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Creating Kaveri Delta beneath our feet: An experiment in grounding socio-hydrology in Tamil Nadu, India

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ABSTRACT

This paper presents an experiment in grounding socio-hydrology in the Kaveri Delta, Tamil Nadu. It follows a care-ful research attitude that shows a willingness to be blindsided and confronted with surprises, cultivates concerns by immersion in the case, and actively contributes to desired realities and futures. The paper centres and reflects on ways of participatory data collection, from monitoring borewells to gathering groundwater ethnographies. An earlier developed hydrogeological model is introduced and then mirrored to collected well data and grounded in the practices, knowledges and logics of engineers, activists and farmers working and living in the delta. We show engineers maintaining a network of weirs and irrigation canals, water worship and grassroots rejuvenation of tanks, and farmers' borewell adaptations and insights to oscillating water levels. Bringing logics into dialogue offers openings to reconsider aquifer conceptualisations, embrace recharge opportunities and appreciate local ways of dealing with groundwater. The message from of this experiment is that it is difficult, if not impossible, to integrate all logics and knowledges in one overarching model or framework but that there are merits when staying with, and respecting, the differences among logics as it offers a potential for mutual learning, reflection and discussion.

1. Introduction

In March 2024, people in the Kaveri[1] Delta were sharing pictures and comments on social media about cracked soils and wilted plants, attributing these to tanks[2] being empty and groundwater being depleted. They also mentioned the absence of monsoon rains earlier in the year, and pointed accusing fingers at upstream neighbour Karnataka State for not releasing enough water to the delta. In Ayyampettai, one of the villages that we studied, farmers expressed similar concerns: "Borewells do not supply enough water. Agricultural fields in the delta are drying". It affected their *kodai* or summer crop.

Not three months later, head PWD[3] engineers decided that the sluices of the Mettur Dam, which releases river water to the delta, would not be opened on its customary date, 12th June, because storage levels were too low. With the arrival of Kaveri water postponed, the agricultural calendar of delta farmers, who receive this surface water through an

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[1] While the spellings 'Kaveri' and 'Cauvery' are typically used interchangeably, we adhere to the former, non-anglicised spelling in this paper, unless directly quoting sources which spell the river name in the latter way.

[2] Tanks are created water bodies found throughout Tamil Nadu (and southern India). Water (by rain or river) is stored and (later) used for irrigation, fishing and/or domestic uses (See for example Mosse, 2003; Aubriot and Prabhakar, 2011).

[3] The PWD or Public Works Department in Tamil Nadu split in 2021, into a Buildings branch and a separate Water Resources Department. Colloquially 'PWD' remains the used term for now – which we do too.

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intricate network of canals and weirs, gets further disrupted. The news was all over the media. While PWD engineers advised farmers to forego double-cropping paddy and focus on sowing the long-duration *samba* variety, farmers went out to protest – demanding immediate release of water and compensation measures. In the village of Ayyampettai, farmer struggles worsened, as Kaveri water is the only source to fill up their tank.

The dry conditions of 2024 are reminiscent of those of 2017, one of the most severe droughts ever recorded in the region that was ascribed to multiple monsoon failures. The 2017 drought drove farmers to despair, with some even committing suicide (Sabarisakthi, 2019). In Ayyampettai and surrounding areas, the farmers who could, constructed, new borewells; well beyond 250 feet – or 80 m, which was the common depth in 2017. Water is everything in the agrarian plains of the Kaveri Delta.

While the delta earned its reputation as the 'rice bowl of Southern India' thanks to the availability of surface water for irrigation, it is now common knowledge that the delta is suffering a water crisis (Srinivasan, 2019; Natarajan, 2021). Tanks are encroached by people or *Prosopis*, dam releases decrease and aquifers are overexploited (cf. Neelakantan et al., 2017; Janakarajan, 2019). The Kaveri Delta is 'drying'. Indeed, engineers and farmers, but also activists and hydrologists, seem to agree on this (see also Schneider, 2017; Balaganesh et al., 2020). However, their experiences with, reasonings about what to do and understandings of this crisis and the Kaveri flows in general, are diverse. Their concerns are multiple, using different logics, practices, expressions, measurements and maps to diagnose and make sense of what is happening and how to respond. Also, within our project team, different members use different terms and explanations for the behaviours of water.

In this paper, we document and compare these differences, which we encountered while jointly working on projects aimed at improving our understandings of the changing (ground)water dynamics in the Kaveri Delta. We are a fluid, transdisciplinary action-research collective with backgrounds spanning from (socio)hydrology to cultural geography and science and technology studies (STS), from people living in the Kaveri Delta to people far beyond the Indian subcontinent. In our approach we strive to conduct research with local actors in the delta, improving and furthering their projects and interests (a practical engagement), through joint-learning; and by slowing it down to forge solidarities and bonds that go beyond the immediate research question or objective (an emotional engagement) (see Stengers, 2018; Mol and Hardon, 2020; Verzijl, 2020; Zwarteveen et al., 2021).

In our collaborative endeavours, which started in May 2019, we initially focused on volumetrically assessing changing water availabilities in the delta, in view of better anticipating futures. While we started with an emphasis on the collection of hydrological and geo-hydrological data, our approach widened when social scientists and anthropologists joined the team. They used different ways of gauging socio-hydrological dynamics, paying more attention to how people experience and make sense of these. The poor quality of groundwater data from government sources was another trigger that changed our methods of data collection (see Prayag et al., 2023; Verzijl et al., 2023). We decided to experiment with participatory data collection, setting up a program that would help us monitor how wells have changed over time. This we did simultaneously with developing a hydrogeological model and with the collection of ethnographic stories, which yielded insights that sometimes contradicted earlier findings, while also drawing attention to the prominence of other than scientific ways to detect groundwater (dowsing or divining, see Verzijl et al., 2023). In addition, it helped spark the interest of team members in ongoing activist and grassroot initiatives aimed at water harvesting and recharging groundwater (see Citizen Science Engagement in Cauvery Delta, 2022).

Focusing on our experiences with the participatory data collection program, this paper documents our collective attempts to understand and navigate the different 'hydro-logics' we encountered in the project; and to carefully combine these different logics without reducing or subsuming one to the other. Perhaps the single most important lesson of our experiment is that it is difficult, if not impossible, to integrate all logics and knowledges in one overarching model or framework that accounts for all actors and actions. Instead, our experiment shows the merits of staying with, and respecting, the differences among different ways of knowing, and nurturing the potential to use them for mutual learning, reflection and discussion; it shows the potential of a kind of care-ful research, one could say (see Law and Lin, 2020; Law, 2021).

1.1. Grounding socio-hydrology through care-ful research

In their quest for data and predictions that can support techno-managerial solutions to water problems – such as drought or floods – most socio-hydrologists are rather explicit about how what they do is motivated by concerns about real-world problems. Indeed, many socio-hydrologists do what they do because they care. Herein we understand care as "the emotional engagement of being concerned and the practical engagement of contributing to restoring, sustaining, or improving something" (Mol and Hardon 2020, p. 185). Paradoxically, however, while caring means engaging and getting connected, socio-hydrologists tend adopt an epistemological stance that insists on detachment as a condition for scientific objectivity (see Wesselink et al., 2017). The scientific objectivity that many hold on to in socio-hydrology believes that knowledge can be obtained without recourse to particular perspectives, value judgements community bias or personal interests. This knowledge, in other words, is generated by "interchangeable knowers whose specificities of embodiment and subjective location disappear in the process" of knowledge-making (Zwarteveen, 2023, p. 65). Indeed, the importance of detachment for scientific legitimacy explains why most (socio-)hydrologists only refer to their care when justifying what they do. More so, it helps explain their relative silence about how their alliances, networks and collaborations may have shaped their scientific choices, believing that these have no bearing on knowledge creation (ter Horst el al., 2023). The discipline's preference for computer-based hydrological modelling over ethnographic stories (Srinivasan, 2017) further facilitates such a dispassionate and detached research attitude.

We maintain that grounding socio-hydrology requires letting go of the ideal of objectivity-as-detachment, to instead explicitly acknowledge how doing research always implies connecting and situating. Put in another way, grounding importantly means coming to terms with the 'caring' that socio-hydrological research almost always entails. This is about more than learning to be upfront about the concerns that motivated the research. It is also about the research(er(s))'s social and political identifications and aspirations (see also Zwarteveen et al., 2024). After all, this situatedness – one's position and connections – "structures what we notice in the world, […] what we think are the burning issues, and how we think the world should be" (Law and Lin, 2020, p. 3). A more situated and caring research attitude, secondly, also means letting go of the belief in holism that continues to pervade much socio-hydrological research. This is the belief that it is possible to integrate all social and natural variables, and their inter-relationships, in a single model, system or theory (Srinivasan, 2017; see also Wesselink et al., 2017). Caring instead means being open about how one's choices – choices about what and who to connect to, care for/about, or about what good care means (Mol and Hardin, 2020) – inevitably imply that research results are partial (Verzijl 2020).

In socio-hydrology, this may translate as learning to acknowledge and reflect on how specific models favour or afford some solutions – on how to restore, sustain or improve something – and not others (see also Krueger and Alba, 2022). Acknowledging partiality also comes with a realisation that other possible (interpretations of) hydrological realities or other diagnoses of seemingly similar water problems are plausible – and that researchers should take seriously "what realities" they will intervene in, support or co-create (Verzijl, 2020, p. 209). It means owning up to the world-making powers of models, by becoming accountable to the effects they have on shaping solution pathways (ter Horst et al., 2023).

For us, then, grounding socio-hydrology importantly implies cultivating such a caring and situated research attitude. The ideas about 'care-ful research' developed by John Law and Wen-Yuan Lin (Law and Lin 2020) provide inspiration and guidance about how to do this. According to them, care-ful and situated research is research that encourages openness to being confronted with surprises and thrown off-track, and a willingness to enter into unfamiliar worlds (and logics). Rather than a neat process with a templatised, linear approach, care-ful research is a messy, iterative, and slow-going process of 'staying with the trouble' (Haraway, 2016). A researcher's engagement – or indeed care and groundedness – is shown through: 1) a willingness to be blindsided and uncomfortable; 2) cultivating concerns and sensibilities by immersion in the case study; 3) helping shape the worlds and realities one identifies with – or cares about (see also Law and Lin, 2020). In the next sections, we show how we have tried to follow these guidelines while studying the Kaveri Delta.

2. Methodology

As part of the special issue on grounded socio-hydrology (see also Barreteau et al., 2022), this methodology section might feel a bit counterintuitive to a hydrology readership. Yet if the question is how to ground a hydrological model, we might consider the model as given, while analysing the grounding processes. In our paper, thus, participatory data collection is not presented as a method but as result to be discussed, while a hydrogeological model is not the outcome, but context (we purposefully fore-ground). Before we present the model-as-study-area, however, it is useful to point out why we decided to set up a participatory data collection platform.

We embarked upon participatory data collection – early in 2020 – when the corona pandemic made international and interstate travel impossible. The topic was groundwater. Participatory data collection, using an online platform, would allow us to continue our collective research efforts and engage with local actors at the same time. Or so we hoped. Corona played a decisive role, but the reasons to start this went beyond the pandemic and were identified before it. We present these reasons in Table 1 and will refer back to it through the remainder of the paper.

Table 1
Reasons to set up a participatory data collection program.

	Reasons
1	There was limited (poor quality) well data available (see also Prayag et al., 2023)
2	There were apparent inconsistencies among government data sets, indicating both overexploitation and stable water levels.
3	There were farmer claims about drought and drilling deeper borewells that could not be explained by available data and early versions of our model.
4	There was a need to collect potential stories about farmer experiences with and perceptions of groundwater (see also Verzijl et al. 2023).
5	While certainly born out of necessity by the pandemic, there was also the aim to foster joint learning through public involvement with groundwater monitoring and awareness (see also Citizen Science Engagement in Cauvery Delta, 2022).

2.1. Study area

The Kaveri Delta is a vast fluvial plains at the end of the Kaveri River in Tamil Nadu, India (Groundwater year book, Government of Tamil Nadu, 2019). The river gathers water from a catchment of 40,660 square kilometres before it arrives at the Grand Anicut Barrage, which is considered the start of the delta. Here, it dissects into four channels with corresponding command areas: the Kollidam (53,000 ha), the Kaveri (200,000 ha), the Vennar (190,000 ha) and the Grand Anicut Canal (121,000 ha). The four tributaries, in turn, split over and over again, forming a labyrinth of irrigation canals that is over 2000 years old (Inauguration of the Mettur Dam and Reservoir, 1934; Chinnasamy and Agoramoorthy, 2015). The Kollidam River and the Grand Anicut Canal form the Northern and Western borders of the delta respectively. To the South and East, Kaveri waters flow into the Bay of Bengal, with the coastal strip suffering from sea water intrusion.

Water allocation at the Kaveri basin level is subject of a longstanding conflict between Tamil Nadu and upstream the state of Karnataka; it is generally accepted – though reasons differ – that the delta share of river water is decreasing (Prayag et al, 2023). For the last three decades, thus, borewells and groundwater were becoming the main source of irrigation. Recently, more and more reports are surfacing about dropping groundwater levels, drying borewells and farmer struggles (Hardikar, 2017; Janakarajan, 2019; Janakarajan, 2023; John, 2017; Sridhar, 2023), which resonates with the stories from Ayyampettai village mentioned in the introduction.

2.1.1. The model

Based on these problems and challenges, we developed elsewhere a conceptual model of the Kaveri Delta that we will present again here (see Fig. 1).[4] On its left is a digital elevation map of the delta with the political administrative boundaries (or districts),[5] and the main canal infrastructure of the Kaveri, Vennar and Grand Anicut Canal command areas.[6]

From a hydrogeological perspective, the delta is composed of layers made of deposits of sand, silt and clay (and in some parts calcareous concretions) (Geological Survey of India, 2017, 2023a, 2023b). Layers with a high sand percentage are able to store and transmit water well, functioning as aquifers, while clay layers form the aquitards that separate aquifers[7] from each other (Kitterød, 2022). For our model we used the aquifer characteristics from an Asian Development Bank (ADB) report which discussed four types of aquifer properties corresponding to different depths (ADB, 2011, p. 122). This was translated to the following schematic cross section of the aquifer under the delta (Fig. 2). The colours resonate with Fig. 1, on the right of the cross-section is the Bay of Bengal, on the left the Grand Anicut Barrage. Layer 1 represents the open aquifer up to a depth of 45 m (or 130 feet), layers 2–4 are deeper confined aquifers (see Prayag et al., 2023).

For this model, 75 borewells and 94 dug wells across the delta were analysed (ibid.). An overview of groundwater in and out flow indicates that rainfall recharge and canal leakage on the one hand and well abstractions on the other differ but are in the same order of magnitude. In the transient model, water levels in borewells show a decreasing trend in the

[4] See Prayag et al (2023). The model was developed in 2021.

[5] Administratively, the largest part of the delta is located in four districts, Thanjavur, Thiruvarur, Nagapattinam and Mayilaruduthurai. Mayilarduthurai separated from Nagapattinam in December 2020, but they are considered here as a single district. Additionally, the Karaikal district (of the Union Territory of Puducherry) and small pieces of Trichy and Pudukkottai districts make up the delta.

[6] In the figures the Kollidam (or Coleroon) command area is not shown.

[7] The aquifers have a specific yield of 13–870 litre/minute/metre of drawdown and a transmissivity of 11–1200 m^2/day, and average groundwater flow velocity of 0.057 metre/day (Dunlop et al., 2019; Prayag et al., 2023).

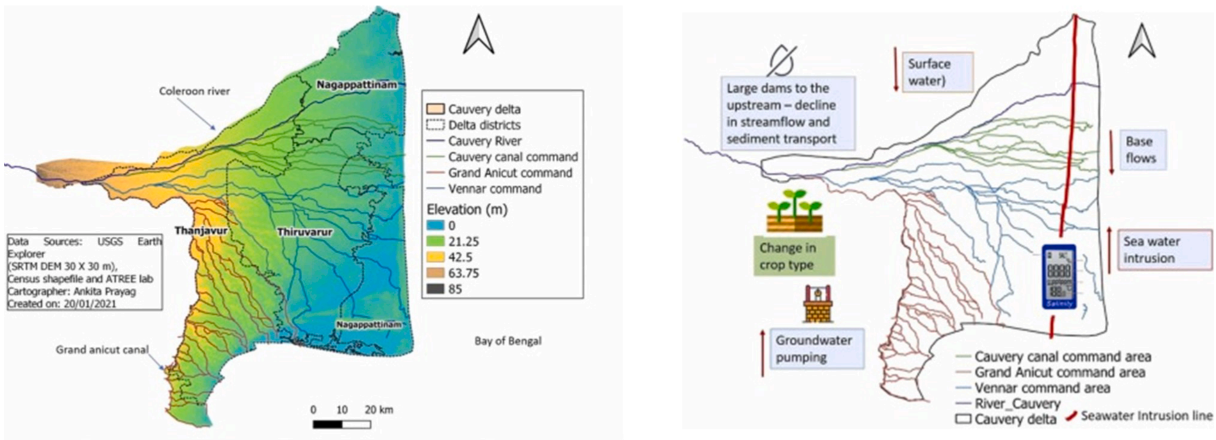

Fig. 1. The digital elevation map (left) and conceptual model (right) of the Kaveri delta (taken from Prayag et al 2023, p. 2.).

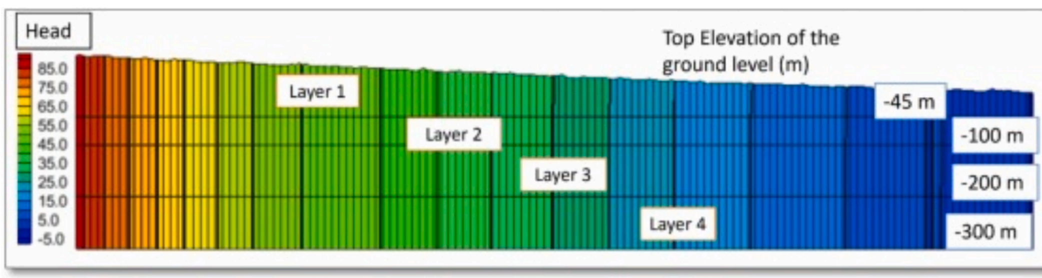

Fig. 2. Cross section of aquifers (taken from Prayag et al 2023, p. 4).

confined layers, while for the first layer it could not be computed (ibid.).

Seawater intrusion is three times greater today when compared to 1990 (when groundwater irrigation became dominant) leading to inland salinity and brackish groundwater (becoming more saline with depth). This affects, in particular, the coastal zone and South-East region of the delta. It contrasts with other parts of the delta where borewell depth is increasing over time. For these latter regions, model results show that the deeper or confined aquifers are "exploited every year, especially during years when groundwater levels were dropping significantly. We also conclude[d] that the increased pumping coincides with the dry months of pre-monsoon summer and also during the drought years" (ibid, p. 14). During the 2019 calibration year[8], well abstraction was calculated to be 1651 MMC while the total inflow was 1395 MMC, with rainfall recharge and canal leakage being 996 and 217 MMC respectively.

2.1.2. Uncertainties and ambiguities

Data availability and trustworthiness is an issue in Tamil Nadu and India. Basically, government data sets – form the Central Groundwater Board (CGWB) and Public Works Department (PWD-WRD) are of relatively poor quality *and* the only sources around. Due to this, our "model contains uncertainties in the conceptualization of the aquifer system, layer properties, and recharge and abstractions" (Prayag et al., 2023, p. 14). One of the main issues is a granularity problem, which we have acknowledged elsewhere (Verzijl et al., 2023). Besides this, we discovered contradictory conclusions among CGWB and PWD-WRD groundwater assessments.

The Indian government periodically conducts a 'Dynamic Ground Water Resources Assessment' for Tamil Nadu and India, based on guidelines provided by the Groundwater Estimation Committee or GEC-2015 (CGWB, 2017b). The GEC computes recharge and extraction and classifies zones as 'Safe', 'Semi-critical', 'Critical' and 'Over Exploited' when their abstraction rates (in comparison with 'extractable groundwater resources') are less than 70 %, 70–90 %, 90–100 %, and over 100 % respectively. We analysed data on the stage of exploitation, recharge and abstraction coming from these 2004, 2009, 2011, 2013, 2017, 2020 and 2022 GEC reports and visualized them in Fig. 3.

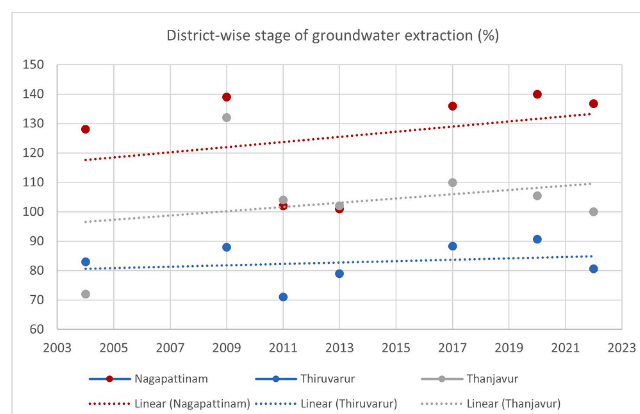

Fig. 3. District-wise stage of groundwater extraction (%) for the years 2004, 2009, 2011, 2013, 2017, 2020 and 2022. Data source: CGWB (2006, 2011, 2014, 2017a, 2019, 2021, 2022). Figure source: Authors.

It shows that Nagapattinam (~the coastal zone and South-East region) is overexploited every year; Thanjavur (~the upper delta and Grand Anicut Canal command area) is overexploited since 2009; Thiruvarur (~the central delta) is at a semi-critical stage.

Observed well data, however, shows groundwater stability. Both the

8 We note that 2019 is the year following cyclone Gaja when, because of damage, large parts of the delta were left uncultivated.

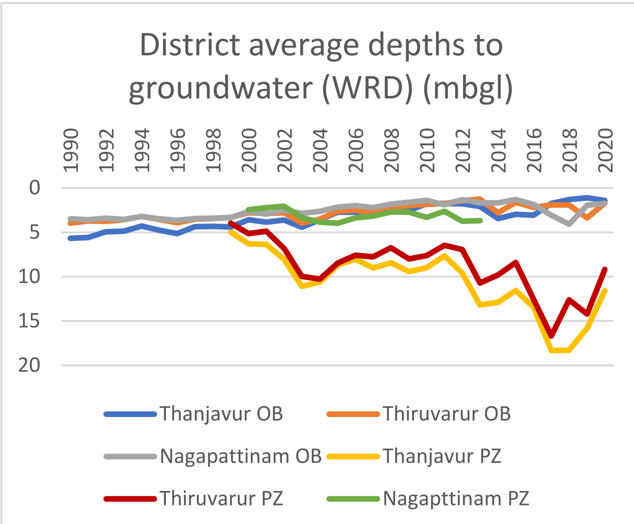

Fig. 4. Government monitoring well data. Water Resources Department (PWD-WRD) district average depths to groundwater. OB indicates observation well data (open well data) and PZ indicates piezometric data. Image source: Authors.

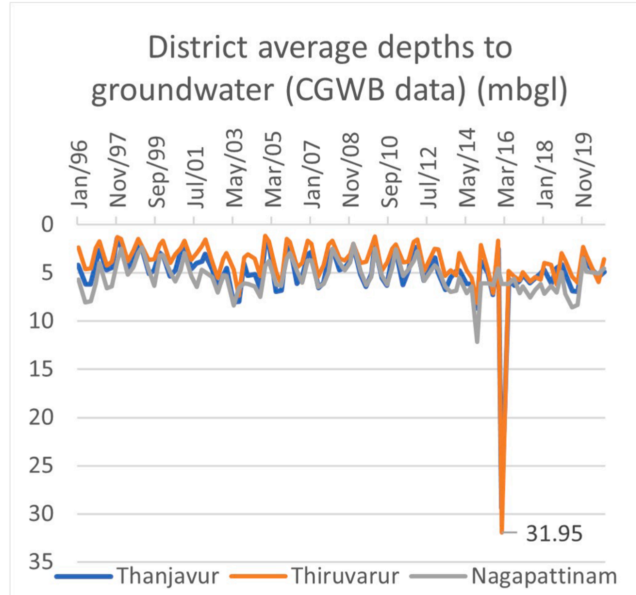

Fig. 5. Government monitoring well data. Central Groundwater Board (CGWB) district average depths to groundwater. Image source: Authors.

national CGWB and Tamil Nadu PWD-WRD report shallow and steady water levels across the board (see Fig. 4 and Fig. 5 respectively). The CGWB data indicates an average depth of 4.7 metres below ground level (mbgl); noting an outlier in 2016 of 31.95mbgl. The PWD-WRD's observation well data (OB) in Fig. 5 too records shallow groundwater levels for all districts, even showing a slightly rising trend. Its piezometric data (PZ) shows a declining trend (yet recovering after 2017) for Thiruvarur and Thanjavur, but surprisingly indicates shallow and stable levels for Nagapattinam, the district for which the GEC computes serious and rising overexploitation.

So far three ways, or three different methods (our numerical model, government computation, and observed well data), of hydrologically making sense of groundwater reveal a lot of ambiguity.[9] It is why we decided to set up a participatory data collection program to gather new data and, importantly, new understandings of groundwater flows (see also Table 1).

2.1.3. *A provisional water balance*

We pointed to rainfall recharge and canal leakage as model inflows, and consider it prudent to briefly mention these other sources that feed not only groundwater but also tanks. Firstly, rain: the delta receives an average rainfall of about 1250 mm (see Fig. 6), with some rain falling during the South-West monsoon (June-September), and most rainfall occurring during the North-East monsoon (October-January), while the summer (February-May) is hot and dry with sporadic rain.

These three seasons, running from June to May, correspond, to farmers' paddy cultivation cycles and calendar (see Table 2).

Generally, one can say that water for the canal irrigation schemes in the delta is stored behind the Mettur Dam, located some 200 kilometres upstream of the Grand Anicut Barrage, near the Karnataka State border. The volume of water to be stored is the topic of a longstanding conflict between Tamil Nadu and Karnataka, where the headwaters of the Kaveri reside. The latter state is by law obliged to release 5000 MCM annually (see Kitterød, 2022) but the actual water amount varies highly – showing a downward trend, but also large variations over time (see Fig. 7).[10]

With the data presented above we can make a provisional water balance, not meant to be correct or precise but to get a ball-park idea of the volumes and provide some insight into what farmers can grow and what their room for manoeuvre is.

- The command areas of Kollidam (Coleroon), Kaveri, Vennar and Grand Anicut Canal make up a delta surface area of 5640 km^2.
- The average rainfall of 1250 mm combined with the surface area of the delta means a total amount of rain water of 7050 MCM.
- From this rainfall we assume one fifth (20 %), or 1410 MCM, drains into the sea (mainly during the North-East monsoon).
- Our model indicates that 996 MCM of rain infiltrates as recharge, leaving an effective rainfall of (7050 – 1410 – 996 =) 4644 MCM.
- For surface water discharge, we use the mandated release of 5000 MCM of water to Tamil Nadu by Karnataka. Furthermore, we assume that 70 % of the discharged surface water is allocated to the delta districts. This corresponds to 3500 MCM.
- We use the 2019 well abstractions from our model. This corresponds to 1650 MCM.
- Following this, the total amount of water for crop production in the delta is 4644 + 3500 + 1650 = 9794 MCM.
- Divided by the combined command areas of the delta gives an amount of 1.74 MCM/km^2 or 1700 mm of available water.
- The rule of thumb for rice cultivation is 10 mm/day, meaning the *kuruvai* crop consumes 1100 mm of water.
- Based on this provisional water balance, about half of the farmers will not have the possibility of a second or third crop, if they were to rely on annual inflows water alone.

This water balance is for an imagined year. On purpose. We realize it is possible to extract per year rainfall and Mettur discharge from Figs. 6

[9] It is beyond the scope of this paper to study how these different datasets might be enrolled for particular aims, but the GEC reports tend to be mobilised in academic papers and newspapers that speak of a drying delta and alarming abstractions. The observed well data of the delta – and government reports stating that "surface water canals are the major sources of irrigation … [being 89 %], while the remaining 11% is accounted for by …wells" (Department of Geology and Mines Thiruvarur District, 2019, p. 32) – could actually support policies to improve surface water infrastructure instead of, for example, focusing on transformation to sustainable groundwater governance.

[10] It is important to note that over the last five years (not in the figure) the delta saw high volumes of water, with the June 2022 – May 2023 season registering outflows above 18,000 MMC.

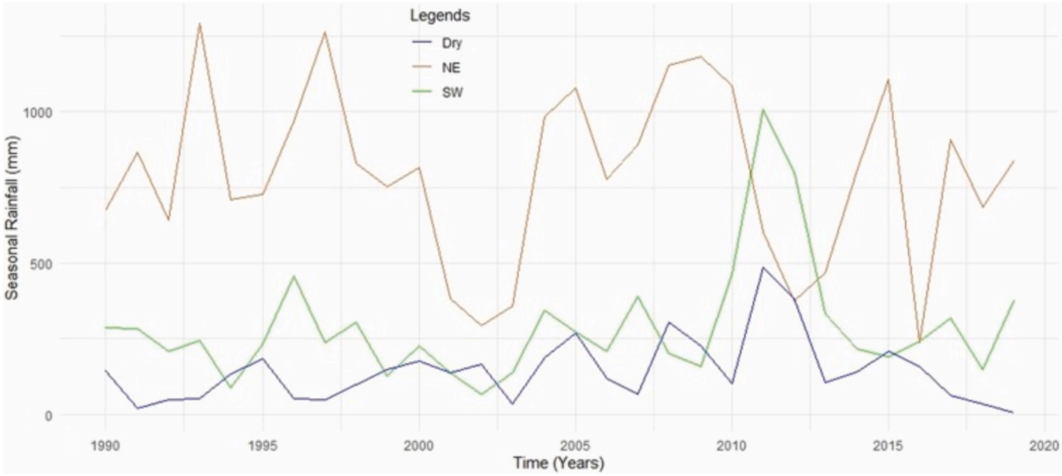

Fig. 6. Seasonal rainfall over the past three decades (taken from Prayag et al 2023, p. 3).

Table 2
Farmer crop calendar.

Season name	Description
Kuruvai	*Kuru* means short in Tamil. It is a short-term variety with a duration of 110 days grown normally in June-September
Thaladi	*Thal* means straw and *adi* means under. It is a variety sown immediately after Kuruvai harvest, so quickly that rice straws of the latter are left the field. It has a duration of 135 days and is grown, normally, from October-January
Samba	Samba is a long-duration crop of 145 days. It also corresponds to the North-East monsoon and is usually grown by farmers who only grow a single paddy crop a year.
Kodai	*Kodai* means summer, the period where often grams (or pulses) are sown, but a third paddy crop is also possible. Kodai paddy has a duration of less than 105 days[b]

[b] See also https://agritech.tnau.ac.in/agriculture/agri_seasonandvarieties_rice.html (accessed on 15-07-2024).

and 7. We are also aware of other numbers for the delta surface area or other cropping patterns. That is not the point we would like to make. What the water balance and these figures show is that, for a large group of farmers, the issue of a second or third crop is precarious as well as a matter of adaptation and going with the flow.

2.2. A grounding approach

We set up a participatory data collection program after we started working on a hydro-geological model of the Kaveri Delta that would assess groundwater resources and surface water interactions (see Prayag et al., 2023). The decision was also propelled by the social scientists with an affinity for ethnography, who joined the team. They started to document how actors – engineers, farmers, activists, modelers – make sense of Kaveri water flows (see Verzijl et al., 2023). That being said, these three activities – developing a participatory program to monitor wells jointly with farmers, making a hydrogeological model and collecting ethnographic stories – occurred largely simultaneously. They coincided with, inspired, overlapped, complicated and enriched each other.

The entanglement of the three activities mainly happened during weekly online meetings, which became something regular during the Corona period and which we keep up till today as important moments of knowledge exchange and sharing. Given the transdisciplinary

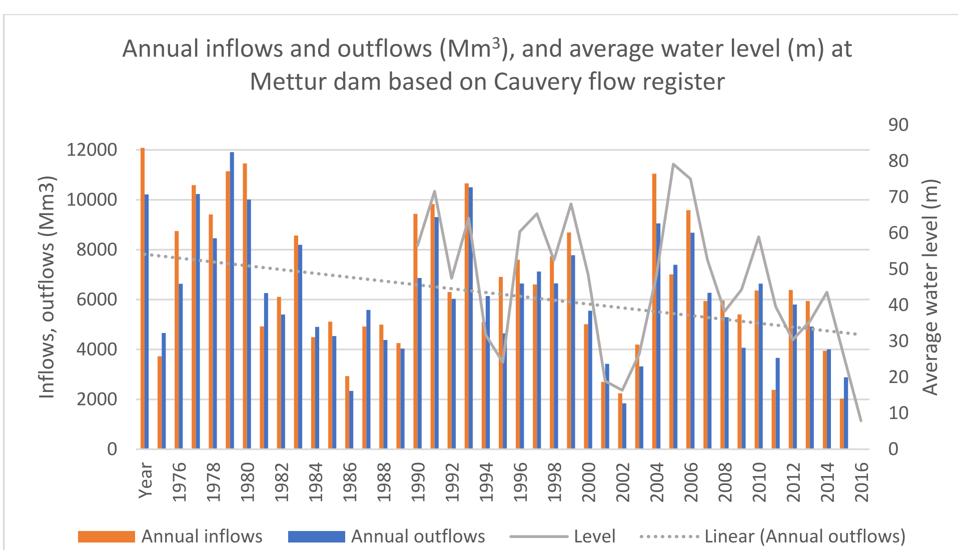

Fig. 7. Mettur discharge analysis. Figure source: Authors.

constellation of the action research team, it was crucial to dedicate enough time in learning to understand and appreciate the logics, methods, definitions and languages of the other team members. This required slowing down, and being open to, and actively engaging with, one another.

As we discussed how to comprehend Kaveri water flows, we helped one another to advance these three activities – creating interview guides, websites and instruction videos, writing field reports and data request letters, finding clues and informants, interpreting calibration data and empirical material, and so on. To us, this too is part of participatory data collection. During meetings, our conversations ranged from aquifer dynamics to celebrating a water goddess, and from inter-state distributive politics to fluid common property institutions. Thus, learning to have conversations across and beyond disciplines, turned out to be one important pillar of a method to ground socio-hydrology.

A second important pillar of our grounding method consists of active efforts to understand how those directly experiencing (ground)water dynamics make sense of it: for example, the farmers who see their wells running dry, the engineers responsible for managing canals, or the activists involved in improving groundwater re-charge through the restoration of rundown tanks. Interviews about how they know Kaveri water and what they do with it, often took the form of a conversation with questions back and forth, blurring demarcations of interview(er)(ee). It is a collaborative endeavour that we also consider as participatory data collection. There are engineers, activists and farmers to whom we frequently return. They have effectively become co-researchers.

For this paper we coded transcripts and field notes from 11 engineer, 48 farmer and 11 activist interviews in a dozen villages and cities, for their understanding of water and drought in the delta, and their day-to-day practices and motivations. Farmers were mostly men from the villages' higher castes (though often these were Backward Castes) because of a focus on land- and borewell-owners. Engineers typically worked for local PWD branches linked to the Vennar and Grand Anicut Canal command areas, while the activists we mention are associated with or can be traced to the 'Kadaimadai Integrated Farmers Association' (KAIFA), a group from the Peravurani Taluk. The results described in the next section are based on these interviews but also on countless of other small talk moments and exchanges, as well as insights that can only come after longstanding and care-ful engagement with actors in the field.

Following care-ful research ideas, our approach was iterative, with next steps in the research process being decided upon based on the processed and agreed upon insights from earlier steps. Continuously keeping one another informed about findings and interpretations proved crucial here. Validating data and reflecting back on what farmers were telling us, we constantly moved back and forth between the hydrological data at hand and the stories from the field. This then informed further data collection and analysis. Grounding therefore meant agreeing to progress slowly and iteratively, without fully knowing where the process would end or what the outcomes would be. How we got surprised along the way, and what the participatory data collection program taught us is discussed next.

3. Results

The results described in this section were gathered over a period of four years and at different places in the delta. Throughout, as said, our research efforts (modelling, participatory data collection, ethnographic work) were intimately entwined. More so, when we spoke with farmers they commented on engineers and vice versa. In our analysis here, we purposefully disentangle these narratives and present what we believe are the decisive practices, methods and experiments of actors by which they not only make sense of the delta, but also through which they 'do' (or bring forth a logic of) the delta. How these logics then combine, we discuss and reflect on in section four.

3.1. What the program did

It turned out nothing like we expected, this participatory data collection program; and what we expected was probably a naïve over-estimation of what was feasible.[11] We called it a citizen science campaign, in 2020, and created an online dashboard and social media accounts on X and Facebook, while we recorded a short movie clip explaining our objective. Simultaneously, we developed a questionnaire in English and Tamil on the Open Data Kit or ODK app. It covered issues such as cropping patterns, groundwater levels and water quality, but also groundwater experiences and interpretations and traditional institutions. We uploaded an instruction video in both languages on how to use the ODK app. Next, we compiled a list with civil society organizations and targeted them with our initiative, and piloted the questionnaire with contacts from the field.

Among them were some activists from KAIFA that were promoting tank rejuvenation to recharge groundwater. They provided contacts of farmers where we could install borewell sensors to monitor groundwater. At ten places in the delta, we planned to monitor real time data about water levels, together with the help of an IoT start-up. When installing the sensors, we, by coincidence, found out how most small farmers decide where to drill their borewell. They called upon the service of diviners. To us, this was unfamiliar and we decided to follow up on it (see Verzijl et al 2023). An important insight from tracing divining practices is that many farmers want to know the most auspicious time to drill a well – which a diviner might indicate together with the place where water is detected. Aside of this unexpected groundwater story, our efforts yielded only a few contributions on the dashboard. Corona might have slowed things down, but we also heard back that the targeted participants did not know how to take measurements and use the app.

In 2021, we decided to change tactic. This happened because an acquaintance of one of the team members, who was professor at a local college in the delta, proposed that his students help in collecting and monitoring data as part of their practical course work. We started to give training to students on how to collect the data and upload the results on the platform. We awarded certificates afterwards and occasionally covered their travel expenses. This proved more successful and the dashboard quickly revealed several hundred data points (see Fig. 8).

The 2021 course of action also had a surprising outcome. Two of the students that we had trained reached out on Facebook asking if they could be interns with the project. Both were farmers' sons who studied civil engineering. One of them was from Ayyampettai, the other spearheaded the rehabilitation of a tank in his village, Munavalkottai, five kilometres away. After a period of internship, they were hired as team members. Through them, the participatory collection of well data got an impulse. They became trainers of new batches of students at their engineering college and the collected data was used as input for the student's research reports.

So far, we have gathered data of more than 800 wells. The parameters measured include GPS coordinates, date of construction, depths of borewells, casing and submersible pump, depth to groundwater on the day of measurement, electrical conductivity and temperature. Questions that were in the original ODK app questionnaire about water institutions and groundwater sense-making were no longer asked. Yet many stories emerged as the two new team members joined our weekly meetings.

As of August 2023, the participatory nature of our research developed further as the first author resided in the delta to conduct her

[11] As our initiative went on, we learned more about participatory methods and citizen science (see for example Roque et al., 2022), and became more aware of the ethical and methodological challenges that participatory initiatives entail (Fouqueray et al., 2023), such as tokenism (Prokopy, 2004); power imbalances between (co–)researchers (Cornwall and Jewkes, 1995); and the accuracy and adequacy of participatory data (ibid.).

Fig. 8. Program dashboard (on the right measured points).

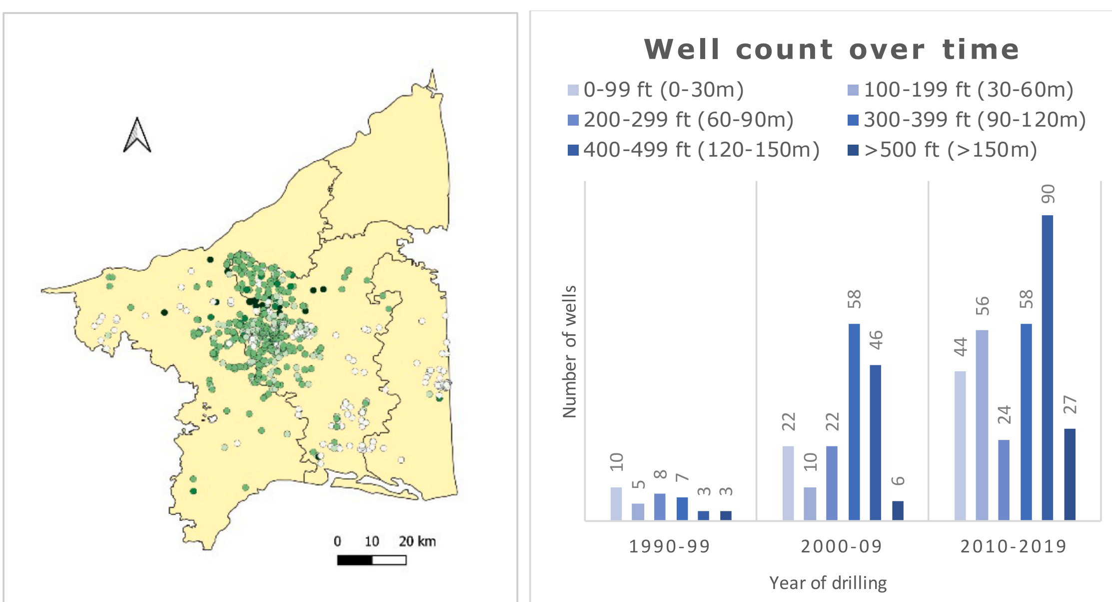

Fig. 9. Participatory well data. Figure source: Authors.

fieldwork, focussing, among other things, on groundwater salinity. The farmers she encountered took a lot of interest in her work, taking her to agricultural wells around the village or bringing groundwater samples that they wanted her to test. In total she recorded 373 wells, but the process was very much driven by engaged and proactive farmers.

Amongst other things, the participatory data on borewell construction indicate a decadal increase in both the number and depth of agricultural wells over a thirty-year period, from 1990 to 2019. This is visualized in Fig. 9. The map shows the monitored wells classified by well depth. The darker the colour of the point, the deeper the well. We see more shallow wells on the coast and South-East region of the delta while deeper wells are found in the centre. The chart (on the right) represents the well count, colour coded by well depth, over time. It shows that the number and depth of wells have increased over the thirty-year period between 1990 and 2019.

During our meetings we discussed a scientific challenge of the participatory data collection program: it only captured operational borewells. To make up for this survivor bias, we decided to conduct a census of abandoned borewells in the village of Ayyampettai (see Fig. 10).

This census shows two clusters of abandoned wells. The first cluster has shallow wells at 10–20 m, constructed before 1990 and abandoned before 2010; and the second cluster has wells at 60–90 m, constructed after 1990 and abandoned after 2010. The data also shows a depth, between 30–50 m, without wells, possibly indicating an aquitard with an unconfined aquifer above and the first confined aquifer below –

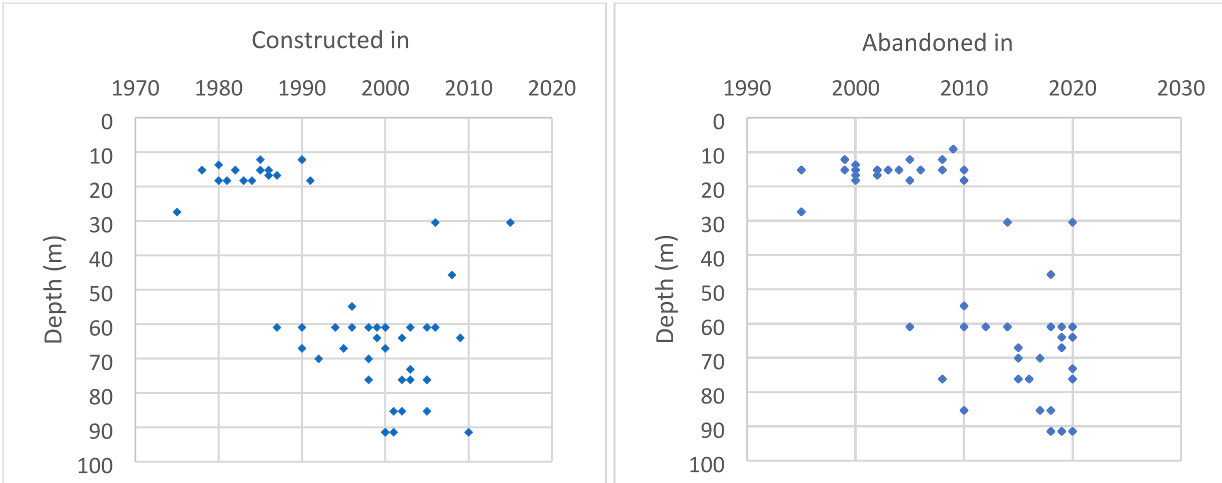

Fig. 10. A census of abandoned wells in Ayyampettai Village. Figure source: Authors.

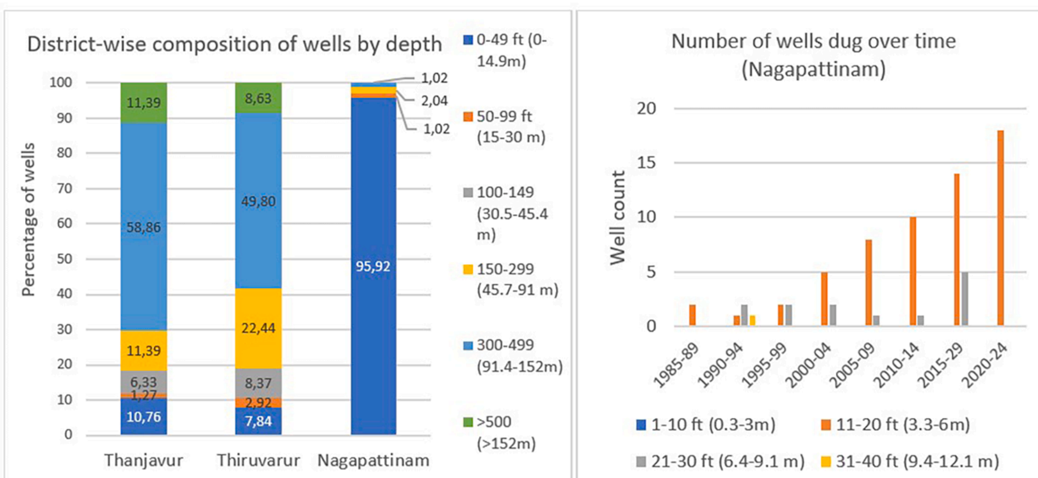

Fig. 11. District-wise composition of wells by depth (left) and well count in Nagapattinam (right). Figure source: Authors.

seemingly corresponding to the aquifer properties of our model (see Fig. 2). While this systematic well census was conducted in one village only, farmers in other villages confirmed the existence of abandoned shallow wells. This seems to substantiate one of the reasons why we embarked on participatory data collection, about farmers claims having to drill ever deeper borewells despite the governmental data showing stable water levels (see Table 1). There is an order of magnitude difference between governmental data and our participatory data, with farmers drilling to more than ten times the depths that the government is measuring groundwater levels at. It seems, therefore, that the government monitors largely shallow wells, leaving unmonitored, water levels at the depths to which farmers are drilling to or pumping from.

Finally, we found that salinity is a big concern mainly for farmers in the coastal area and South-East region (in Nagapattinam). Participatory data shows that most wells here are, relatively, shallow (see Fig. 11). The number of wells in Nagapattinam has increased over the last four decades, but 95% of the wells are less than 15 meters deep (while in the districts of Thanjavur and Thiruvarur the majority of wells are over 90 meters deep). It is likely that saline water intrusion also produces a self-regulation bias, with people only drilling shallow wells to avoid the deeper and more saline aquifers. Salinity changes the game, resulting in a growing number of shallow wells dotting the landscape, with high abstraction but also high recharge rates.

Participatory data reveals abstraction from deeper aquifer layers (see also Fig. 2) that are unmonitored by governmental wells, and salinity in Nagapattinam resulting in shallow wells with high abstraction but also high recharge rates. However, analysing datasets doesn't explain the dynamics causing the increasing number and depths of borewells. It is also unclear why farmers would abandon open wells, if the shallow aquifers have stable water levels. To us these questions confirm the complexity of water and wells in the delta and underline the need to ground socio-hydrology in actual cases. Moving forward, beyond the scope of the paper, we will explore saline realities further (but to get a feel already see Pompoes, 2022), for now, however, we will focus on grounding socio-hydrology in the cases and sites where wells are deepened, like Ayyampettai and the surrounding area, known as the Vadavur extension. The area where our new team members are from.

3.2. What engineers do

In our case, these engineers are PWD engineers. The PWD or Public Works Departments is one of the oldest and most prestigious government agencies in Tamil Nadu. Established in 1859 it was tasked with infrastructure, like buildings, roads and bridges, but the core of what it does are irrigation works[12]. Among its main tasks are the improvement and maintenance of irrigation structures as well as water courses and drainage ways, and the planning and executing of new irrigation schemes for the augmentation of water.[13] The engineering force of the water resources branch was explained to us as existing of more than 3000 individuals and very hierarchical. Additionally, the technical staff (including sluice operators called *laskars*) and temporary positions involved are estimated at 20,000. The task of the technical staff and lower engineer ranks includes frequent field visits, operation of sluices, flow measurements and day-to-day maintenance.[14] PWD engineers manage 75 dams, 4429 km of canals and 10,540 tanks.[15] Among these works, Mettur is the biggest dam, Grand Anicut the most iconic infrastructure and the Kaveri delta the most important irrigation scheme. One PWD engineer explains:

> *The delta starts at GA [Grand Anicut] where the Kaveri divides into 37 distributaries [...] the main Kaveri, Kollidam and Vennar-Vettar are the main distributary systems [...] In 1934, when Mettur reservoir started operating, Grand Anicut had [a command area of] 120,000 ha. Vennar had 190,000 ha. The lower Anicut area is located along the Kumbakonam. It had 53,000 ha. The excess flows are redirected through Kollidam [...] (Interview, 12 Feb 2022).*

PWD engineers make sense of the delta through surface water, quantifications of canal lengths, and flows measured and controlled by the acres of land irrigated in the command areas.

This also includes water levels and volumes of the Mettur Dam. These levels are monitored and communicated on a daily basis and we often hear 120 feet as the number indicating full capacity. Typically, the 12th of June is the day the Mettur is programmed to release Kaveri water. It is the most important date on the calendar of delta PWD engineers, though the day of actual water release varies.[16] Preceding the release date, the PWD executes a humongous desilting operation to clear and clean thousands of kilometres of canals and water ways, a costly and arduous enterprise that takes place during the hottest months of the year. Following the release, it takes Kaveri water two weeks to reach the Grand Anicut Dam and another 4 days to reach the tail-end of the system, after which thousands of *laskars* begin opening the countless sluices and regulators to as many sub-systems of the scheme; this can be considered an even bigger and more complex undertaking then desilting. By the second half of July, all villages should have received water from the PWD. That is the plan at least.

In practice, the infrastructure is in a poor state, or so claim farmers (see next subsections) and available surface water from Mettur is decreasing (see also section 2.1). Engineers acknowledge this decline and observe a drier delta through flow measurements, reduction of command area and decaying canals and weirs. They attribute the steady drop in surface water to increasing impoundment in the upstream riparian state of Karnataka[17] but there is a second, perhaps equally crucial reason, for the decline. One PWD engineer at the Chennai main office shared the following concern: While indeed the department holds 3000 engineering positions, about 40 % are kept vacant due to state budget cuts which also impacts the number of technical staff members. To remedy this, farmers would have to pay for irrigation water, but state-sanctioned price ceilings for paddy means there is too little margin on farmer income. Somewhat emotionally, the engineer expressed his despair about this. He shared that he even played with the thought of leaving his job, as in this condition, the PWD is not able to perform as it should. Interestingly, the reasoning of some engineers is that if the agreed water quantities are released by Karnataka and PWD is properly staffed, the delta scheme would operate smoothly.

It goes to show how engineers and technical staff care, make sense of and practice the delta; by connecting canals and regulators, measurements and infinite small water flows, and thousands of operators, to the Mettur Dam, the Grand Anicut and a long history of successful surface irrigation going back to the early Chola dynasties of the second century CE. The PWD's emphasis and coordination centres on surface water. However, groundwater matters are not completely unrecognised. For instance, an interviewed PWD engineer in the New delta reported:

> *"[The groundwater level] has generally decreased from 2008 onwards. There was good rain in 2014 to 2018. Then, less rain because of climate change. 20 years ago, average bore depth was 200-300ft, not 500-700ft."*

However, they do not 'practice' groundwater. *Laskars* do not operate wells, as they do sluices, obviously, but Assistant Engineers also do not monitor wells like they measure flows. This is why groundwater decline is not typically recognised as a major problem by most of the PWD staff we engaged with.

3.3. What activists do

At the end of 2020, a Facebook post was shared in the team, about "a youngster who restored lakes and agriculture" in the Kaveri delta.[18] His name is Nimal. We reached out to him and found that he was from a farming family. He had been living and working abroad, but engaged with and was concerned about the water and agricultural problems in his hometown taluk of Peravurani, located in the Grand Anicut Canal command area. From a distance, he was involved in organising protests against hydrocarbon extraction and then returned home to help with relief works after cyclone Gaja destroyed, among other things, large parts of the delta's coconut groves in 2019. He decided to stay. Together with others "who are willing to work for the society and for the welfare of the people", he set up KAIFA, a farmer association.

One of the problems Nimal looked to tackle early, was that of abandoned (bore)wells in the delta. It got a lot of attention due to an unfortunate incident of a child getting trapped in a well. Rescue attempts were covered extensively on (social)media. After this, KAIFA communicated through its social media accounts that it would voluntarily help transform abandoned borewells into water harvesting instruments – covering the wells (by filling them with gravel) and recharging groundwater at the same time. It got dozens of requests within days. Quickly however, Nimal's main focus changed, to the restoration of lakes or tanks.

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[12] This was evidenced when, in 2021, the department split up into a buildings organisation and water resources department (WRD), with 68% of assets and staff becoming part of the new WRD. See also footnote 3.

[13] There is also an office involved with testing quality and quantity of groundwater (managing data sets presented in Fig. 4) but this office is marginally staffed, located at the central office in Chennai, and staff do not go to the field regularly.

[14] When we consider what engineers do, we also include the technical staff, although certain PWD engineers comment that these are non-engineer positions ("they lack the training and degree" we were told,) but might have 20 years of field experience.

[15] See https://wrd.tn.gov.in/PWD-150Years.htm (Date accessed: 15-07-2024).

[16] In practice only 19 times – including the 5 years prior to 2024 – was the water released on the 12th of June.

[17] The Cauvery River dispute is a longstanding political conflict between two states about the allocation of Kaveri water. The courts intervened and attempted to settle the conflict, but it remains a source of protest of farmers in both states (see also Khandekar and Srinivasan, 2021).

[18] See https://youtu.be/b_crCvaukGk (Date accessed: 10–07-2024).

Tanks are common in the delta, particularly in the Vennar and Grand Anicut Canal command areas. They are used, administered and maintained by local villagers, though the PWD is also involved in case of bigger tanks. Today many tanks are found in a state of degradation and disuse. An activist explains this development:

> *"30 years ago, [the tank] was used for irrigation, over a command area of 30–40 acres […] [With increasing] wells, no one thought about the tank [anymore]. As the tank is without usage, people started encroaching [it]."*

Generally, tanks rely on rainfall, but also on Kaveri water, which fills the tanks first, in July and August. Activists do not emphasize the arrival of Kaveri water to Mettur dam levels. On social media and in interviews, Nimal shares how, in his hometown, Kaveri is welcomed as a god[des]; when she arrives "everyone started worshipping the water". In a video he posted, people are praying and meeting the Kaveri water head-on, taking off their shoes and prostrating on the riverbed in gratitude, only to stand up seconds before she arrives to let her pass and continue her way to the tanks. Activists also explained to us how tanks used to be interconnected and how rejuvenation work also entails restabilising this connection: "*We made that new culvert […]. After water is filled [in that tank], it will reach here. From here it will reach the next tank […] The tanks will be filled one by one*".

The practices that Nimal shares are linked to Aadi Peruku, a religious celebration where waterbodies (such as rivers and tanks) are worshipped. This often happens in connection to village *Amman* (meaning Mother) goddesses and temples, with Kaveri Amman being the most revered one. Aadi Peruku is celebrated widely across Tamil Nadu with its epicentre being the Kaveri delta. It is a monsoon festival at the end of July or early August because this is the time when (Peruku means rising) rivers come back to life. Revived, Kaveri brings prosperity to its devotees, fertility to the land, and water to the tanks.[19]

For activists, these celebratory practices and the element of local cultural heritage of the tanks are important as they help mobilise and enrol other actors in their cause: to restore the tanks and secure water for the future of delta villages. Tank rejuvenation is carried out, not just by Nimal and his recently set up Mega Foundations, but by many youth groups in delta villages that through social media reach out to one another to start rejuvenation work (see also de Raad, 2021). So far, they have rejuvenated more than 150 tanks.

This work, though different in each case, has many constant elements. An assessment of the situation has to be made, because often tank beds have been encroached upon. The PWD is informed, as engineers need to approve of the rehabilitation. Although the latter usually respond positively, people using the tank bed are often confrontational. One of the most important activities is the gathering of funds through crowd-funding. Although much cheaper than government-led rehabilitation of tanks, money is still needed for machinery that clears vegetation, removes sand and create kilometres-long bunds. Everyone who donates will be added, if possible, to a WhatsApp group to follow the restoration process and assure accountability. Activists post online the stories of young children donating pocket money, or newlyweds coming to donate on their wedding day. But there are also cases of villagers who emigrated and organise food sales at artisanal markets, mobilising Indian or Tamil communities in their new countries.

The message coming from activist work is that tanks are more than water-holding infrastructures, they are entangled with local village life and a (*trans*-local) sense of belonging. That is why in many of the (bigger) rejuvenated tanks, islands are created and planted with native species, for the sake of biodiversity care and rejuvenation, beyond irrigation purposes. That is not to say that activists are not aware of the precarious groundwater availability situation or connection to the aquifer. In fact, it is a main motivation.

[19] Many insights on Aadi Perukku we obtained from a conversation with Indira Arumugam and her forthcoming work on "Ambivalent Ati [Aadi]".

Youth group activists from Munavalkottai spearheaded the rehabilitation of a local tank in their village where none would actually use it for irrigation. They did it for recharge purposes. Elsewhere another activist said that:

> *"Even farmers with borewells contributed [to tank rejuvenation] because they knew that if there is no water in the lake, their water level will go down.* The activists acknowledge that for many farmers, groundwater is the "*biggest challenge in the region. Not only the inaccessibility […] The rainfall is not reliable anymore*".

Borewells, although commonly around for only 30 years, cannot be separated from farmer practices and livelihoods anymore. But the danger of overexploitation looms as activists described the historic delta development of (bore)well use to us:

> *"First we were making [open] wells and taking out water. After that […] we had to take out water with a jet motor. The water level was 300 feet, the bore was at 350. When the water level [further] reduced, we started making bores and using submersible pumps. Now it's 700 feet […] The reason is we didn't store water in water bodies."*

Through their in-situ and online activities activists connect tanks to the arrival of Kaveri river, water worship, rainfall (monsoons) and recharge. But also, with irrigation.

3.4. What farmers do

In February 2024 we were present when an impromptu poll was organized at an engineering college in the middle of the delta, not far from Ayyampettai village. Among the students are many sons and daughters of farming families. We were there to explain our work and to hand out certificates to those involved in the participatory data collection program. There were over a hundred persons in the lecture hall. The question posed by the college professor was about the water source for irrigation. Very few students acknowledged the Kaveri River in this sense. Most confirmed that irrigation is done with borewells. Indeed, in answering questions about where their water comes from, farmers explain flows and technology at the field scale:

> *"Our bore is beyond the Eucalyptus trees here. From there, water will come through pipes to my brother's field. Then from there, water will flow through channels to my field."*

Borewells have been a fundamental part of the delta for more than a generation now. In Ayyampettai, many villagers celebrate Aadi Peruku, not by going to the river or one of the many tributaries. Instead fathers take their sons to the family well on the 18th day of the Aadi month, where they "make worship to the god[ess]" by performing a pooja and paying gratitude to groundwater.[20] At the same time, women of the village gather, dressed in yellow, at an Amman temple, a practice which has remained for generations. The connection to canals, sluices and weirs appears less significant – at least in this part of the delta. However, farmers in the delta do remember a different time:

> *"Up to the '80s, […] we didn't have any borewells here. We used to irrigate using Kaveri water, and could even take two crops a year. We also practiced open well irrigation. After that, there was only enough canal water for one season. In 1998, we finally drilled a 280 feet [85 m] borewell. In the 2017 drought, the borewell failed."*

In Ayyampettai, they recall (their fathers saying) that when canals flowed, water levels in open wells rose. But canal infrastructure to the farmer fields is no longer operational. It is degraded or encroached and

[20] The connection between the river goddess and divinity found in groundwater and borewells is something we look to explore further. There are interesting stories, to that fact, about how India's sacred rivers goddesses, like Kaveri and Ganga, can travel and meet underground (Sharma and Sruthi, 2017).

levelled to become part of farming plots. What is still working is the supply canal of the local tank. Collective action at the village level assures this. Although there is no *neeranikam* anymore,[21] village men gather in the temple located near the tank to discuss maintenance and distribution, but they also talk about paddy varieties, yields and other on farm matters. In the delta, growing paddy is one of the most important things to do with your water. It is a cultural institution and matter of pride to have your own paddy. And this is best irrigated with tanks, so says one farmer from the Grand Anicut Canal command area:

> "*borewell water is hot*[22] *and evaporates very fast when irrigated. On the other hand, tank water is cool and keeps the land hydrated for longer. […] [Crops] look alive when irrigated with tank water, bore water just makes them survive.*"

Yet, the reality for many farmers is that they can grow tank-irrigated paddy only for a single season on only part of their land – maybe just enough for home consumption. This year, with a shortage of water behind the Mettur Dam, filling the tank in Ayyampettai is in jeopardy. To make a living farmers thus need to rely on groundwater. This is why the current situation in the area of Ayyampettai, where borewells are exhausted and turn up empty during *kodai*, is causing so much distress.

Surprisingly, the problem was not water, but energy. Because of the (hot) summer, and because of the monsoon failure earlier in the year leading to empty tanks, too many farmers turned to their borewells too often. The electricity grid collapsed. When we discussed this during one of the online team meetings in June, it led to the paradoxical observation by one of the members that "if there is good rainfall, the borewell gets enough current".

Trying to unpack this statement offers a nuance to the story of digging ever deeper wells as well as a possible alternative take on groundwater levels – for this particular case. What follows is a summary of a team conversation where questions and clarifications about groundwater levels were asked back and forth and wherein sidebars in Tamil and internet searches for explanations and pump specifications were needed more than once.

A significant year – or season – was that of 2017/18. It was a rock-bottom moment during one of the most severe droughts in delta history. Before this, farmers had already deepened their wells. Many of them had drilled up to 200 feet (or 60 m) and more, while they were pumping water from only 120 feet,[23] often with a submersible pump of 10 HP (horse power). As water levels dropped, they would lower their pumps. However, at 180 feet, a 10 HP pump no longer delivers enough water for irrigation. Farmers, en-masse, bought new, more powerful pumps, of 15 or 20 HP. Many combined this with drilling new, deeper, borewells up to 500 feet, for safety. All these new, 20 HP, submergible pumps created an electricity problem in 2018 as the energy grid was overexploited. The problem temporarily vanished as the next years saw plenty of rain and surface water – meaning filled tanks and higher groundwater levels.

The families of our team members also bought new pumps. One of them is from Ayyampettai. His family bought a 15 HP pump and drilled a new well with a depth of 250 feet. The other, from Munnavalkottai, already owned one of 500 feet, constructed in 2004 and installed a 20 HP pump. According to his farther the reason for this depth was to anticipate future droughts. He also told his son they hit sandy layers only, so no rocks or clay, during drilling.

As the conversation continued, we found that since 2018, when water levels had dropped to 250 feet (the maximum depth in village history), the aquifer recovered. In September 2022 water "was found at less than 50 feet […]. In some cases, water was [even] flowing out of the borewell". In June this year in Ayyampettai, groundwater can be found at 150 feet in proximity to the tank, and 180 feet away from it, indicating a potent connection, even when the tank was without water for half a year already.

There was a sidebar conversation in Tamil during the team meeting, some consultation, then an explanation that in Munnavalkottai, farmers generally keep their pump fixed at a deep level. In Ayyampettai, on the other hand, farmers lowered and lifted their pumps with oscillating water levels. The former recognizes the extra energy it costs to keep the pump at the lower level, but maintains that moving is a lot of hassle, while the latter reasons that moving the pump up when possible will give more water.

Some team members chuckled and were flabbergasted by these revelations.[24] Such a fast recovery – of something that was modelled as a confined aquifer – was unexpected, and a little uncomfortable maybe, at first. Can this highly dynamic groundwater behaviour be found in other parts of the delta? Through farmers stories and participatory data collection we found there is a high degree of heterogeneity in the lithologies: the sediment layers that make up the aquifers of the delta are horizontally discontinuous and irregularly stacked atop each other. Wells of the same depth, sometimes even within hundred metres of each other, can therefore be quite different in their yield and salinity. A fast recovery is not a given.

One team member remembered the comments from farmers from the Peravurani Taluk (in the Grand Anicut Canal command area). These Peravurani farmers often expressed how good the groundwater around Ayyampettai (and the Vadavur extension) is; "the taste is good [… compared to ours]. You [guys in Vadavur] easily get water. You put a bamboo pipe in and water comes out".

It seems to set this Vadavur area apart from the Grand Anicut Canal command area, where groundwater seems less readily available or trickier to find; and apart from Naggapattinam and the coast, where groundwater quickly turns saline. Regardless, farmer practices connect groundwater to reverence, borewell technologies, paddy cultivation, electricity, recharge and in season adaptions, while Kaveri (surface) water is known, but apparently seen more as from a distan(ce)(t) (past).

4. Discussion and conclusion

In this paper, we have described an experiment in grounding socio-hydrology through care-ful research, comparing and contrasting a modelling exercise to the logics and practices of activists, farmers and engineers along with and connected to a program of participatory data collection (Law and Lin 2020; Law 2021). Through the experiment, we demonstrated: 1) a willingness to be blindsided and uncomfortable, and allowing for surprises along the way; 2) the cultivation of new concerns and sensibilities – together with local actors – by immersion in the case study; 3) a support of researchers in shaping the actor-worlds and realities they identify with – or care about (ibid.). We will next discuss our findings and grounding attempts, keeping these three points close.

There was no shortage of unexpected things in our research trajectory. Some surprises came fast, like the presence of water diviners in the Kaveri Basin, while others were revealed gradually, like the wide-spread practice of drilling deeper wells. Some were welcomed, like the

[21] *Neeranikams* are traditional tank (sluice) operators in the delta (and elsewhere) often connected to a local temple (see de Raad, 2021).

[22] Farmers understand water quality in sensory ways. Next to temperature, they know about taste (water being salty) and nutrient content (water being muddy). Good water is cool, muddy and not salty.

[23] Mirroring our aquifer conceptualisation (see Fig. 2): a depth of 120 feet is within the unconfined layer 1, while 200 feet is part of layer 2, the first confined aquifer.

[24] The story about electricity failure and highly dynamic groundwater levels serves us to explain what farmers do and to ground different logics, at the same time it needs to be further researched in resonance with confined aquifer (see Raman, 2018; Prayag et al., 2023), groundwater recovery conceptualizations (Hora et al., 2019) and disconnection with recharge tanks (Aubriot and Prabhakar, 2011).

commitment of interns, others were uncomfortable, like the size of the groundwater-share in our model. There were also matters that surprised some team members and not others. Like the electricity grid problem or considering water deities as part of serious research. All of these were, in one way or another, embraced – through iterations and reflections. Some leads were followed, others shelved.

In the end, for this paper, we foregrounded a hydro-geological model, mirrored this to two government data sets, and found that the three approaches lead to three different conclusions about groundwater. The questions this raised for us were translated to a participatory data collection program. On the one hand the program provided new well information and confirmation about farmers drilling deeper wells in at least part of the delta. On the other hand, the participatory data collection allowed ethnographies that helped to further ground our model (and provisionally derived water balance) in the practices, knowledges and experiences of engineers, activists and farmers.

These different practices, and materials and elements mobilised through them, inform different ways of making sense of Kaveri water – or of her absence and drought. They form different logics that are not easily commensurable (see also Domínguez Guzmán et al., 2017; Yates et al., 2017). What we mean by that is that a hydrological model brings forth a particular version of the delta (consisting of cells, conceptual aquifer layers, numerical computations and more), that is different from, let's say, what comes about through the sensemaking and practices of a farmer (consisting of singular borewell behaviour, paddy varieties, free electricity, sense of belonging and more). They cannot be compared using the same yardstick. The implication is that it is hard work for a farmer to make a hydrologist aware of the farming delta and vice versa. Understanding or being aware of other versions is equally arduous, and takes time, effort and enthusiasm.

We carefully explored each logic on its own terms, symmetrically, following the concerns of the involved actors; and afterwards combining these logics without reducing or incorporating one to or in the other (see also Hasan et al. 2021). This yielded, we feel, several insights, leads and contradictions. The Kaveri Delta, we found, is about aquifer over-exploitation, (rain)water harvesting in tanks, energy shortage, goddess worship, rapidly rising groundwater levels, policy impasse (between operational funds and subsidy on rice), salinity concerns, declining river water, flooding, stability in shallow wells, and sense of belonging, to name but a few.

Here we acknowledge the appeal of integration work, among socio-hydrologists, in order to improve their craft and the world (see also Srinivasan, 2017). It is itself a manifestation of care (Mol and Hardon, 2020). We nevertheless maintain that it is not possible or prudent to bring together all logics and knowledge in one overarching framework or model. Instead we call for an approach that considers all knowledges or logics to be partial, yet entangled (or connected). Being partially connected means that a logic is brought about through a network of elements, practices and methods of which some are shared with other logics, while others are not (Strathern, 2004; Yates et al., 2017; Verzijl, 2020). Models and goddesses tell partial stories – not part of a whole story. In adhering to such an approach, we also recognize that the cultivated concerns of different actors, derived from how Kaveri is made sense of, are different; as are the ways to improve situations or versions of care – both practically and emotionally (Domínguez-Guzmán et al., 2021).

This modest approach to navigating the simultaneous existence of different knowledges, different ways of making sense of and experiencing water dynamics, we argue, provides a promising basis for grounding social-hydrological research. In comparison to integrative approaches, it is inherently more symmetrical in its treatment of different knowledges and logics, as well as more reflexive about methods and outcomes (see also Verzijl et al., 2023; Zwarteveen et al., 2024). It is also an approach that consciously situates and embeds hydrological models (and modelling) in the actors and relations that make up the (ground)waterscape, thereby forcing socio-hydrological research (and researchers) to much more explicitly acknowledge their identifications and interests.

What then might be a way forward? How can different logics be carefully navigated without reducing or subsuming one to the other, as we asked ourselves in the introduction? We learned that this takes meaningful conversations, active (practical and emotional) engagement and a willingness to learn from each other. This is a necessarily slow process, as embracing and nurturing difference takes time (Stengers, 2018). What would such a dialogue among logics be like? Based on our findings we envision one:

After a hydrologist explains the model (and provisional water balance), a delta engineer might point out that the amount of groundwater abstraction is less than surface water or rainfall. But it fluctuates highly, a critical observer adds. There are times when it is more: especially soon after moments of water abundance, groundwater abstractions can and will be much higher. Grounding that knowledge in the case of the Ayyampettai farmers, they will maintain that groundwater is the most important source for irrigation. It is more reliable in any given year where rain and surface water can be scarce. And their well shafts show great safety margins. Drought, nonetheless, is very real, and disastrous if the *kodai* crop needed to cover costs and make a living is compromised.

Free electricity to operate wells compensates for low paddy prices, where investing in motorized pumps is not feasible. And maybe not fair. Here, a hydrologist might observe that the electricity grid also acts, at times of scarcity, as a safeguard against over-exploitation of groundwater, regardless of level or borewell depth. When there is no surface water, there is not enough current. Yet the aquifer dynamics in Ayyampettai and surroundings seem extraordinary in their recovery. Farmers insist on infiltration (or the vigour of the Kaveri rising) and that each borewell behaves differently, which leads others to entertain the idea that there are locations, in the Vadavur extension at least, where the unconfined aquifer runs down to over 80 metres, calling for a re-evaluation or recalibration of the model – and maybe tailoring it to this local situation.

Activists involved in tank rejuvenation might be inspired to revive or even construct new tanks in this place to capture rain water and revive their countryside. Here farmers corroborate the connection between surface water and their wells, recalling stories of their fathers about how canal water used to augment their dug wells in the past and how goddess Kaveri rises (*peruku*) every year during Aadi, also from beneath their feet. But for now, canals are in a poor state, comments the engineer. He pleads collective maintenance is needed. All actors consider important their own concerns and ways to improve (desilt canals, store rain, nurture paddy, raise families, revive tanks and sense of belonging, monitor local groundwater dynamics), and start cultivating shared ones.

This is a story of a made-up dialogue. Yes. But it is also one that can be. In fact, the different persona mentioned above are, or at one point were, team members or close collaborators of this participatory data collection program entertaining these concerns. And it is through this program – maybe we should call it a participatory data collection movement, or grounded approach, or research as version of care – that we are actively co-shaping a delta reality we identify with and care deeply about.

The participatory data collection was in many ways, an entwined, sometimes messy, and largely imperfect process that did reveal interesting insights. We started it (see the points in Table 1) because of contrasting data sets and narratives, and can now situate that multiplicity; to understand why farmers drill deeper wells and can now follow their logic of securing livelihoods during a future drought (and drop in groundwater levels); to identify potential stories of groundwater realities and have now learned from dowsers and Kaveri devotees; to foster joint learning and solidarities and are now (and will be) working with local actors about advocating tank rejuvenation and awareness about surface–groundwater connections.

This is all at small scale. We are/were but a dozen or so people. Yet, our approach brought together willing people from different places and backgrounds – blurring boundaries of natural-social science, of qualitative-quantitative data, and of research subject-object. Borewell ethnographies grounded a hydrological model, tutoring by farmer sons grounded scientists. Blessed with support from different projects and other people, it forged longstanding collaborations and solidarities among team members and the field which is, we believe, essential for grounding socio-hydrology. Our approach helped us to improve our understanding of groundwater flows in the delta and advocate ways forward – it allowed us to collectively create Kaveri Delta beneath our feet.

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CRediT authorship contribution statement

Tanvi Agrawal: Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis, Data curation, Conceptualization. **Richard Pompoes:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Andres Verzijl:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization, Formal analysis, Investigation. **Veena Srinivasan:** Supervision, Formal analysis, Conceptualization. **Jyoti Nair:** Project administration, Formal analysis. **Edward Huijbens:** Writing – review & editing, Supervision, Conceptualization. **Kalaivendhan Kannadhasan:** Investigation, Writing – review & editing. **Kuloth Chokkalingam:** Investigation, Writing – review & editing. **Vivek Murugan:** Investigation, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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