Geoforum 119 (2021) 1–10

Contents lists available at ScienceDirect

Geoforum

journal homepage: www.elsevier.com/locate/geoforum

Between fragments and ordering: Engineering water infrastructures in a postcolonial city

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ARTICLE INFO

Keywords:
Urban water infrastructure
Fragmentation
Civil and chemical engineering
Technological practice
Social difference
Socio-technical

ABSTRACT

This paper explores the work of engineers amidst the fragments of access and use mechanisms that make up water infrastructures in the city of Chennai in south India. It sets its ethnographic investigation against a dual backdrop. One is that infrastructures in the global south have almost unequivocally come to be accepted as fragmented, even as the fragments themselves are little examined. The second is the mandate and will to order that engineering work is presumed to operate on by academic research and city managers alike. This paper brings these two provocations in juxtaposition by examining engineering work that occurs in the fragments of Chennai's water infrastructures. In doing so, it argues that engineering modern infrastructures involves multiple, often fragmentary epistemologies that rarely fit into a singular overarching tendency, to order or otherwise. It draws attention to the distinct sub-disciplines as well as the layers of technical jobs and technological cultures constituting the profession of engineering. Tracing the social differentiation between some of these engineering pathways, the paper calls for a rethink of what counts as engineering for the purpose of infrastructure research; and how that shapes our visibility and understanding of cities and their socio-technical support structures.

1. Introduction

> *"There are many passionate engineers in Metrowater[1] and the Government, who believe in environmental management. But, by and large, the engineering ethos is to prefer large projects than decentralised or smaller ones as they are easier to manage."*
> *– Administrative Official, State Planning Commission, Tamil Nadu, India*

Water engineers in the city of Chennai on the south eastern coast of India are caught in a peculiar paradox. Their profession is under critique from city managers like the official quoted above and academics alike for its supposed centralising and positivist impulses. At the same time, the infrastructures they build have also been deemed fragmented, and so in need of more managerial oversight and technocratic planning. This paper posits that it would be a paradox inherent to urban infrastructures as long as fragmentation is seen as a deficient or incomplete state, contingent upon historical or contemporary structural reasons (Graham and Marvin, 2001; Silver, 2015). Drawing on ethnographic research with the wide range of engineers and technicians involved in making and maintaining Chennai's water systems, it argues that engineering modern infrastructures involves multiple, often fragmentary epistemologies that seldom fit into a singular ethos. This makes infrastructure building a fundamentally fragmented exercise and engineering a composite technological practice. It is only by attending to these socio-technical fragments (Furlong and Kooy, 2017; McFarlane, 2018) do we build a critical understanding of infrastructures as they exist in much of the world.

As infrastructure development gains new footing around the world as a particular articulation of the 21st century state (Barry, 2016), it also mobilises particular forms of globalised knowledge such as consultant-led expertise and evidence-based managerialism (Björkman and Harris, 2018). Yet in Chennai, as elsewhere in the global south, everyday technical practice continues to produce and reproduce water flows and (dis)connections. This is not only because of the city's highly dispersed water system, but also because infrastructures now can employ a range of technical specialists from varied disciplinary, social and epistemic backgrounds, contributing into the system through their technological practice. These engineers, in turn, work with discrete, incremental systems developing contingent epistemologies and practices that often go

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[1] Chennai Metropolitan Water Supply and Sewerage Board, or Metrowater for short, is the public utility that officially provides water supply and sewerage services to the city of Chennai on the south eastern coast of India. It is an autonomous institution overseen by the Tamil Nadu State Government and Chennai City Corporation. Chennai is the capital city of the State of Tamil Nadu within the Union of India.

https://doi.org/10.1016/j.geoforum.2020.12.018
Received 30 March 2020; Received in revised form 8 October 2020; Accepted 18 December 2020
Available online 31 December 2020

unattended under the broad brush of fragmentation or ordering (Gandy, 2008; McFarlane and Rutherford 2008).

In this context this paper argues that it is important to get into the folds of the so-called fragments of urban infrastructure to examine what kind of engineering work goes into the undergirding of cities. It will focus specifically on the various engineering epistemologies and technological cultures at play, paying attention to disciplinary training, institutional and social backgrounds, and workplace practices of engineers. In doing so, it aims to show that the multiplicity of technological practices and knowledges shaping Chennai's waterscapes is characteristic of infrastructural work; and that engaging with them is crucial to 'worlding' (Roy and Ong, 2011) as well as 'contouring' (Roy, 2009) our understanding of infrastructures in the rich spectrum between fragmentation and ordering.

In the first section the paper traces broadly how social research has engaged with engineering, its histories and role in contemporary cities, identifying a gap in the social understanding of engineering work in southern cities. The paper will then proceed to argue why Chennai can be termed a 'techno-populist' city (Arabindoo, 2011) and so, offers a privileged case through which to reorient our understanding of how technological cultures shape infrastructures. In order to do this, it will focus on two major engineering disciplines prevalent in the city's water management today – civil and chemical engineering. By delineating the practice of these disciplines in distinct infrastructural environments, the paper argues for an approach to cities that attends to their fragments.

2. (Dis)ordering histories of engineering

The recent prominence of infrastructures in the study of cities owes primarily to how it allows us to forefront the technical and the material in our understanding of urbanising social worlds. Indeed the infrastructural turn (Burchardt, 2016; Harvey et al., 2016), and its focus on the technical systems running through cities has come a long way since Olivier Coutard's (1999) observation that they were 'engineers' stuff' that social scientists tended to ignore. Yet, the work of engineers itself in building or running these infrastructures remains curiously understudied, and instead subsumed within a narrative of technocratic ordering revealed by official plans (Gandy, 2014; Harris, 2013; Usher, 2018). Administrators and city managers in Chennai, like the official quoted above, enthusiastically share this view equating engineering with technocracy. Backed by a heightened global mandate for economic and environmentally informed water management (Bakker, 2005; Mollinga, 2008), and under local pressure over successive floods and droughts, (Jayaraman, 2015a; Natarajan, 2019) they pin Chennai's difficulties with water down to its supposedly engineering-led centralising, asocial and positivist approach.

Engineering, however, wasn't always believed to be distinct from political or social economies. Historians have shown that peninsular India's pre-colonial agrarian network of rainfed lakes and canals, while attributed vaguely to traditional knowledge today, were in fact complex engineering projects materialised in collusion with the ruling and warrior castes of the region (Mosse & Sivan, 2003; Shah, 2008). Engineers then, distinguished from their modern counterparts as 'artisans', were associated with technologies of rule, kinship and state-making, perhaps more accurately reflecting the socio-technical nature of engineering work (ibid). The apparent separation of engineering from political work is often traced to the founding of the Institute of Civil Engineers in London in 1818, which distinguished the work of building infrastructures like roads or water pipes meant for civilian use rather than their primarily military purpose so far (Florman, 2014). These tensions between technical practice as artisanal, political or military work and as a profession co-opted into nation-building also played out in the same period in French engineering history (Bradley, 1975; Mukerji, 2015).

By the end of the 19th, century ostensibly technical disputes over the construction of sewers in cities like London and Paris demarcated the state's role from engineering work for good. The state went from engaging directly in engineering activity to being its arbiter, setting standards and parameters (Joyce, 2003) marking the onset of liberal governmentalities of state power than any depoliticisation of engineering or technology (Gandy, 1999; Osborne, 1996). Naturally, engineering became instrumental in the exercise of colonial governmentalities across European empires (Dossal, 1988; Kooy and Bakker, 2008a; Mitchell, 2002). Since water engineering in the post-colony derives primarily from this tradition of civil engineering[2], it is often linked inextricably to the bureaucratic functioning of state power ie., colonial hydrocracies (Akhter, 2015; Benedikter, 2014; D'Souza, 2006; Molle et al, 2009). The shift from artisanal craft to professional engineering also owes to appropriation of technical practice from labouring castes to elite castes under the colonial regime in the Indian case (Subramanian, 2019).

Investigations specifically into urban water engineering have followed a similar pattern in parallel, associating circulatory water systems, and by extension, its engineers with technologies of ordering and control in cities, tracing a direct line from liberal governmentalities of rule in the late 19th century to contemporary neoliberal governmentalities (Gandy, 2006; McFarlane, 2008; Usher, 2018). This line of argument however presumes a 'particular relationship' between 'official regimes of knowledge' and engineering practice (Björkman and Harris, 2018). That is, these studies continue to treat the work of engineering itself as 'arcane' (Gandy, 2014; Graham and Marvin, 2001), instead training their lens on broader structures of authority that are expected to be employing engineering for the heft of scientific reasoning it lends to nation and city-building plans. They implicate engineering practice in governmentalities of (neo)liberal modernity without any serious engagement with the actual work of engineers.

Harvey and Knox (2015), whose ethnography of road construction in Peru remains a rare nuanced take on the work of engineers, argue that these critical scholarly accounts:

> "…run up against the limits of their own presuppositions and pay scant attention to the anxieties and internal critiques that have always been integral to modernist thinking. They also ignore the craft dimensions of engineering practice, a foundational craftiness that informs the particular ingenuity of the engineer." - (Harvey and Knox, 2015: 8)

It is this 'craft dimension' of engineering work that this paper is after. An engineer's craft could certainly be that driven by individual ingenuity. But, more fundamentally, it is the experimental, negotiated and material dimension of engineering practice that's shaped by everyday socio-technical work as much as by authoritative regimes of knowledge and governance (Reuss, 2008; Trevelyan, 2010). Here, these are termed 'engineering epistemologies', borrowing from the field of engineering studies (Brown et al., 2009; Trevelyan, 2010) and used as a framework to consider the making and running of urban water infrastructures.

In contrast to the standard positivist view that modern engineering and technological practice are informed by scientific theory and precise models and structures (Channell, 2017), recent scholarship in STS (Science & Technology Studies) has pointed out that what we recognise as peak technological development during colonial, wartime and cold war periods were experimental rather than applied science (Bijker, 2001; Mitcham, 1994). That is, modern engineering work has more in common with pre-industrial artisanal craft than is widely acknowledged. The classic idea of 'technoscience' (Latour, 1987) in STS pushes

[2] Chennai Metowater, for example, in the brief institutional history it includes on its website unequivocally credits a colonial engineer with setting up the first water supply channel from a nearby river to the then colonial city of Madras. It also dutifully mentions Mr Madley, another colonial engineer who's said to have set up the city's sewerage system and lends his name to a busy road in Chennai today: https://chennaimetrowater.tn.gov.in/historical_background.html

this argument further to formulate that technical expertise stems not only from an amalgam of craft and scientific process, but also from the set of institutional and social conditions that shape and sustain those knowledges.

This paper builds on the idea of technoscience to consider the multivalence of technological practice constituting the engineering of Chennai's water infrastructure, through its lens of 'engineering epistemologies.' This varied epistemology, the paper contends, makes infrastructures as well as cities fragmented in shape and process, where fragmentation isn't a breakdown of a complete whole but is simply the condition of 'infrastructuring'. In engineering studies, concerns with 'epistemologies' have primarily been about ethics in technical practice and pedagogy (Brown et al., 2009). Here, the term is used to refer to a broader set of contingencies ie., disciplinary, institutional and social ones driving engineering approaches and indeed ethics in making and maintaining water infrastructures. A serious engagement with everyday water engineering in Chennai reveals this diversity, thus bringing up two curious research gaps in existing accounts of engineering.

One is the almost non-existent attention to the wide range of disciplines that make up engineering – electrical, environmental, chemical, civil, mechanical etc. – in social studies of urban technical networks. In Chennai, they are not all often encountered within the offices of the centralised water utility, but in the many fragments of everyday water supply and access mechanisms in the city. This, in turn, brings up the second gap, in attending to everyday practices and enactments of engineering in the postcolonial context, despite engineering training and deployment having been a widely adapted path to postcolonial development in many countries (Akhter, 2015).

The paper will thus foreground its arguments by providing a brief overview of engineering in postcolonial Chennai and how it fits into the geography of its water infrastructures. In doing so it attempts to complicate the role of engineering in urban infrastructures, arguing that Chennai represents a 'techno-populist' city (Arabindoo, 2011) where expertise is distributed (Trevelyan, 2010) and is politicised through socio-technical interactions.

3. Methodology

The paper is based on ethnographic research on Chennai's waterways and infrastructures conducted by the author over a period of 10 months between 2013 and 2019. About 5 months of this research work was spent in sustained engagement with the everyday work of engineers in building and managing the city's water infrastructures, and following them through society (Latour, 1987), which is the material this paper draws heavily on. The study was informed by an 'ethnography of infrastructures' approach (Larkin, 2013; Star, 1999) and this meant that the interactions with engineers were complimented by further engagement with state officials like ministers and bureaucrats, and with activists and water users in order to situate technical practice as well as follow the thread of 'infrastructuring' ie., how infrastructures came to be made in the everyday functioning of the city and how this in turn reinforced or remade existing urban social and techno-political relations. A total of 90 interactions were recorded over 5 months, in which 36 were engineers actively working with water infrastructures. Analysis of this textual material required a multistep process of first identifying broad themes, spotting the contexts in which they arose and most importantly, considering how that theme was enacted or materialised in that context. Thus, the themes became distinct narrative threads or stories by the end of the analytical process, which were then brought together to understand infrastructures.

4. A techno-populist archipelago

Chennai's water infrastructure can be characterised as what Karen Bakker (2003) called the 'archipelago' model prevalent in the global south. That is, it consists of "linked 'islands' of networked supply" (Bakker, 2003: 337) rather than one centralised network, those islands being comprised of a range of sources and technological mediators. Middle and upper class households in Chennai typically rely heavily on a backyard or common borewells shared between flats in a housing complex. The centralised network operated by the state-run utility Metrowater fills in almost as a supplement to this, with other sources like water lorries, public pumps and packaged water filling in the gaps (Srinivasan, 2008). The urban poor access water from many of the above sources, including borewells, but depend on lorries and public pumps operated by Metrowater for affordable even if considerably laborious access. Given this 'throwntogetherness' (Massey, 2005) of infrastructures, exclusions occur because of the time and investment they require by the water user. For instance, households typically need an overhead, underground or indoor tank where they fill water from these different sources and purify it using filters of varying capabilities.

It isn't that Metrowater is unimportant or that it has no engineering projects to its credit. When it was created in 1978 as an autonomous but state-managed entity (Coelho, 2010), it inherited mainly a distribution network pumping water from two rainfed reservoirs constructed under the colonial administration (MAWS, 2014). Since then, major projects completed for augmenting supply volumes and expanding the network, including the two recently constructed seawater desalination plants, have been associated with specific political parties in government at the time (MAWS, 2014). That is, they were planned and executed as political responses to the city's recurring water crises, in bits and pieces over the years, often scaled down in scope, rather than as engineering ambitions. As Gopakumar (2009) has argued these infrastructure projects were classic articulations of the Tamil state which has been adept at co-opting socio-technical work into its political ambitions.

There exist myriad of technological mediators – as material artefacts or technical practices - that ensure everyday water access at the household level from Metrowater pipelines or other sources. These include household borewells, electric motors, sensors and purifiers, and most recently the reverse osmosis filter, whose popularity is indicated by its simple colloquial moniker, RO. RO filters are used widely to remove mineral salts from water and hence popular in making saline groundwater potable, recycling wastewater and in the seawater desalination plants mentioned above. The use of these technologies, as we shall see, has been accompanied by the emergence of a whole range of engineering occupations in the city.

But, technology professionals 'outside the network', far from working in parallel to state-run water supply, act as their extensions, working closely with Metrowater and other institutional engineers as well as with water users. This strengthens and materialises the infrastructural articulation of what Joe Painter (2006) has called 'prosaic stateness' – an experience of the effect or presence of the state where water access is achieved or sometimes simply attempted. This pervasiveness of the Tamil state means that institutional or material divisions and consolidations are all seen under the umbrella of government action by the user. All of this has meant that Chennai's waterscapes have always been directed by an impulse of 'technopopulism' (Arabindoo, 2011), where politicians, engineers, administrators and residents reach for small or large scale technologies that achieve water access by possible means, rather than be led by engineering ambitions or the book of planning. An example is the short-lived small scale thermal desalination unit that was installed at one of the city's iconic beaches to supply water only for the fishing settlement on the seashore (Wabag, nd). Despite its limited success, it is almost memorialised today as an artefact on the beach and in the stories fishers tell about their relationship to salt water and government (fieldwork interviews). This piecemeal approach has, of course, had certain disastrous consequences like floods and droughts, portended only by fast disappearing surface water bodies and a rapidly deteriorating groundwater table.

A material record of the city's precarious technological mediation with water are the large number of institutes of technical education built over existing water bodies across the city and its periphery (Jayaraman, 2015b). Chennai is arguably criss-crossed by institutions of technical education as much as by water bodies and connecting canals. When information technology (IT) industries took off in India around the turn of the century, south Indian cities became prime hubs of technological service provision and training. Chennai, consequently, houses numerous state-funded and private engineering colleges, apart from hosting Nehruvian era central government institutions of advanced research like the Indian Institute of Technology and the National Institute of Ocean Technology. A number of newly opened private engineering colleges have been catering almost exclusively to the IT industry by teaching only what are colloquially called 'circuit' engineering branches – electronics, computer science etc., and not the 'core' branches – civil, mechanical or electrical engineering (Subramanian, 2008). So, while social research on engineering in other places and times focuses on infrastructure or industrial engineering, in India it has unsurprisingly emerged largely in relation to its aspirant and practising software engineers (Fuller and Narasimhan, 2006; Upadhya, 2016). However, as Anirudh Krishna (2014) shows through a survey of engineering colleges across geographies and tiers in India, there is a significant caste and origin-based variation in who gets to be an engineer and of what kind.

The educational and research institutions discussed above still only reflect the top rung of technical education ie., they usually award full degrees in engineering. The second tier is comprised of government-funded ITIs (Industrial Training Institutes) and Polytechnic colleges enabling students to acquire a trade accreditation or diploma in a technological discipline (DoTE, 2016). These are typically considered a lesser qualification, associated with technical occupations taken up by lowered castes and classes – building contractors, plumbers or maintenance engineers. In Tamil Nadu, a history of affirmative action and investment in primary education has meant that all these avenues leading to a technical profession are widely pursued by people from eclectic backgrounds, if only striated by caste and class[3]. Since engineering graduates from the most elite institutions often aim to and succeed in going abroad to pursue their careers, it is students of other avenues of technical training who are involved in city-building (Subramanian, 2019). The many tiers and types of technical education and its alumni, thus, form a spatial and hierarchical infrastructure supporting everyday urban life and the physical built environment. This also means that there exists a variety of engineering knowledges, out of which emerges a pragmatic quasi-technocratic approach to everyday water access that feeds well into a techno-populist zeitgeist.

So, the multivalence in engineering epistemologies that this paper set out to explore isn't simply about the panoply of water access technologies, but about the widespread technological culture, shaped by interlinked social hierarchies and institutional difference. While recent academic work on infrastructures in Indian cities acknowledges this diversity especially in the production of technical knowledge, it often reserves the title of 'engineer' to the municipal/state engineer or elite technocrats (Anand, 2011; Harris, 2018; Ranganathan, 2015; Ranganathan et al, 2009) as distinct, for instance, from the unrulier or 'simpler' plumber (Björkman, 2018; Reuss, 2008). Engineers are recognised only when their expertise is set apart from 'normal people' (Anand, 2015). This distinction blurs quickly when water users, urban residents and a variety of workers in the water sector all have some technological qualification to their name and lay claim to technical competence or at least ability in matters of water engineering.

A case in point is the rainwater harvesting initiative that the Government of Tamil Nadu brought in by municipal ordinance in 2002 and later wrote into law (Arabindoo, 2011). While many of the city's affluent residents in fact complained at the time of authoritarian tendencies behind a government ordinance making rainwater harvesting compulsory for individual houses and buildings, their narration by the time this research was conducted was more of pride in having figured out and got the techno-material intervention done, and being good environmental citizens. It was another matter that residents had always collected rainwater using pots and pans or reused greywater through household adjustments. There is also little evidence today of the legal intervention having actually made a meaningful difference or of the technical, structural adjustments then made being useful and resilient. Yet, such an ambitiously sweeping material change could not have been simply laid down in an ordinance by the then Tamil Nadu Government without expectation that the technical requirements for the job would be available or could be summoned across the city, however imperfectly.

Such 'small re-engineering services', as Bhuvaneshwari Raman (2013) argues, are entwined with regional political and social structures, and are sometimes even instrumental in the making of cities beyond masterplans or governance initiatives. They, however, seldom make it into analyses of 'tech cities' or 'engineering expertise'. It is important to engage with these diverse engineering professions in the reading of urban infrastructures or expertise not only in order to stay empirically true to city-building processes but also to acknowledge engineering work beyond elite and appropriated regimes of technical knowledge (Subramanian, 2019). The following sections delve into some such semi-entrepreneurial engineering practices in Chennai, especially around the growing industry in reverse osmosis membranes. While doing so, it helps to keep in mind that this city is entangled within a wider regional political economy of engineering and technological trade.

4.1. Operational chemistry of membrane technologies

A key event in the annual calendar of water engineers in the city is the Chennai Water Expo & Watman Conference (see Water Expo, nd), a business-to-business conference conducted by a local trade publication. Manufacturers and traders put up row upon rows of stalls showcasing pumps, purifiers, filters, sensors and various other water access related products to potential clients – usually builders, plumbing contractors, commercial institutions and office managers. It is but a reflection of Chennai's highly decentralised and processual water infrastructure mediated by myriad of technological artefacts and assembled by an eclectic range of techno-managerial professionals. It's also a space for the city's civil, environmental, chemical and hydraulic engineers to interact not only about technology but also about their jobs, financial pressures on their projects and their bureaucratic managers. It is here that a testing engineer – let's call him T – was giving a talk on environmental impact assessments.

> *"These tests are often only a formality. As chemical engineers, we know what values [of contaminants] will fall under the limit and make sure we enter that, unless there is something dramatically wrong in the readings."*

A field engineer confirmed this practice, explaining that if he was required to measure and record a number, he would make sure to enter an unambiguous number – usually one that would allow a given project to continue. This, he clarified, wasn't about fudging numbers but about using their discretion born of engineering experience to ascertain if a reading was dangerous or an acceptable deviation. It was only when the reading exceeded limits dramatically that the desire for lack of ambiguity might work against said project. Rather than the routine oversight in banal infrastructural work that Nikhil Anand (2018) has critiqued, these testing engineers held the agency to exercise discretion. They worked as part of the team to make a contribution, which negative readings didn't seem to count as. "Well, that's what engineering education teaches us, isn't it?" another water engineer wondered aloud:

> *"[In engineering college] We knew what the outcome of our experiments were supposed to be. So, we made sure that we entered the appropriate values in our record books even if that's not exactly the result we got. I*

[3] Gender works slightly differently in this situation – many young women do take up technical education at all levels, but their participation in the workforce falls, especially when it comes to work on 'field' sites as is often the case with water engineering work.

mean, it was important to learn to work the machines, but at the end, the record needed to show the correct values. So, we learnt to work the machines to give us the values we desired."

In a sense, this is what engineering is about – manufacturing a world that fits into one's expectations and values, even while knowing that it wouldn't ever be an exact fit. It was far from a heroic stance and the impulse to order is only so far as it confirms to pressures of the project.

Yet, it is the imagination of the material world as modelling clay that drives fantastic projects like desalination. This privilege has only recently been extended to chemical engineering, traditionally thought of as not engineering enough in comparison to its mechanical counterpart valourised in manufacturing industries. Tracing its development as a discipline in 20th century Britain, historian of technology Colin Divall (1996) writes that the term 'chemical engineering' was considered something of a misnomer since it involved merely managing and containing chemicals during manufacturing or 'physical' processes and not the engineering of chemical processes as such. The latter role, where it applied, was done by chemists rather than chemical engineers (ibid). It's only with the attempt towards 'sustainability transitions' across industries, that chemical engineering practice ie., working with thermodynamics, energy balances and a systems approach, came to be considered useful (Clift, 1998; Byrne & Fitzpatrick, 2009). In Chennai, this moment seems to have arrived accompanying membrane technologies – reverse osmosis and other chemical filtration membranes used widely for making hard or saline water potable.

A large part of Chennai's archipelago infrastructure for accessing water now involves membrane technologies of some kind. With heavy reliance on overexploited groundwater reserves (Srinivasan, 2008), the city depends widely on membrane filters to make increasingly saline groundwater potable and fit for household use. These filters appear in household purifier units, colloquially called simply 'RO' referring to the reverse osmosis filtration they perform, as well as in the two seawater desalination plants that Metrowater constructed in 2010 and 2013 respectively. This professional rise of chemical engineering was reflected in the research profile of Chennai's engineering colleges, as in the exhibits at the Watman Expo.

At the Expo, raised pedestals with dazzling displays showcased membranes aided by the expertise of an engineer who acquired his technological training abroad – usually in the Middle East or Singapore. At a stall with a giant flowchart explaining how membranes treat effluents, however, the resident expert introduced himself as a researcher based in Côte d'Ivoire. That wasn't unusual, he clarified, engineers interested in water technologies could be found in unexpected places, wherever they could learn the trade affordably.

"Water technologies evolve according to local necessity, right? And so inevitably we find other places where similar conditions prevail and local engineers seek technological solutions. In my case, this was to do with fouling – clogging of membrane pores due to scaling and bacterial deposits."

This would become apparent to me as a narrative typical of emerging fields within water engineering. Unlike the civil engineers who emphasized their training in a long lineage of public engineering projects, chemical or environmental engineers stressed their mobility, reflexivity and adaptability to a fast changing industry and environment. But, when discussing the novelty of their work, they would also insist that there is very little room for negotiation with the technological artefact, which should run on strict parameters. This was partly in response to the perceived illegibility of membranes and such novel interventions stoking fears of potential hazards. But, these technical epistemologies and cultures with which engineers identified were not strictly down to their disciplinary background, but depended also on their professional or institutional status.

For instance, the engineers working in either of Chennai's two desalination plants, located at the northern and southern fringes of the city respectively, were typically Polytechnic graduates ie., they held a diploma from an Industrial Training Institute or Polytechnic College rather than a Bachelors degree. The northern plant, located amidst an industrial cluster in the island of Kattupalli, runs on what's called a DeBoot (Design-Build-Own-Operate-Transfer) model of public–private partnership. Metrowater purchases water from the private company running the plant for a period of 25 years at the end of which the plant transfers to the state utility. The southern plant at Nemmeli, a fishing village off the scenic East Coast Road, was built on what's called an EPC (Engineering, Procurement and Construction) contract which meant that the plant was funded and owned by Metrowater, and a private company only held a fixed term contract to construct, run and maintain the plant (TNSPC, 2007, 2012). These differences in ownership, operation and even geographical positioning meant that the Nemmeli plant was more of a flagship for Metrowater as well as the Tamil Nadu Government while the Kattupalli one remained invisible to the city at large (see Fig. 1). Nemmeli was a closely monitored plant where visiting consultants and policymakers were usually taken to showcase Chennai's expertise and innovation. This was reflected in the work and public engagement that engineers in the two plants did.

One such engineer – let's call him K for he worked in Kattupalli – held a diploma in chemical engineering and worked in the plant's control room, or SCADA room as it was referred to, SCADA being Supervisory Control and Data Acquisition, the programmable control system used to monitor the plant. His work, as he explained, only involved monitoring the SCADA, which can do very little to modify the desalination process. Any significant changes to the plant would have to be done at the programming stage, he explained, which can only be actioned by programmers or electronic engineers who weren't on the site at all. He had

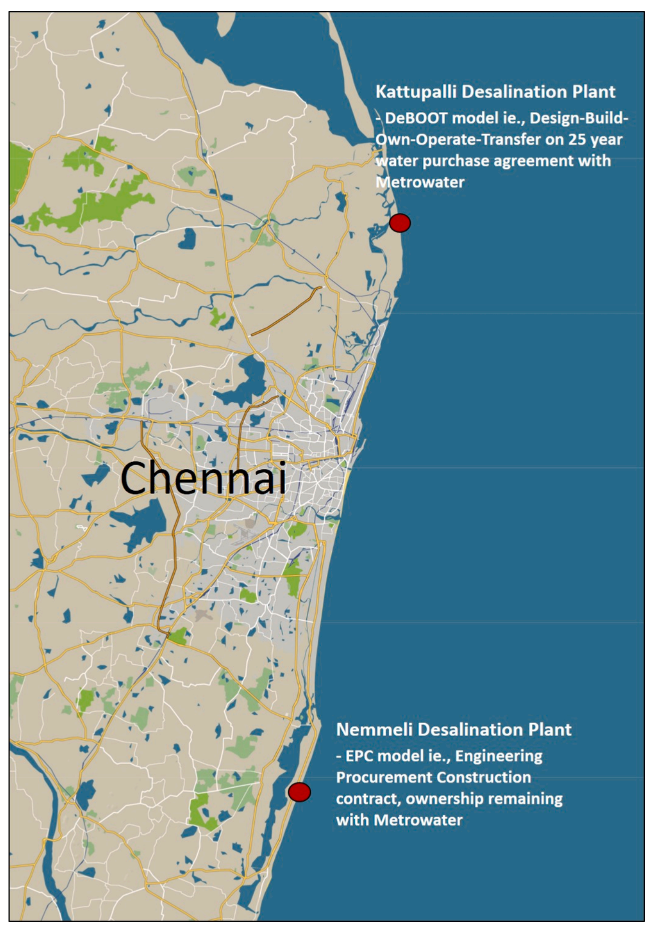

Fig. 1. The two desalination plants of Chennai, separated by geography and socio-technical differentiation. Map data: Google.

worked in a power company within Tamil Nadu before, subsequently going abroad to East and then, West Asia to work on more industrial water systems, sometimes involving desalination. There were three vital statistics he monitored daily, K said: pH, turbidity and conductivity. But, this was a desalination plant, there had to be salinity surely.

> *"Oh, that is conductivity. Salinity = Conductivity * 0.55. Water engineers just prefer to use salinity because it makes it seem like a lower numerical value. Desalination brings down conductivity of water; and finally, lime is added to equalise its pH"*

Is that what gave the water some taste finally? "It equalises pH," K responded in deadpan. The systems engineer in Nemmeli, let's call him N, did not find this remotely amusing though.

> *"This is what happens when engineers understand only machines and not the process it works. We use electrical control instruments to run the plant, right? So, we need to convert chemical qualities of water, like salinity, into a measure that the machines understand – an electrical measure. Hence, salinity becomes conductivity. Chlorine content becomes oxidation reduction potential (ORP). And so on."*

He was well practised in presenting the plant accessibly to a lay or specialist audience. Just the previous day, a State Minister had brought a foreign delegation to visit the plant.

Nonetheless, both chemical engineers occupied largely techno-mathematical fragments of the city's water infrastructure. They exercised agency to modify their environment only in reporting or recording data, their mathematical approach often in tension with a traditional idea of engineering. Far from being driven by an inherently engineering ethos, their practice was determined by the institutional and technical set up they worked with on an everyday basis.

4.2. Engineering public and provisional civilities

Chennai's institutions of water governance have neatly divided up the engineering functions of handling the city's waterscape. Metrowater concerns itself with the supply of water and the disposal of sewerage; the public works department (PWD), in historical continuity (Ramesh, 2018), takes care of its water bodies; the city corporation is responsible for stormwater drains, essentially managing surface flows when it rains. In this triad of engineered water management, Metrowater's engineers believe they're holding fort as representatives of what they believe to be the purpose of civil engineering – public health and resource distribution. "It's right there in our title - we're called civil engineers!" exclaimed one of them – let's call him C – interpreting civil not in contrast to military but as oriented towards 'civic' or public obligations. His indignation was directed towards the increasing emphasis on engineering obligations towards environmental and economic efficiency.

Senior engineers in Metrowater recounted that they've been encouraged to hire more students of environmental engineering, but this did not mean they were about change what they believed was their critical role in the city. "We can hire consultants to guide us on the environment, but we need our engineers to focus on what we need to be doing and are good at – distribution," a superintendent engineer rued. Metrowater, as we saw earlier on, was directing its energies primarily towards distribution of water across the city until recently when more 'resource augmentation' plans or projects to increase supply volumes were planned. So, the key expertise held by civil engineers in Metrowater was in the social and material geographies of water distribution in the city. This gave them claim to being 'public' engineers unlike emerging experts in projects like desalination and environmental water management. "The worst is when they hire consultants to tell us how to do our job," C lamented, "They borrow our watches to tell us the time."

Metrowater engineers have reason to be worried after all. The role of its sister organisation, the PWD, has been reduced to mainly publishing environmental data (WRD, nd) that go largely unnoticed unless it holds something sensational or provides useful information in favour of a popular project. Surface water bodies in Chennai that the PWD would be managing have now been identified as ecological services to be provisioned by the Municipal Corporation for the benefit of the city. This however has meant an embrace and attempt at valorisation of environmental engineering as valuable expertise within the Corporation. Since the formation of Metrowater in 1978 which took over water supply and sewerage functions in the city, the Chennai Corporation's role in Chennai's waterscape had been primarily storm drainage, ideally the basis for flood control. As a senior project engineer in the Corporation said:

> *"So, in the past four decades, we've been thinking about Chennai's rivers and marshland systems only as drainage basins. Now there's an opportunity to think about them as biologically rich systems, with social and natural functions. It's exciting!"*

Many of the Corporation's initiatives in providing ecological services – reshaping lakes as spaces of urban leisure or 'river clean-ups' have rightly come under heavy criticism for the logic of bourgeois environmentalism or neoliberal regeneration characterising them (Coelho & Raman 2010). The Corporation's approach to environmental engineering, however, showed that 'engineering ethos' in making water infrastructures shifted pretty quickly in response to institutional and political contingencies.

Still, an overarching 'public'-ness, in the sense of an obligation to a particular sociality, seemed to be central to the identity and practice of civil engineers in these state institutions. This stemmed partly from the logic of numbers required to run a supply or sewerage system, as a Metrowater engineer working on sewerage functions explained. That is, the water network needed to have sufficient subscribers in order to be carrying a volume of water capable of exerting the necessary pressure to reach the length and breadth of the city. For this reason, it needed to be public. In the interest of maintaining this publicness and securing their own role in the urban waterscape, Metrowater engineers had even set up an organisation called the Society for Public Health and Environmental Engineers (SoPHEE). It is this view of water systems as public infrastructures, members of the organisation contended, that was construed as the centralising impulse of engineers towards large infrastructure projects.

A momentary overtaking of environmental governmentalities over volume requirements of the centralised system now means that new private housing developments in Chennai, often at the urban peripheries, build their own sewerage treatment plants (STPs) in order to obtain planning approvals. Since self-built sewage tanks as well as borewells and overhead storage tanks have long been a part of this urban landscape, building STPs isn't a far cry for builders, especially since they employ reverse osmosis membranes. This is where the all-encompassing yet highly specialised role of the MEP or Mechanical-Electrical-Plumbing engineer, common in the construction industry, comes in. MEPs were typically civil engineers, who had become critical to the construction industry because of the multi-layered, negotiated knowledge they carried and the eclectic tasks they performed. As an MEP, let's call him M, at the site of a high-rise development (see Fig. 2) remarked:

> *"What do you expect? The first step in housing development would be to test the soil to see if it can withstand pumping groundwater for the whole building. Who would arrange that? The MEP, of course."*

The MEP was no geologist, but they would be the one who can find the right expertise for the job based on his knowledge of social geography. They were akin to building contractors but specialising in just the infrastructural requirements of the building. Contrary to Metrowater or other civil engineers in water companies who had bachelors and even masters degrees from reputed universities to their name, MEPs held basic degrees or diplomas, often in disciplines like chemical or electrical engineering, from one of the many private colleges that had opened

Fig. 2. The 'water infrastructure shed' at a construction site in the urban periphery. Photo credit: Author.

initially to cater to the software industry and now the construction industry. Their job was usually a freelance one, and hence, more precarious.

As we spoke at M's makeshift office in the project site at the southern margins of the city, a steady stream of assistants and contractors popped in to consult with him or get some purchase signed off. In Chennai, building development of all sizes use groundwater pumped up from an onsite borewell for construction - to mix concrete, to cement bricks in place, to plaster over them. But the groundwater on this site, as many others these days, was found to be too hard even for construction. So, along with borewell, a reverse osmosis treatment plant was also installed. "Construction workers, as you know, will be staying in the site itself," M explained. "They will have to end up drinking the hard water if we don't treat it on site." Construction labourers were almost always migrant workers hired on contract. They moved from project to project, setting up house with their families in the very sites they work in. With little stability, protection or entitlement in their contracts, they depended on such rationalities of their employers to access basic services like water, health or childcare.

Once the building was constructed, the reverse osmosis unit would be repurposed for sewage treatment for the entire building because "residents of such flats did not like to have a centralised purification unit for their water supply," M informed. Sewage treatment, on the other hand, would be impractical at the household level and so the central unit worked out well. If this were an office building, the unit would be converted to a recycling plant, to supply greywater for the toilets in the building, M's colleague who worked on a different project chipped in.

In this particular fragment of Chennai's waterscape – the elite high rise development nearly an island in the archipelago metaphor – civil engineering practice involved a constant juggling of rationalities and functions for a technological intervention, depending on social, spatial and temporal contingency. It remained far from the conventional ideas of public-ness expressed by Metrowater engineers, yet the repurposing of the reverse osmosis unit constituted an attempt at sustaining its purpose and even commoning it if only across temporal separation – in short, 'infrastructuring' it. This practice illuminates, from the point of view of the engineer, how infrastructures are constituted – as a flexible, provisional configuration of artefact requiring engineering work, that is to say socio-technical work, to animate its function.

5. Discussion

If there was a common engineering ethos that could be identified across the fragments of Chennai's water infrastructure, it seemed to be recognition of its minimal role in shaping or running the city's water systems. Water engineers were quick to acknowledge the limitations of their own expertise and how much control they had even on the fragment they worked in, let alone the larger sprawling system. This is sometimes institutionally employed to deflect accountability to factors outside their control like rainfall, planning or even political pressures. As anthropologist Karen Coelho (2006) explains in her critique of Metrowater's bureaucracy, apparently natural factors 'such as gravity, slope and depth' are invoked to justify the inclusions and exclusions that the system has made through history. In practice, however, engineering waters in Chennai has involved negotiating with not only water users, bureaucrats and other human actors invested in a particular fragment, but also other material and moving parts of the city's water infrastructures. As shown above, the MEPs constructing water supply and sewerage systems within a private development complex - nearly off-grid systems, were still connected to and worked around the changing demands of a public or environmentalist ethos driving the centralised network.

The MEPs as well as Metrowater engineers working in the field also acknowledged that they learnt from local residents, plumbers and contractors about groundwater, topology and local politics over the course of their work. In Metrowater's case, the 15 Area Engineers corresponding to the utility's supply zones also mediated between the rationalities of their bureaucratic managers and the socio-material flows of the area they oversaw. Some developed an ethics of practice distinct from the official line because of what they saw as an erosion of their public or civil obligations by the regime of neoliberal governance to which their managerial superiors belonged. This was also why environmental governmentalities were often resented as they were seen to replace their familiar civic responsibilities. Yet, as engineers in the Municipal Corporation expressed, when much of their traditional function had already been diverted to other departments or institutions, environmental engineering was embraced as an opportunity for renewed public engagement.

On the whole, what all of these engineering practices reflected were fluctuating technological epistemologies and indeed a fragmented approach to urban water infrastructures. But, this fragmentation was natural to organised infrastructure making considering the plurality of institutions, technological capabilities and engineering specialisations involved in the process. This multivalence of technological practice owed to and reinforced the ‘techno-populism’ (Arabindoo, 2011) of urban development in the region, but the distributed nature of technical expertise did not mean that those knowledges and practices had equal agencies. It is only by taking the fragments seriously as legitimate infrastructural form and attending to their workings do we uncover forms of social differentiation that a critique of fragmentation itself based on Northern infrastructural norms misses.

In the case of water engineering in Chennai, sub-disciplines and occupations, linked to the social, training and institutional background of the engineers concerned, were differentiated and stratified in the capacity they held for urban ordering as well as in who gets to be in those positions. An example of this were the chemical engineers involved in desalination or wastewater recycling and MEPs contracted by private developments, both roles having come into their own in infrastructure building thanks to the recent popularity of reverse osmosis membranes in dealing with socio-material changes in the city’s waterscape. These engineers tended to be from non-elite social backgrounds and were in an unfavourable hierarchy with civil or environmental engineers working for public utilities. Their job was also, accordingly, more mathematical and operational than involve long term planning for urban infrastructures, yet engineering the urban environment in discrete ways. These are “distinct forms of fragmentation” (Furlong and Kooy, 2017) that are revealed outside the network imagination of infrastructures.

Fragmentation, Colin McFarlane (2018) has argued, is a central theme in the history of urban studies. “As critical urban research has repeatedly shown, urban capitalist growth often requires the fragmentation of urban space and sociality,” he observes (McFarlane, 2018: 1007). A focus on the structural process of fragmentation has resulted in analyses of neoliberalism (Graham and Marvin, 2001) and colonialism (Kooy and Bakker, 2008b; Zérah, 2008). But to echo McFarlane’s (2018) question, “what about the fragments themselves?” Fragments do not necessarily come from the fragmentation of a whole. Nor are they at a state of incompleteness, on their way to becoming full and final (Coutard, 2008). Rather, they are discrete and shifting formations from which cities and infrastructures are made incrementally, iteratively. They are simply what constitutes infrastructure, especially in cities of the global south where their visibility makes this evident. It is in the work of constituting it, often through technological practice, that infrastructures can be identified. As AbdouMaliq Simone (2015) puts it, infrastructure “is a movement that gathers up remnants, the disparate, and that which has been cut loose from discernible modes of belonging” (Simone, 2015: 151). It is the constant act of moving that constitutes infrastructures rather than the consistency of its material stability. As long as there are fragments, the act of infrastructuring is on and so, infrastructures are sustained.

6. Conclusion

The encounters above with engineers in Chennai delve into the fragments of the city’s infrastructure. By elaborating on the disparate technological practices that go into distinct parcels of infrastructure, this paper has attempted to show the fragmentation inherent to infrastructure making. The differentiation in social backgrounds and professional status shaping engineering functions indicated multivalence not only within the infrastructural set-up but also in the role and nature of engineering in building it. Yet it is in engineers that an impulse to order, centralise and consolidate the fragments is located by academic research and city managers alike. The ethnographic narrative in this paper, however, sought to go beyond the official mandate of what engineering is supposed to do, to an exploration of what its many variations actually do in the infrastructural assembly.

Much of this work, as Susan Leigh-Star (1999) observed decades ago is dull and invisible albeit more in the sense of not being taken seriously as engineering at all. For instance, chemical engineering, despite its moment in the sun in Chennai recently, isn’t privileged like mechanical engineering is in industrial activity or civil engineering in urban development. Even within specific disciplines, most of the technical jobs discussed in this paper – testing engineer, control/process engineer, construction site MEP etc. – are neither given the power to order nor valourised for the functions they fulfil. They are only recognised as less than engineering technical professions, like plumber or contractor, even in academic research that does consider and delve into their contributions (Anand, 2015, Björkman, 2018). This not only flattens the terrain of what we come to recognise as engineering expertise but also erases historical as well as contemporary artisanal and technical work in favour of elite appropriation of engineering as qualification rather than craft (Subramanian, 2019).

The parts of science and technology, indeed the physical world, that social research chooses to take up for consideration and analysis has implications for how we understand that world and the kind of social theory produced from it (Barry, 2015). The preoccupation with planning and engineering of large infrastructures or at least circulatory flows may have swept a myriad of other engineering professions under the radar of urban research. But, it is precisely the wide range of near invisible technological practice that makes infrastructures political (Anand, 2018) as their legibility is distributed over fragments of knowledges and practices, each performed as everyday work by numerous actors. The capacity of infrastructures for unsustainable or unequal distribution of resources is wrought banal through the ‘will to ignore’ (ibid) on the part of several actors, among whom feature many types of engineers, like the testing engineers doing environmental impact assessments that this paper discussed. The nature of engineering agency, then, is banal in the way it is exercised as everyday contributions to urban development rather than as a grand vision.

This paper has, hence, argued for more serious attention to the fragments that constitute infrastructures in many cities around the world. By tracing engineering work done around membrane technologies, primarily reverse osmosis membranes that help filter mineral salts from water, in Chennai, it has brought to the fore discrete, incremental, unheroic technical work that make apparent fragments into infrastructure. These findings are, however, not meant to be a theory of southern or fragmented infrastructures. Neither are they a finding about the nature of postcolonial engineering. Instead, they are a call to identify and treat fragments within infrastructure “as ‘process’ rather than ‘trait’ geographies” (Roy, 2009: 829). By going beyond overarching critiques of fragmentation and narrowing its lens to distinct environments of ‘infrastructuring’ instead, the paper has presented insight into engineering as a practice of different epistemologies and differentiated agencies shaped by socio-material as well as institutional contingencies.

CRediT authorship contribution statement

Niranjana Ramesh: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Validation, Writing - original draft, Writing - review & editing.

Acknowledgements

I’m grateful to the two anonymous reviewers whose feedback was immensely helpful in bringing this paper to publication.

I’m deeply thankful to Dr. Pushpa Arabindoo, Prof. Andrew Barry, Prof. AbdouMaliq Simone and Dr. Kasia Paprocki, who have mentored and encouraged me through to publishing this ethnographic research as a paper.

Many thanks also to the members of the LSE Writing the World programme, who read a previous draft of this paper and helped me workshop this article.

I'm grateful to the UCL Institute for Sustainable Resources and UCL Department of Geography for awarding me the UCL Impact PhD Studentship which allowed me to take up this project.

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