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# How shifts in societal priorities link to reform in agricultural water management: Analytical framework and evidence from Germany, India and Tanzania

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## HIGHLIGHTS

- Reform in agricultural water management is vital to accommodate societal priorities
- Frameworks do not analyse links between societal priorities and reform
- A framework and variables are tested on reform cases in Germany, Tanzania and India
- The framework offers a realistic lense to study agricultural water management reform
- Further research should focus on testing research methods in in-depth case studies

## ARTICLE INFO

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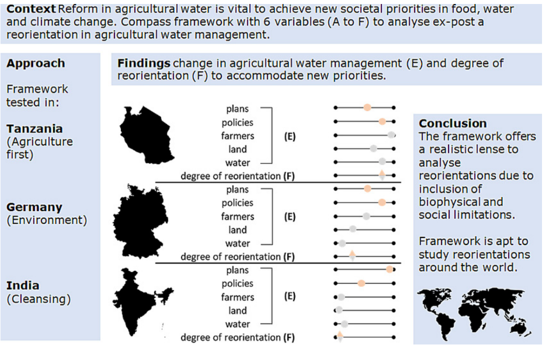
## GRAPHICAL ABSTRACT



**Context** Reform in agricultural water is vital to achieve new societal priorities in food, water and climate change. Compass framework with 6 variables (A to F) to analyse ex-post a reorientation in agricultural water management.

**Approach**

Framework tested in:

**Tanzania** (Agriculture first)

**Germany** (Environment)

**India** (Cleansing)

**Findings** change in agricultural water management (E) and degree of reorientation (F) to accommodate new priorities.

**Conclusion** The framework offers a realistic lense to analyse reorientations due to inclusion of biophysical and social limitations.

Framework is apt to study reorientations around the world.

## ABSTRACT

Climate change, environmental awareness, and food security are just some of the new priorities societies pursue. Due to the very large influence of agriculture on water quantity and quality, often a certain degree of reform in agricultural water management is required to accommodate such new priorities. To assess the degree of reform an analytical framework is introduced to account for social (e.g. contestation, path dependency) and biophysical limitations (water balance as a zero-sum game, limited gains in biomass productivity) to reform in agricultural water management. The hypothesis tested in this paper is whether the framework is capable to link shifts in societal priorities to actual reform in agricultural water management and if the framework can assess to what extent agricultural water management has changed to accommodate shifting societal priorities. The analytical framework and variables assess ex-post the degree of a reorientation, which is understood as the interplay between shifts in societal priorities and reform in agricultural water management to accommodate such shifts. The framework offers a causal chain of 6 variables to assess a reorientation. A test is performed by probing the framework in diverse contexts of Germany, India and Tanzania. Evidence from Germany, India and Tanzania confirm the validity of the social and biophysical limitations as they acted as real boundaries for the amount of reform achieved. In Tanzania much reform was achieved and agricultural water management accommodated the new priority of agricultural expansion, whereas in Germany and India few farm-level changes were achieved making new priorities of environmental conservation unattainable. Based on the test it can be concluded that the framework offers a realistic lense to study reorientations around the world. For further research, in-depth case studies are recommended to further develop the framework and advance insight in the complex biophysical and social interrelationships of reorientations.

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## 1. Introduction

Climate change adaptation and mitigation (IPCC, 2022), environmental conservation (IPBES, 2019), and renewed attention for food security (Hellegers, 2022) are just some of the priorities societies are increasingly pursuing in the past years. This paper is about the interplay between shifts in societal priorities and changes in agricultural water management to accommodate those shifts. The interplay between societal priorities and agricultural water may appear far-fetched, but is from a water resources perspective utmost relevant when one combines the insights that i) agriculture is the largest water user accounting for 72 % of the freshwater withdrawals (FAO, 2021), ii) agriculture is responsible for 56 % of volumetric effluent discharged into the environment (FAO, 2021), and iii) water resources are increasingly scarce due to growing demands and climate change, resulting in fiercer competition for water (Vörösmarty et al., 2000). Hence when priorities in society shift from for instance agricultural intensification to environmental conservation, or from agricultural expansion to urban growth, changes in agricultural water management become almost a prerequisite to accommodate water-wise the novel priorities as it often involves redistributions of scarce water and improvements in water quality. This interplay is visible in many regions around the world. A scoping study of 21 examples found that agricultural water management is more easily altered to accommodate agricultural growth priorities of land rehabilitation, expansion, and intensification, then to accommodate priorities related to environmental conservation such as biodiversity enhancement, clean river flow, and capping groundwater extraction (Seijger and Hellegers, 2023).

The aim of this paper is to increase the understanding how shifts in societal priorities require a certain degree of reform in agricultural water management, by introducing and testing the usefulness of an analytical framework and variables. So far, the concept of reorientation has been defined as a shift in broader societal priorities that drives reform of agricultural water management. Existing analytical frameworks hold major limitations to analyse a reorientation. First, reform in agricultural water management is not explicitly linked to shifting societal priorities and observed changes in agricultural water management (e.g. Molden, 2007; Mollinga et al., 2007; Sehring, 2009). Second, specific types of reform in agricultural water management are covered and include water pricing (Zhang and Oki, 2023), reform in a country (Gany et al., 2018) or reform related to a particular objective of poverty reduction (Namara et al., 2010); but a more generic framework with variables and indicators to study different types of reform in the context of changing societal priorities remains absent. Third, other frameworks may have clear variables (Ostrom, 2009; Köhler et al., 2019) but they are not tailored to the unique context of agricultural water management which has a strong path-dependency (Molle and Wester, 2009), complicated patterns of water use and return flows (Keller and Keller, 1995), and fast and slow system response times to interventions (Holling, 1986). An analysis on reform in agricultural water management becomes more accurate when these limitations are included as they represent interrelated, real boundaries for the amount of reform to be achieved in agricultural water management.

Due to those limitations, recently a call was made to develop a novel interdisciplinary analytical framework that also accounts for the social and biophysical limits for change in agricultural water management (Seijger and Hellegers, 2023). Agricultural water management is frequently portrayed as a complex phenomenon. The complexity relates not only to the management of water among upstream and downstream farmers (Chambers, 1989) and to achieving some kind of institutional reform (Mollinga et al., 2007), but also to properly understanding interactions in biophysical, sociopolitical and institutional subsystems (Molden et al., 2010; Bjornlund and Bjornlund, 2019; Zhu et al., 2019). Hence, to further advance the understanding how shifts in societal priorities relate to reform in agricultural water management, we introduce in the remainder of this paper an analytical framework and variables to study a reorientation. We probe the usefulness of the framework in different contexts and for different types of reorientations in Tanzania (agricultural intensification), Germany (environmental conservation) and India (cleansing).

## 2. Methodology

### 2.1. Limitations for reform in agricultural water management

From literature five biophysical and social limitations are identified which together largely co-determine the extent that agricultural water management can be reformed; namely: the water balance being a zero-sum game, limited potential for gains in biomass water productivity, contestations, path-dependency, and system response time.

First, agricultural water management is from a water resources perspective, irrespective of scale, a zero-sum game that is well-captured in the water balance. The water balance quantifies for a system the incoming, outgoing and storage changes of water. The total amount of water in a water balance remains the same, meaning that if one water component changes this has a direct bearing on other parts of the water balance. Accounting for water, and all its uses and return flows within a water system is thus necessary to understand impacts of interventions as a redistribution of water resources. In agricultural water management technological interventions may look good at farm-field level as they reduce local water losses, yet they often reduce return flows (excess of surface drainage water, percolation to groundwater) and thus result in lesser water for downstream use (Keller and Keller, 1995). For instance, modernized irrigation systems (e.g. drip, sprinkler, center-pivot systems) are frequently touted for their water saving potential at farm level, yet as long as water inputs into the irrigation systems are not equally reduced to the water saving amount, it is more likely that production increases and return flows diminish, meaning that less water becomes available to reallocate to other sectors and water users (Grafton et al., 2018; Pérez-Blanco et al., 2021).

Second, transpiration of crops is by far the largest agricultural water user, yet making gains in producing more biomass with same amounts of transpiration is extremely challenging as it is largely fixed by the photosynthetic efficiency of a crop. Meaning, there is little scope to increase biomass production with the same amount of water (Sinclair et al., 1984; Molden and Oweis, 2007; Steduto et al., 2007). An exception to this is the possibility to make gains in commercial yield with the same amount of water. This has been one of the main successes of the green revolution (more commercial yield per crop) yet the reported global crop yields by FAO over the past 20 years for key crops are fairly stable except for increases in bananas and potatoes (FAOSTAT, 2022). Indeed agronomists also recently warned that yield gains in major staple food grains (maize, rice and wheat) are slowing (Peng et al., 1999; Valvo et al., 2018; Rizzo et al., 2022). Gains in agricultural production should thus be assessed against increases in general agricultural inputs (e.g. water use, agricultural land, agrochemicals).

Third, decisions around agricultural water management are contested as diverse actors have divergent perspectives and interests, and they try to shape and reshape decisions (Mollinga and Bolding, 2004; Boelens et al., 2016; Zwarteveen et al., 2017). Whether decisions relate to more water, less water, water of a different quality or hydraulic infrastructures, any change of course for agricultural water management is likely to evoke disputes over decisions, norms, knowledge and authority as actors attempt to reshape decisions to fit their own perspective (Boelens et al., 2019; Hommes, 2022). Shaping and implementing new policies, new agricultural water projects or innovative farming practices are therefore always surrounded by contestations and uncertain outcomes.

Fourth, a social-historical context largely determines what kind of changes are feasible and attainable in agricultural water management. River basins and deltas are typically on a path-dependent trajectory of water overexploitation; the construction of large dams, dikes, irrigation schemes, interbasin transfer schemes and groundwater pumps create lock-in situations of preferred technologies and institutions which lead to closure of river basins and sinking of deltas (Molle and Wester, 2009; Seijger et al., 2018). Also modernization of irrigation systems represents a lock-in of choices for irrigation improvements and institutions (Perez-Blanco et al., 2021). Alternatives are generally shut out, and changing the status quo is very challenging as it often requires consent from a range of actors, institutional reform, and wide-spread experiments with alternative technologies and institutions (Sehring, 2009; Seijger et al., 2019).

Fifth, impacts of changed farming and irrigation practices on land and water resources may not be directly observable due to a system response time to an intervention. Fast and slow response times are distinguished (Holling, 1986). Biophysical processes of groundwater recharge, soil and water quality have a slow response time as it may take many years before changes are clearly observable (Meals et al., 2010; Min et al., 2019). Processes with a fast response time are observable within days to years and relate to land use, land management, crop yields, water withdrawal (Ward et al., 2019). Hence when assessing impacts of changes in agricultural water management it is necessary to acknowledge both the fastand slow response times of the environment for a more accurate analysis. Coming to an accurate analysis is challenging as policies, especially national and subnational ones, have a limited time-horizon and generally lack a framework to properly account for slow response times.

### 2.2. Compass analytical framework

Due to the earlier-described limitations of existing frameworks, we propose here a novel interdisciplinary "Compass" framework for the structured ex-post study of reorientations over time at different levels (Fig. 1). The framework offers insight into shifts in broader societal priorities and the degree of reform of agricultural water management to accommodate newly dominant priorities regarding, for instance, agriculture, water scarcity, environmental awareness and climate change. Similar to other interdisciplinary frameworks in the environmental sciences (Molden, 2007; Ostrom, 2009), agricultural water management is studied as manifest in an interlinked constellation of plans, policies, farming practices, land and water resources. The "compass" refers to the new course set for agricultural water management, such as with new priorities for crops, water systems, farmer livelihoods and changes in the water system. The degree of reform in agricultural water management is largely co-determined by biophysical and social limitations discussed in the previous section.

Having outlined and visualised the theoretical construct of a reorientation, variables and indicators are needed (George and Bennett, 2005) to empirically study a reorientation. Following Baron and Kenny (1986) we distinguish four sorts of variables to study causal mechanisms: independent variables (starting points for change), dependent variables (outcomes to be explained), mediating variables (which relate the independent variable to the dependent variable) and moderating variables (which modify the relation between the independent and dependent variables). Due to the complexity of understanding reform in agricultural water management, we interpret variables as a set of interrelated qualitative descriptors and not as a set of quantitative descriptors which are assessed statistically. Thus, the Compass framework contains the following six variables:

- Independent variable A: shifts in broader societal priorities
- Mediating variable B: status quo of agricultural water management as manifest in a constellation of plans, policies, farming practices, land and water resources a region (say, region X), before societal priorities shifted
- Moderating variable C: efforts to adjust agricultural water management to accommodate shifted priorities
- Moderating variable D: other factors (to account for inclusion of case-specific explanatory factors)
- Mediating variable E: agricultural water management accommodating shifted priorities in region X, as manifest in a constellation of plans, policies, farming practices, land and water resources
- Dependent variable F: the degree that reform in agricultural water management accommodates the shift in societal priorities.

A reorientation process is then analysed through the different variables and their interlinkages. The interrelation between shifting societal priorities and reform in agricultural water management is centrally captured in the Compass framework through variables A, B, E and F. Variable C and D are included to convert the framework from a largely descriptive framework that describes the degree to which a reorientation occurs (variable F) as the difference between variables B and E, to a descriptive-explanatory framework which also explains why agricultural water management has changed. Variable B and E both capture agricultural water management as manifest in a constellation, yet they do so in a different timespan using partly different indicators (see Table 1) that justifies the use of separate variables B and E. Indicators are thus used to measure the variables. Which indicators are used is case- and context-dependent, and part of the operationalisation process of a study when the framework is further operationalized. To that end Table 1 not only provides numerous indicators, but also references for further reading and considerations for operationalisation.

The biophysical and social limitations for change in agricultural water management have directly informed the framework and variables. *Path dependency* is captured in the 'from – to' logic of the framework, with priorities shifting from one to another (variable A), and with agricultural water management changing from a status quo situation to another configuration accommodating shifted priorities (variable B and E). The *water balance* being a zero-sum game is captured in variable B and E by indicators on water resources use, withdrawal and replenishment and by critically analysing what kind of changes are effectively made in the in- and outflowing water resources of the area of interest (variable E). Gains in *water productivity* (or producing more food with relatively less water) are assessed by indicators on production patterns and water used (in variables B and E). *Contestations* are covered under variable C by studying actor support and opposition to

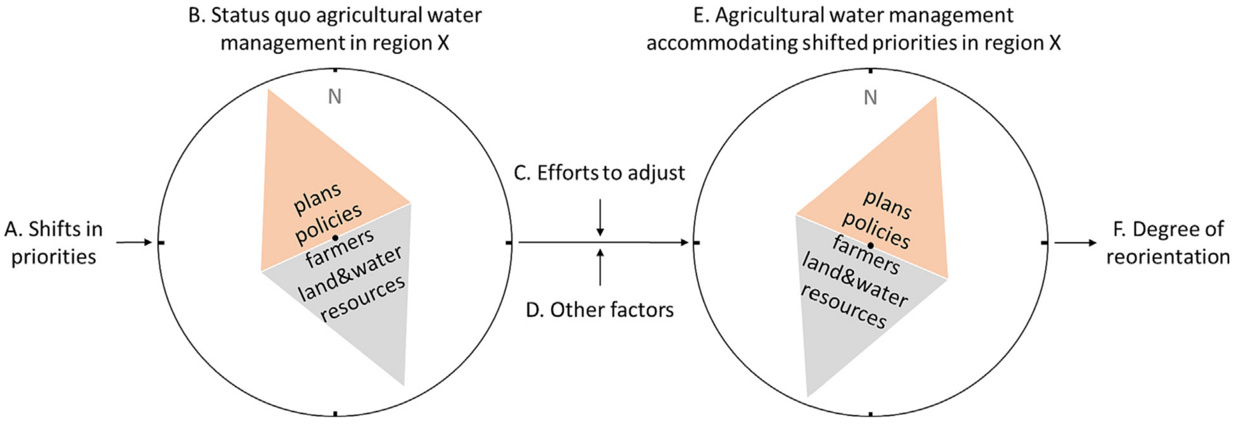

**Fig. 1.** Compass analytical framework to study a reorientation.

**Table 1**
Variables and indicators for study of a reorientation.

| Variables | Indicators | References and considerations for operationalisation |
|---|---|---|
| Independent variable A: shifts in priorities | Current and past societal priorities, as manifest in plans, policies and investments to serve economic, agricultural, water distribution, environmental, climate change and other interests | Distinct shift with direct consequences for agricultural water management (Kirschke et al., 2019; Vo et al., 2019) |
| Mediating variable B: status quo of agricultural water management in region X | National and regional plans and policies for agriculture and water that capture the status quo of agricultural water management before priorities began to shift | (Molle et al., 2009; Griewald, 2018) |
| | Rules, both formal (e.g., policy documents, decision-making, water distribution) and informal, governing land and water allocations and farming practices | (Mollinga et al., 2007; Hoogesteger and Wester, 2017) |
| | Farm size, key agricultural subsectors, cropping and production patterns, farm socio-economics | (Meurs and Bogushev, 2008; FAOSTAT, 2022) |
| | Land and water resources quality, use and infrastructure, water withdrawal and replenishment, in- and outflowing water resources | (FAO, 2020; FAO AQUASTAT, 2022) |
| | Sustainability of natural resource base, including ecosystem sustainability, environmental degradation, and social and intergenerational equity | (Gordon et al., 2010; Reganold and Wachter, 2016) |
| Moderating variable C: efforts to adjust agricultural water management to shifted priorities | Actor support in terms of consent and opposition to changes in policies, farming practices and management of the land and water system | (Checkland and Scholes, 1990; Seijger et al., 2019) |
| | Policy instruments such as export taxes, crop subsidies, water prices, training and other mechanisms with a regulatory, economic or information purpose | (Hellegers and Van Ierland, 2003; Garrett et al., 2018) |
| | Interventions in agricultural water management, related to water distribution, consumption, crops and cropping intensity, agrochemicals and soil management | (Douxchamps et al., 2014; Iglesias and Garrote, 2015) |
| | Learning, motivation and abilities of actors to adopt and scale up policy instruments, interventions, farming practices and the water management system | (De Fraiture et al., 2010; Lebel et al., 2010; Phi et al., 2015) |
| Moderating variable D: other key factors | Context dependent, for instance, citizen advocacy, a food/health crisis or an environmental disaster | Include when (E) is not largely explained by (C) |
| Mediating variable E: agricultural water management accommodating shifted priorities in region X | Response time for land and water resources to respond to changes in farming practices and water systems; other indicators similar to variable B | (Meals et al., 2010; Min et al., 2019; Hasselquist et al., 2020) |
| Dependent variable F: degree to which a reorientation occurs in region X | No indicators, as it depends on the other variables | Compare B with E and assess if novel priority A is accommodated |

changes in policies, farming, and management of the land and water system. *System response time* to an intervention is addressed in variable E. The influence of the different limitations is then qualitatively discussed under variable F when an explanation is given for the degree that reform in agricultural water management accommodates the shift in societal priorities.

### 2.3. Method to probe the compass analytical framework

Different kinds of objectives exist in case study research. A plausibility probe is a preliminary case study that aims to explore the usefulness of relatively untested theories and hypotheses for a phenomenon under study (George and Bennet, 2005). The hypothesis tested in this paper is whether the Compass framework is capable to link shifts in societal priorities to actual reform in agricultural water management and if the framework can assess to what extent agricultural water management has changed to accommodate shifting societal priorities. Scoping research on reorientations already identified that reorientations take place around the world, and vary in type and outcome (Seijger and Hellegers, 2023). For the probe 3 cases were selected (Germany, India, Tanzania) that represent this diversity in reorientations, to conduct a strong test for the wide applicability of the Compass framework. Table 2 summarises these very different reorientation cases.

The case analyses were created through a desk study with scientific articles as primary source of case information listed at the start of Section 3.1. In addition, policy and planning documents were analysed and the internet was browsed to obtain additional info on the latest developments in for instance EU Court rulings (Germany) and impact of Covid-lockdown on water quality (Ganges). Based on those sources, an initial case analysis was written that covered all variables. The case analyses presented in this paper were revised during subsequent rounds of writing. Each case analysis contains a narrative summary of the reorientation by discussing variables (A) to (F) and highlighting key contextual limitations for reform in agricultural water management. The cases are then compared, and the achieved change is quantitatively assessed (variable E and F) across the three cases on a continuous scale ranging from “not present” to “somewhat present” and “very present”. The quantifications were derived from the case analyses, and they were made through expert judgment by the author. The

**Table 2**
Characteristics of three very different cases of reorientation.

| | | Germany | India | Tanzania | Source |
|---|---|---|---|---|---|
| Social-economics | Institutional context | Federal state and parliamentary democracy | Federal state and parliamentary democracy | Dominant-party system | |
| | Level of country income | High | Lower middle | Lower middle | (World Bank Open Data, 2022) |
| | Population | 83.1 million | 1.39 billion | 61.4 million | (World Bank Open Data, 2022) |
| Agricultural water management | Main climate zones | Temperate, humid continental (Cfb, Dfb) | Temperate, arid, tropical (Cwa, BSh, Aw) | Tropical, Arid (As/Aw, Bsh) | (Beck et al., 2018) |
| | Renewable internal water resources | 1291 m3 per capita | 1069 m3 per capita | 1492 m3 per capita | (World Bank Open Data, 2022) |
| | Main type of agricultural water management | >75 % of production from rainfed areas | 50–75 % production from irrigated areas | >75 % production from rainfed areas | (Molden, 2007) |
| | Top 5 agricultural crops produced | Sugar beet, wheat, potatoes, barley, maize | Sugarcane, rice, wheat, potatoes, vegetables | Cassava, maize, rice, sweet potatoe, sugarcane | (FAOSTAT, 2022) |
| Type of reorientation | | From agricultural intensification to environmental conservation | From agricultural intensification to cleansing | From small-scale agriculture to agricultural expansion and intensification | (Seijger and Hellegers, 2023) |

plausibility probe is preliminary and serves to test the Compass Framework and variables, more detailed in-depth case studies are an essential part of upcoming research.

## 3. Plausibility probes of reorientations in Tanzania, Germany, India

### 3.1. Case summaries

This section presents summary compass analyses of reorientations related to agricultural intensification in Tanzania (Haug and Hella, 2013; Eeden et al., 2016; Wineman et al., 2020), cleaner surface water and groundwater in Germany (Salomon et al., 2016; Kirschke et al., 2019; Schaub, 2021), and cleaner and more continuous river flow in the Ganges river and Hindon sub-basin in India (INTACH, 2017; Chaudhary and Walker, 2019; Dutta et al., 2020; Sen, 2020).

In Tanzania, societal priorities shifted from small-scale agriculture to agricultural intensification (A). The status quo for agricultural water management was smallholder farming under fairly water-abundant conditions (B). Efforts to adjust emerged with the Kilimo Kwanza plan (in English, “Agriculture First”) and policy instruments to promote the use of agrochemicals, machinery and improved seeds (C). This led to a change in farm composition, specifically, a 10 % drop in the share of smallholder subsistence farms and an increase in small and medium-sized commercial farms (E). Arable lands expanded by 38 %, but production increased much less (8 %). Water scarcity rose due to the strong increase in land expansion, and, inequalities among farmers deepened due to increased land and water grabbing (D). Overall, the compass analysis reveals that agricultural water management was modernized to accommodate the strategy of agricultural expansion and intensification (F). However, that strategy ultimately led to increased water scarcity and inequity. The degree to which the reorientation unfolded is nonetheless significant, as major changes were observed in plans, policies, farming practices, land and water resources, to accommodate the shift in priority from small-scale agriculture to agricultural intensification. This summary not only highlights how the water balance is a zero-sum game (strong increase in agricultural water use immediately results in increased water scarcity) with contested use of land and water resources, but also that gains in agricultural productivity do not automatically follow from a strong increase in arable land expansion.

In Germany, priorities shifted from agricultural intensification to environmental conservation, due to growing societal concern about water pollution (A). The status quo was decades of intensive agriculture with excessive fertilisation (more than crops could absorb), resulting in polluted surface water and groundwater, and failure of Germany to meet EU water quality targets (B). Contestations arose among actors in favour of environmental reform (i.e. environmental organizations, water associations, green and left-wing political parties) and actors in favour of the status quo (i.e. farmer associations, central- and right -wing political parties). Farmers had measures at their disposal, for example, reducing manure and increasing buffer zones on their fields, but these were hardly implemented on a larger scale, as regulations were not rigorously enforced and economic instruments such as taxing or compensating to reduce nitrogen were barely applied (C). Hence, little change occurred and high nitrogen concentrations have remained in water bodies (both surface and groundwater) (E). Germany is, however, accountable to the EU Court of Justice, which ruled in 2018 that the country had neglected its obligation to take strong measures to combat nitrogen water pollution (D). In this case, the compass analysis unveils that despite the shift to environmental conservation as a societal priority, agricultural water management has not changed, as measures to reduce nitrogen at the farm level have hardly been scaled up and pollution of surface and groundwater bodies has continued (F). The degree to which this reorientation unfolded was therefore small. While some changes were observed in policies, there was very little change at the farm level or in land and water resources. This summary reveals a strong path dependency with decades of excessive fertilisation use, which is strongly locked-in and visible in two deeply divided actor coalitions who were unable to resolve their conflict on improving water quality, ultimately resulting in the ruling of the EU Court of Justice.

In India in the Ganges river basin priorities shifted since the 1980s from agricultural intensification to cleansing, for spiritual (Hindus regard the Ganges a sacred river) and environmental reasons as the river has become polluted and pre- and post-monsoonflow has strongly reduced (A). In the Hindon sub-basin, the status-quo for agricultural water management has been cultivation of sugarcane as primary crop with high requirements for water and agrochemicals. Encroachment of flood plains led to additional arable land. Groundwater is overexploited to irrigate sugarcane and other crops, resulting in a near disappearance of year-round river flow and strong increases in pesticide consumption (B). Different ambitious master plans were launched (National Mission for Clean Ganga, 2011; Namami Gange, 2014) to steer Ganges river flow from “ polluted and sluggish flow” to “ unpolluted and continuous flow”. Farmers and water managers have roughly two options to contribute to more clean and continuous flow, either a reduction of pollution and crop water use at field level, or usage of former farmer areas as water purification entities. Yet it remains unclear what sort of farm-level interventions are feasible and financeable (C). A brief rapid improvement in Ganges water quality occurred in 2020 during an eight-week Covid-19 lockdown as polluting industries were closed and agricultural run-off was limited due to harvesting season, quality deteriorated again once industrial and agricultural activities were resumed (D). Despite decades of Ganges management plans and Pollution Control Boards, the application of pesticides per hectare of agricultural land increased in Uttar Pradesh, and sugarcane remained the primary crop in the Hindon, and responsible for an estimated 70 % of the irrigation water demands (E). Overall, the compass analysis indicates that although cleansing of the Ganges has been a national priority for decades which is promoted in plans and policies, farm practices have intensified and further contribute to polluted and sluggish river flow (F). The degree to which this reorientation unfolded was very small as plans were in place but agricultural water management did not change to support the shift in societal priorities from agricultural intensification to clean river flow. This summary highlights typical slow response times in water quality and an exceptional rapid response time when nearly all pollution sources are closed. The zero-sum nature of the water balance is also clear as agricultural evapotranspiration strongly increased which led to declining groundwater resources and river flow. The path-dependency of agricultural intensification is strong as decades of strategic planning have not been effective to steer the Ganges and Hindon sub-basin from polluted-sluggish to clean-continuous flow.

### 3.2. Comparison of reorientation outcomes

The compass analyses for Tanzania, Germany and India reveal different outcomes for the degree to which a reorientation unfolded. In Tanzania, agricultural water management was largely reformed to accommodate the shift in broader societal priorities from small-scale agriculture to agricultural expansion and commercialisation. A system of water permits and water rights was created to monitor water abstraction, yet there was inability to monitor and enforce the water rights, resulting in land and water grabbing by large commercial farming enterprises, leaving very limited water access for smaller farmers. In Germany, agricultural water management remained largely unchanged. Farm-level environmental conservation measures were hardly scaled up, because regulations and economic instruments were barely applied. As a result, agricultural water management has (so far) not been reformed to accommodate the shift in societal priority from agricultural intensification to environmental conservation, as observed in the continued high nitrogen concentrations in groundwater and surface water. In India, agricultural water management in the Hindon sub-basin also remained largely unchanged despite decades of ambitious master plans to steer Ganges river flow from polluted and sluggish flow to (a more) clean and continuous flow. Farmers lacked attractive options to reduce agricultural water use and pesticide consumption. As a result agricultural water management has not been reformed to accommodate the shift in priorities form polluted and sluggish to clean and continuous flow.

Fig. 2 depicts these compass analyses, starting with the shift in societal priorities (A), the status quo (B), and the efforts made to reform agricultural water management to accommodate the shifted priorities (C). A reorientation manifests in plans, policies, farming practices, land and water resources (E). By looking at this constellation of aspects, an expert judgment was made on the degree to which a reorientation unfolded (F). The change was very large in Tanzania, as indicated by the shrinking share of smallholders, the increase, albeit slight, in agricultural production and increased water use. In Germany, the degree of reorientation achieved was small, as very few changes were observed in land and water resources. In India ambitious plans and strategies to clean the Ganga are present for nearly 4 decades, yet translation into policies and farm practices remain behind and thus very few changes are observed in land and water resources that align with the reorientation to clean and continuous flow.

### *3.3. Lessons of plausibility probe*

The plausibility probe revealed that the Compass analytical framework is capable to link shifts in societal priorities to reform in agricultural water management in very different contexts of Tanzania, Germany and India. In addition the probe shows that the analytical framework has the capacity to draw conclusions to what extent agricultural water management has changed to accommodate very different shifting societal priorities related to agriculture, economic growth, environmental and cleansing. The variables A to F offer a descriptive explanation on shifts in priorities, efforts to intervene, and reform in agricultural water management as manifest in changes in a constellation of plans, policies, farming practices, land and water resources. The case summaries underscored the importance of including variable D ‘other factors’ to account for unexpected dynamics, as each case summary uncovered contextual influences ranging from increased land and water grabbing in Tanzania to the EU Court of Justice in Germany and the Covid-19 lock-down in India. The Compass analytical framework thus appears parsimonious as the number of variables is limited to six, and all variables are needed to understand how shifts in societal priorities are linked to reform in agricultural water management.

The case summaries confirmed the validity of the five biophysical and social limitations for determining change in agricultural water management. The limitations offer explanations why and to what extent changes did occur in agricultural water management. The zero-sum game of the water balance was a very clear limitation in the Indian and Tanzanian cases where agricultural water use strongly increased either at the expense of smallholder farmers (Tanzania) or at the expense of reduced river flows (India). Despite gains in agricultural water use, the Tanzanian case also revealed that productivity gains could be very limited. Divergent viewpoints and contestations were ubiquitous in combination with preferences to maintain the status quo (Germany, India) or support commercial farming (Tanzania). Different system response times were observed with changes in farm land and agricultural water use being fairly rapid (Tanzania) whereas changes in water quality and groundwater depletion were much slower (Germany, India). The limitations form a reality check to critically examine the real changes made in agricultural water management as the changes are likely to be smaller than foreseen due to the zero-sum game of water resources, limited gains in agricultural productivity, contestations, path-dependency, fast and slow response times.

Although the wide applicability of the Compass framework and variables to study reorientations has been demonstrated by the probe, the case summaries remain summaries and the probe was a first test of the framework. Further in-depth case study research is needed regarding feasible research methods, indicator selection, and interlinkages among variables and limitations. Several ideas for further research are provided in the next section.

## 4. Discussion and conclusion

The hypothesis tested in this paper is whether the Compass framework is capable to link shifts in societal priorities to actual reform in agricultural water management and if the framework can assess to what extent agricultural water management has changed to accommodate shifting societal priorities. The Compass analytical framework and variables were introduced and tested through a plausibility probe case study of reorientations in

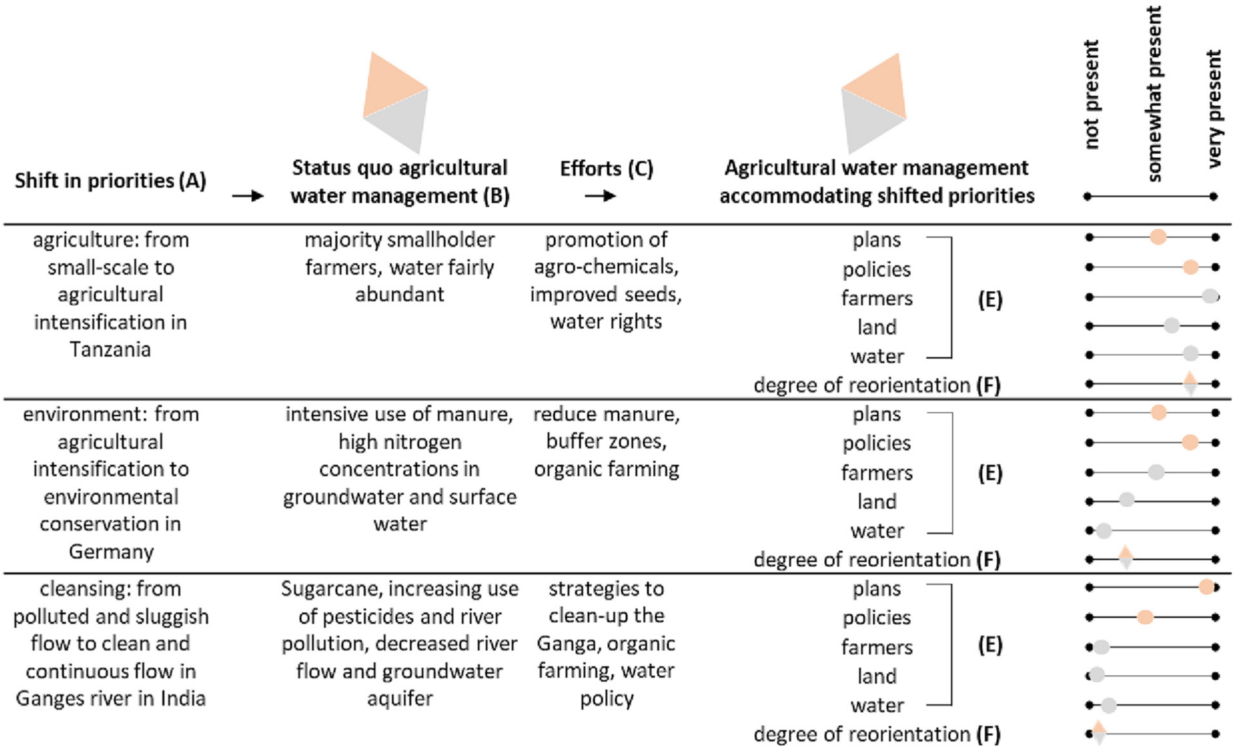

**Fig. 2.** Compass analyses of reorientations in agricultural water management to accommodate shifts in societal priorities in Tanzania, Germany and India.

Tanzania, Germany and India. The probe revealed that the analytical framework is effective and efficient in analysing ex-post a reorientation in very different contexts. The understanding provided by the Compass framework is both descriptive, describing how a reorientation proceeds, and explanatory as biophysical and social limitations are covered which together largely determine how much reform can be achieved in agricultural water management. The probe has contributed in three ways to an enhanced understanding of reform in agricultural water management.

First, the Compass Framework and variables introduce a causal chain to empirically assess how a shift in societal priorities leads to efforts to adjust the status quo of agricultural water management, and these efforts result in reform in agricultural water management and a degree of accommodation of the shifted societal priorities. Through the specification of this causal chain, this paper makes a contribution to the analysis of reform in agricultural water management as the variables and their interlinkages offer a structure for analysis, without excluding particular outcomes for the degree of reorientation achieved. Other scholars are invited to further test the causal chain for reform in agricultural water management. The framework offers new analytical research opportunities to link proposed strategies in agriculture and water (e.g. Radmehr et al., 2022; Qadir et al., 2003) to actual changes in land and water resources. In addition, interventions for agricultural water management in a context of water scarcity and climate change (Barron et al., 2015; Iglesias and Garrote, 2015) can now be linked to a broader social-historical context of shifting societal priorities and changing strategies for agricultural water management.

Second, the probe showed that the Compass framework and variables are operationalized for the unique features of agricultural water management by including social and biophysical limitations. The case summaries revealed that each of the contextual limitations limits change in farmer practices or land and water resources; the framework thus offers a realistic lense to study reform in agricultural water management. The water balance highlights that a gain in water use for one interest is a loss (or lost return flow) for another, and gains in agricultural productivity generally come with equal increases in water use. Any plan or intervention to adjust agricultural water management will be surrounded by contestation among actors partly due to the strong path dependency in agricultural water management institutions and technologies. In addition, fast and slow response times may explain why changes are (not yet) observed in land and water resources despite the implementation of interventions. Although comprehensiveness is a strong point of the analytical framework, there is also a risk of overanalysis as many aspects need to be studied to comprehend a reorientation. Hence further in-depth case studies are needed to explore which research methods can be applied within one study to cover the variables of the Compass Framework without missing important insights. Multiple methods should be applied, ranging from i) a document analysis on shifting priorities, plans and policies to ii) a stakeholder consent analysis (e.g. Seijger et al., 2019), iii) trend analysis in agriculture and farming practices (e.g. FAO, 2021), and iv) a water balance accounting for in- and outflowing water resources and return flows (e.g. Molden and Sakthivadivel, 1999; Venot et al., 2008). Having established Compass assessments, an essential next step is validation of analyses by local stakeholders (e.g. farmers, water managers, public servants, NGO workers, researchers) who know the region and reorientation well (e.g. Schaller et al., 2018).

Third, the Compass framework was probed for different types of reorientations in widely differing contexts in northern and southern regions of the world. Despite differences in climate, water availability, social-economics and cultural contexts, the case summaries demonstrated that the analytical framework can be applied successfully to analyse the process and outcomes of reorientation processes around the world. The probe showed that the dependency on agricultural water management to facilitate shifting societal priorities is indeed very present, and that tremendous effort is needed to achieve reform in agricultural water management in line with novel priorities. In the cases of Germany and India, changes were not as high as hoped for whereas in Tanzania change occurred but also involved unintended increases in land and water grabbing. Further research may seek to understand the inherent tensions of steered interventions in agricultural water management and uncertain or unintended outcomes in a constellation of plans, policies, farmers, land and water resources. Focusing on uncertain and unintended outcomes (e.g. for food systems see Leeuwis et al., 2021) makes a relevant supplement to uncertainty research in environmental planning which has mostly focused on uncertain knowledges, uncertain futures and social complexity (e.g. Voss et al., 2007; Zandvoort et al., 2018).

Based on these three enhanced understandings it can be concluded that the Compass analytical framework provides insight into the actual reform processes in agricultural water management in the light of changing societal priorities. The framework holds a realistic approach towards change in agricultural water management as biophysical and social limitations have a prominent role, and reform is comprehensively assessed across plans, policies, farmers, land and water resources. However, the probe wass a first test of the framework and there are also some limitations that require further research as outlined above. With the reorientation concept and analytical framework established, a series of case studies is a logical next step to obtain a better analytical understanding about indicator selection, research methods and stakeholder validation of reorientation analyses. Furthermore, in-depth case studies will increase empirical insight how reorientations may proceed as they document for a specific reorientation case the complex social and biophysical interrelationships.

## CRediT authorship contribution statement

Chris Seijger: Conceptualization, Methodology, Validation, Analysis, Writing, Visualization.

## Data availability

Data will be made available on request.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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