methods allowing qualitative insights on the path-dependent evolution of institutions to inform quantitative animations of SES dynamics. Linking complementary methods has served the purpose of an integrated study of decision-making within the irrigation water sector. The thesis has been able to unpack the social-ecological drivers of user behaviour particularly with regards to the adherence of users to shared norms driven by institutional fragility.

b. Methodological contribution

The methodological innovation of modelling bounded rationality of water users in a fragile political SES is facilitated by an evolutionary game of the SES informed by qualitative empirical evidence. Interwoven causal pathways are thereby studied in a transdisciplinary multi-method approach that bridges

social-historical explorations with computational simulations of user behaviour. The methodological framework pays careful attention to causal analysis in the context of complexity through a combination of integrated qualitative-quantitative methods.

The thesis has highlighted why it is important to consult the past to better understand resources dilemmas of the present: In the case of Tunisia, because former Authoritarian regimes built institutions of water allocation and use in their image with social dependencies and public expectations that are relevant to this day (paper 1). These insights expand theories of state legitimisation, repression, and co-optation to the water-agriculture nexus. The thesis has argued that water user behaviour and resulting collective outcomes need to be explained using a trans-disciplinary methodological approach that takes Tunisia's post-Authoritarian context seriously. Where human-environment processes are deeply intertwined, this thesis has modelled interacting social-institutional norms and hydrogeological dynamics in a "digital twin" of the SES (paper 3). It has thereby contributed to SES research by integrating multidimensional trust relations to models of asynchronous user behaviours. The bridging of qualitative and qualitative tools and data has responded to calls in SES research to innovate across disciplines to better understand the complexity inherent to SES (Preiser *et al.*, 2022). Empirical and modelling insights of this thesis also carry practical policy implications for the water-agriculture-poverty nexus (Balasubramanya and Stifel, 2020), where knowledge gaps have limited the capacity to secure livelihoods in water-scarce agricultural contexts.

Each of the three papers has been able to advance their respective scholarship with innovations in each of the three methods applied. For applications of

historical institutionalism and process tracing, this work advanced respective tools to study the evolution of practices of state-building and repression under authoritarian control in the water-agriculture nexus. Process tracing has proven an appropriate tool in exploring novel patterns of “soft state control”, or in the words of Hibou (2011) “the force of obedience”, on water users and water user behaviour in authoritarian governance regimes. For QCA, a strong focus on contextual diagnostics and empirical case study data was able to enhance the ability of the method to visualise pathways of collective action within settings of low hope and generalised trust in government. For ABM, the methodological innovation lies in animating water user behaviour and interacting norms using horizontal and vertical mechanisms of trust and leadership, and by grounding model design and calibration in empirical qualitative and quantitative datasets. This triangulation of data and methods has allowed for a context-sensitive understanding of causal mechanisms underlying human decision-making in complex adaptive SES.

Epistemological tensions across different methods were addressed and overcome using a pragmatic yet sensitive approach grounded in a strongly case study-based methodology. In-depth contextual knowledge facilitated the research design process and a purposeful choosing of methods to address chosen research questions. Complementarities across methods, both qualitative and quantitative, give a more realistic insight into practical water governance challenges in the post-Authoritarian context of Tunisia. Where qualitative approaches are limited in animating and testing process-driven questions of causality, and where quantitative approaches are limited in grasping contextual details of path-dependent social preferences and norms, a combination of methods allows for a well-calibrated representation of key drivers in the SES. Even though the study of collective action is empirically grounded in the

Tunisian context, it provides new methods of engagement with fragile path-dependent SES.

c. Discussion of Results

Motivated by real-world challenges of groundwater resources management in Tunisia, this thesis put forth the ambition to provide practical insights on potential policy interventions. Results from the three papers have highlighted the limits of (top-down) policy implementation and (bottom-up) collective action in the face of path-dependent groundwater depletion and political fragility. The thesis elaborated on the limits to both approaches to water governance including challenges in polycentric governance across scales by unpacking social-ecological dynamics through a historical lens. At the national level, Tunisian water governance struggles with a weak regulatory system that fails to establish and enforce regulatory limits to extraction. In the case of groundwater withdrawals, the water code of 1975 and amendment law no. 78-814 lack implementation mechanisms for volumetric measurements of prescribed water permits. Similar to insufficient implementation mechanisms for legal withdrawals, regulatory protocols to combat illicit wells are non-existent. Beyond these regulatory capacities, the three papers have shown that even in the case of updated legislature, policy implementation in the post-authoritarian fragile context is socially fraught. Low levels of generalised trust in government and hope as well as a legacy of social unrest following (perceived) threats of social security render new means of monitoring and enforcement challenging (paper 1 and 2).

At the local level, collective action struggles with aquifer overexploitation and the lack of local institutional capacity – both due to a historical legacy of

repressive Authoritarian regimes: The former as a social promise for irrigation agriculture and thus social development, and the latter as a result of the dismantling of decentralised technical and institutional capacity in favour of a centralised bureaucratic apparatus of repression and co-optation. While the historic focus on agricultural cooperatives could be an opportunity for collective action, future policy efforts that target the institutional strengthening of said water user groups need to take into account embedded post-Authoritarian rules such as mechanisms of subtle social supervision and the remains of a rigid administrative apparatus (paper 1). Paper 2 has further highlighted practical limits to collective action, where water user groups with low levels of hope and trust in government are more frequently associated with conflict among water users. On the other hand, results were able to illustrate that, given the systemic erosion of institutional trust, farmers see local coping mechanisms as an alternative to formal rules and the coercive power of the state (paper 2 and 3). QCA in paper 2, for example, has shown that local mechanisms such as social cohesion and the expectation that other water users stick to local, often informal, rules increase the likelihood of collective action, i.e. fee recovery, under systemic fragility. Similar insights have been found by Bastakoti *et al.* (2010) in Nepal and Thailand where local institutions have played an important alternative option regarding irrigation water use by mediating external shocks and pressures.

The thesis was further able to demonstrate that the challenge of illicit wells is not merely a regulatory or enforcement challenge, where ‘well legalization processes take much longer than intended, with deadlines continuously extended, and are rarely completed’ or where drilling bans are insufficiently enforced (Molle and Closas, 2020: 1970). Many water users in Tunisia choose to continue to withdraw illicitly due to the collective memory of an arbitrary

administrative apparatus and the resulting distrust in state institutions (paper 1 and 2) as well as practical considerations such as a reliable source of irrigation water in the face of bankrupt water user groups (paper 3). The path dependence associated with illicit welling is tied to its historic legacy of illicit wells as an institutionalised safety valve. Once paired with authoritarian tactics of control and hence silently accepted by the regimes, now tied to the state of political fragility of an unstable democracy unable to implement unpopular reforms: Either way, given the resulting practical reliance on groundwater for irrigation and livelihoods under increasing water scarcity, the process of groundwater overextraction, whether legal or illicit, is impossible to reverse without concerted mitigation efforts to buffer repercussions for rural livelihoods.

The state of fragility is inherently tied to questions of good water governance. Historically, regimes toppled when citizens felt that the so-called security pact was violated, when the ability of citizens to make a decent living was compromised. The bread riots of 1983/1984, the on-set Arab spring of 2010/2011, are examples of events, where individuals and collectives felt that the “social contract of a decent life” was broken. In a democratic Tunisia (info-box 2), the lingering potential for social unrest continues to be rooted in these feelings of injustice whenever promises of social security are compromised. Threating small-holder farmers with the closing of illicit wells (where wells portray the last resort of preventing poverty - as demonstrated in paper 3) represents a social-political powder keg. Perceptions of social injustice (linked to social promises engrained in Tunisia’s Authoritarian past - as demonstrated in paper 1) are to be taken seriously when addressing challenges of water resources management. Where water users feel hopeless, abandoned, and betrayed by their current government or wish back old authoritarian control (as

demonstrated in paper 2), new policy efforts need to take into account on-the-ground realities of water users. Blatter (2009) argues that 'research in water governance should pay more attention to the symbolic value of water that makes it prone to being used as a tool for the representation of general identities and relationships between the involved actors' (106). This thesis has shown that water carries fundamental associations and attachments and can therefore actively be employed and manipulated as an emotive policy tool.

In this spirit of path dependence, it is also important however to recognise the positive potential for collective action based on the historical legacy and centralised recognition of self-governing water user groups in Tunisia (Ostrom, 1990). Grounded in formal laws (no. 87-35 and 2004-24), water user groups have the regulatory backing to successfully organise water users around a shared resource. Along with this regulatory guarantee, water user groups further have the opportunity to benefit from former centralisation efforts such as the National Agricultural Investment Agency (APIA – *Agence de Promotion des Investissements Agricoles*), which grants subsidies to farmers throughout Tunisia and enjoys wide-spread popularity with farmers. Despite this potential for collective action, mere calls for increasingly polycentric approaches, e.g. Schipanski *et al.* (2023), are not sufficient in overcoming challenges of the decade-long break-down of institutional trust and capacity of these collective action groups. In order to facilitate effective polycentric governance systems it is essential to rebuilding local capacities and re-establish eroded institutional trust - both of which necessitate sensitive, well-balanced policy approaches and, most importantly, time. Regional administrations (CRDAs) responsible for coordination with local water user groups (GDAs), which have historically been repurposed to fit authoritarian tactics of repression, currently lack the technical and financial capacity to provide much needed support to local water user

groups. The bureaucratic heaviness of a centralised administrative apparatus remains a practical hurdle for farmers to legalise their illicit wells. The slow process of rebuilding trust in local and regional institutions could involve re-decentralisation efforts, where transparency and proximity of service for rural farmers can be re-established.

Independent of good governance efforts, the practical burden of decreased groundwater levels is difficult to overcome. Individual farmers who need to make a living by irrigating their crops may find their hands tied when faced with the decision to withdraw groundwater outside of formal and informal rules, and may see their best option in delaying poverty outcomes by continued overharvesting of the resource (as demonstrated in paper 3). While paper 2 found that low groundwater levels can lead to cooperation, i.e. fee recovery, among water users, results further revealed that these collective action groups eventually fail (because wells run dry) and are more prone to conflict. In such circumstances, where both state rules and collective action fails, illicit wells can provide a practical buffer for farmers to delay a crash in agricultural revenues. Another factor delaying the collapse of the SES of irrigation agriculture can be found in the switch from high-water/high-value crops to low-water/low-value crops (paper 3). Policies targeted at rational water economies as well as Tunisia’s negative water import-export balance (as a legacy of post-colonialism and neoliberal trade policies of the 1970s) are useful measures but may prove difficult to implement since farmers generally prefer higher returns on investment within the current fragile political climate.

d. Policy Recommendations

This thesis has outlined critical junctures in Tunisian water governance (paper 1), their social outcomes (paper 1 and 2), and has modelled their dynamics within the SES at large (paper 3). The case of Tunisian water governance reiterates the need for in-depth case knowledge when drafting meaningful action plans for a sustainable water resources future. The combined results from the three papers seek to inform more realistic policy reforms tailored to the path-dependent water governance system at hand.

The following set of policy recommendations are modest and recognise difficulties in implementing reforms in a fragile political context. Beyond these institutional challenges, the set of policy recommendations outlined here are further tailored to the context of water scarcity - predicted to be further exacerbated by climate change. Recommendations are engrained in the understanding that water resources management is not merely a technical but a social challenge that can only be addressed by combining technical and social tools. Where methods of technical supply management have reached their physical limits, future approaches to water governance need to be sensitive to path-dependent interwoven social-ecological dynamics of the SES.

The following recommendations are formulated:

1. *"Re-establish trust"*: This first recommendation is more theoretical than practical and perhaps serves rather as a reminder of the overarching challenge of degraded trust in formal institutions (paper 1 and 2). Nevertheless, slow progress at re-establishing trust may be achieved in tandem with the following recommendations.

2. *Carefully reform regulatory framework:* A modest water reform should target the closing of gaps in the coordination between nested scales of governance (paper 1). Bureaucratic processes should be streamlined, simplified, and decentralised (at the regional level of CRDAs). Prior to establishing new (on-paper) regulatory agencies and enforcement mechanisms (such as the "water police") aimed at shutting down illicit wells, policies should revisit the feasibility of these interventions (paper 2) and the social-economic function illicit wells fulfil for rural small-holder farmers (paper 3). Caution is required regarding the militarisation/rigid enforcement of rules as a response to illicit water use as this can backfire into social unrest and conflict. Policy-makers need to revisit existing legal codes, address inherent inconsistencies, and calibrate efforts with regards to what is feasible, e.g. limits to groundwater withdrawals by means of volumetric measurement.

3. *Support and strengthen local institutions:* Policies should target capacity strengthening of local water user groups (GDAs). This could include a revision of the voluntary nature of GDA leadership councils as well as providing hands-on technical, institutional, and financial support via regional administrations (CRDAs), e.g. regarding the transition to water-efficient crops (paper 3). Enhanced coordination between GDAs and CRDAs may give rise to opportunities to scale successes in local water resources management.

4. *Adapt agricultural strategies to reduce water demand*: Water users should be incentivised to shift to water less-intensive crops (paper 3). On-going farmer subsidy programmes of the national agency of

agricultural investments (APIA) should be instrumentalised particularly given the agency's good standing among farmers. Incentives for water-intensive crops need to be reconsidered, while positive incentives for low-water or rainfed crops should be leveraged. Realism on where (rainfed) agriculture is still feasible under growing water scarcity needs to be practiced and strategies updated routinely.

5. *Diversify incomes beyond (irrigation) agriculture and prepare for livelihood transitions:* Where sustainable livelihoods from agriculture are rendered increasingly difficult, water users will be required to diversify their incomes beyond (irrigation) agriculture (paper 3). The Tunisian government should prepare for wide-spread regions, previously dependent on irrigation-agriculture for livelihoods, to be faced with severe water scarcity and a possible discontinuation of agricultural production.

6. *Address inherent trade imbalance:* While this thesis did not have the ambition to address global trade imbalances and associated patterns of inequality engrained in the international trade market, Tunisia's negative water trade imbalance (more water exported than imported) should be addressed at the highest political level. Limiting water-intensive crops for export has the potential to affect changes in water demand for local agricultural production.

e. Conclusion

In conclusion, this thesis has outlined meaningful ways of engagement with complex SES that face path-dependent groundwater depletion and systemic

fragility. Paying more nuanced attention to context and its historical process can help policy- and decision-makers make more informed decisions on how to better support livelihoods in fragile water-scarce agricultural settings. Path dependence, however, does not need to equate to doomsday catastrophism. Pierson (2000) elaborates the following claims regarding path dependence, 'that specific patterns of timing and sequence matter; that a wide range of social outcomes are often possible, and large consequences may result from relatively small and contingent events; that particular courses of action, once introduced, are often virtually difficult or impossible to reverse even if their consequences prove to be disastrous; and that consequently, political development is punctuated by critical moments or junctures which shape the basic contours of life' (9). In this thesis, tracing social-ecological dynamics served the purpose of identifying components within the context that can help elaborate best-possible strategies moving forward.

This thesis ends by reiterating the need for social approaches to inherently social problems of water governance. Water governance problems in the SES of Tunisia are not to be reduced to climate change, population growth, nor the nature of the resource or resource users per se. Historically interwoven and co-evolving events, processes, and patterns co-construct the context-specific realities of collective action challenges in Tunisia. These realities include the erosion of institutional trust, hopelessness, and rapid groundwater decline with deleterious impacts for associated livelihoods. Solutions to path-dependent problems are notoriously difficult to implement: Limiting (illicit) groundwater overextraction, amending established agricultural strategies to more water-efficient (but perhaps lower-value) crops, or cross-sectoral livelihood transitions will pose immense challenges to the Tunisian water sector. Policy- and decision-makers need to be modest and realistic about limits of "good water governance"

and target context-sensitive interventions that take into account social-ecological dynamics and feedback.

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8. Appendices

Appendix 1 Impressions from the first field season conducting archival research and interviews in Tunis in 2021

Appendix 2 Impressions from the second field season conducting interviews with rural farmers in Kairouan in 2022

Appendix 3 Methods training, funding, academic collaborations, and conferences

In the summer of 2021, I attended a two-week methods training on Qualitative Comparative Analyses (QCA) by the European Consortium for Political Research (ecpr) supported by an ecpr research grant. In 2022, I won a Royal Geographical Society (RGS-IBG) Postgraduate Research Award to conduct fieldwork for my second and third paper. In the summer of 2022, I spent three months at the Young Scientists Summer Programme (YSSP) of the International Institute of Applied Systems Analysis (IIASA) in Laxenburg, Austria setting the foundations of my Agent-Based Model (ABM) under the supervision of Dr. Matthias Wildemeersch. In January 2023, I advanced my ABM during a three-week visiting fellowship at the University of Central Florida (UCF) under the supervision of Dr. Jacopo Baggio. Collaborations with Prof. Jamila Tarhouni at the National Agronomic Institute of Tunisia (INAT) target the integration of existing groundwater models with evolution games and are part of on-going efforts to facilitate local research collaboration and co-creation of knowledge. I am grateful for my previous employers at the German Federal Institute for Geosciences and Resources (BGR) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) for their immense logistical support during fieldwork, their practical advice, and encouragement.

Each of the research papers was presented at an international conference relevant to the respective publication:

- **Paper 1** was presented online at the 2022 Joint Session Workshop of the European Consortium for Political Research (ecpr) ‘Authoritarianism across space, time, and scale’ in April 2022.

- **Paper 2** was presented at the 2023 Conference on Natural Resource Management and Conflict in Africa organised by the Institute of African Studies (IAS), University of Ghana, and the Danish Institute for International Studies (DIIS) in Copenhagen, Denmark in June 2023.

- **Paper 3** was presented at the 2023 European Geophysical Union (EGU) General Assembly in Vienna, Austria in April 2023.

Appendix 4 Interview questions and corresponding variables and anchor points

Type	Variable	Questions	Anchor points
C	Trust in government	Generally speaking, can you trust the government to do what is right? Do you think the government understands the challenges the GDA faces? Does the government help your GDA? What do you think of current water policies? Do you think they adequately address your needs?	0: The GDA “can never trust the government to do what is right”. Policies are counterproductive (the government works against the will of the people). The government couldn't care less about water users. 0.33: The GDA “can rarely/sometimes trust the government to do what is right”. Policies are neither helpful nor hurtful. The government has a poor understanding of farmers' needs. 0.67: The GDA “can mostly trust the government to do what is right”. Policies are imperfect but somewhat address needs. The government tries to help but not very successfully. 1: The GDA “can always trust the government to do what is right”. Policies adequately address water users' needs. The government supports the GDA.
C	Hope	Is a positive future for sustainable water management possible?	0: There is no future/the future of water resources is bleak. 0.33: There is little hope for a sustainable water future. The future will be difficult. 0.67: There is some hope that water users will be able to manage. The government will support farmers to cope. 1: There is a future for water resources.
C	Social cohesion/ reputation	Do you think members care about the profits of the other members? Do you think it is important for users what other users think of them? Is social peace important (in relation to other targets)?	0: There is no social cohesion. Members don't care about their reputation or other water users' profits. Social peace is not a priority. 0.5: There is some social cohesion. Members generally care about each other but they care more about their own livelihoods than their reputation and other water users' profits. Social peace is not a priority.

			1: There is social cohesion. Members care about their reputation and about the profits of others. Social peace is a priority.
C	Expectation of rule-following	Without monitoring, if a member says they will withdraw a specific volume and pay the agreed upon price, do you expect that they will do just that? Do you have a sense of whether members follow rules?	If a GDA member says they will do x, e.g. pay their fees, you expect that without monitoring … 0: the member will not do x. 0.33: the member will only sometimes do x. 0.67: the member will mostly do x. 1: The member will do exactly what they say.
C	Discounting/ ability to long-term planning	Would GDA members be willing to use less groundwater this year if you were promised more/stable groundwater in the future? What is the price per m3 that water is sold to farmers? Do you think farmers should pay less, the same, or more for water than right now?	0: Leaders only consider present benefits and do not consider over-extraction, and fees that do not cover costs a problem. 0.33: Leaders have some but little understanding of the need for sustainable groundwater extraction and fee setting. ""There is little that can be done about these problems"". 0.67: Leaders understand the need for sustainable groundwater extraction and fee setting but largely see their hands tied. There have been efforts to increase fees/limit water use but not sufficiently. 1: Leaders understand the need for sustainable groundwater extraction and fee setting. Efforts to increase fees/limit water use are effective.
C	Leadership	What motivates you/the CA to do their job? Do you think this motivation influences other members? In your own words, what is the purpose/mission of the GDA? Whose responsibility should it be to ensure that the GDA is functioning well? What was the role of the CA in solving conflicts?	0: Leaders are unmotivated and uninterested in managing the GDA. They see responsibility of managing the GDA, and guaranteeing its functioning, elsewhere. The CA does not engage in conflict resolution. 0.33: Leaders are somewhat motivated but struggle to translate this motivation to members of the GDA. There is some understanding of CA responsibility (e.g. responsibility lies with the entire GDA) but not in action. CA does not effectively engage in conflict resolution. 0.67: Leaders are motivated but struggle to translate this motivation to members of the GDA. There is an understanding of CA responsibility and some limited success in managing the GDA. Involvement but limited success in conflict resolution. 1: Leaders are very motivated and translate this motivation to members of the GDA. CA assumes full responsibility in managing the GDA and guaranteeing its functioning. The CA successfully resolves conflicts. "
O	Fee recovery	What is the percentage of fees recovered from farmers?	0: <= 40% of farmers pay continuous scale based on data

			1: 100% of farmers pay
O	Conflict	How frequent (and severe) are tensions or conflicts (vandalism) between users? What causes these conflicts?	0: There have been no conflicts between users. 0.33: There have been few but not severe conflicts. 0.67: There have been a number of conflicts (some of them severe but not all). 1: There are frequent (and severe) conflicts.

Appendix 5 Results of necessity and sufficiency analyses on the absence of outcomes

Outcome of fee recovery

a. Necessity analysis for absence of the outcome of fee recovery:

```
                           inclN   RoN   covN
-----------------------------------------------
1  ~TV_NAT*~TH_RULES       0.892  0.718  0.745
2  ~TV_HOPE*~TH_RULES      0.846  0.712  0.722
3  ~TH_RULES*~LEADERSHIP   0.895  0.817  0.819
4  ~TH_RULES*~DISCOUNT     0.883  0.736  0.754
5  ILL_DENSITY + ~TH_COHES 0.832  0.721  0.723
-----------------------------------------------
```

b. ESA for absence of the outcome of fee recovery - Conservative solution:

```
M1: ~HH*~TV_NAT*~TV_HOPE*~TH_COHES*~TH_RULES*~LEADERSHIP*~DISCOUNT*~EQUITY +
    ~HH*~ILL_DENSITY*~TV_NAT*TV_HOPE*TH_COHES*~TH_RULES*LEADERSHIP*~DISCOUNT*EQUITY +
    ~HH*ILL_DENSITY*~TV_NAT*~TV_HOPE*TH_COHES*~TH_RULES*~LEADERSHIP*~DISCOUNT*EQUITY -> ~COOP_FEES

                                                                                                                  inclS   PRI   covS   covU
-------------------------------------------------------------------------------------------------------------------------------------------
1           ~HH*~TV_NAT*~TV_HOPE*~TH_COHES*~TH_RULES*~LEADERSHIP*~DISCOUNT*~EQUITY  0.991  0.986  0.432  0.328
2   ~HH*~ILL_DENSITY*~TV_NAT*TV_HOPE*TH_COHES*~TH_RULES*LEADERSHIP*~DISCOUNT*EQUITY  0.975  0.897  0.151  0.038
3  ~HH*ILL_DENSITY*~TV_NAT*~TV_HOPE*TH_COHES*~TH_RULES*~LEADERSHIP*~DISCOUNT*EQUITY  0.972  0.947  0.271  0.111
-------------------------------------------------------------------------------------------------------------------------------------------
                                                                                                        M1  0.984  0.974  0.654
```

Outcome of conflict

a. Necessity analysis for absence of the outcome of conflict:

```
                       inclN   RoN   covN
-----------------------------------------
1  TH_RULES            0.833  0.870  0.700
2  ~TV_NAT*TH_RULES    0.810  0.879  0.708
3  TH_COHES*TH_RULES   0.833  0.870  0.700
4  TH_RULES*EQUITY     0.833  0.948  0.854
-----------------------------------------
```

b. ESA for absence of the outcome of conflict - Conservative solution:

```
M1: HH*~ILL_DENSITY*~TV_NAT*TV_HOPE*TH_COHES*TH_RULES*~LEADERSHIP*~DISCOUNT*EQUITY -> ~CONFLICT_USER

                                                                                                                  inclS   PRI   covS   covU
-------------------------------------------------------------------------------------------------------------------------------------------
1  HH*~ILL_DENSITY*~TV_NAT*TV_HOPE*TH_COHES*TH_RULES*~LEADERSHIP*~DISCOUNT*EQUITY  0.920  0.900  0.274    -
-------------------------------------------------------------------------------------------------------------------------------------------
                                                                                                        M1  0.920  0.900  0.274
```

Appendix 6 Calibration and data sources of scenarios of unfavourable and favourable resource settings

Parameter	Description	Unfavourable	Favourable	Source
loc	Location of the GDA (required for surrogate hydrogeological model)	Location of representative GDA in Sisseb aquifer	Location of representative GDA in AinBoumorra aquifer	MODFLOW model
hh (t_0)	Initial hydraulic head (m)	70	180	MODFLOW model (at what time??)
λ	Density of illicit wells (number of illicit wells in 3 km radius)	175	10	Inventory of illicit wells
den^{1km}	Density of illicit wells (number of illicit wells in 1 km radius)	26	5	Inventory of illicit wells
w^{ill} (t_0)	Initial annual illicit withdrawals by water users (m^3)	525252.53	101010.10	Assumption based on literature (MARHP, 2017) and inventory of illicit wells*
V_P (t_0)	Total pumping at time 0 ($m^3\ s^{-1}$)	1	0.8	MODFLOW model
thr_{hyd}	Hydrogeological threshold (decline in m when well is assumed to run dry)	3	10	Empiric accounts from informal interviews

*It is estimated that on average half of all groundwater wells in Tunisia are illegal. We assume that withdrawals whether legal or illicit are the same/similar for a given well. Using data from the illicit well inventory (number of illicit wells in 1 km radius), we further assume a linear relationship where 0 illicit wells = 0 illicit water, and average illicit wells = allocated water = illicit water.

Appendix 7 Ranges of social and institutional parameters

Parameter	Description	Minimum	Maximum	Type
$\mathbf{V_T}$	Vertical trust	0	1	continuous
$\mathbf{H_T}$	Horizontal trust	0	1	continuous
$\mathbf{V_L}$	Leadership	0	1	continuous
α^{V_T}	Vertical trust penalty weight	0	2.670763282*	continuous
$\alpha^{H,int}$	Horizontal trust penalty weight	0	1.082790324*	continuous
α^{V_L}	Leadership penalty weight	0	12130.5*	continuous
$\alpha^{H,ext}$	Social pressure from outside GDA weight	0	2.670763282*	continuous
equ	Equity	0**	1**	binary
sust	Sustainability of price-setting and allocation	0***	1***	binary

* we assume that penalties range from around 0 to maximum 50% of individual profits per norm. 50% represents the highest possible penalty, e.g. highest $w_{ill}(t)$ and highest Tv values in MC simulations (modelled on scenarios of unfavourable ecological and low value/low water crop)
** 0 = one-fifth of GDA members receive twice as much water than they would have had the water been allocated equitably; 1 = equitable distribution
*** 0 = static price of 0.15 TND per m^3 (source: interviews) and increasing withdrawals (based on MODFLOW defined growth rate); 1 = price calculated based on extraction and operation costs, and the expectation of fee recovery; withdrawals remain static

Appendix 8 Calibration of crop parameters

Parameter	Description	High-water/ high-value	Low-water/ low-value	Source
k_c	Crop coefficient	0.8	0.54	FAO (2012), Vermeiren and Jobling (1980), Ahmed *et al.* (2007), Saadi *et al.* (2015)
K_y	Yield coefficient	0.8	0.6	FAO (2012), Vermeiren and Jobling (1980), Ahmed *et al.* (2007), Zairi *et al.* (2003)
ET_{min}	Min evapotranspiration needed to generate yield (m/year)	0.624	0.3	FAO (2012), Vermeiren and Jobling (1980), Ahmed *et al.* (2007), Zairi *et al.* (2003)
ET_{max}	Evapotranspiration for given max yield (m/year)	1.264	0.6	FAO (2012), Vermeiren and Jobling (1980), Ahmed *et al.* (2007), Zairi *et al.* (2003)
y_{max}	Maximum yield possible (kg/ha)	75000	22750	FAO (2012), Vermeiren and Jobling (1980), Ahmed *et al.* (2007), Soethoudt *et al.* (2018) (assuming maximum yield based on average yield)
c^c	Cultivation cost (TND/y)	8500	1600	Data collection (WEAP)
P^c	Price of crop sold on the free market (TND/kg)	0.47	1.19	Data collection (WEAP)

Appendix 9 Calibration and data sources of model variables

Variable	Description	Value	Source
n	Number of farmers in GDA	30	Interview data
$w^{alloc}(t_0)$	Initial groundwater allocated annually to water users (m^3)	200000	Interview data and administrative records; averaged based on representative GDA in the given resource setting
fee_{perc}	Expectation of initial percentage of GDA member paying their fees	0.5	Interview data
ζ	Beta parameter of logistic function	1	Assumption based on interviews
p_{pre}	Cash at start (TND)	15000	Assumption based on poverty threshold; tested during calibration
a	Average size of agricultural land per farmer (m^2)	23500	Administrative records
thr_{fin}	Threshold for GDA bankruptcy (TND)	-30000	Based on data from administrative records indicated operational status and financial debt of GDAs
thr_{pov}	Poverty threshold for farmers (TND)	7505	World Bank Group (2019); assuming 1 household consists of 5 people
c_{op}	Annual costs for maintenance, personnel, etc. (TND)	20000	Assumption based on interviews
c^{ill}	Cost of groundwater from illicit sources	c_E * 1.5	Assumption based on the literature and interviews
ε	Error when copying illegal water withdrawals	0.2	Assumption
c^{den}	Density effect (rate at which penalty declines)	1/max. density (= 0.0057)	Inventory of illicit wells
$c^{\lambda 0}$	Maximum possible penalty (when lambda_den = 0)	1	Assumption
c^{alloc}	Initial price of allocated water (TND per m^3)	0.15	Interview data