CA Discussion Paper 4

COMPREHENSIVE Assessment of water management in agriculture

Groundwater Pollution and Emerging Environmental Challenges of Industrial Effluent Irrigation in Mettupalayam Taluk, Tamil Nadu

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Contents

Abstract

Industrial disposal of effluents on land and the subsequent pollution of groundwater and soil of surrounding farmlands – is a relatively new area of research. The environmental and socioeconomic aspects of industrial effluent irrigation have not been studied as extensively as domestic sewage based irrigation practices, at least for a developing country like India. The disposal of effluents on land has become a regular practice for some industries. Industries located in Mettupalayam Taluk, Tamil Nadu, dispose their effluents on land, and the farmers of the adjacent farmlands have complained that their shallow open wells get polluted and also the salt content of the soil has started building up slowly. This study attempts to capture the environmental and socioeconomic impacts of industrial effluent irrigation in different industrial locations at Mettupalayam Taluk, Tamil Nadu, through primary surveys and secondary information.

This study found that the continuous disposal of industrial effluents on land, which has limited capacity to assimilate the pollution load, has led to groundwater pollution. The quality of groundwater in shallow open wells surrounding the industrial locations has deteriorated, and the application of polluted groundwater for irrigation has resulted in increased salt content of soils. In some locations drinking water wells (deep bore wells) also have a high concentration of salts. Since the farmers had already shifted their cropping pattern to salt-tolerant crops (like jasmine, curry leaf, tobacco, etc.) and substituted their irrigation source from shallow open wells to deep bore wells and/or river water, the impact of pollution on livelihoods was minimized.

Since the local administration is supplying drinking water to households, the impact in the domestic sector has been minimized. It has also been noticed that in some locations industries are supplying drinking water to the affected households. However, if the pollution continues unabated it could pose serious problems in the future.

1. INTRODUCTION

With the growing competition for water and declining freshwater resources, the utilization of marginal quality water for agriculture has posed a new challenge for environmental management.[1] In water scarce areas there are competing demands from different sectors for the limited available water resources. Though the industrial use of water is very low when compared to agricultural use, the disposal of industrial effluents on land and/or on surface water bodies make water resources unsuitable for other uses (Buechler and Mekala 2005; Ghosh 2005; Behera and Reddy 2002; Tiwari and Mahapatra 1999). A water accounting study conducted by MIDS (1997) for the Lower Bhavani River Basin (location map in Appendix A) shows that industrial water use (45 million cubic meters (Mm^3)) is almost 2 percent of the total water use in the basin (2,341 Mm^3) and agriculture has the highest share, more than 67 percent or 1,575 Mm^3. Industry is a small user of water in terms of quantity, but has a significant impact on quality. Over three-quarter of freshwater drawn by the domestic and industrial sector, return as domestic sewage and industrial effluents which inevitably end up in surface water bodies or in the groundwater, thereby affecting water quality. The 'marginal quality water' could potentially be used for other uses like irrigation. Hence, the reuse of wastewater for irrigation using domestic sewage or treated industrial effluents has been widely advocated by experts and is practiced in many parts of India, particularly in water scarce regions. However, the environmental and socioeconomic impact of reuse is not well documented, at least for industrial effluents, particularly for a developing country like India where the irrigation requirements are large.

The reuse of industrial effluents for irrigation has become more widespread in the State of Tamil Nadu after a High Court order in the early 1990s, which restricted industries from locating within 1 kilometer (km) from the embankments of a list of rivers, streams, reservoirs, etc.[2] The intention of this order was to stop industries from contaminating surface water sources. Apart from the High Court order, industrial effluent discharge standards for disposal on inland surface water bodies are stringent when compared to disposal on land for irrigation, specifically for Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Residual Chlorine (TRC) and heavy metals (see CPCB 2001; and Appendix C, Table C1 for more details). Therefore, industries prefer to discharge their effluents on land. Continuous irrigation using even treated effluents may lead to groundwater and soil degradation through the accumulation of pollutants. Currently, industries are practicing effluent irrigation without giving adequate consideration to the assimilation capacity of the land. As a result the hydraulic and pollution load often exceeds the assimilative capacity of the land and pollutes groundwater and the soil. Apart from the disposal of industrial effluents on land, untreated effluents and hazardous wastes are also injected into groundwater through infiltration ditches and injection wells in some industrial locations in India to avoid pollution abatement costs (Sharma 2005; Ghosh 2005; Behera and Reddy 2002; Tiwari and Mahapatra 1999). As a result, groundwater resources of surrounding areas become unsuitable for agriculture and/or drinking purposes. Continuous application of polluted groundwater for irrigation can also increase the soil salinity or alkalinity problems in farmlands.

[1]Marginal-quality water contains one or more chemical constituents at levels higher than in freshwater.

[2]According to the Ministry of Environment and Forests (MoEF), Government of Tamil Nadu (GoTN), G. O. Ms. No: 1 dated 06 February 1984, no industry causing serious water pollution should be permitted within one kilometer from the embankments of rivers, streams, dams, etc. The MoEF, GoTN passed another G. O. Ms. No: 213 dated 30 March 1989 amending the above order which put a total ban on the setting up of only fourteen categories of highly polluting industries, which include Pulp and Paper (with digestor) and Textile Dyeing Units, within one kilometre from the embankments of a list of rivers, streams, reservoirs, etc., including the Bhavani River (Source: http://www.tn.gov.in/gorders/eandf/ef-e-213-1989.htm - accessed on October 10, 2006).

Industrial pollution in Mettupalayam Taluk of the Bhavani River Basin is very location specific and occurs mainly in Thekkampatti, Jadayampalayam and Irumborai villages.[3] These areas are in the upstream segments of the Bhavani River Basin located immediately after the thickly forested catchments of the river, upstream of the Bhavanisagar Reservoir (location map in Appendix A). Ten industrial units, which include textiles, paper and pulp, are located in Mettupalayam Taluk. These water intensive units are basically large and medium scale units, which meet their water requirement (approximately 10 million liters per day) directly from the Bhavani River, as their average distance from the river is 1.89 km (0.8 – 4.2 km.).[4] Most of the units discharge their effluents (estimated to be 7 million liters daily (mld); see Appendix B. Table B2) on land ostensibly for irrigation within their premises. Over time, the effluents have percolated to the groundwater causing contamination (WTC, TNAU and MSE 2005). As a result, farmers in the adjoining areas have found the groundwater unsuitable for irrigation. In some cases, drinking water wells (deep bore wells) have also been affected. Continuous application of polluted groundwater for irrigation has also resulted in rising salinity in soil. To some extent farmers are coping with the problem by cultivating salt-tolerant crops and/or by using other sources such as river water for irrigation. Since the local administration is supplying drinking water to households mostly from the Bhavani River and since the water quality of the river is not polluted, the quality of drinking water seems to be good, and the impact in the domestic sector has been minimized. It has also been noticed that, in some locations, industries are supplying drinking water to the affected households from the Bhavani River.

The objectives of this study are to (a) investigate the quality of soil and groundwater of surrounding farmlands in different industrial locations in Mettupalayam Taluk, Tamil Nadu, where industrial units dispose effluents on their own land for irrigation, (b) understand the impacts of groundwater and soil pollution on livelihoods, and (c) document the ways and means adopted by the farmers to mitigate the problem of pollution.

2. ISSUES ASSOCIATED WITH INDUSTRIAL EFFLUENT IRRIGATION

Domestic wastewater has always been a low cost option for farmers to go in for irrigated agriculture in water scarce regions of the world. Apart from its resource value as water, the high nutrient content of domestic wastewater helps the farmers to fertilize their crops without spending substantial amounts on additional fertilizers. In addition, temporal and spatial water scarcity, along with the rising demand for water from competing sectors (growing population, urbanization and industrialization), have also forced the farmers to go for wastewater irrigation. However, safe utilization of wastewater for irrigation requires the use of proper treatment and several precautionary measures in place, as it may cause environmental and human health hazards (Buechler and Scott 2005; Butt et al. 2005; Minhas and Samra 2004; Bradford et al. 2003; Ensink et al. 2002; van der Hoek et al. 2002; Abdulraheem 1989). Currently in India, most of the urban local bodies cannot afford to make large investments in infrastructure for collection, treatment and disposal of wastewater, and as a result wastewater is mostly used without proper treatment and adequate precautionary measures. In a

[3]The Bhavani River is the second largest perennial river of Tamil Nadu and one of the most important tributaries of the Cauvery River.

[4]In India, manufacturing industries are divided into large/medium and small-scale industries on the basis of the limit of capital employed in plant and machinery. Units below the prescribed limit of Rs. 1 Crore are called small-scale industrial (SSI) units, while the rest are called large and medium scale units.

developing country like India, industrial effluents as well as hospital and commercial waste often get mixed with domestic sewage, and unlike developed countries where industrial effluents often get mixed with domestic sewage to dilute industrial pollutants and toxicants for better/easier treatment, in India mostly urban diffused industrial units (mostly SSIs) dispose their untreated effluents in public sewers as a regular practice to avoid the costs of effluent treatment. In India only 24 percent of wastewater is treated (primary only) before it is used in agriculture and disposed into rivers, and that is also for Metrocities and Class – I cities (Minhas and Samra 2004). When treatment is not adequate, the application of domestic wastewater on land might cause various environmental problems like groundwater contamination (bacteriological and chemical), soil degradation, and contamination of crops grown on polluted water (McCornick et al. 2003, 2004; Scott et al. 2004). Irrigation with treated/untreated industrial effluent is a relatively new practice, since it is seen (a) as a low cost option for wastewater disposal, (b) as a reliable, assured and cheap source for irrigated agriculture, especially in water starved arid and semi-arid parts of tropical countries, (c) as a way of keeping surface water bodies less polluted, and also (d) as an important economic resource for agriculture due to its nutrient value.

Instances of industrial effluent disposal (mostly untreated or partially treated) on land for irrigation are very limited in developed countries like the USA, UK, Canada and Australia. In India having the option to dispose effluents on land encourages the industries to discharge their effluents either on their own land or on the surrounding farmlands in the hope that it will get assimilated in the environment through percolation, seepage and evaporation without causing any environmental hazards. Environmental problems related to industrial effluent disposal on land have been reported from various parts of India and other countries. Disposal on land has become a regular practice for some industries and creates local/regional environmental problems (Kumar and Shah n.d.; Rahmani 2007; Müller et al. 2007; Ghosh 2005; Jain et al. 2005; Kisku et al. 2003; Behera and Reddy 2002; Salunke and Karande 2002; Senthil Kumar and Narayanaswamy 2002; Barman et al. 2001; Singh et al. 2001; Gurunadha Rao et al. 2001; Subrahmanyam and Yadaiah 2001; Gowd and Kotaiah 2000; Pathak et al. 1999; Tiwari and Mahapatra 1999; Subba Rao et al. 1998; NGRI 1998; Singh and Parwana 1998; Lone and Rizwan 1997; Kaushik et al. 1996; Shivkumar and Biksham 1995; Narwal et al. 1992; Kannan and Oblisami 1990). There is substantial literature on the benefits and costs of domestic sewage based irrigation practices (Scott et al. 2004; Keraita and Drechsel 2004; IWMI 2003; van der Hoek et al. 2002; Qadir et al. 2000; Qadir et al. 2007). However, the disposal of industrial effluents on land for irrigation is a comparatively new area of research and hence throws new challenges for environmental and agricultural management (Narwal et al. 2006; Garg and Kaushik 2006; Singh and Bhati 2005; Buechler and Mekala 2005; Bhamoriya 2004; Chandra et al. 2004; Lakshman 2002; Sundramoorthy and Lakshmanachary 2002; Behera and Reddy 2002; Gurunadha Rao et al. 2001; Singh et al. 2001; and Subba Rao et al. 1998).

Water quality problems related to the disposal of industrial effluents on land and surface water bodies, are generally considered as a legal problem – a violation of environmental rules and regulations. However, Indian pollution abatement rules and regulations provide options to industries to dispose their effluents in different environmental media, e.g., on surface water bodies, on land for irrigation, in public sewers or marine disposal, according to their location, convenience and feasibility. There are different prescribed standards for different effluent disposal options (CPCB 2001). As far as industries are concerned, their objective is to meet any one of those standards, which is feasible and convenient for them to discharge their effluents. The standards are set with the assumptions that the environmental media have the capacity to assimilate the pollution load so that no environmental problems will arise. However, when the assimilative capacity of the environmental media (surface water bodies or land) reach/cross the limits, large-scale pollution of surface water and groundwater occurs. Such instances have been recorded from industrial clusters in various parts of the country - Ambur; Thirupathur; Vellore; Ranipet; Thuthipeth; Valayambattu and Vaniyambadi of Vellore District,[5] Kangeyam; Dharapuram and Vellakoil of Erode District, Tiruppur at Coimbatore District and Karur at Karur District[6] in Tamil Nadu (Sankar 2000; Appasamy and Nelliyat 2000; Nelliyat 2003, 2005; Thangarajan 1999); Vadodara, Bharuch, Ankleshwar, Vapi, Valsad, Surat, Navsari, Ankleswar in Gujarat (Hirway 2005); Thane - Belapur in Maharashtra (Shankar et al. 1994); Patancheru, Pashamylaram, Bollarum, Katedan, Kazipally, Visakhapatnam in Andhra Pradesh (Behera and Reddy 2002; Gurunadha Rao et al. 2001; Subrahmanyam and Yadaiah 2001; Subba Rao et al. 1998; NGRI 1998; Shivkumar and Biksham 1995); Ludhiana,[7] Amritsar, Jalandhar, Patiala, Toansa and Nangal - Ropar District in Punjab (Ghosh 2005; Tiwari and Mahapatra 1999). Since all the prescribed standards for disposal are effluent standards, the impact on ambient quality cannot be directly linked to disposal or vice versa, as a result point source in effect acts as non-point source pollution. In India and other developing countries pollution control of non-point sources is mostly neglected, point sources prefer to avoid pollution abatement costs through various pollution-sheltering activities like pumping untreated effluents to the groundwater and disposing hazardous wastes into open wells (Sharma 2005; Ghosh 2005; Behera and Reddy 2002; Tiwari and Mahapatra 1999). Like in many other countries, in India, industry and agriculture coexist in the same geographical area and share the same water resources of the basin. When industries or towns withdraw large quantities of water for their use and/or discharge almost an equivalent amount of wastewater, they cause an 'externality' problem to other users. Their action(s) has an economic impact on other users in the basin. Any pollution sheltering activities or avoidance of pollution abatement costs in terms of disposal of untreated, partially treated or diluted industrial effluents on land or surface water bodies could transfer a large cost to society in terms of environmental pollution and related human health hazards. For example, in India water borne diseases annually put a burden of US$ 3.1 to 8.3 million in 1992 prices (Brandon and Hommann 1995).

2.1 Water Use in Agriculture

In India, the supply of freshwater resources is almost constant and the agriculture sector draws the lion's share, 80-90 percent (Kumar et al. 2005; Gupta and Deshpande 2004; Vira et al. 2004; Chopra 2003). Hence, with the growing demand/competition for water and its rising scarcity, the future demands of water for agricultural use cannot be met by freshwater resources alone, but will gradually depend on marginal quality water or refuse water from domestic and industrial sectors (Bouwer 2000; Gleick 2000). However, both domestic sewage and industrial effluents contain various water pollutants, which need to be treated before use for irrigation. Water quality is a key environmental issue facing the agricultural sector today (Maréchal et al. 2006). Meeting the right quantity and desirable quality of water for agriculture is not only essential for food security but also for food safety.

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[5]See *vide Vellore Citizens' Welfare Forum vs. Union of India & Others, Writ Petition (C) No. 914 of 1991* (Source: http://www.elaw.org/resources/printable.asp?id=199 - accessed on 12 September 2006)

[6]See http://cgwb.gov.in/SECR/mass_aware_prg.htm (accessed on 12 September 2006)

[7]See http://www.tifac.org.in/itsap/water4.htm; and http://www.punjabenvironment.com/water_quality.htm (accessed on 12 September 2006)

2.2 Point Sources can act as Non-point Sources

Apart from effluents, during the rainy season industrial wastes (solid wastes and solid sludge from the effluent treatment plants) also end up in the groundwater as non-point source pollution, as they are openly dumped within the premises of the industries. As a result during the post-monsoon period groundwater pollution is expected to be as high or even higher when compared to the pre-monsoon period.

To understand the environmental impacts of industrial discharge of effluents on land for irrigation, groundwater and soil quality, the study has been taken up across five industrial locations in Mettupalayam Taluk, Tamil Nadu. To understand the impacts of pollution on livelihoods, a household questionnaire survey has been carried out in all the locations. The survey also captures the farmers' perceptions about irrigation and drinking water quantity and quality. A multi-stakeholder meeting was undertaken to disseminate the primary findings, raising awareness and finding ways and means to mitigate the problems.

3. DESCRIPTION OF STUDY AREA AND INDUSTRIAL PROFILE OF METTUPALAYAM TALUK

Most of the major water consuming and polluting industries, located in Thekkampatti and Jadayampalayam villages of Mettupalayam Taluk (upstream of the Bhavanisagar Reservoir), belong to textile bleaching and dyeing, and paper industries. These industries are meeting their water requirements by using water from the Bhavani River, and disposing their effluents on their own land for irrigation. Out of ten industrial units, eight are large, one is medium and one is small (Appendix B, Table B1). Based on the classification of the Tamil Nadu Pollution Control Board (TNPCB), seven of these industrial units are in the red category (highly polluting) and three are in the orange category (moderately polluting). All the industries were established during the 1990s, except for two industries.

Out of ten units, seven units are extracting 10 mld of water from the Bhavani River and the three remaining units depend on wells. Most of the units are located in the upstream part of the river. Since the industries are water-intensive industries, these locations are strategic to meet their water requirements throughout the year. The total quantity of effluents generated by these units is estimated to be 7.2 mld (Appendix B, Table B2). Except for one bleaching unit, all the units are using their partially treated effluents to irrigate their own land. The bleaching unit, which is the oldest unit, directly discharges effluents (1.6 mld) to the Bhavani River. All the units have their own effluent treatment plants and most are equipped with reverse osmosis technology. However, the local NGOs and farmers are sceptical about their functioning. The total annual pollution load discharged by the units is estimated, based on TNPCB data, to be 1,316 tonnes of Total Dissolved Solids (TDS), 94 tonnes of Total Suspended Solids (TSS), 169 tonnes of Chemical Oxygen Demand (COD), and 2 tonnes of oil and grease (Appendix B, Table B3).

At present, since most of the units are not discharging their effluents into the river, there is very little deterioration of the quality of surface water due to industries in the Mettupalayam area. However, there is contamination of river water due to the discharge of sewage from Mettupalayam Municipality. The pollution load discharged by the bleaching unit, which constitutes 494 tonnes of TDS, 22 tonnes of TSS and 24 tonnes of COD per year (MSE 2005), has a negligible effect, especially during times of good flow, on the quality of river water. The discharge of effluents on land and its usage for irrigation has had a significant effect on the quality of groundwater in the vicinity of the industries.

In the town of Sirumugai, a major pulp and viscose rayon plant used to draw 54 mld of water from the Bhavani River and discharge an equivalent amount of partially treated colored effluents into the river. The discharge of highly toxic effluents affected the quality of the water in the river substantially and also fishery activities downstream at the Bhavanisagar Reservoir. Over the years due to protests by the downstream farmers, local NGOs and the intervention of the Court, the unit was forced to consider other options for effluent disposal. With the permission of the TNPCB, the plant started discharging their colored effluents on their farmlands (purchased or under contract with the farmers) at Irumborai village (through a 5 km long pipeline from the plant to the village).[8] Continuous disposal of partially treated effluents resulted in soil and groundwater pollution not only in the effluent irrigated land, but also in the surrounding farmlands, through leaching/percolation and runoff from the effluent irrigated land. Contamination of both soil and groundwater (shallow and deep aquifers) quality were quite evident, since the drinking water turned brown due to lignin in the affected areas (Sundari and Kanakarani 2001). The unit had made a huge investment in terms of pipeline infrastructure and the purchase of land based on the advice of experts in wastewater irrigation.

However, due to the efforts of the farmers, the Bhavani River Protection Council and the intervention of the Supreme Court the scheme was abandoned and finally the plant was forced to close, but the groundwater still remains polluted due to residual pollution. Consecutive droughts during 2001-2003, and low groundwater recharge, has led to severe water quality problems apart from scarcity. Although drinking water is affected, the farmers in the affected areas are able to cultivate selected crops.

4. METHODOLOGY AND DATA SOURCES

To understand the environmental impacts of industrial effluent irrigation, soil and groundwater samples were collected from farmlands and open wells surrounding the industrial units. Samples were purposively selected on the basis of the farmers' perceptions and complaints about soil and groundwater pollution due to effluent irrigation within the premises of the industrial units. Laboratory analyses of samples of groundwater and soil were conducted at the Water Technology Centre (WTC), Tamil Nadu Agricultural University (TNAU). For both soil and water samples, the standard sampling protocols and analytical methods (procedures) were followed as described by Sankaran (1966). For soil samples, 3 to 5 samples were taken from a single field at a depth 0 to 15 centimeters (cm) and 15 to 30 cm, and mixed together to get a composite sample. For both soil and water samples, replicates were analyzed depending on getting the concurrent result for EC and pH. EC was measured on a 1:2.5 soil solution ratio. Soil samples were tested for EC (in dS/m), pH and available nutrients (in kg/ha) - N, P, K. Water samples were tested for EC, pH, anions (in meq/l) – CO_3, HCO_3, Cl, SO_4; cations (in meq/l) – Ca, Mg, Na, K; NH_4^-N, NO_3^-N, F (in PPM) and heavy metals (in PPM) – Zn, Mn, Fe, Cr, Ni, Pb, Cu, Cd. Altogether 83 groundwater (from shallow open wells) and 81 soil samples were collected from farmlands located in the vicinity of the five industrial sites/locations (shown in Table 1). To address both spatial and temporal aspects of environmental quality, water quality sampling and analysis has been carried out for the same sample wells both for pre- and post-monsoon periods. During the post-monsoon period another six control samples were taken up

[8]Initially farmers of water scarce Irumborai village welcomed the proposal, since it was an opportunity to irrigate their crops. Since the village is far away from the river, the farmers used to cultivate only rain-fed crops.

from three villages (Thekkampatti, Jadayampalayam and Irumborai) to understand the natural background level of pollutants. The locations of the control wells were away from the affected farms. However, soil samples were taken and tested once only (pre-monsoon), as it was expected that unlike shallow groundwater quality, soil quality will not change so fast or that the soil quality is not so flexible when compared to shallow groundwater quality.

To substantiate and compare our primary groundwater quality results/findings, secondary groundwater quality data were collected from the Tamil Nadu Water Supply and Drainage (TWAD) Board, Central Ground Water Board and State Ground and Surface Water Resources Data Centre, Public Works Department for analysis. While the TWAD Board regularly tests the water quality of the deep bore wells (fitted with hand pumps or power pumps) to monitor the drinking water quality in the regions, the other data sources are irregular and monitor irrigation water quality, as the water samples are collected from dug wells or open wells.[9] Information on industries and their effluents characteristics were collected from the District Environmental Engineer's office of the TNPCB, Coimbatore. Since the collection of effluent samples from the industrial units are not permitted to us,[10] we collected the shallow groundwater samples from the surrounding farmlands. Industrial unit-wise effluent characteristics were collected from the TNPCB and the pollution load was estimated (Appendix B, Table B3). However, mapping from emission concentration to ambient concentration needs solute transport modelling, which is beyond the capacity of the present investigation. To understand the impact of pollution on the livelihoods of the farmers and their perceptions about irrigation and drinking water quality, a questionnaire survey was administered to 55 farm households, purposively selected on the basis of their pre-monsoon groundwater quality information. Of the 55 sample households, 5 households which were not affected by the pollution (as they are located away from the industrial area) served as control samples for the analysis. In Table 1, the distributions of the samples across the five industrial clusters for three ranges of groundwater Electrical Conductivity (EC) concentration in deciSiemens per meter (dS/m) are shown.

Table 1. Household questionnaire survey: Sample size and distribution according to water quality (EC in dS/m).

Site	Location	EC concentration in dS/m			All	Control	Total
		<1.5	1.5 - 2.25	≥2.25			
Site – 1	Thekkampatti Cluster – I	4	7	1	12	0	12
Site – 2	Thekkampatti Cluster – II	0	0	8	8	1	9
Site – 3	Jadayampalayam Cluster- I	1	0	8	9	0	10
Site – 4	Jadayampalayam Cluster – II	2	2	5	9	2	10
Site – 5	Sirumugai Cluster (Irumborai)	0	1	11	12	2	14
	All locations	7	10	33	50	5	55

Note: Irrigation water having EC value less than 1.5 dS/m is considered to be safe for crops. However, a EC value more than 2.25 dS/m is considered to be dangerous.

[9]Locations of the observation wells (bore or open) for a region are different for different agencies.

[10]The Water (Prevention and Control of Pollution) Act, 1974 (*Source:* http://envfor.nic.in/legis/water/wat1.html)

The stakeholder initiatives to overcome the problem of pollution and the need for a multi-stakeholder approach integrating water quantity and quality concerns in the region was also part of the study. Therefore, discussions with the NGOs along with a multi-stakeholder dialogue were organized. The Stakeholder meeting provided some insights on different views and concerns about water quality and environmental problems in the region.

5. RESULTS AND DISCUSSION

5.1 Groundwater Quality

Electrical Conductivity (EC in dS/m) of water, as a measure of total dissolved solids, is one of the most important water quality parameters that affects the water intake of the crops. Irrigation water having a EC value less than 1.5 dS/m is considered to be safe for crops. However, EC more than 2.25 dS/m is considered dangerous (Table 2). The results show that the average concentration of EC has gone up in the post-monsoon samples, which implies that salt leaches to the groundwater during the rainy season. Secondary groundwater data (regular observation well data from the TWAD Board) also show that post-monsoon samples have a high average concentration of EC (≥2.25 dS/m) as compared to pre-monsoon samples.[11]

Table 2. Interpretation of irrigation water quality based on EC measurement.

EC (dS/m at 25°C)	Water class	Interpretation
<0.25	Low salinity (C_1)	Safe with no likelihood of any salinity problem developing
0.25 – 0.75	Medium salinity (C_2)	Need moderate leaching
0.75 – 2.25	High salinity (C_3)	Cannot be used on soils with inadequate drainage, since saline conditions are likely to develop
2.25 – 5.0	Very high salinity (C_4)	Cannot be used on soils with inadequate drainage, since saline conditions are likely to develop

Source: Santhi et al. 2003

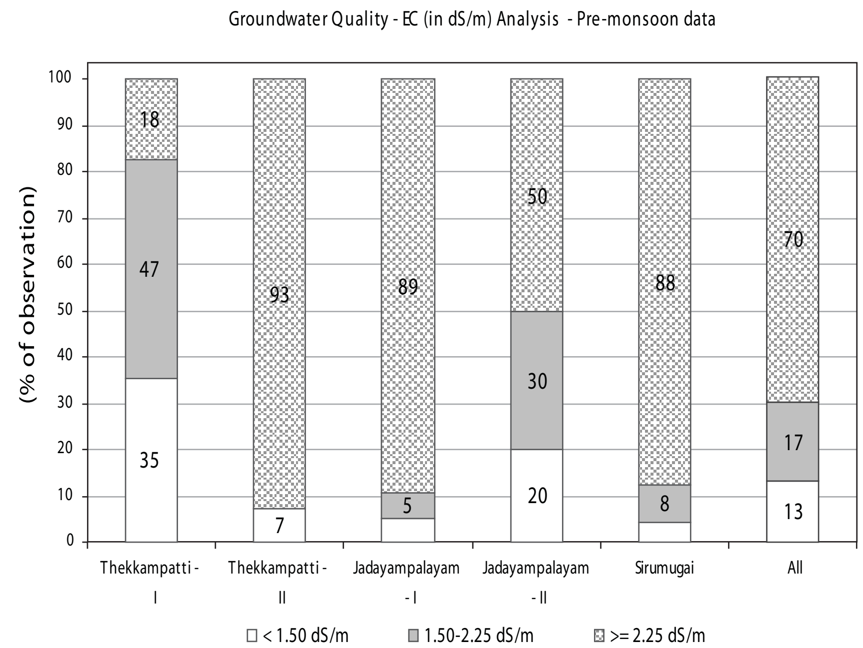
Figure 1 shows that 70 percent of the pre-monsoon samples have EC concentration higher than 2.25 dS/m (2.30 – 9.56, ±4.34), and Figure 2 shows that 74 percent of the post-monsoon samples have EC concentration greater than 2.25 dS/m (2.27 – 10.38, ±4.70). For all the sites the average EC concentration of the post-monsoon samples was as high or even higher than the pre-monsoon samples. Thekkampatti cluster - II and Jadayampalayam cluster – I (site 3) have high salinity (≥2.25 dS/m) both for the pre- and post-monsoon samples (see Tables 3 and 4).

For sites 2, 3 and 5, almost 90 percent of the samples have EC concentration greater than 2.25 dS/m for both pre- and post-monsoon periods. For both the periods the maximum concentration is reported at a site in Jadayampalayam cluster – I, 9.56 and 10.38 dS/m for the pre-monsoon and post-monsoon period, respectively. Among all the sites, site 1 in Thekkampatti is comparatively

[11]TDS (in mg/l) = 600 * EC (in dS/m or millimhos/cm), when EC < 5 dS/m

TDS (in mg/l) = 800 * EC (in dS/m or millimhos/cm), when EC > 5 dS/m

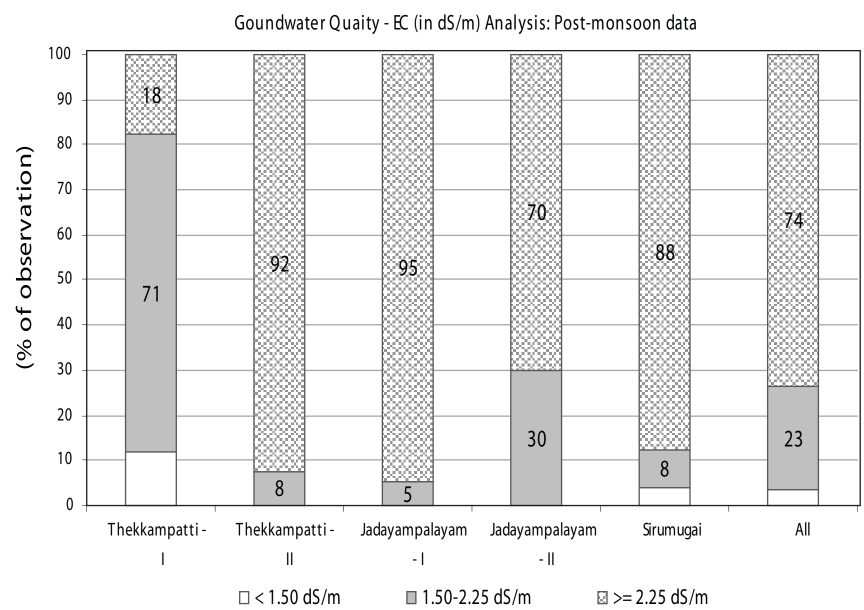
Figure 1. Concentration of EC (in dS/m) in groundwater samples – pre-monsoon.



Source: TNAU survey 2005

less polluted. However, post-monsoon samples show a higher concentration of EC. To understand the seasonal variations of salinity, Analyses of Variances (ANOVA) have been carried out for each of the industrial locations (across pre- and post-monsoon average EC concentrations). These analyses show that, except for the Thekkampatti cluster – II, post-monsoon EC concentrations are not significantly different from pre-monsoon observations or vice versa (Appendix D, Tables D1a to

Figure 2. Concentration of EC (in dS/m) in groundwater samples – post-monsoon.



Source: TNAU survey 2005

Table 3. Groundwater quality based on EC (dS/m) measurement: Pre–monsoon samples.

Sampling location – Industries	Number of samples	Range (dS/m)	Average ± Standard Deviation	Percentage of samples [having EC (dS/m)]		
				Low salinity <1.50	Moderate salinity 1.50-2.25	High salinity ≥2.25
Thekkampatti Cluster – I	17	1.00 – 3.16	1.83 ± 0.59	35.3	47.1	17.7
Thekkampatti Cluster – II	13	1.44 – 4.72	3.03* ± 0.75	7.7	0.0	92.3
Jadayampalayam Cluster – I	19	0.82 – 9.56	5.77 ± 2.16	5.3	5.3	89.5
Jadayampalayam Cluster – II	10	0.91 – 3.82	2.36 ± 1.03	20.0	30.0	50.0
Sirumugai Cluster (Irumborai)	24	0.10- 5.02	3.59 ± 1.13	4.2	8.3	87.5
All sites	83	0.1 – 9.56	3.49 ± 1.9	13.3	16.9	69.9

Source: Primary survey by TNAU
Note: * implies that the average is significantly different (statistically) from the post-monsoon value at 0.05 level (please refer ANOVA Tables D1a to D1f in Appendix D).

Table 4. Groundwater quality based on EC (dS/m) measurement: Post–monsoon samples.

Sampling location – Industries	Number of samples	Range (dS/m)	Average ± Standard Deviation	Percentage of samples [having EC (dS/m)]		
				Low salinity <1.50	Moderate salinity 1.50-2.25	High salinity ≥2.25
Thekkampatti Cluster - I	17	1.33 - 3.32	2.01 ± 0.55	11.76	70.6	17.7
Thekkampatti Cluster -II	13	1.82 - 5.87	3.77* ± 0.98	0	7.7	92.3
Jadayampalayam Cluster - I	19	1.58 - 10.38	6.24 ± 2.52	0	5.3	94.8
Jadayampalayam Cluster - II	10	1.58 - 4.62	2.96 ± 1.2	0	30.0	70.0
Sirumugai Cluster (Irumborai)	24	0.14 - 5.41	3.87 ± 1.22	4.17	8.3	87.5
All sites	83	0.14 - 10.38	3.91 ± 2.07	3.61	22.9	73.5

Source: Primary survey by TNAU
Note: * implies that the average is significantly different (statistically) from the pre-monsoon value at 0.05 level (please refer ANOVA Tables D1a to D1f in Appendix D).

D1f).[12] This implies that variations in the concentration of EC across the seasons are not significantly higher than that of the samples of each of the seasons. To understand the spatial variations of salinity, ANOVA have been carried out for both pre- and post-monsoon average EC values for the industrial locations, which show that all the average EC values are significantly different from each other (see Appendix D, Tables D2a and D2b). This means that average EC values are different for different locations for both pre- and post-monsoon samples. Environmental impacts of industrial effluent irrigation is different for different sites, which is mainly due to the fact that different industries have different pollution potential; and different locations have different assimilative capacities to absorb the pollutants.

[12] For each of the five industrial locations and for all sites taken together, ANOVA has been carried out between pre- and post-monsoon average EC values. Except for industrial location 2, where the mean EC for the pre-monsoon period is significantly (at 5% level) different from post-monsoon values or vice versa, other locations do not have significantly different EC values (see Appendix D for Technical Note).

During the post-monsoon season another six groundwater samples were taken up as control samples (two each from three villages), where the sample open wells were situated far away from the industrial locations (see Table 5). Apart from the samples from the Irumborai village, average concentrations of EC in the samples for Thekkampatti and Jadayampalayam villages are far below the affected samples, which show that the impacts of industrial pollution are evident for Thekkampatti and Jadayampalayam villages. In the case of the Irumborai village, perhaps the residual pollution from the pulp and viscose rayon plant's irrigated area has affected the aquifers, which has in turn affected the whole area.

Table 5. EC (dS/m) concentration for control samples: Post-monsoon.

Locations	Number of samples	Average	Minimum	Maximum
Thekkampatti	2	0.96	0.76	1.16
Jadayampalayam	2	1.07	0.79	1.35
Irumborai	2	3.57	2.98	4.15

Source: Primary survey by TNAU

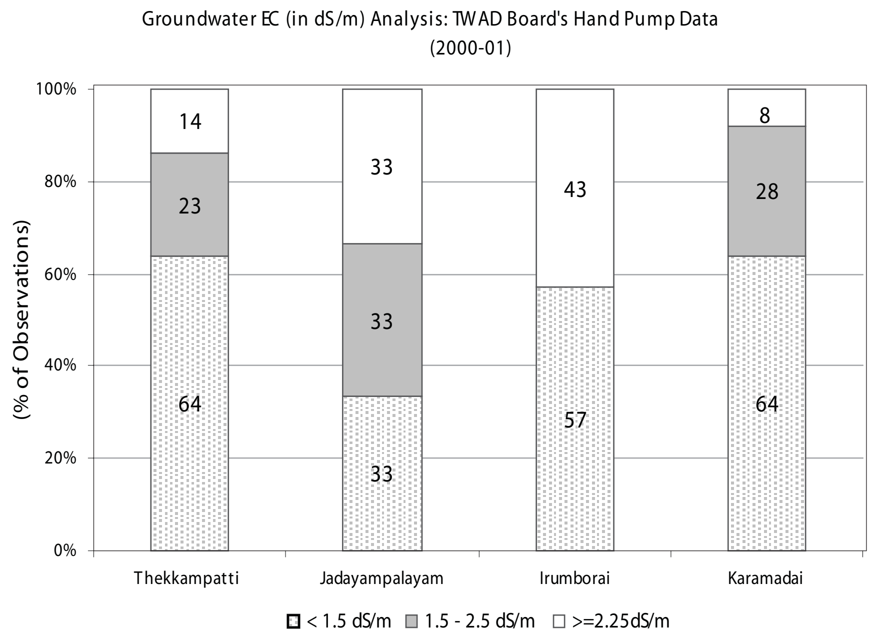
Apart from primary groundwater quality study, an assessment of groundwater quality has also been carried out using secondary data. The assessment highlights the parameters of our concern, as well as the variations of concentration over time and space.

The TWAD Board's hand pump data (2000-2001) analysis shows that the average EC level for Jadayampalayam and Irumborai are high when compared to the EC level for Karamadai samples.[13] However, for Thekkampatti the average EC level is low when compared to Karamadai samples. For Jadayampalayam 33 percent and Irumborai 43 percent of the samples have an EC concentration more than 2.25 dS/m (Figure 3). In Irumborai, the area formerly irrigated by the pulp and viscose rayon plant's effluents continues to be polluted even though the plant closed down more than four years earlier. ANOVA show that, except for Thekkampatti, average EC levels for Jadayampalayam and Irumborai are significantly different from Karamadai samples (Appendix D, Tables D4a to D4c).

To understand the impact of pollution on water quality in the deep aquifers in our study villages, data were collected for the TWAD Board's regular observation wells (OBWs) (bore wells) for the period January 1992 to May 2005 from the TWAD Board, Chennai, and a temporal and spatial analysis have been done. There are four regular OBWs which fall in the Karamadai block, for which a water quality analysis has been done by the Board twice in a year (pre-monsoon sampling is done during May/June and post-monsoon is done during January/February). Out of four OBWs, two fall in our study villages, one each in Thekkampatti and Irumborai villages. The other two (Bellathi and Kalampalayam) fall far away from the industrial locations and could serve as control wells. The data for Thekkampatti, Irumborai and the other two places (clubbed together as Karamadai samples) are given in Table 6.

[13]Groundwater samples (hand pumps) drawn apart from the three villages (viz., Thekkampatti, Jadayampalayam and Irumborai) are clubbed together and named Karamadai samples to understand the natural background level of EC.

Figure 3. Groundwater quality analysis of Mettupalayam area – Hand pump data.



Source: TWAD Board's Hand Pump Data (2000-2001)

Table 6 shows that for both pre- and post-monsoon periods, the percentage of observations having EC concentration greater than 2.25 dS/m is higher for Irumborai village when compared to the Karamadai samples. However, for Thekkampatti on an average EC concentration (for both the periods) is lower than the Irumborai and Karamadai samples. For Irumborai, the average EC concentration for both pre- and post-monsoon samples are significantly different from the corresponding values of the Karamadai samples. For Thekkampatti the average level of EC for the post-monsoon samples is significantly different from the post-monsoon samples of Karamadai (Table 6; and Appendix D, Tables D5a to D5d).

Table 6. Groundwater quality (EC in dS/m) analysis: TWAD Board's Regular Observation Well Data (January 1992 to May 2005).

Descriptions		Irumborai		Thekkampatti		Karamadai	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Number of observations		14	11	11	9	26	22
Average ± Standard Deviation		2.24* ± 0.63	2.62** ± 1.00	1.34 ± 0.55	1.33** ± 0.66	1.65 ± 0.75	1.65 ± 0.88
Range		1.48 - 3.61	1.1 - 4.19	0.77 - 2.54	0.78 - 2.85	0.79 - 3.42	0.77 - 4.1
% of Observations	<1.5	7.14	18.18	72.73	77.78	53.85	59.09
having EC	1.5 - 2.25	50.00	9.09	18.18	11.11	23.08	18.18
Concentration	≥2.25	42.86	72.73	9.09	11.11	23.08	22.73
(in dS/m)							

Source: TWAD Board's Regular Observation Wells (OBWs) Data (2005).

Notes: * implies that the value is significantly different from the corresponding value of Karamadai at 0.05 level (please refer ANOVA Tables D4a to D4c in Appendix D).

** implies that value is significantly different from the corresponding value of Karamadai at 0.01 level.

Table 7a. Analysis of groundwater samples for heavy metal content (PPM) – Pre-monsoon.

Heavy metals	Zn	Mn	Fe	Cr	Ni	Pb	Cu	Cd
Maximum Permissible Conc. (mg/l)*	2.0	0.20	5.0	0.10	0.20	5.0	0.20	0.01
Thekkampatti Cluster -I	0.009 ± 0.009 (Tr – 0.021)	0.002 ± 0.000 (Tr - 0.002)	0.106 ± 0.104 (Tr - 0.337)	0.242 ± 0.228 (Tr - 0.674)	0.234 ± 0.168 (Tr - 0.561)	0.091 ± 0.068 (Tr - 0.2)	0.005 ± 0.003 (Tr - 0.013)	Tr (Tr - 0)
Thekkampatti Cluster -II	0.008 ± 0.009 (Tr - 0.021)	Tr (Tr - 0)	0.144 ± 0.121 (Tr - 0.334)	0.822 (Tr - 0.822)	0.162 ± 0.121 (Tr - 0.346)	0.259 ± 0.059 (Tr – 0.38)	0.008 ± 0.002 (Tr - 0.01)	Tr (Tr - 0)
Jadayampalayam Cluster – I	0.044 ± 0.034 (Tr - 0.113)	0.023 ± 0.010 (Tr - 0.031)	0.258 ± 0.153 (Tr - 0.522)	0.228 ± 0.183 (Tr - 0.357)	0.204 ± 0.163 (Tr - 0.567)	0.219 ± 0.063 (Tr – 0.31)	0.019 ± 0.011 (Tr - 0.04)	Tr (Tr - 0)
Jadayampalayam Cluster – II	0.018 ± 0.019 (Tr - 0.054)	0.008 ± 0.003 (Tr - 0.011)	Tr (Tr - 0)	Tr (Tr - 0)	0.129 ± 0.107 (Tr - 0.251)	0.194 ± 0.039 (Tr – 0.26)	0.057 ± 0.015 (Tr - 0.071)	Tr (Tr - 0)
Sirumugai Cluster	0.022 ± 0.014 (Tr – 0.04)	0.011 ± 0.006 (Tr - 0.023)	0.058 ± 0.011 (Tr - 0.076)	Tr (Tr - 0)	0.203 ± 0.133 (Tr - 0.463)	0.229 ± 0.051 (Tr – 0.32)	0.083 ± 0.008 (Tr - 0.098)	Tr (Tr - 0)
All-Sites	0.027 ± 0.027 (Tr - 0.113)	0.012 ± 0.008 (Tr - 0.031)	0.158 ± 0.140 (Tr - 0.522)	0.303 ± 0.273 (Tr - 0.822)	0.194 ± 0.143 (Tr - 0.567)	0.208 ± 0.075 (Tr - 0.38)	0.037 ± 0.034 (Tr - 0.098)	Tr (Tr - 0)

Source: Primary survey by TNAU

Note: Tr implies Trace

Conc. (mg/l) implies Concentration (milligram/liter)

* implies the recommended maximum concentration of trace elements in irrigation water (Ayers and Westcot 1985)

Table 7b. Analysis of groundwater samples for heavy metal content (PPM) – Post-monsoon.

Heavy metals	Zn	Mn	Fe	Cr	Ni	Pb	Cu	Cd
Maximum Permissible Conc. (mg/l)*	2.0	0.20	5.0	0.10	0.20	5.0	0.20	0.01
Thekkampatti	Tr	0.028 ± 0.022	0.002	Tr	0.159 ± 0.152	0.081 ± 0.077	Tr	0.005 ± 0.002
Cluster -I	(Tr - 0)	(Tr - 0.086)	(Tr - 0.002)	(Tr - 0)	(Tr - 0.266)	(Tr - 0.26)	(Tr - 0)	(Tr - 0.008)
Thekkampatti	Tr	0.055 ± 0.013	0.024	Tr	Tr	0.227 ± 0.052	Tr	0.004 ± 0.002
Cluster -II	(Tr - 0)	(Tr - 0.076)	(Tr - 0.024)	(Tr - 0)	(Tr - 0)	(Tr - 0.35)	(Tr - 0)	(Tr - 0.006)
Jadayampalayam	Tr	0.056 ± 0.036	0.004	Tr	Tr	0.204 ± 0.061	Tr	0.004 ± 0.003
Cluster – I	(Tr - 0)	(Tr - 0.111)	(Tr - 0.004)	(Tr - 0)	(Tr - 0)	(Tr - 0.3)	(Tr - 0)	(Tr - 0.011)
Jadayampalayam	Tr	0.024 ± 0.036	Tr	Tr	0.039	0.170 ± 0.037	Tr	0.004 ± 0.002
Cluster – II	(Tr - 0)	(Tr - 0.095)	(Tr - 0)	(Tr - 0)	(Tr - 0.039)	(Tr - 0.24)	(Tr - 0)	(Tr - 0.006)
Sirumugai	Tr	0.013 ± 0.008	Tr	Tr	Tr	0.210 ± 0.054	Tr	0.003 ± 0.003
Cluster	(Tr - 0)	(Tr - 0.024)	(Tr - 0)	(Tr - 0)	(Tr - 0)	(Tr - 0.3)	(Tr - 0)	(Tr - 0.007)
All-Sites	Tr	0.039 ± 0.031	0.010 ± 0.012	Tr	0.119 ± 0.128	0.190 ±0.072	Tr	0.004 ± 0.002
	(Tr - 0)	(Tr - 0.111)	(Tr - 0.024)	(Tr - 0)	(Tr - 0.266)	(Tr - 0.35)	(Tr - 0)	(Tr - 0.011)

Source: Primary survey by TNAU
Note: Tr implies Trace
* implies the recommended maximum concentration of trace elements in irrigation water (Ayers and Westcot 1985)

Except for Manganese (Mn) and Cadmium (Cd), post-monsoon water samples have lower concentrations of heavy metals e.g., Zinc (Zn), Iron (Fe), Cromium (Cr), Nickel (Ni), Lead (Pb) and Copper (Cu), when compared to pre-monsoon samples (Tables 7a and 7b). For Mn and Cd, concentrations have increased in post-monsoon samples. For cluster 1, 2 and 3, pre-monsoon samples have concentrations of Cr and Ni higher than the maximum permissible limit for irrigation. However, post-monsoon samples have lower concentrations.

5.2 Soil Quality

The pH content of the soil samples collected from the polluted areas of the farmers' field varied between 5.44 to 9.17, and the EC varied between 0.07 to 2.08 dS/m. High EC values are observed in several fields in the Jadayampalayam Cluster – II and the Sirumugai Cluster (Table 8). This may be due to continuous irrigation using polluted well water for raising the crops. If the polluted well water is used continuously for irrigation it may create salinity/alkalinity problems in the soil in due course. The high EC in the soils are commonly noticed wherever the fields and wells are located near the industries. The ANOVA table (see Appendix D, Table D3) for average EC values for different industrial locations shows that the average EC values are significantly different for different locations.

Table 8. Soil quality analysis – EC (in dS/m) and pH.

Location	Number of observations	Soil EC (in dS/m)		Soil pH	
		Average ± Standard Dev.	Range	Average ± Standard Dev.	Range
Thekkampatti Cluster - I	15	0.19 ± 0.08	0.09 - 0.38	8.61 ± 0.29	8.15 - 8.95
Thekkampatti Cluster - II	13	0.26 ± 0.1	0.13 - 0.48	8.51 ± 0.25	8.16 - 9.17
Jadayampalayam Cluster - I	19	0.48 ± 0.41	0.11 - 1.67	8.38 ± 0.2	8.03 - 8.71
Jadayampalayam Cluster - II	10	0.35 ± 0.49	0.12 - 1.74	8.51 ± 0.18	8.19 - 8.84
Sirumugai Cluster	24	0.37 ± 0.39	0.07 - 2.08	8.26 ± 0.64	5.44 - 8.75
All Sites	81	0.34 ± 0.35	0.07 - 2.08	8.42 ± 0.41	5.44 - 9.17

Source: Primary survey by TNAU

Table 9 shows that under the 'no salinity' category (EC in dS/m < 0.75), 49 percent and 40 percent of the overall soil samples fall under the 'moderately alkaline' (pH: 8.0 to 8.5) and 'strongly alkaline' (pH: 8.5 to 9.0) categories, respectively. Under the 'slight salinity' category (EC: 0.75 to 1.5), 5 percent of the overall samples fall under the 'moderately alkaline' category. Only 4 percent of the samples fall under the 'moderate salinity' category (EC ≥1.5 dS/m). Since the farmers mostly irrigate their crops under flood conditions, the soil salinity did not build up in our study locations.

Continuous disposal of industrial effluents on land, which has limited capacity to assimilate the pollution load, has led to groundwater pollution. The groundwater quality of shallow open wells surrounding the industrial locations has deteriorated, and also the salt content of the soil has started building up slowly due to the application of polluted groundwater for irrigation. In some locations drinking water wells (deep bore wells) also have a high concentration of salts.

Table 9. Soil salinity and alkalinity (figures are in percentage of observations).

Descriptions		Soil salinity classifications	No salinity	Slight salinity	Moderate salinity	All
		Soil EC (in dS/m)	<0.75	0.75 - 1.50	≥1.50	
Soil alkalinity classifications	Soil pH	Sample range	0.07 - 0.56	0.81 - 0.98	1.67 - 2.08	0.07 - 2.08
Safe	<7.5	5.44 - 5.44	1.2	0	0	1.2
Slightly alkaline	7.5 - 8.0	7.86 - 7.86	0	0	1.2	1.2
Moderately alkaline	8.0 - 8.5	8.03 - 8.49	49.4	4.9	2.5	56.8
Strongly alkaline	8.5 - 9.0	8.50 - 8.95	39.5	0	0	39.5
Very strongly alkaline	≥9.0	9.17 - 9.17	1.2	0	0	1.2
All		5.44 - 9.17	91.3	4.9	3.7	100

Source: Primary survey by TNAU

5.3 Impacts of Groundwater Pollution on Livelihoods

5.3.1 Socioeconomic background of the sample households

The average years of residency of the households in our study sites is 63 years (6 – 100, ±37), which shows that the households have several years of experience with the environmental situation/ conditions of the area in both the pre- and post-industrialization eras, as most of the industries were set up during the 1990s. The average age of the respondents (head of the family) is 54 years (28 – 85, ±12). We have found that, even though the farmers have limited exposure in formal education – the average years of education of our respondents is only 6 years (1 – 15, ±3) - they are innovative and advanced farmers, as they are engaged in continuous agricultural innovations in cropping patterns, agricultural practices, and water management techniques. The average family size is 5 (1 – 11, ±1) of which at least two members (1 – 6, ±1) are economically active. Small family size also implies that farmers are progressive. In most of the cases, we have found that women also participate in on-farm activities apart from looking after their livestock and other household chores. High female workforce participation in agriculture and allied activities helps the farm household to cultivate certain crops, which require post-harvest processing and sorting e.g., coconut (*Cocos nucifera L.*), areca nut (*Areca catechu L.*), chilli (*Capsicum annum L.*), jasmine (*Jasminum grandiflorum*), tobacco (*Nicotiana tabacum*), etc. Most of the sample farmers are small and medium farmers, with an average area of cultivation of 4 acres (0.6 – 16, ±3.5) (Table 10).[14]

[14] 1 acre = 0.405 hectares or 1 hectare = 2.471 acres.

Table 10. Socioeconomic background of the sample households.

Descriptions	Site-1	Site-2	Site-3	Site-4	Site-5	All Sites	Control
Number of sample households	12	8	9	9	12	50	5
Average age of the respondent	49 ± 9 (34 – 60)	47 ± 6 (39 – 55)	54 ± 13 (28 – 70)	58 ± 13 (39 – 79)	59 ± 14 (35 – 85)	54 ± 12 (28 – 85)	71 ± 8 (62 – 81)
Average years of education	6 ± 5 (0 – 15)	9 ± 2 (7 – 10)	6 ± 3 (2 – 9)	8 ± 2 (5 – 10)	6 ± 2 (4 – 10)	6 ± 3 (0 – 15)	6 ± 3 (3 – 10)
Average years of residency	55 ± 35 (8 – 100)	20 ± 15 (10 – 50)	60 ± 32 (18 – 100)	76 ± 36 (18 – 100)	87 ± 32 (6 – 100)	63 ± 37 (6 – 100)	63 ± 23 (45 – 100)
Average family size	5 ± 3 (2 – 11)	4 ± 0 (4 – 5)	4 ± 1 (1 – 6)	4 ± 1 (3 – 6)	5 ± 1 (4 – 9)	5 ± 1 (1 – 11)	5 ± 1 (2 – 10)
Average number of economically active persons	2 ± 1 (1 – 5)	2 ± 1 (1 – 5)	3 ± 1 (1 – 5)	2 ± 1 (2 – 4)	3 ± 1 (2 – 6)	3 ± 1 (1 – 6)	2 ± 1 (2 – 10)
Average area of cultivation (in acres)	4 ± 1.9 (0.9 - 6.5)	6 ± 4.2 (1.3 – 12.0)	3 ± 1.6 (1.0 – 6.0)	2 ± 1.5 (0.6 – 5.0)	6 ± 5.3 (1.7 – 16.0)	4 ± 3.5 (0.6 – 16.0)	5 ± 3.6 (2 – 11)

Note: Values in the parenthesis show the range for the corresponding average value
Source: Primary survey by MSE

5.3.2 Impacts of Groundwater Pollution on Income

Apart from agriculture, animal husbandry contributes to the total income of households; on an average, it has an 18 to 25 percent share in the total income of households (Table 11). The results show that the average income from agriculture for the households having a groundwater EC concentration of 1.5-2.25 dS/m is comparatively low and significantly different from that of the control samples (Table 11; Appendix D, Tables D6a and D6b).[15] However, the average income from agriculture for the households having an EC concentration greater than 2.25 dS/m is low but not significantly different from that of the control samples, which might be due to the fact that affected farmers had already shifted their cropping pattern to salt-tolerant crops (Table 12) and also substituted their irrigation source from open wells to deep bore wells and/or river water. The total income from all sources differ significantly for the samples having an EC concentration ≥1.5 dS/m from that of the samples having an EC concentration <1.5 dS/m. It is to be noted that samples having EC concentration <1.5 dS/m have a similar pattern of income (both in magnitude and composition) to that of the control samples.

Amongst all the samples, average per capita income for the samples having EC concentration 1.5-2.25 dS/m are comparatively low when compared to the other two categories and that of the control samples. It is to be noted that per capita income has different values for different sites but not significantly different (statistically) from that of the control samples.

Table 11. Average income of the households according to their groundwater quality.

Descriptions	EC concentration (in dS/m)			Control samples
	<1.5	1.5 - 2.25	≥2.25	
Number of sample households	7	10	33	5
Total area under cultivation (in acres)	26.8	33.1	138.3	23.5
Average income from agriculture (Rs./household/year)	42,857 ± 10,991 [75] (20,000 - 56,000)	31,950 ± 8,846 [82] (22,000 - 50,000)	35,409 ± 13,750 [78] (22,000 - 88,000)	40,000 ± 15,443 [74] (28,000 - 65,000)
Average income from animal husbandry (Rs./household/year)	14,214 ± 8,113 [25] (8,500 - 32,000)	7,020** ± 3,445 [18] (4,000 - 14,200)	10,125 ± 5,638 [22] (0 - 25,000)	14,000 ± 1,871 [26] (12,000 - 16,000)
Average total income from all sources (Rs./household/year)	57,071 ± 5,167 (52,000 - 66,000)	38,970* ± 9,436 (28,000 - 55,000)	45,227 ± 17,380 (22,000 - 113,000)	54,000 ± 14,629 (43,000 - 77,000)
Average per capita income from all sources (Rs./person/year)	13,936 ± 2,889 (9,429 - 19,000)	8,959 ± 3,946 (2,818 - 15,000)	10,504 ± 4,328 (4,222 - 22,000)	13,603 ± 10,011 (4,700 - 30,000)

Source: Primary survey by MSE

Note: Figures in the parenthesis show the range for the corresponding value and figure in bracket shows the percentage of total income

** implies that the value is significantly different from the corresponding value of the control samples at 0.01 level (please refer ANOVA Tables D6a and D6b in Appendix D)

* implies that the value is significantly different from the corresponding value of the control samples at 0.05 level

[15] ANOVA has been carried out for the average income from agriculture and related activities between control and affected samples (categorized according to their groundwater EC concentration).

5.3.3 Local Responses to Groundwater Pollution - Cropping Pattern

Table 12 shows the major crops cultivated across the samples having different groundwater EC concentration. A large number of crops are cultivated (which constitute 87 to 92% of the total cultivated area) and they are mostly salt-tolerant and plantation crops. Cash crops are mostly cultivated and traditional crops like paddy and cereals are virtually absent. With the rise in groundwater EC concentration, changes in cropping pattern from less salt-tolerant crops (like banana, coconut, etc.) to more salt-tolerant crops (curry leaf – *Murraya koenigii*, tobacco, etc.) takes place. It is also observed that the control samples have a cropping pattern which is similar to the affected farms, so a change in cropping pattern may not be the response due to the rising pollution problems. Since they have already shifted their cropping pattern, they can cope with the rising salinity of groundwater and soil.

Table 12. Major crops cultivated across the samples having different groundwater quality (figures are as a percentage of cultivated area).

Crop	EC concentration in dS/m			Control samples
	<1.5 dS/m	1.5 - 2.25 dS/m	≥2.5 dS/m	
Banana	44	42	24	10
Coconut	31	19	11	8
Areca nut	—	—	5	—
Jasmine	6	4	6	—
Curry leaf	—	5	19	10
Tobacco	4	6	15	10
Cholam	6	2	7	41
Chilli	0	9	5	—
Total	91	87	92	79

Source: Primary survey by MSE

Since the number of crops cultivated in our study sites are very large and most of these crops are plantation crops like jasmine, curry leaf, coconut, areca nut, etc., the estimation of the production function and the impacts of pollution on productivity of the crops cannot be estimated for the present study. Therefore, the analysis of the impacts of pollution on livelihoods has mostly been restricted to and based on the income as revealed by the respondents.

5.3.4 Farmers' Perception about Irrigation Water

A perception study of the farm households on the quantitative and qualitative aspects of water has also been carried out. The results of the study show that, on an average, over the last six years (1 – 11, ±2) farm households are facing various environmental problems.[16] Previously, water quality was comparatively good for irrigation and other uses. Apart from water quality problems, which have affected all the five study sites, the availability of irrigation water is also a major problem for

[16]In the household questionnaire survey along with other water quality perception related questions, respondents were also asked to state the time period during which the quality of groundwater started deteriorating in their field (in years).

some regions, mostly for sites 4 and 5. Although shallow open wells are polluted in all the sites, Table 13 shows that most of the farmers still depend on their own sources (open wells and bore wells) for irrigation. However, some farmers have stated that they pump river water (lift irrigation) to irrigate their croplands conjunctively with the open well water to dilute the concentration of pollutants. Farmers from site 2 did not agree that they use water from distance source(s) to irrigate their croplands (Table 13); it might be due to the fact that they have the option to use deep bore wells to irrigate their farmlands and/or since the lift irrigation is illegal they do not want to disclose that to us (Saravanan 2001). However, on an average, 50 percent of the respondents stated that they depend on distance source(s) for irrigation as their own sources are polluted and/or inadequate to flush salts from the root zones of the crops. Some farmers from the control samples also use water from distance source(s), but not due to pollution problems. Therefore, the substitution of irrigation source may not be the response due to groundwater and soil pollution, since the farmers had already substituted irrigation source from open wells to deep bore wells and/or to water from the Bhavani River, and they have coped/managed with the pollution problems. Only 4 percent of the farmers agreed that their shift to alternative sources of irrigation was the answer to the pollution problems. It is also observed that both in unaffected and affected areas, farmers cultivate salt-tolerant crops, which has also helped them to manage the rising salinity of soil and irrigation water. In all the locations the quality of groundwater in the control samples are good for irrigation, as it has not been affected by any industrial discharge of effluents.

5.3.5 Local Responses to Groundwater Pollution – Irrigation Source

Previously, farmers used to irrigate their farmlands with water from shallow open wells, where the average depth of the well varied from 41 to 52 feet (1 foot = 0.305 meters or 1 meter = 3.281 feet) (Table 14). The average age of the wells varies from 15 to 36 years. On an average, farmers shifted their irrigation source from open wells to deep bore wells in the last 10-12 years. This shows that water quality of the shallow open wells started deteriorating after the industrial operations started in the Mettupalayam area during the 1990s. However, this is not the result of the over-exploitation of shallow water aquifers, as most of the industrial units draw their water from the River Bhavani, and on an average, the water level for shallow open wells is 14 feet (5-40, ±12) and 261 feet (40-350, ±88) for bore wells (WTC, TNAU and MSE 2005). Groundwater gets recharged from rainfall and also from the Bhavani River. Old open wells have a high concentration of EC when compared to new wells. The growing dependence on deep bore wells put a huge financial burden on farmers, as their initial investment for bore wells was huge. The average depth of the bore wells varies from 276 to 363 feet, which is 7-8 times higher than the depth of the open wells, even though farmers are not very satisfied with their irrigation water quality. Farmers mostly irrigate their crops either blending their water from open wells with the water from bore wells or with the water from the Bhavani River. Some farmers, either individually or with the cooperation of other farmers, started bringing water from the Bhavani River with a sizeable investment for infrastructure. However, this is not a response due to the pollution problem, as river pumping is an old practice in this part of the Bhavani River Basin (MIDS 1993; Malaisamy 2007). Neither rainfall nor the water table shows any sign of water scarcity except for sites 4 and 5. So, the farmers shift to river pumping is not voluntary, at least for some parts of our study locations.

Table 13. Farmers' perceptions about irrigation water.

Descriptions	Site-1	Site-2	Site-3	Site-4	Site-5	All sites	Control
Number of sample households	12	8	9	9	12	50	5
Percentage of farm households satisfied with the *availability of irrigation water*	33	75	63	22	0	36	60
Availability of water in wells (open wells & bore wells) (5: very good, 3: fair and 1: very low)	2.7 ± 0.6 (1 – 3)	3.3 ± 0.5 (3 – 4)	2.9 ± 1.1 (1 – 5)	1.7 ± 0.9 (1 – 3)	1.9 ± 0.7 (1 – 3)	2.4 ± 0.9 (1 – 5)	2.5 ± 0.6 (2 – 3)
Percentage of farm households satisfied with the *irrigation water quality*	0	13	0	0	0	2	100
Water quality of the wells (open wells & bore wells) (5: very good, 3: fair and 1: very bad)	1 ± 0 (1 – 1)	1.3 ± 0.7 (1 – 3)	1 ± 0 (1 – 1)	1.3 ± 0.7 (1 – 3)	1 ± 0 (1 – 1)	1.1 ± 0.4 (1 – 3)	3.4 ± 0.5 (3 – 4)
Time period during which the quality of groundwater (open wells and bore wells) started deteriorating in farmers' field (in years)	6 ± 2.7 (1 – 11)	7 ± 1.8 (5 – 10)	6 ± 2.2 (3 – 10)	7 ± 1 (6 – 8)	5 ± 1 (4 – 6)	6 ± 1.9 (1 – 11)	0 -
Water quality of the irrigation wells (open wells and bore wells) before the period from which water quality started deteriorating (5: very good, 3: fair and 1: very bad)	2.8 ± 1.1 (1 – 4)	3.8 ± 0.5 (3 – 4)	3.1 ± 0.3 (3 – 4)	3 ± 0 (3 – 3)	2.6 ± 1.4 (0 – 4)	3 ± 0.9 (0 – 4)	3.5 ± 0.6 (3 – 4)
Percentage of households dependent on distance source(s) for irrigation, as their own source(s) are inadequate to meet their irrigation demand	0	0	33	56	38	24	25
Percentage of households dependent on distance source(s) for irrigation, as their own source(s) are polluted	33	0	78	67	70	50	0
Percentage of farm households that have adopted irrigation source substitution strategy as a pollution management option	0	0	0	11	8	4	0
Percentage of farm households that have changed their cropping pattern as a pollution management option	0	25	22	22	17	16	0

Source: Primary survey by MSE
Note: Values in the parenthesis show the range for the corresponding average value

Table 14. Sources of irrigation and associated costs.

Descriptions	Concentration of EC in dS/m		
	<1.5	1.5 - 2.25	≥2.25
Number of observations	7	10	33
Average area of cultivation (in acres)	3.8 ± 2.2 (1 – 6.5)	3.3 ± 2.8 (0.9 – 10)	4.2 ± 3.9 (0.6 – 16)
Percentage of area irrigated by open wells (%)	57	40	30
Percentage of area irrigated by open and bore wells (%)	43	30	67
Percentage of area irrigated by open wells and river water (%)	0	30	3
Average depth of the open wells (in feet)	41 ± 10.7 (30 - 60)	52 ± 16.6 (35 - 80)	47 ± 14.6 (25 - 80)
Average age of the open wells (in years)	15 (15 - 15)	26 ± 9.9 (19 - 33)	36 ± 11.8 (20 - 45)
Average depth of the bore wells (in feet)	282 ± 32 (245 - 300)	276 ± 192 (25 - 480)	363 ± 142 (40 - 650)
Average initial investment on bore wells (in thousand Rs.)	76.667 ± 40.415 (30 – 100)	53.125 ± 40.072 (2.5 - 100)	94.950 ± 67.883 (12 - 300)
Average age of the bore wells (in years)	11 ± 2.0 (9 - 13)	12 ± 2.7 (10 - 16)	10 ± 5.6 (3 – 21)
Average age of the river pumping system (in years)	—	9 ± 7 (1 - 14)	7 (7 - 7)
Average length of the pipeline laid down to bring water (in feet)	—	4,111 ± 5,786 (20 – 8,202)	1,728 ± 2,706 (320 – 6,562)

Source: Primary survey by MSE
Note: Values in the parenthesis show the range for the corresponding average value

5.3.6 Farmers' Perceptions about Drinking Water

Public stand-posts and house connections mostly serve as sources of drinking water for the households in all our study sites (Table 15). The farmers are becoming increasingly dependent on a centralized public water supply system, since their own sources (open wells and bore wells) are polluted. Though the quality of the supplied water is not very good, as reflected by the farmers' perception of drinking water quality, they still depend on public sources, as they do not have any other option. The water quality of the public hand pumps is not very good, which shows that industrial pollution has started affecting the deep aquifers and could pose a serious threat in the future. The disposal of domestic sewage and sanitation is another problematic area for rural Mettupalayam Taluk, according to the 2001 house listings operation under the population census, 39 percent of households do not have a bathroom within the premises, 66 percent do not have a latrine, and 47.4 percent do not have sewage discharge facilities. A limited number of farm households (without access to house connection) have access to drinking water supplied by the industries (on an average 49 percent of the households). After much persuasion and strong protests by the local people and NGOs, some industries have agreed to supply drinking water to a limited number of the surrounding farm households. However, the households are not very satisfied with the drinking water quality, and also the quantity supplied by the industries is not adequate (only 12 liters, equivalent to 1 vessel per household).

Table 15. Sources of drinking water and perceptions about water quality.

Descriptions	Site-1	Site-2	Site-3	Site-4	Site-5	All sites	Control
Percentage of households that have *House Connections* as a source of drinking water	8	13	89	78	0	34	80
Percentage of households dependent on *Public Stand-posts* as a source of drinking water	92	88	11	22	100	66	20
Percentage of households satisfied with *drinking water quality*	17	33	25	13	0	16	100
Quality of the supplied drinking water (5: very good, 3: fair and 1: very bad)	3 ± 0 (3 – 3)	3.1 ± 0.4 (3 – 4)	3 ± 0 (3 – 3)	3 ± 0 (3 – 3)	3 ± 0 (3 – 3)	3 ± 0.1 (3 – 4)	2.4 ± 1.3 (0 – 3)
Drinking water quality of public hand pumps (5: very good, 3: fair and 1: very bad)	3 ± 0 (3 – 3)	3.1 ± 0.4 (3 – 4)	3 ± 0 (3 – 3)	3 ± 0 (3 – 3)	3 ± 0 (3 – 3)	3 ± 0.1 (3 – 4)	2.4 ± 1.3 (0 – 3)
Percentage of households that collect water, as their own source(s) of drinking water are polluted	92	88	100	89	100	94	0
Percentage of households that have access to drinking water supplied by industries	50	40	25	0	100	49	0
Percentage of households satisfied with the quality of drinking water supplied by industries	20	33	0	0	9	11	0

Source: Primary survey by MSE
Note: Values in the parenthesis show the range for the corresponding average value

Since the farmers had already shifted their cropping patterns to salinity tolerant crops and substituted their irrigation source from open wells to deep bore wells and/or river water, they have managed to cope with the pollution. Since their own source(s) of drinking water, open wells and bore wells, are polluted, most of the farmers depend on a public water supply to meet their drinking water needs. There are also cases where industry has provided households with free water through a hosepipe, which could be seen as a tacit acceptance by the industry that it is responsible for contaminating the neighboring wells.

6. OBSERVATIONS FROM MULTI-STAKEHOLDER MEETING

A multi-stakeholder meeting was organized as a means of disseminating the primary findings, raising awareness and finding ways and means to mitigate the problems. The participants expressed their views, which are broadly classified under the following headings.

6.1 Physical Deterioration of Environment

Normally, during the initial period of irrigation the pollutants will settle in the soil and then gradually percolate to the groundwater, especially in the rainy season. The flow of groundwater and other hydrogeological aspects influence the migration of pollutants in the aquifer. Hence, groundwater pollution may occur even at distant locations. More detailed studies of pollutant transport within a radius of 0.5 km of the industrial region are needed to gain a better understanding.

6.2 Impact of Pollution on Livelihoods

The impact of pollution on livelihoods has been minimized in the ‘hotspots’, because farmers have adopted certain coping practices. In the Mettupalayam area, farmers had already changed their cropping pattern from food crops (rice, banana, vegetables, etc.) to commercial crops (jasmine, curry leaves, tobacco, etc.) even before the impact of pollution occurred. In some areas, they were able to use river water directly or by mixing it with groundwater. Since these options may not exist in other areas, the impact on livelihoods in these areas may be more serious. A long-term Impact Study on crop productivity and soil quality was recommended.

6.3 Scientific Approach towards Effluent Irrigation

Since industrial effluents contain toxic elements including heavy metals, an adequate level of treatment should be ensured. The enforcement agencies need to strictly monitor all the units and make sure the treated effluents meet the required standards. For certain pollutants like TDS, even if the treated effluents meet the standard of 2,100 mg/l, continuous irrigation may increase the salinity of groundwater and soil in the irrigated areas and in the surrounding area. It must be pointed out that industrial effluents are discharged continuously, whereas irrigation requirements are periodic. Hence, the estimation of hydraulic loading and pollution loading need to be made. Adequate scientific investigations need to be carried out before approving the use of effluent for irrigation. Public and private supported research on safe disposal methods for effluents and sludge needs to be taken up.

6.4 Recycle or Reuse of Effluents by Industries

Given the environmental problems caused by effluent irrigation, recycling the wastewater in the industrial sector may be a better option. Since the high TDS concentration is the major problem in both the textile and tannery industries, these units need to decrease TDS by reverse osmosis (RO) or other technologies. Taxes on polluting inputs and incentives for industries to reduce the pollution load in their effluents through cleaner production technologies, which consume less water and chemicals, could be effective.

6.5 Rainwater Harvesting in Areas Affected by Pollution

Recharge of freshwater through traditional as well as modern rainwater harvesting methods will help to reduce the level of pollution through dilution. In this respect, the construction of more check dams and percolation ponds, and reclamation of tanks and other degraded water sources, could help to overcome the problem. Characteristics of rainfall, and groundwater recharge capacity, play a crucial role for pollutant transport and concentration in the groundwater.

6.6 Awareness and Public Participation

There is a need to create more awareness regarding the adverse consequences of industrial effluent irrigation among different stakeholders (industrialists, farmers, concerned government departments and NGOs). Collective efforts towards pollution management have not taken place in many parts of the country. In the Mettupalayam area, local NGOs have been raising the issue in various forums, but have not been able to find a solution to the problems faced by the farmers.

6.7 Local Area Environmental Committee (LAEC)

In response to the issues raised in this study and by the NGOs, the Tamil Nadu Pollution Control Board (TNPCB) constituted a local area environmental committee to monitor the polluting industries located in Mettupalayam Taluk.[17] The responsibility of the LAEC is to monitor the operation of the effluent treatment plants of the industrial units and their level of compliance with the prescribed standards, and suitably advise the Pollution Control Board to take the necessary action. The formation of the committee made the process more transparent and the Board more accountable to the public. However, farmers and representatives of the local NGOs are not satisfied with the way the LAEC has been functioning since its constitution (November 1, 2005), and are demanding for a permanent LAEC for the region.

[17]The nine-member committee have representatives from the local government (gram panchayat), legislative assembly of the State, local academic institutions, local NGOs and the TNPCB, Coimbatore.

7. SUMMARY AND CONCLUSIONS

To understand the environmental impacts of industrial effluent irrigation on soil and groundwater quality of the surrounding farmlands, an exploratory soil and groundwater quality study has been carried out using both primary and available secondary information. The results indicate that the disposal of industrial effluents on land, which has limited capacity to assimilate the pollution load, has led to groundwater pollution. However, this is a preliminary study and further detailed and comprehensive studies are required. The continuous application of polluted groundwater for irrigation has resulted in the increased salt content of soils. In some locations drinking water wells (deep bore wells) also have a high concentration of salts. In Irumborai village, the area irrigated by a pulp and viscose rayon plant effluents continues to be polluted even though the plant closed down more than four years ago.

To understand the socioeconomic impacts of pollution on farm households, a livelihood impact survey along with a perception study has been carried out for 55 households. The survey of the farmer households revealed that most of them were able to cultivate salt-tolerant crops. The cropping pattern consisted of banana (29.6%), coconut (15.5%), curry leaf (13.9%) and jasmine (4.8%). However, it must be stressed that most of these crops are also raised in the unaffected areas. In other words, the cropping pattern is not really a response to the marginal quality water.

The study shows that the environmental impacts of industrial effluent irrigation is different for different sites, which is mainly due to the fact that different industries have different pollution potential; and different locations have different assimilative capacities to absorb the pollutants. Since the farmers had already shifted their cropping pattern to salt-tolerant crops and/or substituted their irrigation source(s) from open wells to deep bore wells and/or to accessing water from the Bhavani River, most of the farmers are able to cope, to a large extent, with the pollution of the groundwater and, hence, their livelihoods are not significantly affected. This shows that availability of coping options play a crucial role to mitigating pollution problems. However, the degree of severity of the pollution is also a crucial factor which determines the feasibility to adopt averting behavior. This study shows that *ex ante* adoption of precautionary measures (averting behaviour) could mitigate the environmental problems related to pollution.

The perception survey has clearly brought out the fact that the quality of well water has deteriorated significantly and as many as 50 percent of the farmers depend on a distant source such as the river water for irrigation. The situation with regards to drinking water quality is much worse. Ninety-four percent of the sample households have said that their own source of drinking water is polluted and they have to rely on the public supply – street taps or house connections. In a few cases, the industries are supplying river water to the neighboring households.

The less stringent effluent discharge standards for land application as well as the Tamil Nadu High Court’s restriction on locating near a river may have motivated the industries to buy land and use effluents for irrigation. This is a direct threat to the soil quality. Thus, there is urgent need for the regulation of water quality for land application. The experience from the irrigation with a saline and coloured effluent at the now closed pulp and viscose rayon plant at Sirumugai town is a further argument for restricting the use of land application of industrial effluents. It is not only water use that must be placed under control. Land use also has implications for water and environmental quality. The close linkages between land and water in the basin means that a degradation in one of them will also infringe on the other with potential repercussions on human health, yields, product quality, aquatic ecosystems and, generally, socioeconomic opportunities and sustainability.

Sustainable access to safe drinking water is one of the main targets of the United Nations Millennium Development Goals, and indiscriminate disposal of industrial effluents on land and surface water bodies make water resources unsuitable for drinking. Unlike developed countries, developing countries like India should follow the precautionary approach to protect the drinking water sources from point and non-point sources of pollution, as it cannot afford (financially and technically) to go for curative measures. Safe disposal of industrial effluents can support the achievement of this target.

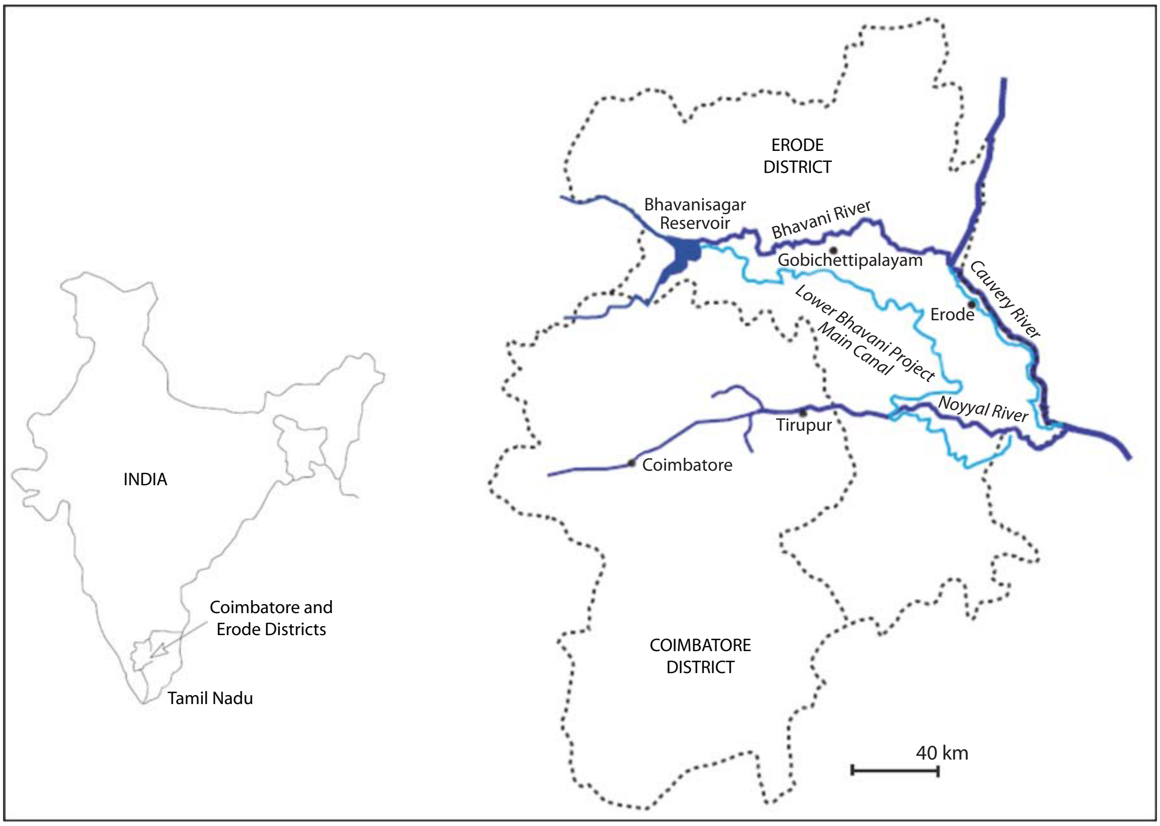
Water quality is critical for the future development along the Bhavani River. Also, industry is aware of, and acts to avoid, quality problems when looking for a suitable location for water using processes. Therefore, an increased interest has been seen towards establishing factories in the upper part of the basin. Since this area is generating freshwater for downstream urban clusters, farmers and environmental groups are trying to stop such development. However, strict regulatory measures are required to stop conversion of catchment areas of the river for industrial uses.

Water is a scarce resource. Thus, any reuse of water is desirable, as long as the costs (both direct and indirect) associated with the reuse is less than the benefits of using it. Detailed cost–benefit studies (both environmental and human health hazards) are essential before going in for industrial effluent irrigation.

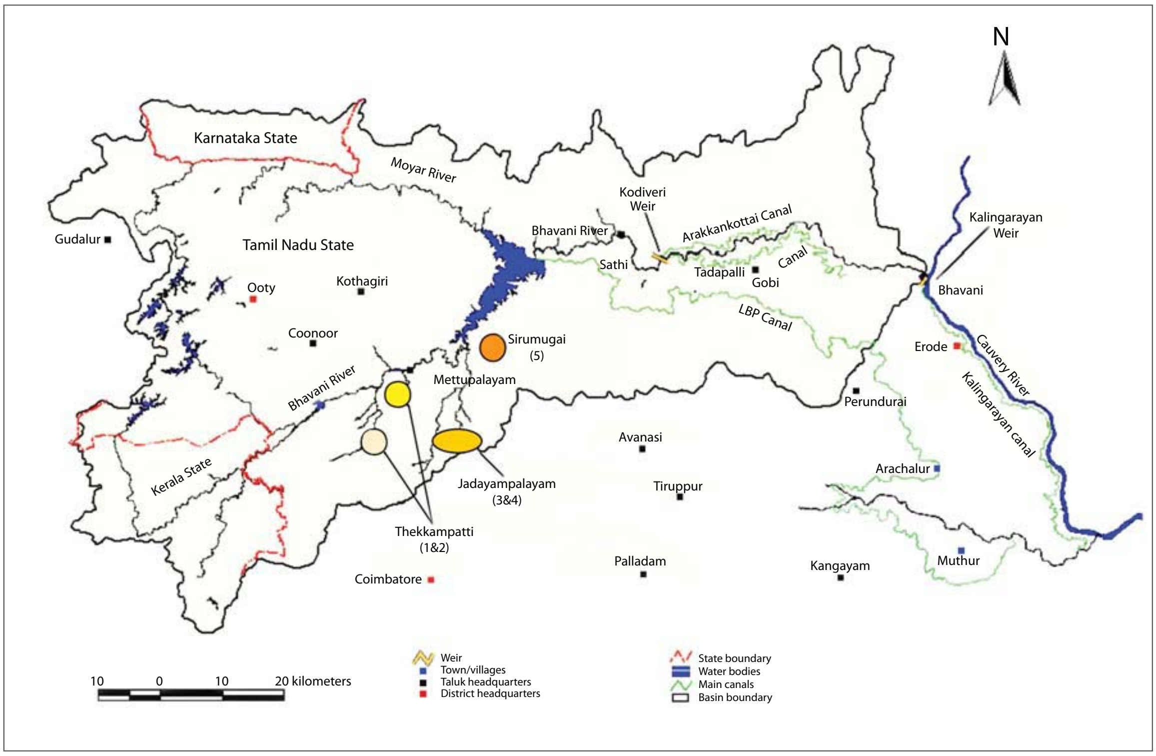
The volume of industrial effluent will increase with economic growth; therefore, in future the land disposal option could be a serious environmental threat to agriculture and other uses of water. Hence, it is essential for the concerned authorities to consider the environmental and socioeconomic impacts of using industrial effluent irrigation, before giving approval to such projects. For developing countries like India, it is imperative to follow the precautionary approach in the case of industrial effluent irrigation, as the long term environmental and human health risks/implications of using marginal quality water are not known.

APPENDIX A.

Location Map



The Bhavani River Basin, Tamil Nadu



APPENDIX B.

Table B1. Industrial profile – 1 (Mettupalayam study area).

Serial No.	Name of the unit	Location	Year of establishment	Activity	Size	Category	GFA (Rs. Crore)	Quantity Production T/M
1	Pulp and Paper Unit - 1	Thekkampatti	1997	Paper board	Large	Orange	243	7,424
2	Textile Bleaching and Dyeing Unit – 1	Thekkampatti	1994	Terry towel	Large	Red	28	100
3	Textile Bleaching and Dyeing Unit – 2	Mettupalayam (M)	1953	Bleaching and dyeing	Large	Red	7.6	530
4	Textile Bleaching and Dyeing Unit – 3	Jadayampalayam	1995	Bleaching and dyeing	Large	Red	10	72.5
5	Textile Bleaching and Dyeing Unit – 4	Jadayampalayam	1995	Bleaching and dyeing	Small	Red	0.7	21.75
6	Textile Bleaching and Dyeing Unit – 5	Jadayampalayam	1995	Bleaching and dyeing	Large	Red	89.6	21 Lakh
7	Pulp and Paper Unit – 2	Jadayampalayam	1991	Paper	Large	Orange	5.02	840
8	Wattle Unit	Mettupalayam (OR)	1967	Wattle	Medium	Red	4.47	NA
9	Chemical Unit	Mettupalayam (Manidur)	1994	Synthetic chemicals	Large	Red	8.52	NA
10	Water Amusement Park	Mettupalayam (Odanthurai)	1997	Water park	Large	Orange	20	—

Source: TNPCB, Coimbatore, 2004.
Note: GFA = Gross Fixed Asset.
T/M = Tonnes per Month.

APPENDIX B (Continued)

Table B2. Industrial profile - 2 (Mettupalayam study area).

S. No.	Name of the unit	Water Consumption (KLD)	Source of Water	Distance from the Bhavani River	Quantity of Effluents (KLD)	Year of Establishment of IETP	Mode of Effluent Discharge	Annual Water Cess (Rs.)
1	Pulp and Paper Unit - 1	5,025	Bhavani River	4.2 km	2,610	1997	O.L Irrigation	187,000
2	Textile Bleaching and Dyeing Unit – 1	620	Bhavani River	1.5 km	600	1994	O.L Irrigation	64,800
3	Textile Bleaching and Dyeing Unit – 2	1,700	Bhavani River	Adjacent River	1,668	1991	Bhavani River	36,883
4	Textile Bleaching and Dyeing Unit – 3	225	Bhavani River	2 km	221.5	1995	O.L Irrigation	13,122
5	Textile Bleaching and Dyeing Unit – 4	41.5	Bhavani River	2.2 km	40.1	1995	O.L Irrigation	4,320
6	Textile Bleaching and Dyeing Unit – 5	1,342	Bhavani River	1.5 km	808	1994	O.L Irrigation	39,324
7	Pulp and Paper Unit – 2	1,001	Bhavani River	0.8 km	981	1991	O.L Irrigation	74,888
8	Wattle Unit	50	Well	1.0 km	50	1989	O.L Irrigation	5,400
9	Chemical Unit	59	Well	-	35	1994	O.L Irrigation	2,520
10	Water Park	150	Well	-	150	1997	O.L Irrigation	1,463
	Total	10,214			7,164			429,720

Source: TNPCB, Coimbatore, 2004.

Note: O.L. Irrigation implies Own Land for Irrigation
KLD implies Kiloliter daily
IETP = Individual Effluent Treatment Plant

APPENDIX B (Continued)

Table B3. Annual pollution load discharged by industries in the Mettupalayam Area (tonnes/year).

S. No.	Name of the unit	Location	TDS	TSS	COD	BOD	Oil and Grease
1	Pulp and Paper Unit - 1	Thekkampatti	272.66	25.85	70.52	4.7	0.58
2	Textile Bleaching & Dyeing Unit – 1	Thekkampatti	132.27	13.14	12.26	1.31	0.21
3	Textile Bleaching & Dyeing Unit – 2	Mettupalayam (M)	494.36	21.91	24.35	4.74	0.6
4	Textile Bleaching & Dyeing Unit – 3	Jadayampalayam	116.09	3.88	14.22	1.09	0.08
5	Textile Bleaching & Dyeing Unit – 4	Jadayampalayam	32.2	1.11	0.3	0.48	0.01
6	Textile Bleaching & Dyeing Unit – 5	Jadayampalayam	70.78	2.35	2.35	1.17	0.29
7	Pulp and Paper Unit – 2	Jadayampalayam	166.14	15.75	42.96	2.86	0.35
8	Wattle Unit	Mettupalayam (OR)	17.59	3.06	1.84	0.09	0.01
9	Chemical Unit	Mettupalayam (Manidur)	13.43	0.71	0.3	0.04	0.01
10	Water Park	Mettupalayam (Odanthurai)	-	6.35	-	1.31	-
TOTAL			1,315.52	94.11	169.1	17.79	2.14

Source: MSE 2005 (Estimation based on TNPCB Data).

APPENDIX C.

Table C1. Maximum permissible limits (mg/liter) for industrial effluent discharges.

Parameter	Into Inland Surface Waters	On Land for Irrigation	Into Public Sewers	Marine Coastal area
Biological Oxygen Demand (for 5 days at 20°C)	30	100	350	100
Chemical Oxygen Demand (COD)	250	-	-	250
Suspended Solids	100	200	600	-
Total dissolved Solids (inorganic)	2,100	2,100	2,100	-
Total Residual Chlorine	1	-	-	1
Cadmium (as Cd)	2	-	1	2
Hexavalent Chromium (as Cr^{+6})	0.1	-	2	1
Copper (as Cu)	3	-	3	3
Lead (as Pb)	0.1	-	1	1
Mercury (as Hg)	0.01	-	0.01	0.01
Nickel (as Ni)	3	-	3	5
Zinc (as Zn)	5	-	15	15
Chloride (as Cl)	1,000	600	1,000	-
Selenium (as Se)	0.05	-	0.05	0.05
Ammoniacal Nitrogen (as N)	50	-	50	50

Source: CPCB 2001

APPENDIX D: TECHNICAL NOTE

Mean Equality Test (ANOVA)

This test is based on a single-factor, between-subjects, analysis of variance (ANOVA). The basic idea is that if the subgroups have the same mean, then the variability between the sample means (between group) should be the same as the variability within any subgroup (within group).

$$H_0 : \bar{x}_{g=1} = \bar{x}_2 = ... = \bar{x}_{g=G}$$
$$H_1 : \bar{x}_{g=1} \neq \bar{x}_2 \neq .... \neq \bar{x}_{g=G}$$

Denote the i-th observation in group g as $x_{g,i}$, where i=1,2,…..,n_g for groups g=1,2,...,G. The between and within sums of squares are defined as

$$SS_B = \sum_{g=1}^{G} n_g (\bar{x}_g - \bar{x})^2$$
$$SS_W = \sum_{g=1}^{G} \sum_{i=1}^{n_g} (x_{g,i} - \bar{x}_g)^2$$

Where $\bar{x}_g$ is the sample mean within group g and $\bar{x}$ is the overall sample mean. The F-statistic for the equality of means is computed as

$$F = \frac{\dfrac{SS_B}{(G-1)}}{\dfrac{SS_W}{(N-G)}} = \frac{MS_B}{MS_W}$$

where N is the total number of observations. The F-statistic has an F-distribution with G-1 numerator degrees of freedom and N-G denominator degrees of freedom under the null hypothesis of independent and identical normal distribution, with equal means and variances in each subgroup.

Summary: Groundwater EC (in dS/m) - Pre-monsoon samples

Groups	Observations	Sum	Average	Variance
Thekkampatti Cluster - I	17	31.0	1.83	0.3497
Thekkampatti Cluster - II	13	39.4	3.03	0.5571
Jadayampalayam Cluster - I	19	109.6	5.77	4.6790
Jadayampalayam Cluster - II	10	23.6	2.36	1.0530
Sirumugai Cluster	24	86.1	3.59	1.2698
All sites	83	289.7	3.49	3.6208

Summary: Groundwater EC (in dS/m) - Post-monsoon samples

Groups	Observations	Sum	Average	Variance
Thekkampatti Cluster - I	17	34.3	2.01	0.2998
Thekkampatti Cluster - II	13	49.0	3.77	0.9685
Jadayampalayam Cluster - I	19	118.6	6.24	6.3530
Jadayampalayam Cluster - II	10	29.6	2.96	1.4518
Sirumugai Cluster	24	92.9	3.87	1.4810
All sites	83	324.4	3.91	4.2891

Table D1a. ANOVA Table for Groundwater EC (in dS/m) Analysis for Thekkampatti Cluster - I: Pre- and Post-monsoon samples.

Sources of Variations	SS	df	MS	F-Stat	P-Value	F-Crit. (df=1,32)
Between Groups	0.303	1	0.303	0.933	0.3413	[.010] 7.5
Within Groups	10.391	32	0.325			[.050] 4.15
Total	10.694	33				

Table D1b. ANOVA Table Groundwater EC (in dS/m) Analysis for Thekkampatti Cluster - II: Pre- and Post-monsoon samples.

Sources of Variations	SS	df	MS	F-Stat	P-Value	F-Crit. (df=1,24)
Between Groups	4.684	1	4.684	6.140	0.0206	[.010] 7.82
Within Groups	18.307	24	0.763			[.050] 4.26
Total	22.991	25				

Table D1c. ANOVA Table Groundwater EC (in dS/m) Analysis for Jadayampalayam Cluster - I: Pre- and Post-monsoon samples.

Sources of Variations	SS	df	MS	F-Stat	P-Value	F-Crit. (df=1,36)
Between Groups	1.903	1	1.903	0.345	0.5606	[.010] 7.4
Within Groups	198.577	36	5.516			[.050] 4.11
Total	200.480	37				

Table D1d. ANOVA Table Groundwater EC (in dS/m) Analysis for Jadayampalayam Cluster - II: Pre- and Post-monsoon samples.

Sources of Variations	SS	df	MS	F-Stat	P-Value	F-Crit. (df=1,18)
Between Groups	3.11	1	3.111	2.484	0.1324	[.010] 8.29
Within Groups	22.54	18	1.252			[.050] 4.41
Total	25.65	19				

Table D1e. ANOVA Table Groundwater EC (in dS/m) Analysis for Sirumugai Cluster: Pre- and Post-monsoon samples.

Sources of Variations	SS	df	MS	F-Stat	P-Value	F-Crit. (df=1,46)
Between Groups	0.684	1	0.684	0.498	0.4839	[.010] 7.22
Within Groups	63.269	46	1.375			[.050] 4.05
Total	63.953	47				

Table D1f. ANOVA Table Groundwater EC (in dS/m) Analysis for All - Sites: Pre- and Post-monsoon samples.

Sources of Variations	SS	df	MS	F-Stat	P-Value	F-Crit. (df=1,164)
Between Groups	1.487	1	1.487	0.779	0.3787	[.010] 6.79
Within Groups	313.087	164	1.909			[.050] 3.9
Total	314.574	165				

Table D2a. ANOVA Table for Groundwater EC (in dS/m) - Pre-monsoon samples.

Source of Variations	SS	df	MS	F-stat	P-Value	F-Crit (df=4,78)
Between Groups	161.7232	4	40.4308	23.328222	<.0001	[.010] 3.57
Within Groups	135.1840	78	1.7331			[.05] 2.49
Total	296.9072					

Table D2b. ANOVA Table for Groundwater EC (in dS/m) - Post-monsoon samples.

Source of Variations	SS	df	MS	F-stat	P-Value	F-Crit (df=4,78)
Between Groups	173.8035	4	43.4509	19.050631	<.0001	[.010] 3.57
Within Groups	177.9032	78	2.2808			[.05] 2.49
Total	351.7067					

Summary: Soil EC (in dS/m)

Groups	Observations	Sum	Average	Variance
Thekkampatti Cluster - I	16	3.0	0.19	0.0057
Thekkampatti Cluster - II	13	3.3	0.26	0.0101
Jadayampalayam Cluster - I	19	10.7	0.56	0.2393
Jadayampalayam Cluster - II	10	2.0	0.20	0.0030
Sirumugai Cluster	23	8.7	0.38	0.1562
All - Sites	81	27.7	0.34	0.1201

Table D3. ANOVA Table for Soil EC (in dS/m).

Source of Variations	SS	df	MS	F-stat	P-Value	F-Crit (df=4,76)
Between Groups	1.6316	4	0.4079	3.8862336	0.0063	[.010] 3.58
Within Groups	7.9768	76	0.1050			[.05] 2.49
Total	9.6084					

Summary: Mettupalayam Taluk groundwater EC (in dS/m) Analysis –Hand pump data – 2000-01

Groups	Observations	Sum	Average	Variance	Range
Thekkampatti	22	29.23	1.33	0.39	0.57 – 2.66
Jadayampalayam	3	6.41	2.14	1.16	1.38 – 3.37
Irumborai	7	12.57	1.80	0.81	0.46 – 2.94
Karamadai	154	214.21	1.39	0.39	0.26 – 3.63

Table D4a. ANOVA Table for Thekkampatti and Karamadai Groundwater EC (in dS/m).

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit (df=1,174)
Between Groups	0.074	1	0.074	0.192	0.6618	[.010] 6.78
Within Groups	67.370	174	0.387			[.050] 3.9
Total	67.444	175				

Table D4b. ANOVA Table for Jadayampalayam and Karamadai Groundwater EC (in dS/m).

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit (df=1,174)
Between Groups	11.770	1	11.770	33.339	<.0001	[.010] 6.78
Within Groups	61.429	174	0.353			[.050] 3.9
Total	73.199	175				

Table D4c. ANOVA Table for Irumborai and Karamadai Groundwater EC (in dS/m).

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit (df=1,174)
Between Groups	3.345	1	3.345	9.101	0.0029	[.010] 6.78
Within Groups	63.957	174	0.368			[.050] 3.9
Total	67.302	175				

Please refer Table 6: Groundwater Quality (EC in dS/m) Analysis – TWAD Board's Regular Observation Wells Data (January 1992 to May 2005)

Table D5a. ANOVA table for Groundwater EC (in dS/m) Analysis: Irumborai (Sitepalayam) and Karamadai – Pre-monsoon.

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit (df=1,38)
Between Groups	3.252	1	3.252	6.356	0.016	[.010] 7.35
Within Groups	19.440	38	0.512			[.050] 4.1
Total	22.692	39				

Table D5b. ANOVA table for Groundwater EC (in dS/m) Analysis: Thekkampatti and Karamadai – Pre-monsoon.

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit (df=1,35)
Between Groups	0.724	1	0.724	1.469	0.2336	[.010] 7.42
Within Groups	17.253	35	0.493			[.050] 4.12
Total	17.977	36				

Table D5c. ANOVA table for Groundwater EC (in dS/m) Analysis: Irumborai (Sitepalayam) and Karamadai – Post-monsoon.

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit (df=1,31)
Between Groups	6.912	1	6.912	8.102	0.0078	[.010] 7.53
Within Groups	26.449	31	0.853			[.050] 4.16
Total	33.361	32				

Table D5d. ANOVA table for Groundwater EC (in dS/m) Analysis: Thekkampatti and Karamadai – Post-monsoon.

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit (df=1,29)
Between Groups	5.272	1	5.272	7.659	0.0097	[.010] 7.6
Within Groups	19.960	29	0.688			[.050] 4.18
Total	25.232	30				

Please refer Table 11: Average income of the households according to their groundwater quality (EC in dS/m)

Table D6a. ANOVA Table for average income from animal husbandry (in Rs./hh/year) for the samples having groundwater EC concentration 1.5-2.25 dS/m and control samples.

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit. (df=1,13)
Between Groups	162,401,333	1	162,401,333	17.472	0.0011	[.010] 9.08
Within Groups	120,836,000	13	92,950,76.9			[.050] 4.67
Total	283,237,333					

Table D6b. ANOVA Table for average total income from all sources (in Rs./hh/year) for the samples having groundwater EC concentration 1.5-2.25 dS/m and control samples.

Source of Variations	SS	df	MS	F-Stat	P-Value	F-Crit. (df=1,13)
Between Groups	753,003,000	1	753,003,000	5.907	0.0303	[.010] 9.08
Within Groups	1,657,281,000	13	127,483,154			[.050] 4.67
Total	2,410,284,000					

Notes: SS – implies Sum of Square Variations
df – implies Degree of Freedom
MS – implies Variability of Sample Means
F-Stat – implies F - Statistic
P-Value – implies Probability Value
F-Crit – implies F – Critical Probability Value

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