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Destabilising Waters, Uneven Adaptation: Shifting Hydrosocial Relations Among Agropastoralists in the Tiva River Basin of Kenya

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ABSTRACT: Seasonal rivers in East Africa's drylands have become destabilised by climatic disruption and landscape changes. Despite widespread adaptation practices and interventions, recurrent droughts and floods continue to damage the agropastoral livelihoods dependent on these rivers. Few studies have explored how destabilising rainfall, river flows and adaptations have transformed hydrosocial relations among agropastoralists living near seasonal rivers. This paper reports on a case study in the Tiva River Basin in Kenya, exploring how agropastoralists have experienced changing river flows, rainfall and adaptation processes over the past 75 years. Based on storytelling workshops and a survey, we find that river flows and rainfall have been experienced as increasingly unpredictable and damaging. Water's perceived role has shifted from being rhythmic and regenerative to being an erosive force and scarce resource to be captured and mobilised. Adaptation has materialised in multiple forms, each of which has, and continues to, reshape reshape the ways in which water is perceived and used. This requires attention from adaptation research with regard to policy and practice in agropastoral drylands. First, public hydraulic infrastructures inscribe norms for capturing and controlling water, while the limits of their functionality are layered into existing arrangements for accessing water. Second, the spread of private irrigation along seasonal rivers supports adaptation, but is only accessible for a small group and leads to inequalities in water access and adaptive capacities. Third, many agropastoralists pursue bottom-up adaptive practices to retain water, but face various hindrances in sustaining their efforts.

KEYWORDS: Dryland, seasonal river, water, agropastoralist, adaptation, Kenya

INTRODUCTION

East African drylands are inhabited by millions of agropastoralists whose livelihoods directly depend on rainfall and on surface water sources including seasonal rivers, streams, pools and ponds. As water is essential for drinking, domestic uses, livestock and crops, any changes to seasonal rainfall and river flows deeply affect many people. Over the past decades, under climatic and socio-environmental changes, rainfall patterns and river water flows have become increasingly unstable, frequently resulting in damaging droughts and floods (Souverijns et al., 2016). These extreme events lead to losses of human lives, livestock, as well as of crops and other livelihood assets (Haile et al., 2019).

Around seasonal rivers and streams, agropastoralists are in continuous interaction with highly variable rainfall and river flows. Seasonal sand rivers, which store water underground in sandy riverbeds during periods of low rainfall, constitute a primary water source for many agropastoral communities (Pearson et al., 2016). These rivers risk even further destabilisation under more erratic rainfall patterns and landscape changes in the coming decades (Huang et al., 2024; Wekesa et al., 2020; Kihwele et al., 2021). High variability requires agropastoralists to adapt to prolonged absences of water and to short intense periods of heavy rainfall, surface runoff and river discharge. Adaptations take the form of diversifying beyond livestock herding and rainfed crop-farming, which rely on seasonal rainfall and water bodies, and moving to activities that are less dependent on stable sources of water. Adaptations include changes in livestock and crop types, altered migratory patterns, income diversification, modified water uses such as small-scale irrigated farming, and the adoption of water harvesting practices (Menghistu et al., 2020; Shikuku et al., 2017; Leal Filho et al., 2020; Duker et al., 2022).

In East Africa's drylands, adaptation is also shaped by organisations in the form of governments, civil society organisations (CSOs), and non-governmental organisations (NGOs), who often fund interventions. These adaptation interventions materialise in thousands of small-scale hydraulic infrastructures including water pans, boreholes, sand dams and irrigation schemes (Tiffen et al., 1994; Weesie and Kronenburg García, 2018; Duker et al., 2023; Piemontese et al., 2024). Typically, interventions aim to capture erratic rainfall and seasonal river flows, or provide access to groundwater, enabling drought-affected agropastoral communities to secure year-round access to water sources. This would allow them to produce crops more intensively, sustain livestock during dry periods, and have stable access to sufficient domestic water (Weesie and Kronenburg García, 2018; Piemontese et al., 2024; Hoque and Hope, 2025). Through these interventions, governmental organisations, CSOs and NGOs are actively reshaping the ways in which agropastoralists access water (Nguimalet, 2018; Muller, 2014).

Adaptation to unstable rainfall and river flows is thus shaped 'from below' through agropastoralists' practices, and 'from above' via interventions by organisations. Adaptation has thus become a key socio-economic and sociopolitical process in addressing water issues (Thornton et al., 2010). It has become a major force in reshaping hydrosocial relations, that is, the ways people access, use, perceive and relate to water (Mills-Novoa et al., 2020). Adaptation processes, when widely undertaken, may affect water flows in dryland seasonal rivers. Some may contribute to a further destabilisation of river water flows through, for example, expansion of irrigated farming (Kihwele et al., 2021; Wamucii et al., 2023). Other practices, such as afforestation or agroforestry in riparian areas, may play a role in increasing the stability of seasonal river flows (Liu et al., 2022). Because multiple measures are implemented concurrently and cumulate over time within specific contexts, it is important not only to scrutinize specific types adaptation interventions and practices, but also to analyse how assemblages of adaptive efforts collectively reshape hydrosocial relations over time. Existing studies of hydrosocial change under adaptation have primarily restricted their attention to the effects of discrete interventions such as dams or irrigation schemes (Mills-Novoa et al., 2017, 2020; Kemerink-Seyoum et al., 2019; Chitata et al., 2021; Quimby et al., 2023; Taylor, 2014; Parsons and Chann, 2019). In research on adaptation processes in agropastoral drylands, there remains a dearth of long-term studies examining how agropastoral relationships with water have changed as seasonal water flows continue to destabilise and multiple adaptation processes unfold. In

Kenya specifically, related research has generally focused on how specific adaptation interventions enable or constrain access to water. Some studies, for example, analyse dryland river governance arrangements' effect on water access (Ontiri and Robinson, 2016; Hoque and Hope, 2025); others evaluate the effects of irrigation schemes and small-scale dams in terms of sustainability or equity (Weesie and Kronenburg García, 2018); still other studies examine the emergence and hydrologic potential of irrigated agriculture along seasonal rivers (Love et al., 2021; Uhlenbrook and Owen, 2011; Walker et al., 2018; Duker et al., 2022); yet others assess the potential of sand dams for adaptation (Lasage et al., 2008; Ryan and Elsner, 2016).

Going beyond analysing specific adaptation interventions, we adopt a longer-term experiential perspective. The objective of this paper is to explore how destabilising rainfall, river flows and the consequent adaptation processes have reshaped hydrosocial relations of agropastoralists with water over time. Drawing on a case study in the seasonal Tiva River Basin in southeastern Kenya, we examine the experiences of agropastoralists from the 1940s until the early 2020s through storytelling workshops and a household survey. By doing so, we aim to provide insights on the co-evolution of destabilising water flows and adaptation around seasonal rivers in East Africa's drylands, with implications for adaptation research, policy and practice.

THEORY: ADAPTATION WITHIN THE HYDROSOCIAL CYCLE

We adopt a hydrosocial perspective to examine changes in how destabilising water flows and adaptation processes have reshaped agropastoral relationships with water. The hydrosocial cycle is described by Linton and Budds (2014: 170) as the "socio-natural process by which water and society make and remake each other over space and time". They explain how it is continuously reconfigured through social, physical and technical interventions, including shifts in water availability and technological change. As water and society interact and coevolve, hydrosocial relations develop which encompass both material and immaterial dimensions. Material relations concern how water flows are accessed and used, while immaterial relations refer to how water is perceived and socially constructed (Budds et al., 2014; Wilson, 2014). Over time, material and immaterial hydrosocial relations mutually shape one another, co-producing patterns of water perception, flow and access, and thereby transforming how people use and relate to water. For example, when a river is dammed, it alters the way people live from, and relate to, the river's water.

In any locality where people and water coexist, hydrosocial relationships are in constant flux. Ever-changing water flows are continuously navigated, interfered with and responded to. With accelerated climatic disruption, adaptation has become an increasingly important part of the hydrosocial cycle, as interventions and practices often fundamentally alter hydrosocial relationships (Mills-Novoa et al., 2017). Adaptation encompasses people's and organisations' efforts to prevent, or protect themselves from, future damages, or to make use of the existing conditions or anticipated opportunities that are afforded by changing socio-environmental conditions (Adger et al., 2005; Eriksen et al., 2015). Adaptation is by no means a neutral or 'natural' process, but value-laden and often conflictive (Parsons and Chann, 2019). Becoming an important part of development outcomes, adaptation interventions can stabilise access to water, but may also produce new inequalities and unsustainable water use. For example, hydraulic infrastructures, in the shape of dams or irrigation schemes, transform power relations through modernising water infrastructures, favouring some water uses, such as agricultural modernisation, over others (Mills-Novoa et al., 2017, 2020).

Adaptation has thus become part of the everyday governance of water, with development projects and practices reshaping hydrosocial relationships. Being a normative process, adaptation is given form by water uses and perceptions of what people's relationships with water should entail. Some actors, for example, perceive that adaptation ought to the form of modern infrastructural measures, while others advocate for nature-based and/or indigenous practices (Locatelli et al., 2022). In practice, however, adaptation outcomes are never as clear-cut, as actors reassemble and reshape the forms in which adaptation plays out (Totin et al., 2025). Interventions trigger various responses of individuals and collectives – who are never passive subjects, rather, they "remake" adaptation projects through situated practices (Liao and Schmidt, 2023). As put by Taylor (2014), receivers of interventions respond by "adapting to adaptation projects". As actors and organisations reassemble adaptation processes, it is their worldviews that underly the ways in which people organise around water (Cleaver et al., 2021). Specific conceptions of water infuse forms of "counter-conduct" (Mills-Novoa et al., 2020), which in turn lead to messy and unpredictable outcomes (Cleaver et al., 2021; Quimby et al., 2023). In the case of irrigation schemes in East African drylands, for example, studies have shown how farmers "tinker" with infrastructures to fit their own needs and "lifeworlds": Water users re-work the infrastructures to "make water flow in the quantities, timing and direction that best suits them" (Kemerink-Seyoum et al., 2019; Chitata et al., 2021; Quimby et al., 2023).

Recognising both structural constraints people's agency in shaping adaptation processes, we follow Cleaver's (2002, 2012) work on institutional bricolage. This perspective is based on Lévi-Strauss's concept of intellectual bricolage: the idea that people, as "bricoleurs", exercise their agency by improvising and "making do" with the available resources at hand (Lévi-Strauss 1966). Bricolage describes processes of experimentation and cobbling together of social practices in order to create something new (Cleaver 2012). As bricoleurs improvise in response to changing conditions, they "use the resources at their disposal and fashion adaptations which work pragmatically and fit their social and cognitive worlds" (Haider & Cleaver, 2023, p.4). Over time, practices may become institutionalised as social norms or collective arrangements (Haider and Cleaver, 2023). This introduces historical path-dependence to the ways in which people organise around natural resources such as water - shaped by institutions (rules, norms, and practices), and patched together by existing social arrangements, traditions, and power relations (Cleaver 2002, 2012; Peloso and Harris, 2017). As such, we understand climate change adaptation as messy and evolving institutional assemblages rather than coherent regimes. As circumstances change, people make do with what is available, adapting old rules and habits to new problems through everyday practices, underpinning particular development outcomes (Cleaver, 2012; Cleaver et al., 2021; Haider and Cleaver, 2023). Adaptation thus materialises from a dialogue between people, institutions, the resources they depend on and the contexts in which they are situated (Eriksen et al., 2015; Parsons and Chann, 2019) - and is undertaken in myriad contradictory ways (Parsons and Chann, 2019). Seeing how adaptation processes unfold through bricolage within the hydrosocial cycle, allows us to examine how people and destabilising water flows have reshaped each other over time.

CONTEXT: WATER AND ADAPTATION IN THE UPPER TIVA RIVER BASIN OF KITUI, KENYA

We conducted our case study in an area along the Tiva River, a major seasonal river in the Kitui County of Kenya. Tiva River is characterised by wide, sandy channels (Figure 1) and flows during each rainy season and for up to one month afterward (Figure 2) (Morimoto et al., 2010; Kitheka, 2016; Weesie et al., 2025). Tiva River is a tributary of the Tana River, Kenya's longest and most important perennial river, running over 1000 km from its headwaters in the Aberdare Mountains to the Indian Ocean. Tiva River is approximately 380 km long and originates in the northern Yatta Plateau in Kitui County, flowing southeast toward the lower Tana Basin, discharging into Tsavo National Park. Its catchment area is estimated at approximately 3,600 km^2 (Kitheka, 2018). The river is fed by bimodal rainfall, which occurs primarily during the rainy seasons of March/April/May (MAM) and October/November/December (OND). The surface water disappears shortly after the rains, but sandy, seasonal rivers such as the Tiva retain subsurface flow within their riverbeds. This subsurface water constitutes a critical domestic water source for agropastoral communities (Hoque and Hope 2018, 2025). Inhabitants obtain the water from seasonal shallow wells, locally called 'scoop-holes', dug into the sandy riverbeds of Tiva River and its tributaries.

Water collection and transport are largely undertaken by women and children, who carry jerrycans using donkeys and ox carts (Morimoto et al., 2010).

Figure 1. The Tiva River, February 2023; near Kathome village

Source: Photo taken in collaboration with Africa Wood Grow Foundation. Note: See Figure 3 for the location of the Basin and its sublocation within Kenya.

Figure 2. The Tiva River's wet-dry fluctuation, observed during and after the October/November/ December rains of 2022 in the Kathome area; clockwise from top left: November 2022, December 2022, January 2023, February 2023.

Source: Photos by author, R.V. Weesie.

The Tiva River Basin is a representative example of an East African dryland with a history destabilising water flows and individual water users and organisations implementing adaptation measures. In the Basin, most inhabitants belong to the Akamba ethnic group and historically maintain agropastoral livelihoods that combine crop-farming with livestock keeping and trade (O'Leary, 1980; Akong'a, 1988; Koster, 2011; Ndanu, 2022). Adaptation practices and interventions have been focused on retaining seasonal rainfall and river flows. Small-scale hydraulic infrastructural projects were already implemented by the government of Kenya during colonial times (Akong'a, 1988). In the 1950s, the British constructed the first boreholes and waterpoints in the area, under the conviction that more infrastructure was needed to improve the water supply for the growing population that was suffering from drought (Akong'a, 1988; O'Leary 1980, 1983; Hoque and Hope 2018, 2025; Weesie et al., 2025). With this, the British colonial administration – and postcolonial governments in their wake – attempted to change the hydrosocial relation of "people going to water" (as it had been during precolonial times) to "water going to the people" (Nyanchaga, 2016; Hoque and Hope 2018, 2025). In the course of ongoing attempts to implement 24/7 water availability to households, Kitui’s landscape and its agriculture were transformed. From the middle of the 20th century onwards, the Tiva Basin has undergone an expansion of cropland, an increase in the density of settlements, and growth of its urban areas; this has come at the expense of forests, rangelands and shrubland (Schmitt et al., 2019), mirroring what can be observed in various other agropastoral drylands in East Africa (Greiner et al., 2021).

As drought issues continued into the 1980s, adaptations materialised in the form of an agricultural transition away from extensive livestock herding and towards more intensive crop-farming alongside keeping of livestock (Akong'a, 1988). In the 1990s, recurrent water insecurity led the regional government, NGOs and CSOs to implement or support a range of measures that sought to improve water access and retention: across the Basin, hundreds of boreholes, sand dams (Lasage et al., 2008) and water pans were constructed (Hoque and Hope, 2025; Weesie et al., 2025). By the early 2010s, Kitui even emerged as a "global leader" in the number of donor-funded sand dams constructed (Ertsen and Ngugi, 2021). Under a "hands-off" approach by governments in a postcolonial 'harambee' (self-help) legacy, communities of water users were made responsible for the management and maintenance of these hydraulic works (Hoque and Hope, 2025).

By the 2010s, the large number of sand dams, water pans, water kiosks and boreholes scattered across the Tiva River Basin even became the subject of study by international and Kenyan teams of scientists, who analysed the technical functionalities of these dryland waterworks (Thomas, 1999; Borst et al., 2006; Lasage et al., 2008; Manzi and Kuria, 2011; Kitheka, 2016; Ryan and Elsner, 2016; Moïse et al., 2019; Ertsen and Ngugi, 2021). Results, however, have been mixed. While new infrastructure relieved water shortages to some extent, a large share of these works became dysfunctional some years after construction (Moïse et al., 2019; Ryan and Elsner, 2016; Ertsen and Ngugi, 2021). A 2017 audit of water infrastructure in Kitui County confirmed that only about half of piped water schemes (including kiosks) and boreholes were fully functioning (Nyaga, 2019). Infrastructure failure has been attributed to a lack of funding available to the communities responsible for their maintenance (Koehler et al., 2015, 2022; Hoque and Hope 2018, 2025). Salinisation has also been a major issue affecting use of these infrastructures, leading to many people avoiding boreholes (Hoque and Hope, 2025).

In Kitui County, most people’s daily reality of obtaining water from the sandy riverbed obscures the past century of institutional reform and investments into hydraulic infrastructures to modernise water supplies (ibid). Meanwhile, largely on their own initiative and partly supported by development programmes, agropastoralists undertook a variety of adaptation measures. These included various forms of rainwater harvesting, erosion control, shifting to drought-tolerant livestock (from cattle to goats), and the reintroduction of drought-tolerant crops (Wens et al., 2020). While adaptation processes are ongoing, the Upper Tiva River Basin continues to be heavily affected by recurrent droughts and floods, which have become increasingly frequent and erosive.[1]

METHODS

From November 2022 to February 2023, in three case study areas within the Upper Tiva River Basin, we combined storytelling, surveying and participatory observations. Storytelling entails the narrating or crafting of stories that recount a sequence of connected events or experiences (Cameron, 2012). Conducting storytelling sessions allowed us to delve into the personal experiences of water users; this gave us an insight into long-term changes in water flows and adaptation processes experienced during participants' lives. Beyond material changes in use and access, storytelling allows for a different insight into how water is conceptually reconstructed over time. To analyse material and immaterial hydrosocial relationships, we subdivided these relationships into a short list of main indicators, which we then assess (Table 1).

Table 1. Indicators used to study hydrosocial relations under changing flows of water and adaptation

Material hydrosocial relations	Experienced changes in water flows (rainfall, river flows, water sources, and drought/flood impacts and responses)
	Experienced changes in water uses (water sources, access, water quality)
	Changes in adaptation measures undertaken (measures taken to prevent further damage and/or take advantage of unstable rainfall and river flows)
Immaterial hydrosocial relations	Experienced changes in how water was perceived (for example, scarcity and stability)
	Experienced changes in predictability of water flows

We organised 39 group storytelling sessions (each lasting 1-3 hours) with in total 218 participants, with an average group size of 6 participants. We selected participants through snowballing in three selected case study areas with different distances to the Tiva River (Figure 3), only including people who (at least partly) engage in agropastoral activities to provide for their livelihoods.

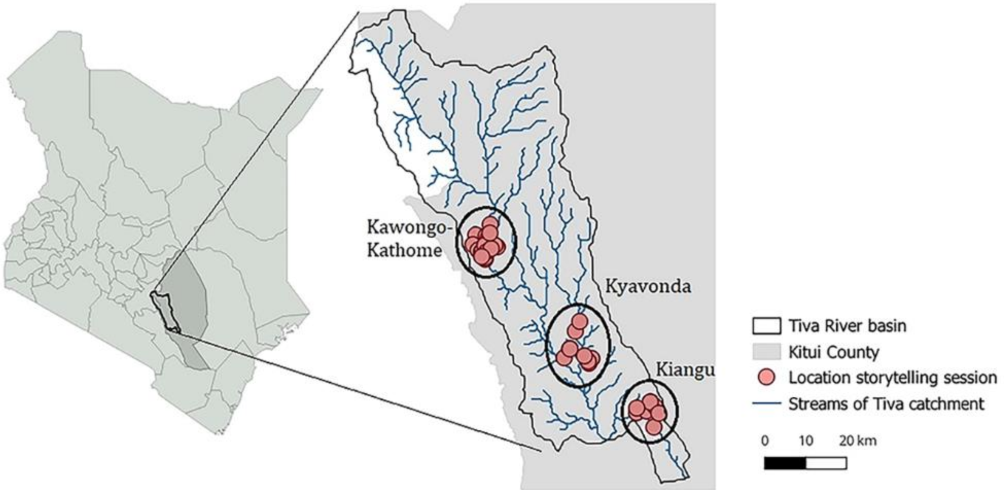
Initial participants were recruited in collaboration with local NGOs. From there on, we snowballed within each case study area. We strived to cover most places with settlements within each area, and for an age and gender representation consistent with the Kitui average as established by the KNSB (2019). The method worked reasonably well in achieving a balanced sample (see Table 2). Especially with the first groups, however, there was a selection bias to first engage with members of households having connections with local NGOs, which tended to be households with a higher level of societal engagement. We attempted to minimise this bias by explicitly asking for potential participants further away or less well connected.

During the sessions, we used prompts in accordance with the indicators listed in Table 1. The storytelling sessions were recorded, transcribed and thematically coded. The codes used for the results of this paper are subcategories of the indicators listed in Table 1, which can be found in the appendix. The transcripts and coded quotations on which the results are built are openly accessible online (Weesie

[1] Our previous work includes a more detailed discussion of experiences of recurrent drought and floods in the Basin; see Weesie et al., 2025.

and Metselaar, 2025). In the results, reference is made to the specific storytelling sessions in which particular findings were mentioned (for example, p1 refers to participant 1, and g1 is group session 1).[2]

Figure 3. Location of 39 storytelling session in the Upper Tiva River Basin in Kitui County, Kenya



Source: Weesie et al. (2025).

Complementing the storytelling, we studied semi-quantifiable trends that reflect material hydrosocial relations through a household survey. The survey was done in the same case study areas with the same target group of agropastoralists, using randomised snowball sampling (n = 232; see Table 2). Respondents had to be adults and had to belong to an agropastoral household. We ensured that no participants were involved in both the storytelling and the survey, and we strived for a representative balance in age groups and gender. The anonymised survey findings can be found here (Weesie and Metselaar, 2025).

Table 2. Overview of survey respondent characteristics

Storytelling (n = 218)			Survey (n = 232)		
Gender			Gender		
Male	93	43%	Male	95	41%
Female	125	57%	Female	137	59%
Age group			Age group		
Youth (18-35)	76	35%	Youth (18-35)	62	27%
Adult (36-65)	96	44%	Adult (36-65)	111	48%
Elder (66+)	46	21%	Elder (66+)	57	25%

Note: For more details on the group compositions and process of the storytelling sessions, see Weesie et al. (2025).

Storytelling and survey data inquiring about past changes relies on recalled memories of respondents, which comes with limitations. At times, specific years or decades of when historical changes occurred were difficult for participants to ascertain, which is often the case when relying on recall (Rose, 2022).

[2] See Weesie et al. (2025) for a more in-depth discussion of the storytelling process, case study site selection, methodological limitations, ethics and positionalities.

However, participants related memories of periods concurrent nationally or locally prominent events; these included elections, or when a specific administration was in power, or major droughts or floods. This pairing allowed us to determine more specific periods and construct a chronological understanding of hydrosocial change over time. Moreover, with using recall, often-repeated routines or particular incidents can be recalled over vast distances of time (Rose, 2022). This was also the case with our participants, who often recalled detailed childhood memories of collecting water. Given that we have not triangulated our results with types of data that were not based on recall, this remains a limitation of the study. Important to note here is that this study did not include a biophysical assessment of water resources. Accordingly, the findings – based on storytelling and survey data – cannot be used to draw decisive conclusions about changes in water availability or access. Rather, the results provide insight into how agropastoralists have experienced impacts of changing water flows, shifts in water uses, and adaptation processes.

RESULTS

The distant past: Rhythmic water flows (1940s-1960s)

Those who could recall the decades from the 1940s to the 1960s, remembered hydrosocial relations as being more stable and rhythmic than the decades that followed. Elderly participants remembered the Tiva River's flow as having been more stable in the distant past than it is today. They narrated how, during colonial times and shortly after independence in the 1960s, streams and major rivers, including the Tiva, were considerably narrower and less sandy. Except for the first few boreholes drilled by the British colonial administration, little hydraulic infrastructure had been constructed in the region at that time. Nearly everyone relied on seasonal rivers, natural springs and ponds for their domestic water and for watering livestock. While the river did not flow year-round, it is remembered to have had a more stable and gentle flow than it did later, persisting for several months into the dry season. Trees, grasses and reeds are recalled as having grown densely along the riverbanks, slowing the flow of water and protecting the banks from erosion. Following rain, relatively clear water would flow gently in the rivers. The Basin was sparsely populated and densely vegetated, with small bodies of water scattered around and wildlife such as buffaloes roaming in the area (g9). In line with historical records (O'Leary, 1980), agropastoralists remembered the Basin as being predominantly covered by semi-open forested rangelands that were used for extensive pastoralism, complemented with some small-scale shifting cultivation. While droughts did occur, hydrosocial relations were remembered as being characterised by rhythm and reliability.

Elderly participants remember that the onset of the rainy seasons was accurately forecast on the basis of environmental indicators, particularly the flowering, budding or changing colour of trees, and observations of animal behaviours and celestial bodies (see Figure 14 in Section 5.7). These served as cues for planning the start of the agricultural season and determining crop choices. At the end of the rainy season, the landscape would be scattered with various bodies of water – swamps, ponds, streams and springs – that would gradually dry up as the dry season progressed (g7). According to the elderly, there was "no need" to construct terraces to retain water or mitigate erosive runoff on cropland, as the terrain and its dense vegetation fulfilled this function (p27). Consequently, the soil was moister and required less rainfall to ensure a successful harvest. During the dry seasons, most people relied on streams and shallow scoop-holes to access water. As one person described it,

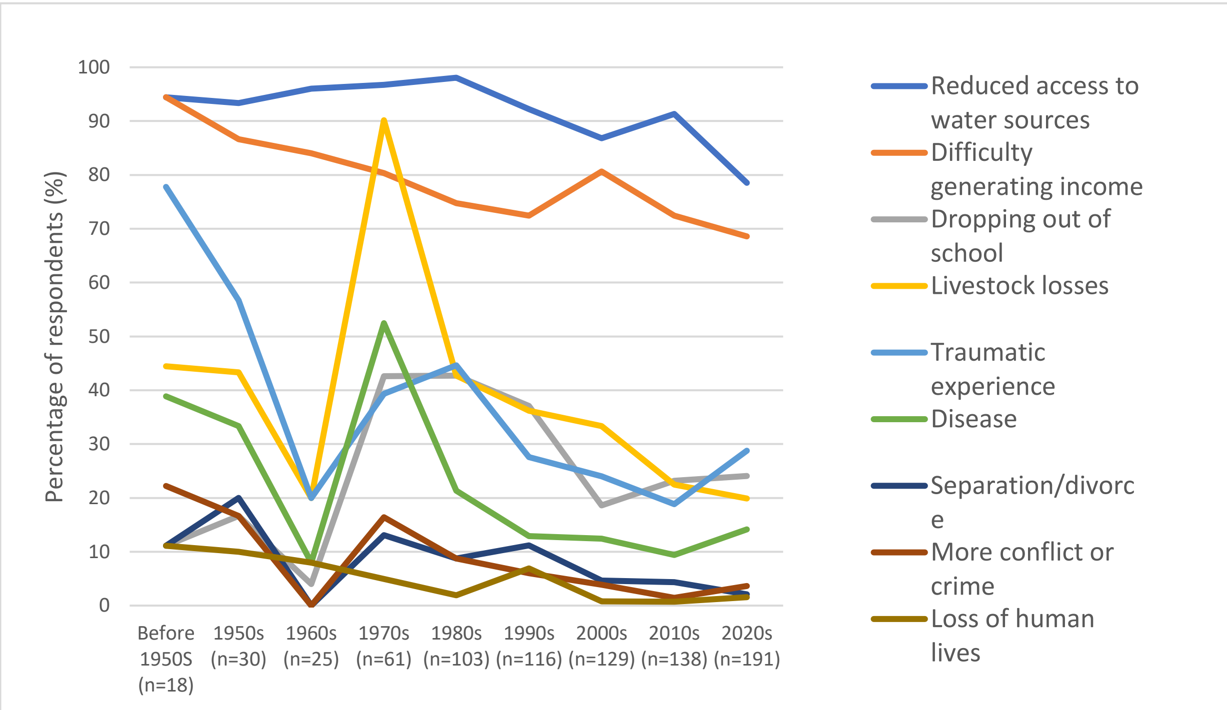
> When [there] was no rain (…), actually there were streams, I can remember very well (…) there were springs where the water was coming from down, and we used to go there to fetch water (…). There were also some small natural ponds (…), where we could take our cows. They stayed long (…) At the leaning point of the dry season is when they become dry. (…) Then it rains again it revives everything and life continues that way (p27).

Destabilisation of water flows (1970s-1990s)

Participants younger than 65 hardly remembered the distant past when water had a stable presence in the Basin. They remembered a different kind of hydrosocial relationship, one marked by long and damaging absences of rainfall, interrupted with periods of revival once rains returned. During the 1970s, water became very scarce due to prolonged droughts; this forced those living away from the Tiva to walk for several hours to where they would dig, and climb down into, deep scoop- holes to access water. Water was passed from one person to the next and involved occasional collapse of the waterholes, sometimes with lethal consequences (p14-16). Elderly women remember how they went with their children to carry water in calabashes and gourds over long distances to meet their families' needs. Men, on the other hand, recall leaving the area during droughts to look for an income elsewhere. This shows some of the gendered dimensions of drought.

Droughts had severe impacts, with up to 90% of respondents remembering losing livestock (Figure 4). While the impacts of droughts have been steadily declining after the 1970s, they are remembered as having persisted during the remaining decades of the 20th century. The graph in Figure 4 is based on respondents' memories of experiences rather than on measurements at the time, so it serves as a representation of recalled impacts.

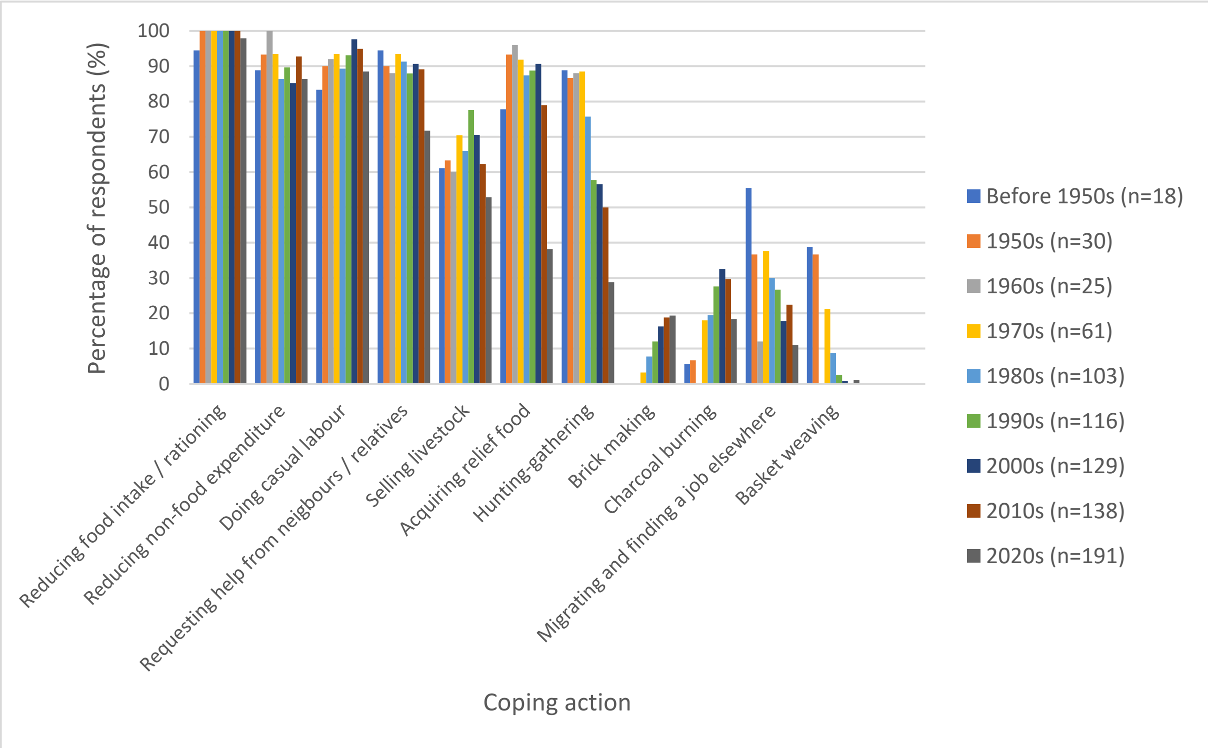
Figure 4. Drought impacts experienced over time



Note: Percentages are based on the total share of participants who reported having experienced impacts in a specific decade, which explains the different values for 'n'; the 1970 to 1977 drought accounts for the most notable livestock losses and other severe impacts (cf. Weesie et al., 2025).

From the 1950s until the 1990s, failed rainy seasons (drought) required nearly all respondents to reduce their food intake and their expenditure on non-food items. Hunting-gathering, requesting help from neighbours, and acquiring relief food were, and still are, important ways to access food during drought (Figure 5). Most other coping mechanisms revolve around ways to generate money to buy food, with nearly all respondents reporting being involved in regular casual labour and many selling livestock. Some respondents (10% to 30%) reported seeking an income through brick making, charcoal burning and labour migration. In times of drought, finding alternative sources of income that can be used to buy food is thus a key coping mechanism.

Figure 5. Drought coping strategies undertaken over time



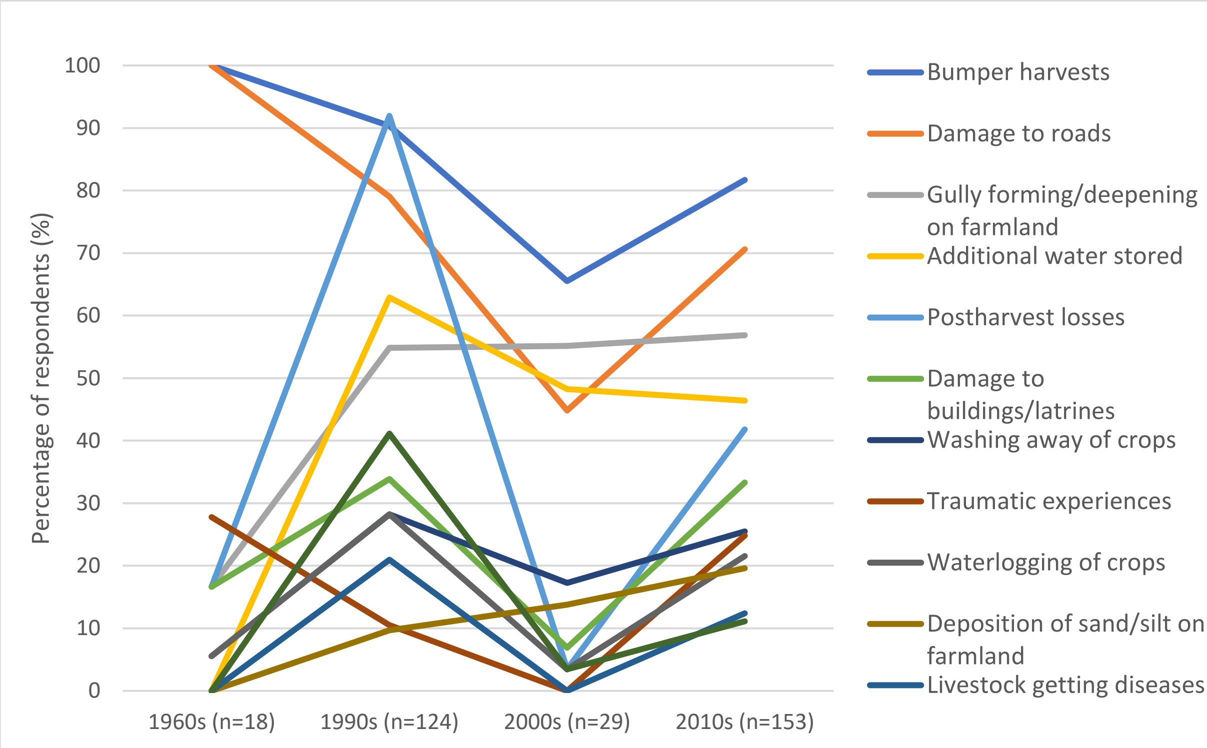
Participants remember feeling relief when water finally started flowing after these long droughts; heavy rains then brought successful harvests that were happily referred to as "bumper harvests" (Figure 6). Over time, however, floods are remembered to have done more and more damage to people and the landscape. Participants narrated how, from the 1980s into the 1990s, the Tiva River and its tributaries transformed from small, stable waterways into more erratic rivers; with each heavy rain they expanded, became wider, and accumulated more organic material and sand in their riverbeds, carried from the land (g6). Rivers and streams began to flow more irregularly, with the increasingly turbulent water rushing rapidly downstream, only to dry up quickly once the rains ceased (g6, g8, g12). Deep gullies started scarring the landscape, carrying rainfall directly to the Tiva River, which then flowed ferociously for some days, fed by all the streams.

During our field visits, farmers showed us the deep gullies that scarred their farmland, which emerged or deepened after floods. According to participants, major floods such as those accompanying the 1998 El Niño event caused vegetation losses leading to increased erosion (Weesie et al., 2025). They believe this loss of vegetation to have contributed to the disappearance of surface water sources across the landscape, including springs and ponds, (g8, p25). Use of these water sources also decreased after this period (see Section 5.6 for an overview of water source changes over time). As one participant stressed,

> We have same areas with natural ponds, but they don't hold water (…); it takes just a week to dry. Before, [water] accumulated there and stayed for months (p25).

Flood impacts became only widespread as from the 1990s, and have thus emerged much more recently than drought as a recurrent matter of concern (Figure 6: note the low n for the pre-1990s, meaning people did not indicate to have been affected by floods).

Figure 6. Flood impacts experienced over time



Note: Only the 1960s, 1990s, 2000s, 2010s are displayed, as the other decades had an n of <10, so results would be highly uncertain; the higher flood impacts in the 1990s result from the El Niño floods.

Often, participants attributed destabilising rainfall and river flows in the second half of the 20th century to landscape changes. They remembered how, over time, the number of people and livestock grew and trees were cleared to make way for settlements and farmland, corresponding with previous observations of landscape change in Kitui (Schmitt et al., 2019). In the 1990s, an emerging middle class was said to have driven a transition in local construction materials from clay bricks to concrete, which led to the extraction of the sand accumulated in Tiva River's bedding, needed for the production of concrete. This led to sand harvesting across the Basin, which effectively stripped some rivers bare and thus lowered their water tables due to decreased moisture retention. Consequently, participants had more difficulty acquiring water from scoop-holes, as water was no longer retained by the sand, and was discharged downstream even more rapidly. This is an example of how class dimensions reshape access to water along the lines of economic capital, where flood-proof concrete houses and businesses are built for wealthier families while negatively affecting the dryland watershed, including the most common public water sources for the majority.

Over time, not only the quantity but the quality of accessible water has become unstable. If river water did flow, it was observed to be no longer clear, but rather to have a brownish-red colour due to the sediments it picked up as it flowed downstream. We made similar observations during our field visits. Moreover, because of high salinity in many of the geologic formations in Kitui, both near-surface and groundwater boreholes suffer from salinisation (Wadira, 2020; Hoque and Hope, 2025). Salinity tends to be lower in sandy riverbeds, but during drought it can rise to levels above the allowable drinking limit (Kitheka, 2016). While salinity renders many key water sources unsuitable for drinking, brackish water sources are repurposed to water livestock and used for non-drinking domestic purposes such as washing clothes (r17-18), demonstrating the 'making do' and repurposing of water sources by its users.

Adaptation responses (2000s)

> People started digging water pans when the springs were gone (g10).

In response to water scarcity in the 1980s and 1990s, hydrosocial relations were reshaped by interventions undertaken by organisations in the form of the regional government, local CSOs such as churches, and a variety of NGOs. Interventions were usually funded by international donors, local donations, and, to a lesser extent, by the regional government. Most interventions had the objective of retaining the water that fell as erratic rainfall, slowing down river flows, securing water access for people and livestock, and preventing further erosion. These interventions took the form of many small-scale structures, both on public land in communities and on smallholder farmland.

Figure 7. Sand dam (left) and water pan (right) constructed by a local NGO (Sahelian Solutions Foundation, or SASOL) and funded by international donors

Source: Photos by author (R.V. Weesie).

At the community level, NGOs initiated in the construction of sand dams, water pans (Figure 7), and rock catchments in and around villages. Implementing organisations recruited income-seeking agropastoralists across the Basin for the construction of these waterworks. Sand dams are concrete barriers placed in the riverbed, with sand accumulated behind them. During the wet season water is retained in the sand, making it accessible for domestic use via a well (Lasage et al., 2008; Moïse et al., 2019; Ryan and Elsner, 2016; Ertsen and Ngugi, 2021). Water pans are depressions that are dug out to capture rainwater, which is used for livestock, and sometimes irrigation, during dry seasons. Rock catchments are concrete barriers that are constructed in seasonal streams in uphill rocky areas to capture and retain rainwater for domestic use. In communities situated further away from the Tiva River, more boreholes were drilled into aquifers to provide drinking water throughout the year. Community-managed water kiosks were established (and are still used), which allow people to purchase borehole water against a maintenance fee.

On the farm level, agropastoralists were incentivised by international NGOs to undertake a range of adaptation measures on their plots. Participants remember that during drought they were digging terraces, contouring trenches and zai pits in return for cash and food payments. Participants deemed the projects very helpful in preventing erosion and retaining more moisture on farmland. In the 2000s, terraces were swiftly adopted by most respondents, and today nearly all have terraced farms (Figure 8).

Figure 8. Terraced farm with contour trenches (Fanya-Juu) and zai pits to prevent erosion and retain moisture. Kathome area

Source: Photo by author (R.V. Weesie).

Moreover, from the 2000s onwards, agropastoralists started to implement a range of additional measures, at times supported by projects but more often on their own initiative: most respondents dug terraces on their farms, installed 120-litre drums to gather rainwater harvested from rooftops, started to plant drought-resistant trees, and/or started protecting existing and naturally sprouting trees, and/or shifted to cash crops, among a range of other practices to adapt to drought (Figure 9).

Meanwhile, as Kenya's economy continued to grow in the early 2000s, socio-economic changes in wider Kitui also produced a small wealthier group of people who became able to invest in methods of extraction and utilisation of water during dry periods. White collar jobs also emerged in nearby towns in the Basin. Working as teachers, civil servants or entrepreneurs (or some combination of these), their income enabled them to invest in hydraulic infrastructures such as 1,000-2,000-litre water tanks, and pipelines for irrigation (these do not appear in the graph above, as this group is smaller than 10% of respondents). Importantly, profitable irrigated farming allows them to hire people to do the farmwork. These labourers, usually local income-seeking agropastoralists, were (and still are) hired to do most of the seasonal maintenance of not only the irrigated farms, but also the terraced rainfed farms of wealthier groups, exemplifying how adaptation takes shape along socio-economic lines.

Changing drought and flood impacts (2010s-2020s)

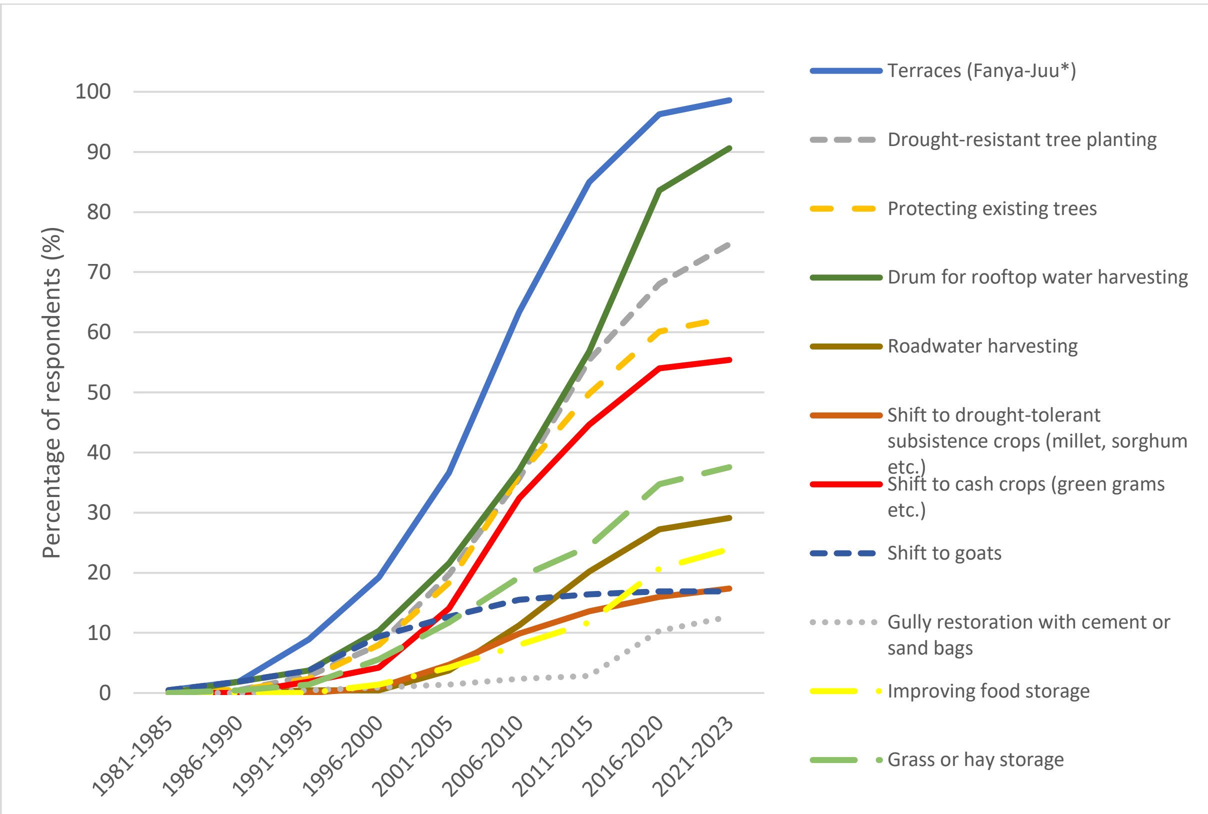
Into the 2010s, life-threatening drought impacts continued to reduce (Figure 4). According to our participants, this has to do with better market access to food and a wider range of income opportunities from rural and urban casual work (g8, g12). Other drought impacts remained prevalent, however, including reduced access to water sources and difficulty generating income, consistently affecting people in their daily lives.

Flood impacts have not necessarily reduced, but have changed in what type of damage is done. Bumper harvests, additional water storage, but also postharvest losses, and diseases – resulting from long periods of rain – have reduced (Figure 5). Despite widespread terracing, damage from short flash floods in the form of gully formations and washing away of crops has emerged as a major impact. When rains arrive, they often result in rapid runoff, which leads to harvest failures. Heavy rains are also increasingly accompanied by strong winds, which occasionally uproot trees and damage the corrugated-sheet roofs of houses. Rivers and streams bordering farmlands continue to erode participants' fields during high flows, leading to losses of cultivated land and trees. Participants reported that since the beginning of the 2020s rain has been falling over shorter periods and with an even higher intensity (p25, p27-28); marking hydrosocial relations characterised by high unpredictability.

Dynamics in agropastoral adaptation

By the 2010s, a high number of agropastoralists had implemented adaptation measures (Figure 9), displaying the widespread efforts that people undertake to adapt to destabilising rainfall and river flows (Figure 9). Adaptation unfolds through informal practices undertaken on respondent's farms, including terracing, afforestation, and water harvesting, all serving to sustain agropastoral livelihood amidst recurrent drought and erosive floods. However, while adaptive practices are undertaken widely, this does not imply that these interventions have remained functional in the years since. Many participants stated

Figure 9. Adaptation measures undertaken over time, cumulative



Note: Measures undertaken by less than 10% of respondents have been excluded for readability; for this respondent group, n = 213. *Fanya-Juu ('throw the soil up' in Kiswahili) refers to a type of terrace that conserves soil and water, where soil is dug from a ditch to create a walled contour trench (see Figure 8).

that much of their effort had been in vain. Within a few years, terraces were left in a state of disrepair, gullies had returned on their land, and water was no longer being retained after rainfall. Participants explained how this was a consequence of having to engage in casual labour on other people's farms once their own rainfed harvests had failed during a drought. This is not new – since the 1960s, nearly everyone (90%) has been engaged in casual labour during droughts (Figure 6). While this and other casual labour is normally a dry season activity, more recurrent harvest failures drive participants to continue doing so before and during the rainy season, a time of year that had previously been reserved for rainfed farming activities. The work they find is often on the farms of the wealthier households whose members have been able to secure the limited formal employment opportunities.

Several stories show how socio-economic inequalities are reinforced by inequalities in the ability to maintain adaptation measures. For example, respondents who had family members working as civil servants (be it teachers or work for the local government), told of how, during the 2008 drought, their irrigation activities allowed them to cultivate grasses to feed their livestock and enabled them to grow vegetables – to sell for high prices given the scarcity of food (p14, p16-18). Meanwhile, most other participants had few options but to seek an income to buy food, not able to undertake or maintain adaptation measures on their family farms. Their terraces have thus, "not [been in a state] where they should be" (g1). Terraces and gullies were left exposed to erosion when the next rains arrived, and tree seedlings were often lost to livestock seeking to graze the sparse vegetation. While casual labour can at times provide the necessary income to invest in adaptive measures, none of the participants reported that they had been able to do so, as their earnings were barely enough to sustain their families with sufficient food. The large number of people seeking a casual job during drought caused payments from such work to drop and left many agropastoralists "feel[ing] taken advantage of" (r17-18). The lower reliability of rainfed farming has contributed to water being perceived as a scarce and valuable resource by many participants. As farmers are preoccupied coping with drought, adaptation practices to retain water are very difficult to maintain.

Besides being unable to maintain terraces, the need to seek an income during drought also severy affects the ability of many participants to conserve trees on their land. Even when protecting of trees is done by most respondents (62%; Figure 9), many expressed the difficulty to successfully preserve trees to maturity. During dry seasons and drought, seedlings tend to dry up or fall victim to grazing livestock. Mature trees are also difficult to protect, as those in dire need of an income cut them to sell firewood, produce charcoal, or bake bricks from river clay (g13). Those who could afford to conserve mature trees on their land often faced significant social pressure to sell them to less fortunate members of the community who asked to cut them down. Some participants, stated that they were sometimes regrettably forced to cut down trees and produce charcoal in recent droughts, as there was "no alternative" (p4). Participants undertake these coping practices often alongside adaptive measures such as terracing of farms or planting new trees, depending on food and water reserves for the household during a specific season. Adapting and coping with drought thus takes contradictory forms. Efforts to restore tree coverage in the area is thus significantly hindered.

Despite the difficulties in adapting outlined above, some well-organised participant groups who have not been able to invest in water extraction actively attempt to circumvent exploitative labour relations. Some proudly shared how they worked in small collectives to manually irrigate shared plots and vegetable gardens, organise loan schemes by pooling investments in goats, conserve trees and grasses in public riparian areas, exchange seedlings, and restore and protect riverbeds and gullies. Women's groups in particular (g4, g5, g13) expressed the ways in which their collaborative efforts to access and maintain water during dry periods have been very helpful. As they put it,

> We have trained ourselves (…) Doing vegetable growing. (…) Just outside our houses. (…) We would fetch water with the donkeys and go water them (…). We were sowing them together (…) and then

> dividing the seedlings later (…) It helps us in our bodies a lot, because mostly we eat foods without nutrients (g4, g5).

Participants also learned from one another to adopt efficient methods for recycling household wastewater, such as adding ash to it and using it for vegetable irrigation (p11-12). These stories are a display of agency among agropastoralists, who actively seek ways to adapt to sustain their livelihoods with the limited resources at hand. While considered to be very helpful, these adaptive practices do require no immediate shortages of food, and a supportive and informative social network, not always available to the poorest groups.

Water usage and access over time

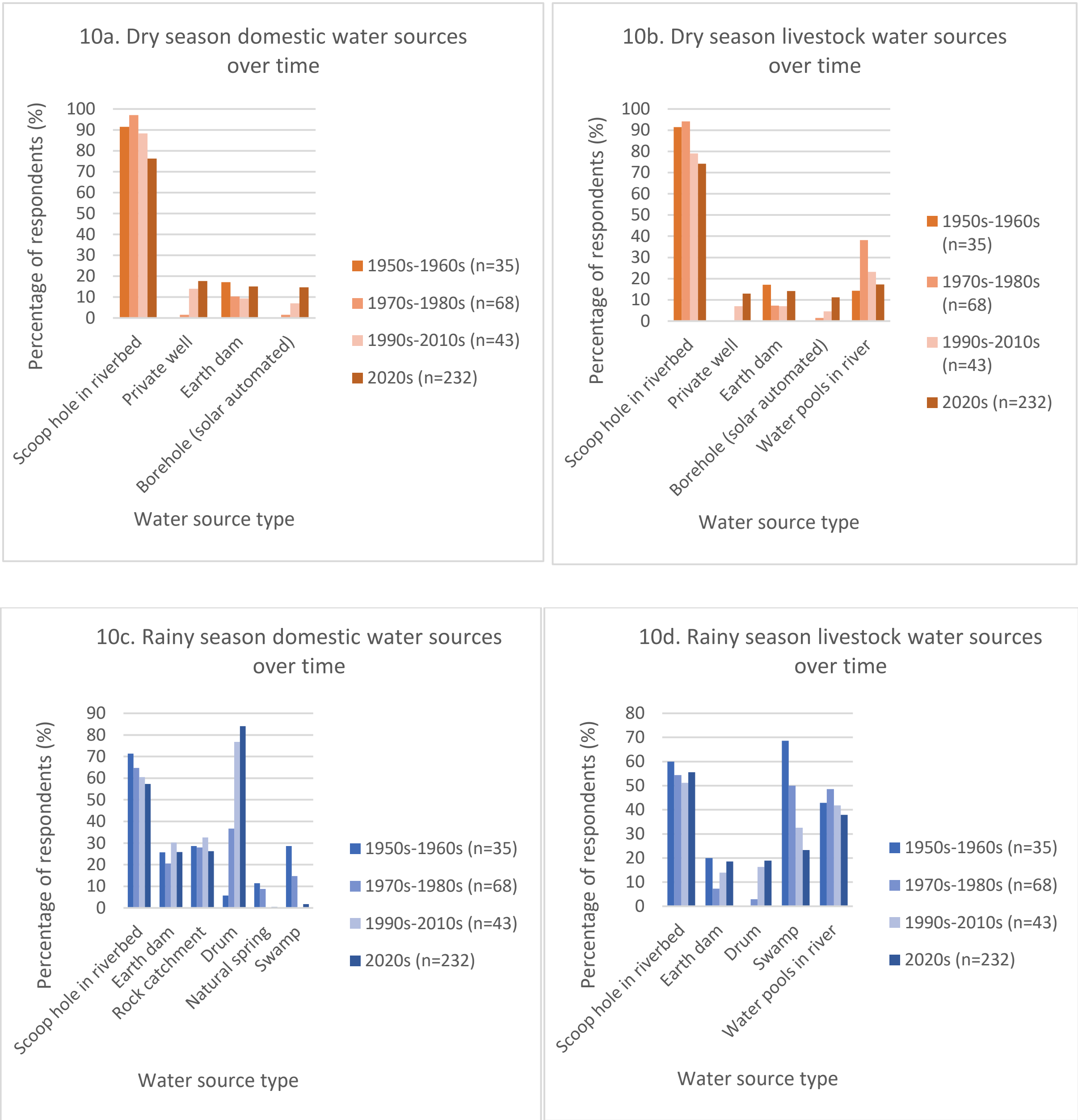
Changes in access and uses of over time can be observed from analysing the type of water sources that agropastoralists have utilised. Our survey quantifies some of these changes differentiated along season (dry or wet) and use type (domestic or livestock).

During the dry seasons, scoop-holes remain the most common source of domestic water and water for livestock, their usage has dropped somewhat, declining from 91% in the 1950s to 76% in the 2020s for domestic use (Figure 10a) and for livestock respectively from 91% to 74% (Figure 10b). By the 2020s, there had been some uptake of public water catchments (earth dams, rock catchments) and infrastructures (boreholes), but these remain restricted to 10% to 20% of respondents (see Figures 10a and 10b). This demonstrates that during dry seasons, scoop-holes remain more widely accessible compared to newly introduced public water catchments. As respondents who indicate to use public water catchments and infrastructures often also use scoop-holes, these introduced sources of water do not replace but rather complement existing ways of accessing water. Participants narrated how scoop-holes are carefully managed by the families that dig them out on a seasonal basis, and distribute responsibilities for maintenance amongst themselves – a display of informal institutions being shaped around the most important water sources.

There has also been an increase in private wells, which is an example of a higher-cost private investment that has been used by 18% of respondents for domestic water by the 2020s. This shows how, since the 2010s, a growing minority has accessed domestic water through private investments when their economic means allowed them to do so.

During rainy seasons, water sources shift and diversify. The use of public water catchments (earth dams, rock catchments) is higher than in the dry season, as these are replenished with rainwater and temporarily replace the scoop-holes as rivers are flowing. Still, only 20% to 30% of respondents currently report using them today. Scoop-holes are relied on by over half of the respondents (Figure 10c; Figure 11), indicating that riverbeds tend to dry up sufficiently to do so during rainy seasons. The biggest change is visible in the usage of water pools and swamps to water livestock, which has nearly halved (Figure 10d). This fits the narrative that, compared to the past, rainwater today is not as well retained within the landscape and runs off into rivers, discharging downstream toward Tsavo National Park. In line with the large uptake of farm-level adaptation measures, private farm-level methods to capture unstable rains have become more widespread, with 120-litre drums for storing rooftop rainwater becoming the most common source of water for domestic use (Figure 10c). Not visible in Figure 10c are the only 9% who now use a larger 1,000-2,000 litre private tanks for water storage during the rainy season. Being relatively expensive, these tanks are probably only affordable for a small, economically advantaged group, as has been observed elsewhere in Kitui (Nyaga, 2019; Ngugi et al., 2020; Wens et al., 2020).

Figures 10a-d. Types of water sources used over time; 10a: dry season domestic sources; 10b: dry season livestock sources; 10c: rainy season domestic sources; 10d: rainy season livestock sources



Note: Sources used by fewer than 10% during the entire period have been excluded for readability.

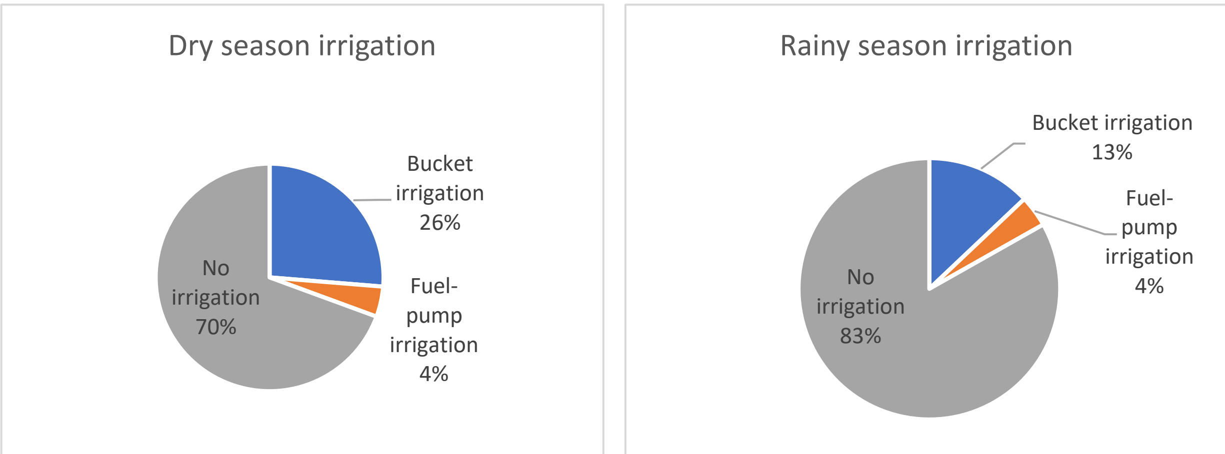
Disappearing water sources from the dryland landscape demonstrates how informal practices for accessing water are reshaped by changing water flows in a rapidly changing dryland. The reduced use of natural springs and swamps and the increase in the use of drums, private wells and tanks largely confirms the storytelling narratives that surface water is increasingly difficult to access. As people adapt by investing in small-scale water harvesting technologies to use alongside older ways of accessing water (scoop-holes), the diverse usage of a wider range of water sources demonstrates how people make do with the different options at hand through informal practices. Higher-cost investments into more secure private water supplies (private tanks and boreholes) remain reserved for economically advantaged groups.

Figure 11. Scoop-hole in Tiva's seasonal riverbed, the most-used source of water throughout the year

Source: Photo by author, R.V. Weesie.

Irrigation largely continues during the rainy seasons, with fuel pumps being used year-round by 4% of respondents; manual irrigation, on the other hand, is done by 26% in dry seasons and 13% in rainy seasons (Figures 12a-b). Permanent irrigation reflects the low reliability of rainy seasons today, as it is apparently beneficial to continue irrigating all year.

Figures 12a-b: Share of agropastoralists conducting irrigation types in dry and rainy seasons (n = 232)



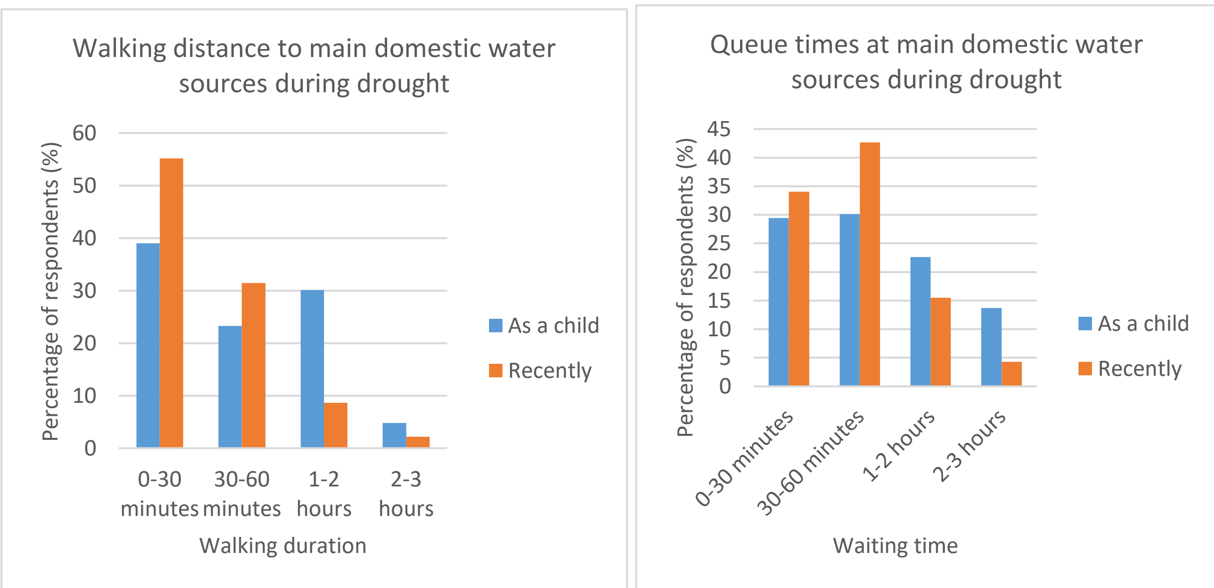
An important reason for the limited use of hydraulic infrastructures that came up during the storytelling sessions is the cost of the required maintenance and use. First, rainwater harvesting reservoirs (locally referred to as "water pans" or "earth dams") require costly regular desilting as they quickly fill with silt after heavy downpours and are prone to breaking a few years after construction. Community managers often have limited access to funds for ensuring seasonal maintenance of these waterworks, leading to many reservoirs not functioning adequately some years after construction. Second, maintenance fees for community-managed water kiosks pumping water from a borehole or well are often avoided by most families, who have a limited daily budget and prefer to use lower-cost river water. Third, public boreholes often suffer from salinisation. While aware of the health risks, some households are compelled to consume it in dry periods when affordable alternatives are not available:

> I drink [the desalinised water] with my family alone. If you were just passing by and want drinking water, I. can only offer the salty one (p6).

Participants (g1, p18) mentioned the damaging consequences to their health such as rashes, swollen abdomens, and gastrointestinal illnesses. Medical treatment is difficult to access and afford. A participant stated that especially children, when not in company of adults, often underestimate the health risks of drinking saline water (p18). Efforts to combat salinity include costly technological interventions such as desalinisation kiosks, an occasional one of which is invested in by NGOs; however, many people either cannot afford, or are unwilling to pay, the associated maintenance fees. These kiosks are also at risk of breaking down or of have their expensive hardware stolen.

There have been some reductions in walking distances to main domestic water sources and in queue times at these waterpoints during drought (Figures 13a-b). This could be a result of the construction of hydraulic infrastructures. Participants located more than three hours walking distance from the Tiva River narrated how they can now access water sources closer to home, from boreholes or water kiosks if they can afford the fees. Walking and queueing times to access water remain high for many, however; around half of the respondents still need to walk for more than half an hour to their main domestic water source and need to wait there for more than half an hour (Figures 13a-b). Acquiring domestic water thus remains a time-consuming task for those responsible – primarily women and children with the help of donkeys. Water scarcities affect some much more than others, along the lines of gender and age. Indeed, during dry seasons, women and children need to start moving towards their main water source during the night (p4) or must spend the night at waterpoints to reduce their queue time, as otherwise they will not have time to fulfil their other domestic tasks. Women state that it puts them to great risk of being harassed by men, or attacked by snakes and other wildlife attracted by water sources (p9).

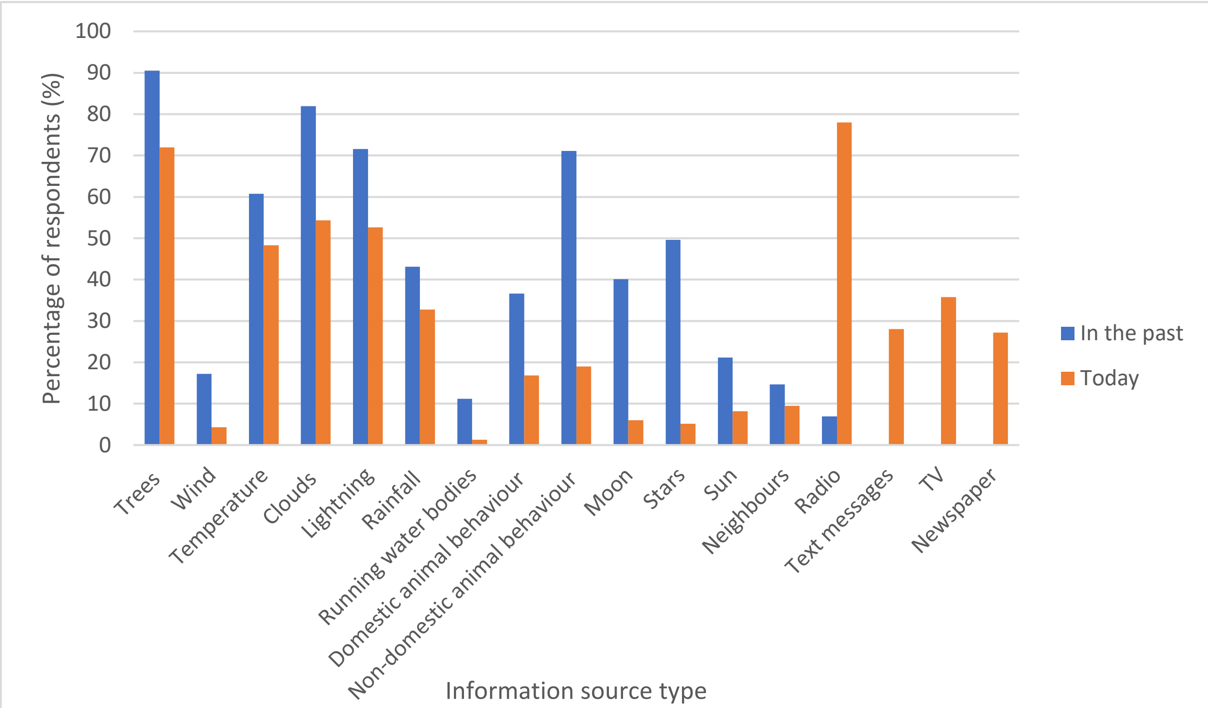
Figure 13a-b. Walking distances to, and queue times at, main domestic water sources during drought



Anticipating unstable waters

Finally, in order to analyse changes in how erratic rainfall has been anticipated, we briefly consider changes in the ways in which respondents have predicted unstable water flows. According to participants, rainy seasons are experienced to fail more frequently today than they did in the 20th century. While still used by especially adults and the elderly, environmental cues are less and less regarded as reliable indicators of impending rainfall today. Trees, for example, communicating rainfall onsets through their flowering and budding, have lost some of their age-old value as weeks-in-advance predictors of rainfall. While 72% of respondents still use them to predict rainfall (Figure 14), some see trees as being "confused" in their communication of rainfall onsets (p25). Other previously important environmental signs for forecasting weather are often no longer deemed to be as reliable as they used to be; these signs include celestial phenomena such as the moon and star constellations, animal behaviour, cloud formations, and lightning.

Figure 14. Information sources used to predict droughts and floods, in the past and today



Note: Sources used by fewer than 10% of respondents have been removed for readability.

Today, most people rely more on weather forecasts from meteorological services, communicated through radio, TV, and the mobile network. These information sources have partially replaced, but also complement, environmental cues. This, however, has not helped make rainfall be seen as more predictable; indeed, 94% of the respondents think that rainfall is less predictable than before. Participants narrated how determining the timing of land preparation and selecting appropriate crops has become more difficult. Farmers continue to face uncertainty in choosing between early maturing, drought-resistant crops such as millet and sorghum or the slower-maturing and water-demanding maize. While anticipating rainfall has been shifting from local environmental indicators towards meteorological information sources, hydrosocial relations remain marked by increasing uncertainty.

DISCUSSION

Destabilising waters and adaptation in the Tiva River Basin

Over the last decades, agropastoralists have experienced destabilising water flows in the Tiva River Basin, in line with what has been observed with regard to other seasonal rivers across East African drylands (Huang et al., 2024; Wekesa et al., 2020; Kihwele et al., 2021). The dryland landscape of today is experienced as retaining less water than it did in the mid-20th century and it is felt that rainfall is being discharged through more forceful river flows. Rain is seen as being more unpredictable and uneven and as more intense when it does fall. It is felt to have more damaging consequences than earlier, with harvests recurrently failing, farmland eroding and infrastructure failing, leading to food and water insecurity. Water's perceived role has changed from being regenerative and rhythmic, to being an erosive force and scarce resource that needs to be captured and mobilised.

Over time, changing water flows have worked in tandem with adaptation processes to reshape hydrosocial relations. The results of our study empirically demonstrate institutional bricolage by revealing the various ways in which agropastoralists navigate a fragmented and evolving water landscape. We conclude by discussing three major forms of adaptation: public infrastructures, private investments, and bottom-up practices. Public infrastructures often become at least partly dysfunctional, are selectively used, and are layered onto existing practices rather than replacing them. Private irrigation supports adaptation for some, but also introduces unequal, capital-driven forms of adaptation that reshape water access and labour relations. Meanwhile, widespread bottom-up practices illustrate everyday ways of "making do", as farmers combine existing knowledge, externally introduced techniques, and social networks in order to adapt to erratic water flows. Together, these findings reveal adaptation to be not a coherent or planned process, but rather a socially differentiated and continuously reassembled set of practices and institutions.

Adaptation through public infrastructure

Across the Tiva Basin, the first adaptation process altering hydrosocial relations has been the implementation of public, community-scale hydraulic land-works and infrastructures. Over the past 75 years, successive layers of infrastructure have been constructed by the regional government, NGOs and CSOs in the form of boreholes, reservoirs, sand dams and water kiosks. These interventions are certainly not restricted to the Tiva Basin and continue to be promoted and constructed by NGOs and governments across East African drylands (Piemontese et al., 2024). In Kenya, infrastructures aimed at expanding irrigated farming remain widely regarded in development agendas as viable adaptation strategies to push for a transition from rainfed agropastoralism to irrigated farming; this is the case not only in Kitui *(The Star*, 2022) but also nationally. This position is visible in the government's development strategies as outlined in Kenya Vision 2030 (Republic of Kenya, 2007) and in the National Adaptation Plan 2015-2030 (Republic of Kenya, 2015). The persistent efforts to capture and economise on water reflects the understandable desire of those involved in adaptation and water planning to gain control of increasingly unstable waters. Infrastructural works, as a form of adaptation, embody a continuation of the "hydraulic mission". This refers to the enduring fixation on creating "modern water" through technological control (Linton and Budds, 2014), which has characterised water policy approaches in Southern and Eastern African drylands over the last seven decades (Fontein, 2008; Hoque and Hope, 2018, 2025).

We learned from the Tiva Basin's inhabitants how the push for adaptation through public infrastructure has by no means been a straightforward process leading to improvements in water access. While used by some, the infrastructures have shown high rates of (at least partial) failure some years after construction; this has included broken sand dams, silted water pans, and saline boreholes. This is consistent with earlier case studies conducted in Kitui County (Manzi and Kuria, 2011; Kitheka, 2016; Ngugi et al., 2020; Moïse et al., 2019; Ertsen and Ngugi 2021). We learned how adaptation in the shape of public infrastructure constitutes path-dependent and layered institutional bricolage. On the one hand, our case demonstrates how infrastructural interventions reshape hydrosocial relations by reproducing modern ideals of the hydraulic mission in East Africa, the goal being to capture and control increasingly erratic water flows. In this way, the Tiva Basin demonstrates how belief systems and worldviews give shape to adaptation processes (Frick-Trzebitzky, 2017), interacting with contemporary water and development initiatives to produce particular outcomes (Cleaver et al., 2021). A hydrosocial perspective allowed us to see how infrastructure, once in place, itself reproduces norms and values that shape how water should be used and managed (Hommes et al., 2016, 2022). The accumulation of partly functional layers of infrastructure over time in the Tiva Basin has reshaped conceptions, norms and practices around water; this is as true for the many other agropastoral drylands in East Africa that have received similar interventions. The damage done to these infrastructural interventions by recurrent floods establishes a perception of water as an erosive force that damages homes, farmland, and infrastructures. In Kitui, largely dysfunctional infrastructures inscribed in the waterscape continue to frame water as a scarce resource to be captured. As anthropologist Onneweer (2014: 100-101) noted in his observations in Kitui, "Silted dams, dry wells, and broken pumps: the problems surrounding resource mobilization sedimented into the landscape as continual reminders of the area's undeveloped potential value."

During our scoping visits to the Basin, local NGOs, governmental representatives and scientists stressed how water could be controlled with modern hydraulic infrastructure only if the infrastructure was "done well". With the Tiva River Basin's numerous hydraulic interventions aimed at capturing and supplying water, it is an example of how adaptation is shaped by persistent, preconceived and arbitrary notions of how water should be controlled and utilised (Parsons and Chann, 2019). Preconceptions of how people *ought* to organise around water thus add a form of path dependency to adaptation processes over time through the cementing of norms into water governance institutions. Destabilising water flows only strengthen "modern" conceptions of water, as recurrent drought and flood impacts work in tandem with failing infrastructures to establish water as a scarce "resource to be managed" (Mills-Novoa et al., 2020).

On the other hand, the dominance of modern preconceptions of water in adaptation planning does not at all mean that water users turn into passive victims of droughts, floods and infrastructural failure. Public waterworks are either ignored, repurposed, selectively used, or layered into existing practices around water. Agropastoralists tinker and make do with a variety of water sources that coexist alongside introduced infrastructures. Saline boreholes and half-broken sand dams, for example, are repurposed into livestock watering points; investments are made in private water harvesting; and scoop-holes are carefully managed through informal arrangements. Seeing how agropastoralists tinker not only with irrigation schemes (cf. Kemerink-Seyoum et al., 2019; Chitata et al., 2021) but also with boreholes, dams, water kiosks and wells demonstrates how adaptation processes unfold through institutional bricolage. The Tiva Basin's inhabitants have shown how, in East Africa's drylands, agropastoralists adapt through informal arrangements and how they form a "patchwork of the new and the second-hand" (Cleaver, 2012: 46).

Private irrigation as uneven adaptation

Along the Tiva River, and along many seasonal rivers in East Africa's drylands, private investment in irrigated crop-farming is the second major form of adaptation that has been reshaping hydrosocial relations. Hydrosocial configurations where actors invest in fuel-pumped irrigation along seasonal rivers, reservoirs and lakes are increasingly common in African drylands, where irrigation is feasible (Weesie and Kronenburg García, 2018; Hebinck et al., 2019; Duker et al., 2023). From our case study, we learned how private irrigation can aid families to adapt to erratic rainfall and river flows, but that it can also introduce unequal, capital-driven forms of adaptation that reshape access to water and labour relations. Along Kitui's rivers, a selective group of water users can now successfully access and utilise water through investments in water storage tanks, irrigation pumps and piped systems, which are only affordable and accessible to a few percent of agropastoralists (Ngugi et al., 2020; Wens et al., 2021). Seeing wealthier neighbours pumping water from the subsurface flows in seasonal riverbeds, agropastoralists have narrated how water has shifted from being a broadly accessible element of the dryland landscape into a valuable economic commodity. As irrigation water pumped from riverbeds enables year-round cash crop production, water seems to increasingly "flow to money" (Farnum et al., 2018). These observations point to an earlier significant and established relationship between the economic capital of farmers and their ability to invest in adaptation measures in East African drylands (Wens et al., 2020; Ndung'u and Muriu-Ng'ang'a, 2021). Another reason for the spread of private irrigation is the more frequent harvest failures that are caused by the increasingly unstable rainfall and river flows that result in recurrent droughts and floods. These harvest failures are pushing most smaller rainfed farmers off their own farms, often into the service of the minority who have ensured access to irrigation water. Farmers who become workers on larger farms with private irrigation then see a decline in their ability to conduct their own on-farm adaptive practices such as maintaining terraces. Socio-economic relations thereby shape adaptive capacity and exposure to disruptive water flows (Frick-Trzebitzky, 2017). As private investments in irrigation are spreading along East Africa’s seasonal rivers and as public water works often fail, adaptive capacities are at risk and are becoming increasingly uneven.

Adaptive bottom-up practices

The third form of adaptation we observed in the Tiva Basin are bottom-up practices undertaken by agropastoralists themselves. These widely undertaken practices include manual small-scale irrigation, restoration of eroded farmland, planting and conserving trees, harvesting water, and carrying out various soil conservation measures. When their circumstances allow, agropastoralists often seek to prevent further damage and sustain their livelihoods amid increasingly erratic waters. While faced with a dearth of economic capital, some groups are armed with a social network and have demonstrated how they can actively circumvent exploitative casual labour during drought by leveraging their social capital. Well-organised women’s groups, especially, have been collectively engaged in small-scale agricultural practices and conservation. Previous studies on East Africa’s drylands have equally highlighted that, particularly when economic capital among agropastoralists is low, social capital becomes an important resource for undertaking adaptation measures (Mortimore, 2010; Wens et al., 2021). Participants proudly described collaborative initiatives as a way to maintain agropastoral livelihoods, illustrating how those affected by droughts, floods, unequal labour relations and infrastructural failure are not passive victims, but rather active agents of adaptation. A key concept of bricolage is "making do" with the resources at hand (Lévi-Strauss, 1966), which is an important part of climate change adaptation. Cobbling together social practices (Cleaver, 2012), agropastoralists undertake new adaptations based on pre-existing knowledge, externally introduced techniques, and social networks. The variety of adaptive practices undertaken by agropastoralists demonstrate people’s creative and resourceful use of available resources in the adaptation process (Abu and Reed, 2018). The widespread uptake of a broad range of adaptive practices shows how farmers continuously (re)invent their daily practices to (re)create relationships that enable their resilience over time (Darnhofer, 2021).

Important to note here, however, is that bottom-up adaptive practices ought not to be idealised and uncritically promoted by adaptation research, policy and planning. Our study reveals that agropastoralists face various structural barriers to their efforts to maintain adaptation measures over time. From residents of the Tiva Basin, we learned that high rates of adoption of adaptive practices do not at all mean that these practices remain functional over time. Terracing and revegetating demand continuous seasonal maintenance and require substantial investments of labour; their successful upkeep is thus limited to those who have sufficient resources to do so. Socio-economic barriers to maintaining adaptation measures have been confirmed in various agropastoral areas of Kenya (Khisa et al., 2014; Ifejika Speranza et al., 2010; Okayo et al., 2015). The gap between adoption and long-term maintenance of adaptive practices shows bricolage to be fragile and contingent, not a stable institutional system that spreads over time. The difficulty of maintaining adaptive practices, in turn, can lead to coping strategies that further decrease the stability of water flows. During drought, acute food shortages and no sources of income mean that agropastoralists often have little choice but to rely on coping strategies that consume the remaining trees and shrubs, most notably charcoal burning and clay brick baking. Both activities, when widespread, further reduce vegetative cover in drylands, thereby undermining watershed stability of the drylands. "Making do" when living with erratic flows of water can thus go different and contradictory ways.

CONCLUSION

From agropastoralists living in the Tiva River Basin in dryland Kenya, we have learned how hydrosocial relations have been reshaped by destabilising water flows and adaptation processes. Water's role has changed from being a rhythmic and regenerative force, to an erosive and a scarce resource to be captured and mobilised. Adaptation processes have materialised in multiple and layered interventions and practices, each reshaping the ways in which water flows, and how it is perceived and used. Firstly, public hydraulic infrastructures represent and inscribe norms to capture and control water into the dryland landscape. Through their decay over time, they do not replace but become part of existing institutional arrangements of how agropastoralists navigate erratic waters. Secondly, the spread of irrigation around seasonal rivers in East Africa's drylands is adaptation for some, but risks contributing to inequality in labour dynamics and uneven access to water. This demands attention to how dryland irrigation along seasonal rivers can contribute to broader strengthening of adaptive capacities for the majority of agropastoralists instead of a selective group. Third, widespread uptake of bottom-up adaptive practices risk obscuring their limited functionality over time, as agropastoralists face various structural barriers to sustain them. This demands further inquiry in how adaptive practices can be better maintained after initial uptake. Future adaptation research, policy and practice in agropastoral drylands ought to be aware of these dynamics to more adequately design, incentivise and trigger more sustainable and equitable adaptation processes.

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APPENDIX: CODES USED FOR STORYTELLING ANALYSIS

Indicator used	Codes used in analysis of transcripts
Experienced changes in water flows (rainfall, river flows, water sources)	Water flows changes
	River flow changes
	Rainfall changes
	General weather and climate changes
	Soil changes
	Perceived reasons for changing weather/climate
Experienced changes in water uses (water sources, access, water quality)	Dry season current type of water source
	Dry season past type of water source
	Dry season water source reliability or quality
	Dry season past distance to water
	Dry season current distance to water
	Rainy season current type of water source
	Rainy season past type of water source
	Rainy season water source reliability or quality
	Rainy season past distance to water
	Rainy season current distance to water
	Farming practices (irrigation, planting strategy, etc)
	Water source construction/management
	Barriers/motivations to using a water source
	Water source shift
Changes in adaptation measures undertaken (measures taken to prevent further damage and/or take advantage of unstable water flows)	Barriers to coping or adaptation measures
	Adaptation measures in general
	Group membership and activities
	General practices, changes in life, historical changes

Experienced changes in perceiving water (e.g. scarcity and stability of its presence)	General practices, changes in life, historical changes Perceived reasons for changing weather/climate
Experienced changes in predictability of flows of water	Changes in predictability of rainfall, river flows Past weather prediction Current weather prediction