www.water-alternatives.org Volume 10 | Issue 2
Grönwall , J. and Jonsson, A.C. 2017. The Impact of 'zero' coming
into fashion: Zero Liquid Discharge uptake and socio-technical transitions in Tirupur.
Water Alternatives 10(2): 602-624

The Impact of 'Zero' Coming into Fashion: Zero Liquid Discharge Uptake and Socio-Technical Transitions in Tirupur

Jenny Grönwall

Stockholm International Water Institute (SIWI), Stockholm, Sweden; jenny.gronwall@siwi.org

Anna C. Jonsson

Division of Environmental Change, Department of Thematic Studies, Linköping University, Linköping, Sweden; anna.c.jonsson@liu.se

ABSTRACT: The textile industry is one of the major industrial polluters, and water recycling is yet far from being standard practice. Wastewater generation remains a serious and growing problem, affecting ecosystems, human health and freshwater availability for other uses. India is the world's third largest exporter of textiles and the sector directly employs 45 million people. This case study explores the socio-technical transition of Tirupur, a textile cluster dubbed as the first in India to shift to 'zero liquid discharge' (ZLD) in a systematic manner. It traces a path towards increased environmental sustainability that takes off in a time characterised by no effluent treatment, to the advanced approach to wastewater handling that was the norm in 2016. By adding a multi-scalar perspective, light is shed on where the system changes emerged that inspired key actors during various phases of the defining 35 years.

The process towards ZLD becoming best practice involves conflicts, adaptation, resistance, and vast socioeconomic losses. Eventually, innovative ideas and artefacts replaced old practices, and effluent discharge has become a symbol of noncompliance. Farmers' movements, authority directions and court orders drove the development, which came to inform a policy shift to mainstream water recovery in the textiles industry.

KEYWORDS: Zero liquid discharge, sustainable textiles, water recycling, wastewater treatment, Tirupur, India

INTRODUCTION

We all use textiles in our daily lives and global demand is steadily increasing. This growth results in income generation and job opportunities maintained or created for many actors along the value chain: the industry is hugely important to developing and emerging industrial economies. Asia, particularly Bangladesh, China and India, provides consumers in Europe and North America with low-cost apparel and home textiles. Relatively new players in other parts of Asia (such as Cambodia and Vietnam) offer ever-stronger competition in textile manufacturing, as do some East African countries, with Ethiopia being most prominent.

The textile industry has one of the longest and most complicated manufacturing chains: it is a fragmented and heterogeneous sector dominated by small and medium-sized enterprises (European Commission, 2003). Number 12 of the UN's Sustainable Development Goals (SDGs) encourages responsible consumption and production patterns to achieve economic growth while reducing our ecological footprint by changing how goods and resources are produced and consumed. The strengthening of developing countries' technological and innovative capacities is included in the 2030 Agenda. Efficient management of shared natural resources, including the water cycle, and the disposal of toxic waste and pollutants, are important targets to achieve SDG 12. To do this, it will furthermore be critical to encourage industries, businesses, and consumers to recycle and reduce water usage, and substantially increase water-use efficiency (SDG 6.4).

The bleaching, dyeing, printing, and finishing steps of textile manufacturing, commonly referred to as wet processing, are heavily dependent on access to good-quality raw water. The composition of effluents, especially from this part of the industry, are complex. Very large volumes of wastewater and sludge are generated, containing non-biodegradable components and often heavy metals (ElDefrawy and Shaalan, 2007). The aquatic toxicity problems associated with traditional textile wastewater are yet poorly understood (Moore and Ausley, 2004). This makes the sector one of the major industrial polluters globally along with tanneries, pharmaceutics and paper and pulp. Conventionally, the greater part of freshwater withdrawn and used in wet processing is returned to nature in a deteriorated state. At larger scales and over time, this affects local ecosystems as well as human health and freshwater availability. In most places where such processes are conducted, competition over shared water resources with other sectors in society – and with future generations – is sought to be dealt with by government actors through a combination of policy instruments, economic incentives and technical innovations. Academia and the industry itself have contributed with research and development (R&D) to mitigate negative effects.

India was the world's third largest exporter of textiles in 2015 (WTO, 2016), and the sector generates direct employment to 45 million people (Ministry of Textiles, 2016). In 2015 the federal government took several forceful and unprecedented steps to regulate the sector in an effort to make it more resource-efficient. New guidelines, directions, and standards for textile effluents were all influenced by the 'zero liquid discharge' (ZLD) approach (*explained below*) with the idea to make this mandatory throughout the country (MoEFCC, 2015). While the amended standards enacted by the Ministry of Environment, Forest and Climate Change at the end of 2016 (MoEFCC, 2016) crowned the policy-making process, it raises the question of what led the way and, indeed, what the prospects are for a major shift with respect to wastewater treatment at the level of implementation. A large part of the complex and lengthy answer is found in South Indian Tirupur, known as the first cluster in the country – and probably the world – to systematically opt for ZLD.

Tirupur's journey involves notoriously drawn-out lawsuits, culminating in an infamous closing order in 2011. The Madras High Court in Chennai (state of Tamil Nadu) then demanded that factory units and treatment plants should immediately be shut down by the executive authority, the state Pollution Control Board (PCB), for their failure to achieve no – zero – wastewater discharge from premises. Allegedly, some 300,000 people lost their jobs with the closure of almost 700 units and 20 Common Effluent Treatment Plants (CETPs) that had a chain effect on associated businesses such as knitting mills, suppliers of chemicals and dyestuffs, garment factories and those engaged in embroidery (Valsan, 2011). Five years later, wastewater treatment and recycling of water and inorganic salts had become standard practice and the ZLD approach a mantra.

We studied the environmental degradation and collective action in connection with CETP investments among textile industrialists in Tirupur in the early 1990s (Jonsson, n. Blomqvist, 1996). Since then, the environmental impacts and water management have received their fair share of attention from scholars (including Krishnakumar, 1998; Eswaramoorthi et al., 2004; Appasamy and Nelliyat, 2007; Madhav, 2008; Vishnu et al., 2008; Mani and Madhusudanan, 2014) as well as in the grey literature and mainstream media. Combined, these studies serve to give a comprehensive picture of the sustainability challenges faced in the Tirupur Region. The case of Tirupur has not, however, yet been presented in a way that unpacks the socio-technical changes and transformations that the region has undergone over the past 35 years. This article aims to advance the understanding of the non-linear path from the early 1980s, a time characterised by no effluent treatment, to the advanced approach to wastewater handling that was the norm in 2016, and to shed light on actors and drivers during various phases of the process, the question of where inspiration and know-how behind the changes emerged, and the role of frontrunners.

As important as the discussion on practical implementation is, it lies outside the scope of this paper to establish whether the industry has thus far actually achieved ZLD and the environment been improved as a consequence thereof.

THEORETICAL UNDERPINNING AND METHODS

A socio-technical transition can be described as a long-term process: the result of slow change and short-term fluctuations that initiate a highly nonlinear response to complex and persistent – wicked – problems. Transitions signify structural and essential changes in the way a societal system operates, often explained as major transformations in how functions such as transportation, communication, power production or water supply systems are fulfilled. They involve not only technological changes and reconfigurations, but also shifts in elements such as user practices, policies, rules, norms and individual behaviour, industrial networks, infrastructure, and symbolic meaning, among interrelated sets of actors, institutions and artefacts, that together contribute to greater sustainability (Geels, 2002; Coenen et al., 2012).

This case study uses a *multi-phase* perspective (Rotmans et al., 2001) to organise the narrative of interlinked actors and interests, processes, and drivers into critical stages. The widely accepted model divides the time between two dynamic equilibria into the following phases, marked by indicators for social development:

1. Pre-development – where the status quo does not visibly change but shifts are emerging under the surface;
2. Take-off – in which thresholds are reached and the state of the system begins to shift;
3. Acceleration – where visible structural changes take place rapidly through an accumulation of socio-cultural, economic, ecological and institutional changes that reinforce each other; and
4. Stabilisation phase – where the speed of social change decreases and a new dynamic equilibrium is reached and a new transition process begins.

This study investigates events of an ongoing transition over the defining 35 years, up to the enactment of a new national standard on ZLD at the end of 2016 from the Ministry of Environment, Forest and Climate Change. The changes deemed of relevance have been categorised into four main periods corresponding to the transition phases: the early 1980s to 1988 (pre-development), 1989 to 1998 (take-off), 1999 to 2012 (acceleration); and from ca. 2013 up to and including 2016 (stabilisation).

Following Jørgensen's (2012) alternative approach to the 'Dutch school of transition studies' with its focus on landscapes, regimes and niches as a 'multi-level perspective' to explain socio-technical change (cf. Rotmans et al., 2001), the present case study will treat the Tirupur Region as a 'flat' *arena* in which actors operate in networks that involve institutions, technologies, visions and practices. As such, the arena concept emphasises the temporary and actor-dependent character of the fields that hold social ordering and in which change and transitions take place. The concept offers a stage on which actions and dynamics can be performed, and acknowledges that conflicts are important elements of change.

To complement the picture of Tirupur as an arena where actors and frontrunners have interacted and converged, a *multi-scalar* perspective that explicitly incorporates a spatial scale is added. As noted by Coenen et al. (2012), transition analyses have often neglected where transitions take place. The authors also argue that the literature strongly favours a 'diffusion' model, "where innovations are assumed to start in industrialised countries and slowly trickle down the development gradient into emerging economies and finally developing countries" (ibid). These insights also have a bearing on this case study, which asks where the system changes emerged and if 'diffusion' from one geographical place to another can be traced and deemed to be of relevance to explain technology uptake in Tirupur – or if the reverse is in fact more accurate to describe the development.

This article is based on a triangulation between several different types of primary and secondary sources. Secondary data were retrieved from court orders and legislation, policy guidelines, reports and grey literature, news articles and blogs. Primary data were created during semi-structured interviews and informal discussions with more than 100 informants and from field observations during five field trips to the Tirupur Region and Chennai during 2015-17, involving visits inside and outside garment and wet processing units, and wastewater treatment plants. Respondents included unit owners and managers, representatives of Western retail brands and the Tamil Nadu State Pollution Control Board (TNPCB), lawyers, judges, farmers, female household representatives, sector experts and scholars. The sensitive and sometimes contested nature of the matters discussed made most respondents speak only off the record and under condition of anonymity. Some people who were identified as key respondents declined access; others opened up but clearly gave very intentional and measured responses. Every effort was made to verify narratives and information.

WASTEWATER REGULATION AND THE ZERO LIQUID DISCHARGE METHOD

India's textile manufacturing dates back some four thousand years and is presently the second largest employment generator after agriculture. The negative environmental impact of the sector has been acknowledged since the first regulatory efforts to preserve and protect the country's natural resources with the Water (Prevention and Control of Pollution) Act, 1974. Industrial growth also spurred the federal government to set up a statutory Pollution Control Board organisation under the Water Act. With textile manufacturing being one of the oldest industrial sectors, wastewater handling was already an issue prior to the enactment of environmental laws. For instance, in the 1930s, treatment of effluent from textile mills in Ahmedabad, Gujarat, was done by allowing wastewater to evaporate and percolate through sandy soils on the banks of the river. As described by Ganapati et al. (1965), these 'solar drying beds' were not maintained properly and eventually became holding ponds from which dry solids were recovered and sold as manure. Nonetheless, it was concluded that "the drying beds accomplish a very high degree of purification, or rather stabilisation, at practically no cost by means of biological oxidation" (ibid: 269).

National minimum standards for effluent discharge were laid down in the Environment (Protection) Rules in 1986. Relaxed biological oxygen demand (BOD) and chemical oxygen demand (COD) limits applied if the effluents went via the sewer system to a municipal treatment plant. A limit for total dissolved solids (TDS) – useful to monitor salinity – was however only added after a reform of the regulation of the sector. In September 2015, Directions were issued by the Central PCB to the effect that all Common Effluent Treatment Plants (CETPs) were to install continuous effluent monitoring systems. In January 2016, the Ministry of Environment amended the Environment Rules for CETPs and replaced previous standards for treated effluents with stricter ones. Finally in October 2016, amended standards for discharge of effluents were enacted (Grönwall and Jonsson, 2017).

The entire industry underwent a major shift in the 1990s with the breakthrough in India of reactive dyes. Among the disadvantages with such dyes are, however, that they necessitate large amounts of colour fixation salt – salt that cannot be removed from effluent with conventional primary and secondary treatment. The level of dyes, metals and inorganic compounds (salts and chlorides), measured as TDS and hardness in receiving water bodies, increased severely as a result (cf. Cook, 1994; Thakur et al., 1994). High levels (above 1,200 mg/L) render water non-potable and accumulation in the soil reduces crop yields.

'ZLD' comprises a chain of enabling components but also refers to an approach underlain by the reduce – reuse – recycle principle. It is not possible to attain complete recovery of the influent water as some is inevitably evaporated in the process, but the ZLD method maximises the treatment and recycling of wastewater and minimises the demand for freshwater to that of make-up water. The benchmark in India is held to be a loss of as little as 3% of the water; between 85 and 95% efficiency seems to be the norm (Sustainability Outlook, 2015).

In simple terms the ZLD process starts after secondary treatment, from which the wastewater is passed through membrane filters including reverse osmosis (RO) in several stages to remove dissolved solids including dye fixation salt. So far it has much in common with desalination. The permeate (clean water) is recycled back to the process and the concentrated filter-reject, also known as brine, undergoes 'reject management' by way of evaporation and crystallisation. The resulting condensate water is recycled. The wet sludge (slurry) may go through a filter press and/or different evaporation methods.

The ZLD method leaves a solid waste by-product – dry sludge, often referred to as mixed waste salts – that contains high levels of hazardous chemicals and heavy metals. In Tamil Nadu, as per directions from the PCB applicable in 2015, the sludge was to be stored at the units until more research had been conducted on using it for co-processing in the cement industry. Two years later, many had been permitted to send the dry sludge to be used as fuel in cement kilns. Elsewhere in the country, middlemen are contracted to handle all the sludge as per the Hazardous Waste Rules of 2008. However, this by-product remains a major challenge. Informants testified that it is often dumped to cut costs, littering the landscape and causing secondary impacts on soil and groundwater. The weak link, as so often, is the law enforcement.

There are several ways of optimising the end-result for ZLD and no single best available technique could be identified during this study. The components must always be tailor-made to local conditions, based on a compositional analysis including the volume and quality of influent water and its fluctuation over time, and air humidity. Until the 2011 closing order, Tirupur had a wide range of pre-treatment technologies (primary and secondary stages) in use (cf. Singhal and Gupta, 2010). A certain level of streamlining of the tertiary treatment was carried out after 2011 to make the RO reject-management functional. The RO membranes are mostly combined with micro, ultra and/or nano pore size filters. Neither of those target salts, but the pre-treatment is necessary to keep control of the feed water and minimise energy consumption and fouling of the RO membranes. The crystalliser process can use a forced circulation centrifuge, from which recovery of sodium sulphate salt (Glauber's salt, Na_2SO_4) is done for recycling in the dyeing process. Crystallisation, for the final solid – liquid separation, can take place in multiple stages.

The crucial evaporation can employ spraying, falling film, multiple effect evaporation (MEE), mechanical vapour recompression (MVR), and/or solar evaporation pans on the ground. Efficiency and power consumption differ between those methods and they are often used in combination (Raja Sankar and Rajesh, 2017). MEE is currently considered best practice at large units with Individual Effluent Treatment Plants (IETPs). The CETPs in Tirupur employ MVR and MEEs in combination with solar evaporation pans.

ZLD involves high capital expenditures as well as running costs. The latter, in particular, is high because the RO reject management is extremely energy-intensive, membranes have to be replaced regularly, and technically skilled staff commands higher salaries. A tertiary treatment system with only RO can recover up to 80% of its liquid waste streams. Adding various evaporator and crystallising steps that are necessary to capture the last 20% and deal with the concentrate was earlier estimated to double costs (cf. GWI, 2009). In new factories with modern optimisation and full recovery of water, heat, salts, and chemicals, the additional cost need not be markedly higher. However, interest rates, government subsidies, influent material prices and energy costs contribute to determining economic feasibility.

TIRUPUR'S JOURNEY

'Tirupur', in the South Indian state of Tamil Nadu, refers not only to a city but also to a district that was carved out of Coimbatore District in 2009. It constitutes India's premier textile cluster, and forms the centre of a textile-focused region that includes the adjacent districts of Coimbatore, Karur, Salem, Namakkal and Erode, with the SIPCOT Perundurai industrial park in the latter (Figure 1). With the exception of the SIPCOT Park, growth in this region has been organic and unplanned. Tirupur City is situated on the bank of the non-perennial Noyyal River which also flows through Coimbatore, Karur, and Erode districts before joining the Cauvery River (Figure 2). Rainfall in the region is highly variable due to the rain shadow effect of the Western Ghats mountain chain; agriculture is rain-fed or irrigated from borewells, where the groundwater table and water quality permits, and in parts also from canals (Srinivasan et al., 2014).

Figure 1. Tamil Nadu, India (not to scale).

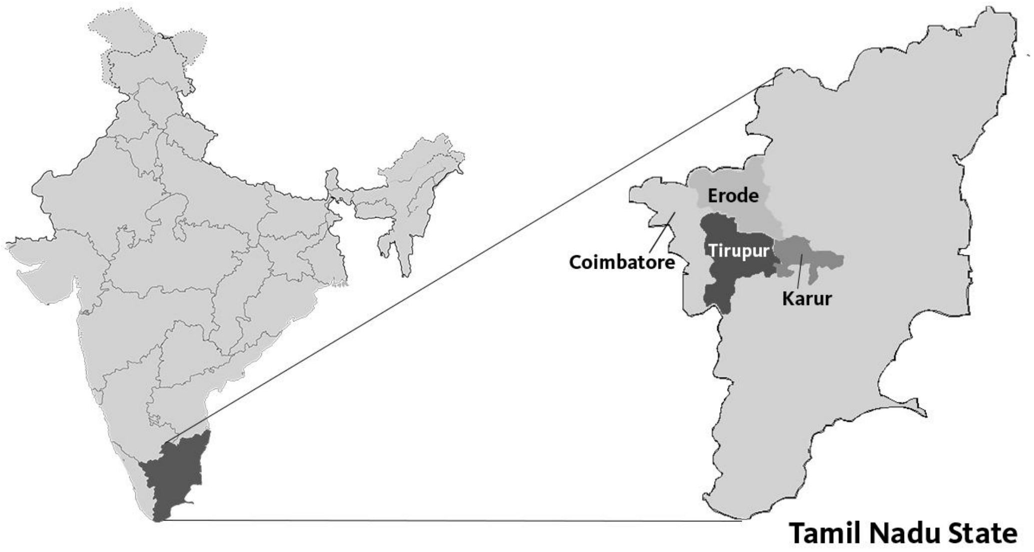


Figure 2. The Tirupur region (not to scale).

The districts in the region are interconnected but largely specialised, with Tirupur renowned as India's knitwear (jersey) capital. Exports of garments to Europe and the US began in the late 1970s. The production of fabrics, hosiery, garments and other predominantly cotton apparel in this region exploded following the liberalisation of the Indian economy in 1991, putting 'Tirupur' on the map, creating jobs, economic growth and investment in infrastructure. Ever since, the region has been deeply integrated into a global producer – buyer network; it has also got involved in a battle revolving round the negative impact on the environment, the agriculture sector, and human health (Blomqvist, 1996; Crow and Batz, 2006; Srinivasan et al., 2014; Nygaard, 2015).

The region's textile sector involves thousands of mainly small and medium-sized factory units, predominantly family-run, many of which form specialised links of the value chain such as knitting, bleaching, dyeing, steam calendaring, finishing, printing, button dyeing or miscellaneous. Factory owners are predominantly of the agrarian *Gounder* caste and many of them were once workers in the industry (Chari, 2000). Erkman and Ramaswamy (2003) estimated that Tirupur had 4000 different kinds of textile units in 1995, but stressed that accurate figures were not available as most are micro-sized or small and not registered with any authorities. No actor has complete records; at the TNPCB, files and licence applications only started to become digitised in 2014/15. In 2016, the Tirupur District provided direct employment to almost 600,000 workers and indirectly to about 1 million people. It counted some 800 garment factories and exporting firms and 1,200 merchant exporters, 425 registered dyeing units and more than 3,000 finishing units, as well as about 2,000 Micro, Small and Medium-sized Enterprises (MSMEs) targeting the domestic market (Confederation of Indian Industry and the Sripuram Trust, 2016). According to the TNPCB, only between 80 and 110 units operated licenced IETPs and around 350 active units were connected to the 18 running CETPs. Those units with IETPs, or being connected to a CETP, are predominantly the export-oriented ones on which Western buyers put higher demands.

The 2011 census counted a population of almost 2.5 million in the Tirupur District. A large proportion of textile workers are migrants from outside and most of them are not registered in Tirupur.

Phase I (pre-development) 1982-1988: From pristine to freshwater-scarce

Tamil Nadu established its Pollution Control Board (PCB) in 1982 and the Board's very first decision, based on powers rendered to it under the Water Act, was to set tolerance limits for trade effluents for various parameters. Some of those depended on the recipient (discharge into inland surface water; public sewers; on land for irrigation; marine coastal areas, respectively). The limit for inorganic dissolved solids (of which TDS is one group) was set at 2,100 mg/L irrespective of the recipient. However, during the 1980s the export-oriented part of the industry in Tirupur began to contribute so significantly to employment generation that it was in practice given a *carte blanche* to operate without restrictions (Blomqvist, 1996). This was the case also in Tamil Nadu's major tannery cluster in Vellore (cf. Kennedy, 1999).

Most of the textile factories in India rely on groundwater, from their own wells and/or purchased from landowners who supply water from deep borewells by tanker. The mid-80s marked the juncture between a time when local freshwater was abundant and of sufficient quality to be fit for the purpose, and the period marked by the practice of bringing in groundwater to Tirupur from a 50 km radius. The water in local aquifers had simply become destroyed from untreated wastewater percolating down and recharging them. A representative of a large dyeing unit reminisced that "[i]n 1984/85 there were no lorries. It was only after that, when the export business started the pollution, got worse and the lorries came … When the people observed that [for] those who were transporting good-quality water from the outside the colours were better, the neighbouring unit would think 'OK, they got better colours just because they are getting water from outside'" (Blomqvist, 1996: 134).

Based on similar experiences, most dyers began to spend a considerable amount of planning time and money to secure freshwater supplies that previously could be taken for granted. Though this was clearly perceived as an increasingly acute problem, not least because of the parallel labour shortage and irregular power supply, alternative solutions such as treatment and recycling were not considered. Neither financial incentives nor social norms prevented further destruction and depletion of surface water and groundwater. The environmental cost could all too easily be externalised on others (ibid).

The negative impact on the environment increased to such an extent that in the late 80s the TNPCB proposed the establishment of a CETP in Tirupur to serve the ca. 250-300 dyeing and bleaching units operating there at the time. The idea was to provide primary treatment before the usual discharge of wastewater. Land was selected and a feasibility study conducted. It was expected that a tenth of the estimated cost of INR 100 million would be covered by federal and state subsidies. But the deadline for the units to register with the CETP by March 1988 came and went and at this point in time, a large number of new units had quickly been set up due to fears that stricter regulations were to be introduced (Sankar, 2001).

Phase II (take-off) 1989-1998: Conflicts and litigations

A Government Order for Tamil Nadu was issued in 1989, imposing a total ban on setting up highly polluting industries such as textile dyeing within one kilometre (1 km) of the embankments of listed rivers. Noyyal was one of them. The Order did, however, not apply to existing units and with a very large number of factories already in place by this time, the intended effect of the ban was very limited. (In 1998, the distance was extended to 5 km.).

By 1991, one single treatment plant was already insufficient. The TNPCB instead proposed that three plants should cater to the then around 500 dyeing and bleaching units in the Tirupur District. In 1995, the Board had no fewer than five new CETPs registered and in operation, with three more coming on line within a year. Private companies were formed for each CETP, and the member units were expected to contribute both as shareholders and with flat monthly fees irrespective of the volume of wastewater sent for treatment. The number of units had grown to around 800 and it was concluded that many of them were located too far from the existing or planned CETPs for which it was considered economically infeasible to lay pipes and connect. Federal and state subsidies had increased in proportion to what the units had to invest themselves; they were later capped at a maximum of INR 5 million per plant. For these reasons, Tirupur was divided into 11 zones, each with a CETP and between 34 to 107 bleaching and/or dyeing units connected to them (Blomqvist, 1996).

But conflict loomed, despite the treatment plants. In the surrounding villages, the over-extraction of groundwater and resulting water scarcity led to heated arguments between farmers and groundwater sellers (Janakarajan, 1999). In Tirupur itself, however, the groundwater table rose in certain areas due to (untreated) effluents from factories being released into streams and injection wells. Aquifers were thereby recharged, but the quality of the groundwater deteriorated. Women in Tirupur's poorer areas in particular began to notice the environmental impacts of the gradually harder water in taste, and in how pulses could not be soaked as usual, the soap would no longer lather well, and how their hair became coarse from washing it with water from streams and wells.

During this phase, much of the negative impact on people and the environment took place by the Orathupalayam Dam, an irrigation reservoir built on the Noyyal River, some 20 km downstream of Tirupur. When it was inaugurated in 1992, the export business in Tirupur had expanded significantly and with it the volumes and toxic contents of discharge, which fundamentally changed the premises of the dam. Farmers interviewed in this area tell how it was looked at as a blessing whilst under construction, until it was realised that instead of freshwater the dam essentially came to store industrial effluent that could not be used on fields. Groundwater also became gradually contaminated, and local wells could no longer provide safe drinking water.

Protests over the Orathupalayam Dam escalated in 1997 when the highly contaminated contents of the dam were released without prior notice, affecting cattle, crops, and residents (Swaminathan, 2014).

Since then, farmers refused to take water from the dam. (In May 2016, records from the Public Works Department, the authority responsible for irrigation matters, showed a TDS level of 3,200 mg/L in the dam. In 2017 the previously productive soils where cotton, turmeric, plantain, vegetables and tobacco used to grow were still subject to proceedings and compensation claims in the National Green Tribunal.)

Simultaneously, farmers and households in the Karur District had begun to bear the brunt of untreated effluent from textiles factories. In 1993, villagers protested when industrial discharge seemed more or less directly connected to the fact that one day, a domestic water supply scheme had red water flowing from the taps. The District Revenue Officer issued notices to 60 factories in the area later that year (Krishnakumar, 1998). It was, however, another chain of action that made residents of Karur – located some 100 km downstream the Noyyal River from Tirupur – stand up against the textile business, and which eventually led to the introduction of the ZLD method. A group of farmers had fought long and hard to have their fields irrigated by water from the Noyyal. One landowner who was also a lawyer by profession, Mr P.R. Kuppusamy (widely known as P.R.K.) drove the process to have an irrigation feeder canal constructed. When finally completed after 15 years of battle in the courts, the farmers woke up to the sour reality that the water that reached their fields was prohibitively polluted and high in TDS. Instead of bringing prosperity to the area, P.R.K.'s accomplishment brought contamination and despair. In 1996, he filed a writ petition, the first sharp shot in the war that ensued.

This request for directions from the Madras High Court that the TNPCB take action against the dyeing and bleaching units was made in the same year as the seminal judgment came in *Vellore Citizens' Welfare Forum vs UoI*, which struck down on tanneries in the state of Tamil Nadu. As ordered by the Supreme Court, the government constituted the 'Loss of Ecology Authority', to review compliance with the order, invoke the polluter pays principle, and deal with all things connected to liability, remedy, and compensation to victims of the environmental degradation. In this order the Supreme Court also made it clear that the maximum TDS effluent standard prescribed by the TNPCB (2,100 mg/L) shall be operative, meaning that the industries would have to adhere to it. Subsequently, the court expanded the jurisdiction of this Authority to cover all industries (Appasamy and Nelliyat, 2007).

P.R.K.'s petition resulted in a report from the TNPCB at the end of 1996, stating that though CETPs were established in Karur as well as in Tirupur the progress was not satisfactory. Consequently, the Madras High Court issued show cause notices to 241 units – requiring them to prove that they were complying with the effluent standards – and closure orders to 53 units. A year later, the Court's Green Bench issued a similar interim order with respect to the Tirupur CETPs and closure of non-complying units. The Dyers Association of Tirupur sought and was granted extended time on behalf of its members. As pointed out by Crow and Batz (2006), in Karur no similar organisation had the clout to protect the industry and there, some 600 dyeing units were closed and the stoppage of work at them affected the whole weaving industry. Two months later, a consensus was reached in Tirupur and some 430 units that had agreed to send their effluents to CETPs were allowed to function until such treatment plants were set up. Shortly thereafter, even those units were found not to be taking serious steps and a large number of them were forced to close (ibid).

While Tirupur's coloured wastewater and the country's renewed efforts to deal with pollution control were making international headlines (cf. Kazmin, 1997), this first conflict between the farming community and households on the one side and the textile industry on the other met with an abrupt ending. P.R.K.'s original petition regarding Tirupur was disposed of by the Madras High Court in 1998 on the basis of a 'consensus approach' laid down in a joint memo filed by the parties (*Kuppusamy vs GoTN*, 1996). As an interim measure the units would be allowed to operate for three more months. If they thereafter failed to obtain formal consent from the TNPCB, the Board would be obliged to [actually] implement the environmental laws of the land, including closing down of units.

The stipulated time passed, and further petitions were filed by P.R.K. and others (*Noyyal River Ayacutdars Protection Ass. vs Government of TN*, 2006). The Court dismissed applications to extend the deadline and ordered closure. The TNPCB was to request the assistance of the District Collector to seal units and disconnect the power supply. However, observations made in 1998 suggest that out of 143 units that were directed to close shop that year, as many as 50% continued to operate illicitly. Night-time operations and alternative power sources such as diesel generators enabled this (Crow and Batz, 2006).

Phase III (acceleration) 1999-2012: New frontrunners enter the stage

By 1999, as per TNPCB records, eight CETPs serving 278 units had begun operations in Tirupur and 424 units had set up IETPs. The plants could – at least on paper – perform primary treatment to remove organic wastes (BOD and COD) to meet national minimum pollution norms, but the majority were not equipped for secondary treatment to remove inorganic salts or to separate dye-bath water from wash-water. The sludge that forms the by-product from the treatment littered the landscape and is visible on satellite images from the time. It piled up and was washed into local water bodies and underground reservoirs by monsoonal rains.

Meanwhile, factory owners may have been more concerned with the need to improve the quality of their garments and to enhance production capacity, all in preparation of the anticipated rise in exports once the textile quotas would be abolished by the World Trade Organization in 2005 (de Neve, 2009).

The year 2002 was marked by two major turning points. One was the start of construction of India's first public – private partnership project to pipe water from the Cauvery River to Tirupur. This was to supply the city's textile industry as well as the domestic users, with the Exporters' Association, the foreign aid agency USAID and the Tamilnadu Water Investment Company, Ltd. (TWIC) involved as some of many stakeholders. When completed in 2005, the New Tirupur Area Development Company, Ltd. could provide nearly 1,000 factories in and around the Tirupur City with a total of around 125 million litres of what is locally called 'L&T water'. Charged initially at 45 INR per cubic metre for a secure and pre-treated source this worked out to be a good deal for the textile business, which had by then largely become accustomed to paying dearly for groundwater trucked in from the hinterland. According to Erkman and Ramaswamy (2003), the industry had paid the equivalent of around USD6 million annually, or almost USD1.00/m^3, for the groundwater in 1995. It was also believed that by enabling a switch from local and sub-standard groundwater – which was still used by many units – the TDS in effluent would decrease, and treatment at CEPTs in particular would become more efficient.

However, as Madhav (2008) has shown, the new supply scheme had several major flaws, including the fact that it was only economically viable if the industry continued to demand the large volume of water it was designed to deliver. Subsequent enforcement of the ZLD method contributed to undermine the model. By 2008 it was clear that the industrial water consumption was far less than expected. According to Mahalingam (2013), this was also due to economic recession, technological advances, and good monsoonal rains that continued to enable the use of water from local wells.

The year 2002 was also the time when local newspapers first mentioned ZLD. The Tamil Nadu edition of *The Hindu* reported that the TNPCB – increasingly pushed by the district administration downstream the river from Tirupur – had begun to advise and direct the region's dyeing units more in detail on how to treat their wastewater more efficiently (Gurumurthy, 2002a, b; Renganathan, 2002). For instance, a deadline was fixed for May 31 for the separation of dye-bath and first rinse waters to reduce their high TDS levels prior to evaporation and subsequent discharge of effluent. The Board had reportedly also advocated the use of an RO process, recovery of Glauber's salt, and MEEs to enable water recycling and – ultimately – 'zero' discharge of wastewater. But the newspapers also mentioned that Tirupur dyers showed hesitance towards trying unproven technology such as solar evaporation pans that they believed may not be viable all year-round and would require space and investments on land that was often leased rather than owned (ibid).

Newspaper reporting and TNPCB's advice did not come out of thin air. Mr K.L. Palaniswamy, a chemical engineer by training and the owner of mid-size dyeing unit Chemtech Processors, had compiled a treatment system consisting of RO membranes and an evaporator, together with a crystalliser of his own design, enabling in-house water recycling. After fine-tuning the system for a year the unit inaugurated its treatment plant in the presence of the TNPCB's chairperson, Ms Sheela Rani Chunkath, and several State Ministers in August 2002. This setup was awarded several times over in the coming year, even by the administration in the country's capital, for delivering what seemed to be a silver bullet in the fight against the ill-effects of wet processing discharges. Palaniswamy could show how to implement the steps on which the TNPCB had begun to advise other units. R&D continued at one CETP, in consultation with the TNPCB, to adopt RO and recovery of water and salts (Eswaramoorthi et al., 2004). In Karur, closure of CETPs in 2002 prompted the Federation of CETPs and ETPs to apply for a government grant via the TNPCB to pilot-test a development of the membrane method in 2003. Further experimenting went on to find alternative energy and fuel sources to firewood, such as windmills (ibid).

Not all Tirupur's dyers and bleachers were happy with this development, however. Shown that it was technically feasible to emit no liquid effluent, the industry faced little choice but to implement the TNPCB's directives on treatment with the stipulated components. Many complied only on paper. Simultaneously, a new round of hearings in the Madras High Court was underway. In 2003, the Noyyal River Ayacutdars Protection Association – another farmers' community – filed a Public Interest Litigation against the dyers. In March 2004, the Court granted interim injunction to restrain the respondents from discharging effluents directly or indirectly into the Noyyal River. Half a year later, the TNPCB followed up by issuing show cause notices to all of the then 729 dyeing or bleaching units in Tirupur, requiring that they implement the effluent treatment standards and achieve ZLD by May 2005. In a parallel intervention, the Court ordered that all dyeing factories and tanneries in Erode District were to adhere to the effluent norms by adopting RO and evaporation for reject management by August 2005 (*People Health and Development vs State of Tamil Nadu*, 2005).

The farmers' grievances and the loss of ecosystem services in the areas affected by the industries in Tirupur were investigated and laid down in a report commissioned by the Loss of Ecology Authority in 2003. Its mandate included identifying the farmers and the amount that they should receive. The Authority awarded compensation in December 2004, to 28,596 farmers in 68 villages in the Noyyal River Basin. The amount to be paid by each industry had been calculated based, among other things, on the level of pollution control. The award was challenged by associations representing irrigation farmers and Tirupur's dyers, and the distribution of the compensation to those affected has been subject to much criticism (Appasamy and Nelliyat, 2007; Venkatachalam, 2015). The initial list of just under 30,000 persons had swelled to 130,000 compensation claim cases before the National Green Tribunal in 2017 (Krishna Chaitanya, 2017).

These could have been the landmark decisions that once and for all settled things. But the deadlines came and went, and no steps were taken to implement the Court orders, no efforts made to get the units to install the necessary equipment and machinery to prevent further deterioration of the water stored in the Orathupalayam Dam (Swaminathan, 2014). It is unclear exactly why the TNPCB as the executive authority did not take measures to ensure compliance. It is possible that, just as in the 1980s, employment generation tipped the balance in favour of the industry, or that the Board became convinced that the technology was new and still needed fine-tuning to function effectively.

Crucial changes to the course of events came in 2005. Two bodies were formed that in many ways became the Court's extended arm. First, the Court found it necessary and appropriate to appoint an Expert Committee to advise on the matters of the Tirupur case. Next, based on a recommendation from the Expert Committee, it appointed a Monitoring Committee consisting of three High Court lawyers. The two Committees investigated the scene more thoroughly from their different perspectives and reached their conclusions (cf. Swaminathan, 2014; Grönwall and Jonsson, 2017). Overall, they pointed out that sludge bags were dumped along river banks, that ZLD was the only recommendable solution to deal with the high TDS levels, and that certain CETPs, who had done better than others, slowed down their work to be on par with the poorly performing CETPs, as they found themselves to be economically in a disadvantageous position after setting up their more expensive ZLD plants. They further said that there was an obvious lack of political will and sense of accountability on most of the involved parties (Swaminathan, 2014; and see summary made in *Noyyal River Ayacutdars Protection Association vs Ramasundara*m, 2011).

In July 2005, the Court directed the TNPCB to immediately close the Tirupur units and CETPs that had not taken concerted steps to establish RO plants. Further extensions were then granted, time and again, for completion of installations. Eventually, the Madras High Court ruled in an interim order at the end of 2006 that ZLD was to be achieved by July, 2007 (*Noyyal River Ayacutdars Protection Ass. and Ors. vs GoTN*). This seminal decision was the first in which a court stipulated technical specifications on ZLD and how this was to be attained through a combination of RO, RO reject management and evaporation.

Electricity power was disconnected at many units and CEPTs unable to provide the required amount towards the cost of installing RO-enabled plants. The interest in upgrading and modernisation was gradual and cautious among those expected to take action. The investment was considered a heavy burden. The industry commissioned TWIC, which is a joint venture of the private financial institution Infrastructure Leasing and Financial Services, Ltd. and the Government of Tamil Nadu, to operate and manage nine of the CEPTs. TWIC approached Italian experts to develop biological treatment methods. At the end of 2010, TWIC was yet to make the RO reject management operational, and all CETPs in Tirupur employed similar approaches, with MVR evaporators – rather than the MEEs that the PCB had suggested – as one key component (cf. Singhal and Gupta, 2010). The MVRs installed soon came under criticism and were retrofitted to optimise their operation. Additional pipes were laid to the member units to enable recycling of RO reject (brine), used instead of, or together with, salt for dye fixation. The solution requires properly trained technical staff and leak-free pipes. Brine cannot be used for light hues, and eventually a surplus volume of the liquid builds up at the units, which must in turn store it.

Appeals and review petitions were lodged and dismissed, and the Supreme Court upheld the 2006 order to close down the industries and treatment plants three times, the final occasion in 2010 (cf. *Noyyal River Ayacutdars Protection Association vs Ramasundaram and Ors*.; 2011). Extended time was repeatedly granted to allow for implementation. Despite the large number of units and CEPTs that were handed closing orders and faced electricity disconnection during this period, it would seem as if the industry attempted at winning the standoff by measured courtroom fatigue.

The Noyyal River Ayacutdars Protection Association filed a contempt petition in 2010, seeking punishment of respondents for wilful disobedience of the 2006 interim order. The Madras High Court in January, 2011 – "fully convinced that unless stringent and deterrent action is taken (…) the water of the Noyyal River cannot be made free from the poisonous substances discharged from these units and the water shall not be fit for human consumption" – ordered immediate closure of all dyeing and bleaching units in the area (*Noyyal River Ayacutdars Protection Association vs Ramasundaram and Ors*.; 2011). Criminal proceedings were to be launched against offenders. This time, the signal was clear.

The Court also ordered the Monitoring Committee, originally set up in 2005, to conduct joint inspections together with the TNPCB, and submit a report for each individual unit. Through such a system, the impact on the industrialists as a collective was reduced. This inspection team found that only a small number of units could be deemed to satisfactorily achieve ZLD. However, assembly elections were held in Tamil Nadu in April 2011, and all parties made the case a campaign issue. Once elected, the new administration formed a high-level committee that reviewed alternative technical solutions, and an INR 2 billion interest-free loan was made available to the CETPs (Valsan, 2011). Seemingly due to political pressure to balance the interests involved – economic growth and job opportunities against local farmers' conditions and environmental protection – the TNPCB recommended that units applying for renewed permissions should have their requests granted.

The acceleration phase completed with a Government Order from the Public Works Department of Tamil Nadu in 2012, prohibiting abstraction of groundwater for commercial purposes. This was issued in large part to guarantee the water supply concession agreement with the New Tirupur Area Development Company, Ltd, whose purpose would be defeated if groundwater could still be pumped and sold by individuals to the textile factories in Tirupur. In addition, by legally hindering the use of groundwater it was hoped that the TDS level in the effluents would be brought down further.

Phase IV (stabilisation) 2013-16: ZLD becomes the norm

For the majority of units, the process to resume production after the closing order of 2011 took up to two years. With such a large number of textile workers having lost their jobs, the impact on the local community was keenly felt for a considerable period, not least the losses of semiskilled workers who left the region altogether. Many CETPs also had a lengthy process ahead of them – 2.5 years in some cases – before they were again up and running. To fulfil contractual obligations the unit owners either outsourced dyeing and bleaching 'job-works' elsewhere in the state or the country, or they themselves set up operations elsewhere. As the 2011 closing order only applied to a limited area – the Tirupur District – some owners were thereby not particularly affected by it, but almost one hundred units never applied for inspection and have not reopened in Tirupur. Some of these factory premises are today overgrown by weeds. Other companies, sources say, are operating on a small (micro-size) scale from residential buildings, discharging their effluent into the municipal sewerage network.

Of the original 20 CETPs 18 were ultimately granted permission to conduct trials. Of those, seven were operated by TWIC, which held a front position among those seeking to advance the technical know-how, and the remainder managed by four different agencies. In 2016 the three top performers were permitted to run at 70 to 75% of their full capacity and the bottom three CETPs to run at just 15%, as per PCB records. Of their constituent members, just over 80% were still operating, ranging from all members connected to one CETP, to only half of them at others. Most units were still struggling to make a profit. The situation mainly affected those connected to CETPs; as none of the plants were yet permitted to operate on full capacity, the units could likewise only send a limited volume of wastewater for treatment and were forced to decline orders that they would otherwise have capacity to take up. Both the CETPs and units with individual ETPs are regularly reviewed by the TNPCB to investigate if the permitted capacity can be raised.

At the end of the timeframe studied, water scarcity no longer constituted a bottleneck to operations among Tirupur-based units. The vast majority of them, which were supplied with the so-called L&T water, paid for it in a way that was essentially unprecedented in India's textile sector (à 78 INR/m^3 in 2017 according to Hussain, 2017). However, outside of the Tirupur District (and Erode) the rules were different in that neither court orders nor generally applicable TNPCB directions existed to make ZLD mandatory. Instead, the Board decided what an individual unit's Consent to Operate was to stipulate on a case-by-case basis.

An increasing number of newspaper articles reported that effluent discharge into surface water bodies continued in Tirupur, (among others, Vimal Kumar, 2015). The Board claimed that it issued notices to noncompliant units and even demolished illegal factories but blamed manpower capacity constraints for not being able to be more proactive in enforcing functional ZLD treatment.

Tirupur's transition I: The multi-phase perspective

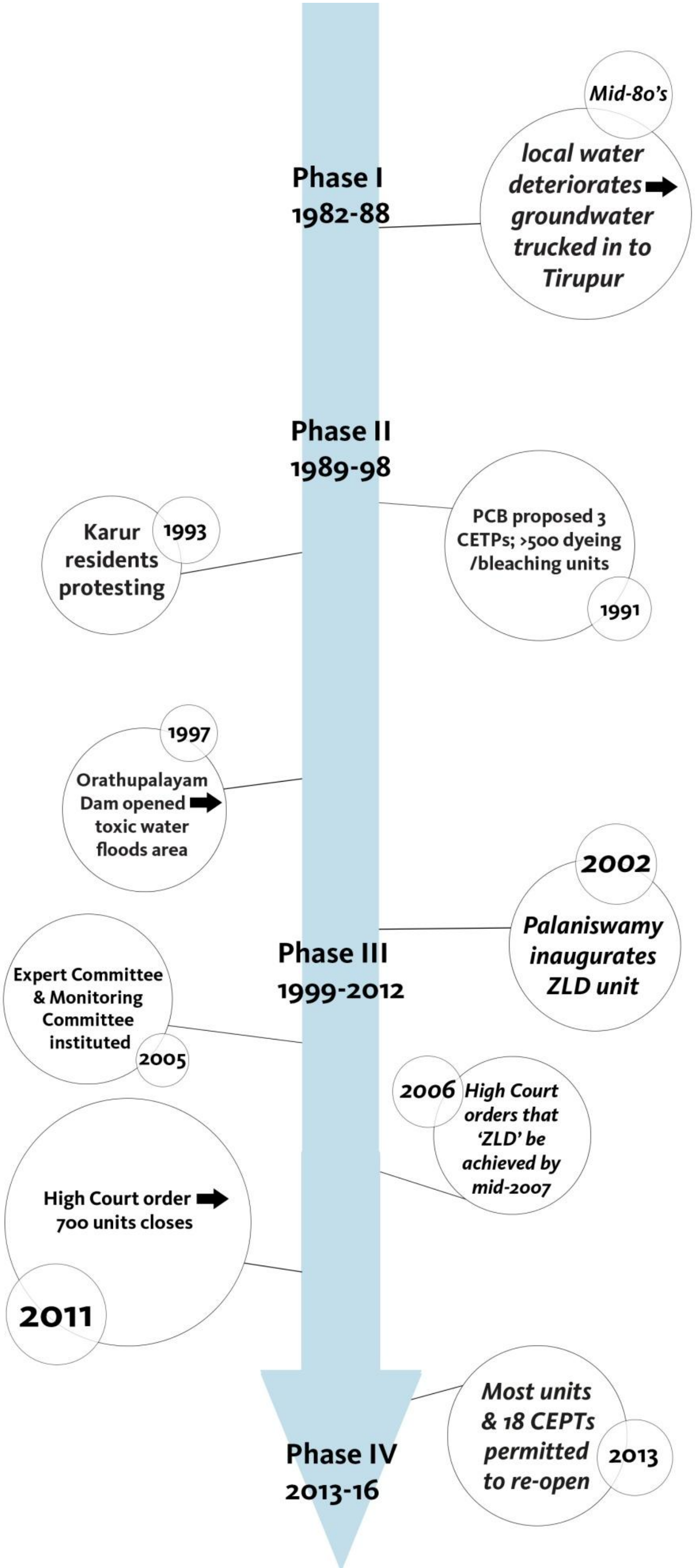
It may be worth recapitulating the situation in Tirupur at the onset of this case study (Figure 3) to conceptualise the initial drivers more clearly. In the early 1980s, Tirupur was already widely renowned as a knitwear hub and deeply engrained in the global textile trade. When thus embarking on its journey towards ZLD, the picture was in most respects the conventional one for the wet processing industry at the time in India: large quantities of water were consumed for the purpose of bleaching and dyeing yarns and fabrics. Effluent was disposed of into surface water bodies and injection wells and onto land, ending up in aquifers and in the river system. But in a major respect, the situation changed into one that was unique: the industry's untreated discharges prevented the use of local water resources, forcing it to source freshwater from further and further away to retain production quality – and fostering the necessity to pay for it.

The first steps of the area's transformation were thus taken. During the second phase, CETPs were seen as key to the win-win-win solution: protecting the environment (technical method); enabling the ever-understaffed TNPCB to control performance at all treatment plants (institutional method); and sharing costs between small and medium-size polluters instead of forcing them to install their own treatment equipment (economics method). There were also – in theory at least – incentives in the form of peer pressure to make the economies of scale work, on the one hand, and to reduce free-riding, on the other. However, the model did not work well for a number of reasons.

The 'take-off' phase in this case is instead marked by conflict, resulting in the two other institutions, the TNPCB and the Madras High Court, stepping in to keep social order in check. A socio-technological transition may start with academic research and gain uptake in society, or be the result of R&D at company level. This can be followed by the policy-maker and/or legislator regulating the field to set enforceable standards which, if not adhered to, are admissible in court. In Tirupur there was essentially a reverse order of development. Protests especially from the farming community put pressure on the TNPCB once the Court had stepped into the arena, forcing a shift to take place much before the sector or the technical research was ready and mature.

Turning to the third, relatively long and eventful phase, three points stand out. First, the mix of change agents – which includes a number of key actors located in Chennai, some of whom had never even visited Tirupur – carried its inherent challenge: from the very beginning no one had the required experience and competence, and thereby legitimacy, to advise based on best practice. No baseline data were available, no pedagogic 'before and after'. In Tirupur the vast majority of unit owners and workers were inexperienced before they learnt on-the-job; the textile industry is India's most important from the point of view that it employs unskilled labour. This fact functions as an impediment both in business transactions with banks and buyers, and when novel technological requirements are raised. Several of the powerful industrial actors showed ingenuity more in the way they managed to postpone compliance with binding standards, and make authorities and the judiciary believe that their units were on track to set up effluent treatment or become constituent members of existing or new CETPs. Jørgensen (2012: 1008) has noted that actors on an arena "require knowledge, since action does not emanate from a central governing body but resides with other actors in the network".

Figure 3. Timeline.



Second, a number of "visible structural changes" (Rotmans et al., 2001) did quite literally alter the landscape, which became marked by artefacts in the form of treatment plants with evaporators and crystallisers towering into the air. The resistance to change can only in part be explained by path dependency in the sense that decisions were based on experience and preference for certain old practices. Rather, the capital expenditures for investing in new treatment equipment together with costs for operation and management – including training of staff – were deterring and continue to deter to this day. Also, there was – and is – a lack of trust in that any of the many different combinations of machinery would be capable of achieving zero discharge of effluent. Early on, some actors instead began fighting for marine outfall – discharging of the effluent at sea via a dedicated pipeline – as an alternative to the ZLD technique. The varied standpoints taken were determined by the range of different attitudes, social norms, and shared assumptions that underlie strategies of companies, associations, and authorities when pushing for their respective vested interests.

Third, though it was not the first court decision to order closing down of a large number of factories, the 2011 order was the culmination of a regulatory risk that very many had neglected or not even registered. Business owners had become accustomed to it being "cheaper to bribe pollution-control officials than comply with the law. 'The bribe just got built into the system'", as a Tirupur middleman was quoted as saying (Subramanian, 2009).

The learning curve in this nonlinear process was steep, and in many ways the acceleration phase resembles the classical S-shape that Rotmans et al. (2001) have used to describe a transition. Nonetheless, it was followed by a fourth phase with signs of stabilisation. It should be stressed that many IETP/CETP operators implemented the directives of the Court and the TNPCB in the years prior to the High Court closing order in 2011. The real take-up of the method, however, came in the last years investigated, when Tirupur stood model for roll-out in the whole country. At this point, ZLD had become the norm for textile effluent handling. Consequently, many actors with stakes in promoting Tirupur's greener production potential claimed that 'zero' discharge was being achieved. Others maintained that Tirupur, just as the vast majority of the textile industry, yet had a long way to go. Either way, everyone in the business must relate to ZLD in 2016.

The stabilisation phase, where a new equilibrium is reached, represents another (relative) equilibrium, which accommodates the seeds of change for the next transition. The fourth phase in this case study can be characterised by maturity and buy-in, and it also paved the way for a phase of pre-development in the next transition, in which the ZLD approach was to be scaled up elsewhere in the country.

Tirupur's transition II: The multi-scalar perspective

Adding a spatial context

In 2015, 'ZLD' had made its break-through in the world of textiles. Several policy reform steps were taken in India that year, most of which with reference to Tirupur's implementing this technique for some time. The approach had also come on the agenda in dominant textile countries such as Bangladesh, China and Ethiopia; a number of experts with deep insights and experience from Tirupur were consulted and made visits to places wishing to set up modern treatment systems enabling water recycling and zero discharge. Vice versa, Tirupur welcomed foreign delegations wishing to learn about ZLD-plants' practical configuration. In short: ZLD was spreading from Tirupur. But the question remains where the approach and technique originally grew and matured, or in other words where the inspiration to adopt and achieve ZLD in Tirupur originated.

Applying a multi-scalar lens to this study challenges simplified explanations regarding Tirupur's uptake of ZLD, such as it being a matter of response to either the regulatory risk connected with the Court repeatedly ordering factory closure, or to water scarcity. Coenen et al. (2012: 977) encourage transition studies to relate explicitly how spatial contexts matter, and generate empirical insights about the distinctive local conditions shaping evolutionary change while making clear "the wider relations of control, dependency, competition and cooperation which influence what can be locally achieved".

With respect to the Indian context it is clear that the socio-technical changes that emerged in Tirupur were locally situated and very much the result of a web of environmental and ecological conditions as well as socio-economic circumstances that spurred a shift and led to technical advances. The industry there went from a freshwater self-sufficiency situation in the 1980s to becoming used to pay dearly for groundwater being trucked in from outside; it still pays a much higher price than elsewhere in India for water from the 'L&T' scheme, wherefore recycling and recovery would appear to be a rational choice. Several spatial dimensions are at play here, such as the industry being forced to source a vital natural resource from the hinterland rather than their own wells, a situation later replaced by the distribution of water from a distant public – private supply scheme with investors as remote as in the US. These constitute a background for ZLD uptake that hardly compares with anywhere else in the country, let alone the world (cf. Valueur, 2013; Hussain, 2017).

However, it is important to remember that Tirupur dyers and bleachers did not implement *zero* liquid discharge so much due to freshwater scarcity, or the high price for sourcing it; but rather, because the Noyyal River provided no dilution effect (assimilative capacity), and the Madras High Court concluded that the river needed concerted revival measures. Tamil Nadu had experienced groundwater and surface water scarcity for an extended period of time; human-induced climate change effects were high on the agenda and the competition over the available water resources fierce and politically charged. This constitutes an additional set of local particularities that may resemble many other places, today or in the future. All the same, the water scarcity picture and pollution are not identical throughout the country, and not all wet processing involves high levels of TDS that require dilution with large volumes of water.

Diffusion?

Another major finding from studying developments in the Tirupur Region is that progress in the field of ZLD gained from semi-coherent but largely uncoordinated pushing from a range of actors – at the regional scale and in the state capital, Chennai, and to some extent elsewhere in India as well as outside the country. Development across the country was, however, a matter of parallel co-evolution rather than diffusion from one place to another. Geographical proximity, market specialisation, and cultural sameness resulted in the transition in the Tirupur District being closely interlinked with and influenced by events, processes, and capacities in other nearby textile and tanneries clusters in the region rather than informed by what may or may not have taken place on the textile arena in, for instance, the state of Gujarat (see below). This is noticeable in how the negative ecological and economic impact among farmers in Karur kick-started the change process against upstream textile industrialists in Tirupur in the mid-90s and how developments reinforced each other.

With regard to the textile sector, did the ZLD innovation trickle down from industrialised countries to eventually take hold in India? The answer is – in some respects – rather the reverse. The historical roots of ZLD are found in the USA. Effluent limitations were regulated under the country's Clean Water Act, 1972, and point source discharges required a permit. The Act set as a target the 'zero discharge' of pollutants into the nation's waters by 1985 (GWI, 2009). The concept's initial development came partly to enable recycling of scarce water resources in the textiles sector (cf. Porter and Brandon, 1976). Moore and Ausley (2004) note that solutions to many aquatic toxicity problems associated with wastewater from wet processing were found and developed as a result of regulatory pressures and industry conditions that existed in the US, Europe, and Japan prior to globalisation, i.e. before the 1995 passage of the North American Free Trade Agreements.

A single attempt at what can be called deliberate diffusion has been found. In 1994, a USAID-funded initiative saw representatives from the Indian textile industry, based in Gujarat and Rajasthan, invited to the US to learn about its application of best available technique and ZLD in the sector. Visits were made to institutions that had carried out extensive research and development work in the minimisation, reduction, and treatment of textile wastewater, as well as facilities that implemented ZLD in their processes (cf. WEC, 1994). Around this time and seemingly in parallel to this initiative, the idea of enabling recycling of scarce water resources and recovery of salts in the dyeing process was evaluated by the North Indian Textile Research Institute (cf. Thakur et al., 1994), but nothing points to there being a relationship between this research and the knowledge exchange spurred by the USAID. Also without any traceable linkages to either of those examples, early adopters in Ahmedabad, Gujarat, seem to have taken up some sort of water recycling and 'ZLD' approach in the early 1990s, but no details are available beyond a brief reference in a court case from the Gujarat High Court in 1995. Some textile processing units held that they applied 'zero effluent discharge', but the Court dismissed this, based on observations that the treatment plants were, in fact, not operational, and that evaporation facilities were under-dimensioned (*Pravinbhai Jashbhai Patel vs State of Gujarat*). Several years later, the same Court directed close to 300 printing and textile dyeing units to apply for requisite clearances under pollution control and other applicable laws. According to reports, this included three industries that claimed to be zero discharge units (*Suo Motu vs Municipal Commissioner*, 2000). To date, it has not been possible to verify whether any textile units actually achieved ZLD, but the concept was apparently familiar in parts of the north and northeast of the country.

The first known ZLD unit in India was the Arvind Mill in Ahmedabad, Gujarat. In the 1990s it was Asia's largest mill. In 1997 it embarked on a major expansion programme in a land-locked part of the country, and set up a new plant with an innovative pollution treatment system. Company managers recall how any possible discharge point into a water stream was prohibitively far away from the planned unit, and instead of laying a pipeline up to such points, or shift the very plant closer to them, it was decided to implement water recycling and zero discharge by installing an MVR evaporator. *Bloomberg News* suggested at the time that the pollution control devices were chosen in part to satisfy an important Western customer, the retail brand Marks & Spencer (cf. Kazmin, 1997).

Frontrunners and enabling actors

With the Arvind example as the exception, there is a striking absence of more in-depth information and knowledge in terms of uptake and adoption of ZLD outside the Tirupur Region until the very last years covered in this study. Nothing suggests that innovations in the textile business in Gujarat in the 1990s, or the capacity-building efforts of the USAID exchange visit, pushed or even influenced technical transformation in the south of the country. Rather, analogous drivers, but also different sets of intermediaries and know-how, were at play to initiate and support change in the south. As mentioned above, there were a bundle of local conditions in the Tirupur Region that drove different actors to change the status quo. Industrialists felt the freshwater scarcity in terms of access to good quality raw water in the 1980s; necessity itself became a factor in the search for solutions for some. After the impact on water quality from the leather and textile factories became a regular topic in the Madras High Court from the early 1990s onwards, and in particular after the Loss of Ecology Authority was established, the TNPCB likely started to feel that the Court was monitoring its actions. Furthermore, the farmers' collectives, at one point led by Mr P.R.K. and the general public put growing pressure on the industry.

It would, however, be wrong to regard the textile industry as one unified actor in the interplay with other stakeholders. Some of its representatives became aware that their activities had a detrimental effect on the environment and ecosystems that their farming parents depended on for their livelihoods. The person who stands out as the frontrunner is Chemtech Processor's owner, Mr Palaniswamy. His travels and learnings about RO membranes used for water desalination in Gulf countries, and about evaporators from the pharmaceutical industry in Ahmedabad, were turned into award-winning ideas of effluent treatment *sans* discharge. This created a certain, albeit limited, level of curiosity and uptake among forward-thinking peers. In comparison, creating the buy-in at the TNPCB was easier and Palaniswamy was also encouraged by seeing that the technique was economically feasible when resource recovery was calculated. The TNPCB is said to have been led by a chairperson with integrity and very strong opinions during a period of three years (2000-2003). This authority within the state's executive body co-shaped the development, with the (Chennai-based) Court impatiently watching. Towards other wet processing units the Board alternated between soft and hard approaches: giving guidance and advice on how to improve treatment (and thereby prevent pollution), and punishing them for not complying with directions (thereby controlling pollution). The TNPCB was instrumental in changing the game, and became further disliked by sections of the industry that preferred business-as-usual and advocated for marine outfall.

Despite enforcement being patchy, the ZLD concept became the new dominant regime first in terms of policy – in the form of TNPCB directives to dyeing units – and judge-made law, and only later through federal law. The role of the regulator may be seen as imperative in promoting and supervising entrepreneurship and steering actors along the decided policy pathway, but the emergence of ZLD in Tirupur can best be labelled as 'bricolage' (using what was available at the time). Many involved describe the journey in terms of trial and error, where components were compiled and combined that had different origins and partly other uses in other sectors and parts of the world. Nonetheless, the construction was far from a simple gathering of whatever was at hand and may work. As found by Valueur (2013), an important step had to be taken by and within the industry in Tirupur: innovation in terms of the adaption of ZLD technology that was pooled from various sources in the world, since no similar setup was found in other countries.

CONCLUDING REMARKS

An integrated *reduce – reuse – recycle – recover* approach has begun to replace end-of-pipe treatment solutions for textiles wastewater in many parts of the world, including India. But recycling and recovery of influent water and chemicals such as fixation salts has only gradually become best practice, despite being developed back in the 1970s in the US along with advances in membrane filtration and reverse osmosis. Issues with technical feasibility, along with socio-economic considerations in terms of the costs involved, have prevented the wider uptake.

In this article we have put a spotlight on Tirupur, the centre stage of a globally important textile region, and identified four phases of its transition over the defining 35 years: from a period characterised by large volumes of freshwater consumption and no treatment of textile effluent; to an advanced approach to wastewater handling with recycling and ZLD as the norm. Progress towards ZLD becoming standard involved bricolage, adaptation, resistance, and socio-economic losses during the non-linear but steep learning curve of the 'acceleration' phase. Competition and conflict over shared natural resources were important drivers. The findings illustrate the role of frontrunners showing the way on an arena with largely uncoordinated actors; and of the benefits – but also the costs – of trial and error. As with most businesses operating on fiercely competitive markets, the textile industry is characterised neither by internal cooperation nor by transparency, but it stands clear that the existence of a number of associations with good networks, which represent various wet processing subsectors, had a certain impact on the outcome of events. In turn, irrigating farmers have their associations, which their members benefit from.

Our findings also suggest that frontrunners in Tirupur were able to draw from innovations in wastewater treatment and desalination with RO membranes in various locations around the world, which helped in pushing for a shift in perception of what modern effluent treatment entails. While development of ZLD across India may have been a matter of parallel co-evolution more than diffusion from one place in the country to another, however, the final tweaking of the method for the textile sector was a very local technical leapfrog made in Tirupur, rather than a trickling down from an industrialised country to a developing one.

Tirupur's journey has had a mixed impact on local communities and the entire textile industry's sustainability. On the one hand, it inspired federal law and policy reform to mainstream ZLD as a standard (which might have levelled the playing field for Tirupur's industrialists had the initial ideas been fully realised, cf. Grönwall and Jonsson, 2017). On the other hand, the impact of this journey came at a high price at least to parts of the business whose reconfigurations were dismissed by the court as failing to achieve ZLD. This resulted in closing down of their operations either for periods of time or permanently, and an ensuing loss of income for a very large group of workers. The absence of a baseline with which to compare, and difficulty to obtain reliable data on today's water consumption and pollution load, prevent the drawing of conclusions in terms of the effects on the environment and people's access to safe drinking water.

The study shows how local conditions and spatial context mattered to initiate and shape transitional change. From being fostered to pay for freshwater, its cost worked as an incentive to recycling it in Tirupur. The picture is different in other parts of India where the factories mainly source raw water from borewells, making water recycling less financially attractive. Uptake elsewhere may also depend on political will to ensure enforcement, and complementary policy instruments such as government subsidies and access to guidance, training and skilled workers.

Though stabilisation seemed to have been reached in 2016, a new process of transition and alteration of practices may be prompted by adaptation and further development of the technology that enables ZLD. The Tirupur case study suggests that there are risks involved in pushing for a certain method with specified components as a silver bullet to achieve greater sustainability in society. This is especially the case when the choice involves a trade-off between water conservation and reduced wastewater discharge on the one hand, and a high energy demand and CO_2 emissions on the other.

Future research will need to shed light on questions as yet unanswered. One relates to the role of pressure – if any – from Western brands and buyers on their suppliers to adopt ZLD. Another relevant question is whether the concept of *minimum* liquid discharge (MLD) is gaining traction at the expense of *zero* liquid discharge, and if this may then lead to an ever-increasing implementation gap. There are also fundamental dimensions of power involved in the transition that Tirupur has undergone, which warrant their own study.

ACKNOWLEDGEMENTS

We are grateful to the more than 100 informants who generously shared their knowledge and perspectives on the transition of Tirupur with us during fieldwork in 2015 to 2017, and to reviewers who provided useful comments on an earlier version of this paper. Funding for this study came from the Swedish Research Council Formas, grant number 2014-8646-27375-33.

REFERENCES

Appasamy, P. and Nelliyat, P. 2007. *Compensating the loss of ecosystem services due to pollution in Noyyal River basin, Tamil Nadu*. Chennai: Madras School of Economics 14/2006.

Blomqvist, A. 1996. Food and fashion: Water management and collective action among irrigation farmers and textile industrialists in South India. Linköping: Linköping Studies in Arts and Science 148.

Chari, S. 2000. The agrarian origins of the knitwear industrial cluster in Tiruppur, India. *World Development* 28(3): 579-599.

Coenen, L.; Benneworth, P. and Truffer, B. 2012. Toward a spatial perspective on sustainability transitions. *Research Policy* 41(6): 968-979.

Cook, F. 1994. Salt requirements put pressure on wet processing plants. *Textile World* 144(8): 83-86.

Confederation of Indian Industry and the Sripuram Trust. 2016. Tirupur vision 2020. Unpublished report; available on file with the authors.

Crow, M. and Batz, M.B. 2006. Clean and competitive? Small-scale bleachers and dyers in Tirupur, India. In Blackman, A. (Ed), *Small firms and the environment in developing countries: Collective impacts collective action*, pp. 147-170. Washington, DC: RFF Press.

de Neve, G. 2009. Power, inequality and corporate social responsibility: The politics of ethical compliance in the South Indian garment industry. *Economic & Political Weekly* 44(22): 63-71.

ElDefrawy, N.M.H. and Shaalan, H.F. 2007. Integrated membrane solutions for green textile industries. *Desalination* 204(1-3): 241-254.

Erkman, S. and Ramaswamy, R. 2003. *Applied industrial ecology: A new platform for planning sustainable societies*. Bangalore: Aicra Publishers.

Eswaramoorthi, S.; Dhanapal, K. and Karpagam, J. 2004. *Zero discharge-treatment options for textile dye effluent: A case study at Manickapurampudur common effluent treatment plant, Tirupur, Tamil N*adu. Hyderabad: EPIC in India. DOI: 10.13140/2.1.2098.7849.

European Commission. 2003. Reference document on best available techniques for the textiles industry. http://eippcb.jrc.ec.europa.eu/reference/BREF/txt_bref_0703.pdf (accessed 30 April 2017)

Ganapati, S.V.; Prasadarao, I.P.S.; Godbole, S.H.; Kothandaraman, V. and Koshy, T. 1965. The ecology of solar sewage drying beds in the Pirana sewage farm at Ahmedabad. *Hydrobiologia* 26(1-2): 242-270.

Geels, F. 2002. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy* 31(8-9): 1257-1274.

GWI (Global Water Intelligence). 2009. From zero to hero – The rise of ZLD. *Global Water Intelligence* 10(12) December.

Grönwall, J. and Jonsson, A.C. 2017. Regulating effluents from India's textile sector: New commands and compliance monitoring for zero liquid discharge. *Law, Environment and Development Journal* 13(1): 13.

Gurumurthy, G. 2002a. TNPCB deadline lapses; no relief in sight for Tirupur dyeing units. *The Hindu Business Line,* 3 June 2002.

Gurumurthy, G. 2002b. Chemtech installs system to treat dye-house waste. *The Hindu Business Line*, 23 August 2002.

Hussain, S.I. 2017. Experiences with ZLD and way forward. Jal Manthan 2017. Ministry of Water Resources. Presentation 13 January 2017. http://wrmin.nic.in/writereaddata/01_Experiences%20in%20ZLD%20and%20way%20forward_ISHusain.pdf (accessed 30 April 2017)

Janakarajan, S. 1999. Conflicts over the invisible resource in Tamil Nadu: Is there a way out? In Moench, M.; Caspari, E. and Dixit, A. (Eds), *Rethinking the mosaic: Investigations into local water management,* pp. 123-59. Kathmandu, Nepal: Nepal Water Conservation Foundation, Kathmandu, and the Institute for Social and Environmental Transition, Boulder, Colorado, USA.

Jørgensen, U. 2012. Mapping and navigating transitions: The multi-level perspective compared with arenas of development. *Research Policy* 41(6): 996-1010.

Kazmin, A.L. 1997. India to industry: Clean up or shut down. *Bloomberg Business*, 28 September 1997.

Kennedy, L. 1999. Cooperating for survival: Tannery pollution and joint action in the Palar Valley (India). *World Development* 27(9): 1673-1691.

Krishna Chaitanya, S.V. 2017. NGT may hear Noyyal, Amaravathi ryots' cases next month. New Indian Express 30 March. www.newindianexpress.com/cities/chennai/2017/mar/30/ngt-may-hear-noyyal-amaravathi-ryots-cases-next-month-1587560.html (accessed 30 April 2017)

Krishnakumar, A. 1998. A pollution challenge. *Frontline* 15(13): June 20 – July 03.

Kuppusamy vs GoTN (W.P. No. 1649/1996). Joint memo filed, Madras High Court.

Madhav, R. 2008. *Tirupur water supply and sanitation project: An impediment to sustainable water management*? IELRC Working Paper. Geneva: International Environmental Law Research Centre.

Mahalingam, A. 2013. Implementing PPP programs in the urban water and sanitation sector: Some insights from the Indian experience in selected states. In Gunawansa, A. and Bhullar, L. (Eds), *Water governance: An evaluation of alternative architectures*, pp. 193–21. Cheltenham, UK: Edward Elgar.

Mani, P. and Madhusudanan, M. 2014. Zero liquid discharge scheme in a common effluent treatment plant for textile industries in Tamilnadu, India. *Nature Environment and Pollution Technology* 13(4): 769-774.

MoEFCC (Ministry of Environment, Forest and Climate Change, Government of India). 2015. Draft notification: Standards for effluents from textile industry. www.moef.gov.in/sites/default/files/Effluents%20from%20Textile%202.12.15.pdf (accessed 30 April 2017)

MoEFCC. 2016. Environment (Protection) Fifth Amendment Rules, 2016: Standards for discharge of effluents from textile industry. G.S.R. 978(E). New Delhi 10 October 2016. www.indiaenvironmentportal.org.in/files/file/Amended%20EPA%20Rules%20textile.pdf (accessed 30 April 2017)

Ministry of Textiles, Government of India. 2016. Annual report 2015-16. http://texmin.nic.in/sites/default/files/ar_15_16_ENG.pdf (accessed 30 April 2017)

Moore, S. and Ausley, L. 2004. Systems thinking and green chemistry in the textile industry: Concepts, technologies and benefits. *Journal of Cleaner Production* 12(6): 585-601.

Noyyal River Ayacutdars Protection Ass. and Ors. vs Government of TN, Public Works Department and Ors.; 22 Dec 2006 (2007 (1) LW 275).

Noyyal River Ayacutdars Protection Association vs S. Ramasundaram, I.A.S. and Ors. 28 January 2011 (LS/Mad/2011/506).

Nygaard, H.H. 2015. Sustainable textile production, Tirupur, India: Final report from a multi-stakeholder pilot implementation project in the Nordic countries and Tirupur, India. Tema Nord. 2015: 527. Copenhagen: Nordic Council of Ministers.

People Health and Development vs State of Tamil Nadu. 2005. 2 MLJ 44 (2).

Porter, J.J. and Brandon, C. 1976. Zero discharge as exemplified by textile dyeing and finishing. *Journal of Chemtech* 6: 402-407.

Pravinbhai Jashbhai Patel and Ors. vs State of Gujarat and Ors., 1995 2 GLR 1210.

Public Works Department, Government of Tamil Nadu. 2012. G.O.(Ms) No. 52. Ground water. New Delhi.

Raja Sankar, P. and Rajesh, S. 2017. A study on zero liquid discharge plant for dyeing industry. International *Journal of Scientific Engineering and Research* 5(4): 67-72.

Renganathan, L. 2002. TNPCB orders closure of Karur dyeing units, CETPs. *The Hindu*, 1 December 2002.

Rotmans, J.; Kemp, R. and van Asselt, M. 2001. More evolution than revolution: Transition management in public policy. *Foresight* 3(1): 15-31.

Sankar, U. 2001. *Economic analysis of environmental problems in tanneries and textile bleaching and dyeing units and suggestions for policy action*. Chennai: Allied Publisher Ltd.

Singhal, V. and Gupta, K.C. 2010. Visit report of effluent treatment plants/common effluent treatment plants in the country. Rajasthan State Pollution Control Board. www.indiaenvironmentportal.org.in/files/visit%20Report%20final%2018_01_2010.pdf (accessed 30 April 2017)

Srinivasan, V.; Kumar, S.D.; Chinnasamy, P.; Sulagna, S.; Sakthivel, D.; Paramasivam, P. and Lele, S. 2014. *Water management in the Noyyal River basin: A situation analysis*. Environment and Development Discussion Paper No. 2. Bangalore: ATREE.

Subramanian, S. 2009. The high price of T-shirts. Audubon Magazine archive.audubonmagazine.org/webexclusives/dyes-webexclusives.html (accessed 22 March 2016)

Suo Motu vs Municipal Commissioner. 2000. 1 GLR 525.

Sustainability Outlook. 2015. Zero liquid discharge: Outlook for Indian industry. http://sustainabilityoutlook.in/content/market/zero-liquid-discharge-outlook-indian-industry-755079 (accessed 30 April 2017)

Swaminathan, P. 2014. Regulating industrialization through public action and legal intervention: Interpreting an ongoing experiment in Tamil Nadu. In Das, K. (Ed), *Globalization and standards. Issues and challenges in Indian business*, pp. 225-244 . New Delhi: Springer.

Thakur, B.; Joshi, M.; Chakraborthy, M. and Pathak, S. 1994. Zero discharge in textile processing through TDS control. *American Dyestuff Reporter* 83(8): 32.

Valsan, B. 2011. Dead river's revenge. *The Times of India*, 21 August 2011.

Valueur, C. 2013. The potential for green textile sourcing from Tirupur – On the path to more sustainable global textile chains. *TemaNord* 2013: 540.

Vellore Citizens' Welfare Forum vs Union of India (AIR 1996 5 SCC 647).

Venkatachalam, L. 2015. Environmental implications of the manufacturing sector: A case study of textile manufacturing in Tiruppur, Tamil Nadu, India. *Review of Development and Change* XX(2): 165-175.

Vimal Kumar, R. 2015. Effluent discharge into water bodies continues in Tirupur. *The Hindu*, May 2 2015.

Vishnu, G.; Palanisamy, S. and Joseph, K. 2008. Assessment of fieldscale zero liquid discharge treatment systems for recovery of water and salt from textile effluents. *Journal of Cleaner Production* 16(10): 1081-1089.

WEC (World Environment Center). 1994. Review of pollution prevention control technology in the textile industry. http://pdf.usaid.gov/pdf_docs/PNABU140.pdf (accessed 30 April 2017)

WTO (World Trade Organization). 2016. World trade statistical review 2016. www.wto.org/english/res_e/statis_e/wts2016_e/wts2016_e.pdf