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Effects of dyeing and bleaching industries on the area around the Orathupalayam Dam in Southern India

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ABSTRACT

Rural people around the 4 km^2 Orathupalayam Dam in southern India live in one of India's most polluted areas. The people were once restricted mainly by scarcity of water but today they cannot drink their well water or cultivate their soil. The dam, created to store floodwater from the Noyyal River, also stores effluent water from the more than 700 dyeing and bleaching industries situated in the town of Tiruppur, 20 km upstream. Although most industries have treatment plants they do not treat total dissolved solids (TDS) and thus NaCl becomes one of the major components of the effluent. 75 to 100 million litres of effluents are released every day.

Through water sampling in open and bore wells, and with the help of GPS, ArcView and Surfer it could be concluded that high TDS levels and concentrations of Cl^-, Ca^{2+}, Mg^{2+} and Na^+ were associated with the dam. A definite spatial pattern of the spreading of polluted water could be determined. Water from the dam was fed to the ground water all around the dam and also affected the groundwater more than 4 km to the southeast. Soil samples and interviews with farmers made it clear that land irrigated with dam water or affected well water soon became uncultivable. The water destroyed the soil structure and seeds did not germinate after irrigation with polluted water.

Through interviews it could be concluded that the local people around the dam paid a large part of the externalities of the polluting activities of the textile industries in terms of negative health effects and lost agricultural land, water resources, fishing and working opportunities. These problems have mostly been caused by the high salt concentration in the effluents but it is unclear to what extent other substances have caused or might cause harmful effects to the environment, people and animals.

Keywords: Dyeing and Bleaching industries, Tiruppur, Orathupalayam Dam, pollution, water quality, soil quality, saline water, saline soil

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ABSTRACT IN TAMIL

சுருக்கம்

ஒரத்துப்பாளையம் நீர்த்தேக்கத்ததினைச் சுற்றி 4 சதுர.கி.மீ சுற்றளவில் உள்ள கிராம மக்கள் இந்தியாவின் மிகவும் மாசுப்பட்ட ஒரு பகுதியில் வாழ்கின்றனர். ஒரு காலத்தில் நீர்ப் பற்றாக்குறையின் காரணமாக மக்கள் சிரமப்பட்டனர். தற்பொழுது அவர்கள் கிணற்று நீரைக் கூட அருந்த முடிவதில்லை, சாகுபடி செய்யவும் இயலவில்லை. நொய்யல் ஆற்றின் வெள்ள நீரை பிடித்து வைத்துக் கொள்ள இந்த நீர்த்தேக்கம் கட்டப்பட்டது. ஆனால் இது தற்பொழுது திருப்பூர் பகுதியில் உள்ள 700 -க்கும் மேற்பட்ட சாயப்பட்டறைகள் மற்றும் தொழிற்சாலைக் கழிவுகளை தேக்கிவைக்கும் களமாக விளங்குகிறது. பெரும்பாலான தொழிற்சாலைகளில் கழிவுநீர் சுத்திகரிப்பு அமைப்புகள் இருந்தும் சுத்திகரிப்பதில்லை. அதில் சோடியம் குளோரைடு கழிவு நீரில் அதிகமாக உள்ளது, ஒவ்வொரு நாளும் 75 முதல் 100 மில்லியன் லிட்டர் கழிவு நீர் வெளியேறுகிறது.

திறந்த வெளிக் கிணறுகளிலும், ஆழ்குழாய் கிணறுகளிலும் நீர் மாதிரி எடுத்து ஆராய்ந்த போது குளோரைடு, கால்சியம், மக்னிசியம் மற்றும் சோடியம் அயனிகளின் அளவு அதிகமாக இருப்பது தெரிய வந்துள்ளது. மாசுபட்ட நீரின் பரவு விகிதத்தை ஒரு குறிப்பிட்ட முறையில் கண்டறிய வேண்டும். நீர்த்தேக்கத்தில் இருந்து நீர் அதனை சுற்றிலும் உள்ள கிணறுகளில் நிலத்தடிநீர் மூலம் சென்றடைகிறது. மேலும் , தென் கிழக்குப் பகுதியில் 4 கிலோ மீட்டருக்கும் மேல் பாதிக்கப்பட்டுள்ளது. மண்மாதிரிகள் எடுத்த போதும், விவசாயிகளிலும் கேட்டறிந்த போதும் அவர்கள் கூற்றின்படி நீர்த்தேக்க நீரையும், நிலத்தடி நிரையும் வைத்து நீர்ப்பாசனம் செய்தால் அவர்கள் நிலம் சாகுபடிக்கு பயனற்றதாகி விடும் என்றுரைத்தனர்.

மாசுபட்ட நீரை உபயோகப்படுத்தும் போது மண் அமைப்பு சிதைவுறுவதால் விதைகளும் முளைப்பதில்லை. உடல் நலக்குறைவு, விவசாய நிலத்தை இழந்துள்ளனர். நீர் நிலைகள், மீன் பிடித்தல் மற்றும் வேலை வாய்ப்புகளையும் மக்கள் இழந்துள்ளனர் என்பது மக்களிடம் கலந்துரையாடியபோது தெரியவந்தது. கழிவு நீரில் அதிக அளவு உப்புகள் இருந்ததால் மேற்கண்ட விளைவுகள் ஏற்பட்டுள்ளது. ஆனால் சுற்றுப்புறச் சூழல், மக்கள் மற்றும் விலங்கினங்களை இன்னும் எந்த அளவிற்கு பாதித்துள்ளது என்பது சரியாக தெரியவில்லை.

முக்கிய குறிப்புகள்

சாயப்பட்டறை மற்றும் நீரை நீக்கும் தொழிற்சாலைகள், திருப்பூர், ஒரத்துப்பாளையம் நீர்த்தேக்கம், மாசுபடு, நீரின் தரம், மண்ணின் தரம், உப்பு நீர், உவர் நிலம்.

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Preface

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APPENDICES

1. **Maps with numbers showing water sample locations with corresponding descriptions**
2. **Results from chemical analysis of water samples in $mmol_c/l$**
3. **Results from chemical analysis of water samples in mg/l**
4. **Percentage difference between cations and anions (Ion balance) in water samples**
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1. INTRODUCTION

How is Your Water? This friendly greeting, common in ancient and indigenous cultures, shows the importance of clean water. The health of the water you are putting into your body is vital for your well being. (Varnum, 2003) It is the same for the environment as a whole. Water is the bloodstream of the biosphere (Falkenmark & Rockström, 2004). Water is life and has many functions. In addition to serving as the basic requirements for humans and ecosystems, water also acts as a sink, solvent and transport vehicle for domestic, agricultural and industrial waste, causing pollution (GWP, no. 4).

Industrial development has caused pollution of water through history and this is very much the reality in the town of Tiruppur in southern India. Cleaning technology has not kept pace with the use of toxic chemicals in the many textile industries in and around the city. Over 700 bleaching and dyeing units, the two most water and chemical consuming industries in the textile production chain, let out virtually all effluents into the Noyyal river which flows through Tiruppur. Detoriating water quality in the Noyyal river influences water usability downstream, threatens human health and aquatic ecosystems and increases competition for water. A barrier was built in 1992 about 20 km downstream of Noyyal River, creating the Orathupalayam Dam. It was built in order to utilize the water in the river during the monsoon season and this dam is the focus of the study.

2. AIM

The main aim of the study was to investigate the effects of the stagnation of polluted water in the Orathupalayam dam on the quality and quantity of groundwater, the effects of irrigating with dam and well water on soil and crops and, consequently, how people have been affected in the surrounding areas. The aim was also to detect the spatial pattern of the spreading of pollution in groundwater and also the reasons for this pattern. Another purpose of the study was to explain how the Orathupalayam dam was built and operates today. An attempt to provide suggestions on the future of the area was also made. The study can be seen as a status report on the area around the Orathupalayam Dam as of September-November 2003.

3. BACKGROUND

The Orathupalayam Dam is located about 20 km downstream of the hosiery centre of India, Tiruppur (Fig. 1), on the border between Kangayam and Perundurai Taluks[1] in Erode District. Erode belongs to Tamil Nadu State, the southernmost state in India (Fig. 2). The dam was constructed by building a barrier across the Noyyal River. The Noyyal crosses three districts, Coimbatore, Erode and Karur (Fig. 3), before it reaches the river Cauvery.

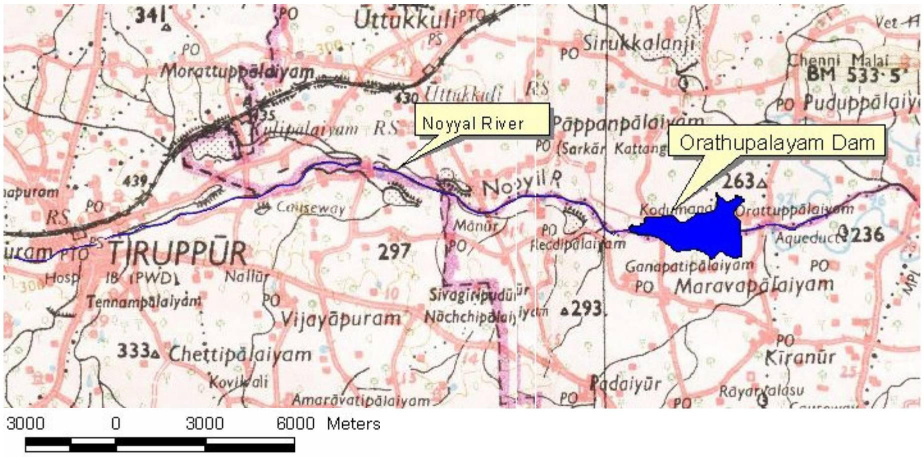

Figure 1. Location of Tiruppur and the Orathupalayam Dam

Figure 2. Location of Tamil Nadu

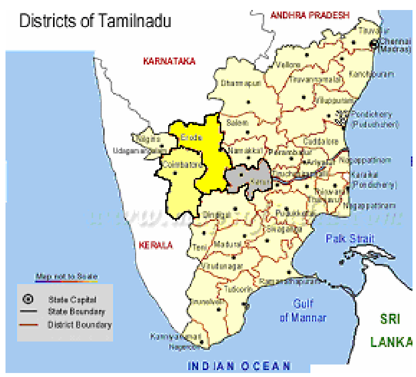

Figure 3. Locations of Coimbatore, Erode and Karur

3.1. NOYYAL RIVER

The Noyyal or *Noi il* river, which translates into "devoid of illness" in Tamil, holds special significance for the Hindus (The Hindu, 2003). It is a divine and holy river that originates in the Vellingiri hills of the Western Ghats and flows from this mountain and valley region towards fairly level areas in the lower catchments, past several urban settlements and over flat to gently undulating ground, before it reaches the river Cauvery about 170 km downstream. The river flows from west to east and its maximum elevation is around 1600 m above sea-level and the minimum elevation is 100 m (Sankararaaj et al. 2002). The total catchment area (Fig. 4) is 3510 km^2 and is located between 10°56' N, 76°41'E and 11°19' N, 77°56'E. The basin is widest in the central part, having a width of 35 km. The average width is about 25 km. (MSE, 2002)

[1] India is divided into **states** and each state consists of several **districts**. Within each district there are a number of **taluks** and each taluk is divided into **blocks**. The blocks are in their turn divided into **revenue villages**, areas which contain the smallest units, the **hamlets**.

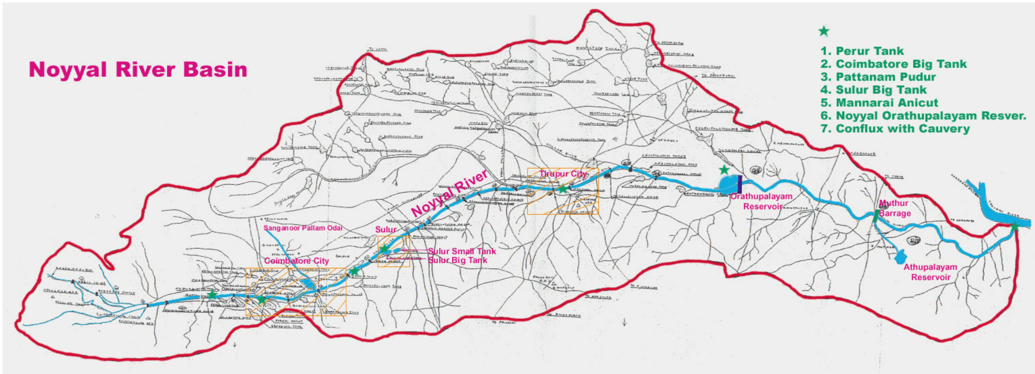

Figure 4. Noyyal River Basin

Noyyal is a seasonal river, fed by the monsoons. The water flow is moderate for a short period during the monsoon season. Occasionally flash floods occur after heavy rain events. There are seven major tributaries, all originating from first or second order streams in the foothills of the Western Ghats. Floods are common during the rainy season due to the steep slopes in the upper part of the catchments. (Sankararaaj et al. 2002) Rainfall in the basin is highly variable due to the orographic effects of the Western Ghats (Sankararaaj et al. 2002). The mountains form a "rain shadow area" over the plain which consequently has a dry climate (Gustavsson et al., 1970). The western and upper reaches usually receive more than 3000 mm annually during the southwest monsoon whereas the eastern part of the basin receives an annual rainfall of 600 mm, which mostly occurs during the northeast monsoon. (MSE, 2002)

The Noyyal has a long and illustrious history as a river influenced by man, which is indicated by the many tanks and canals. Several civilisations have flourished around its banks throughout history (The Hindu, 2003). The present tank and canal system is very different from the one that existed before the start of urbanisation. Today, the basin appears to be fully exploited, having 23 anicuts[2], 30 system tanks, 20 channels and two reservoirs, Orathupalayam and Authupalayam, constructed for irrigation. (MSE, 2002)

Noyyal River is important for the rural people who live along its banks. The river provides water for irrigation and drinking water for livestock and people. It is also believed that the water contains natural medicines and is therefore good for health. (MSE, 2002) Along long stretches of the river this is not true anymore due to industrial and domestic pollution.

Although Noyyal means "devoid of illness" the river has become "ill". It is today one of India's most polluted rivers. The water originating from the hills is tasty and sweet, but soon the quality changes, as much of the household wastes from the urban settlements are dumped into the river. Adding to this, there are a large number of industries, especially hosieries and tanneries in and around Coimbatore and Tiruppur, the industrial majors of the Noyyal basin that discharge their effluents into the river.

Today, parts of the Noyyal river basin are "Industrial Wastelands", areas subjected to degradation as a result of a large-scale discharge of industrial effluents (Sankararaaj et al. 2002). The groundwater close to, and the water in the river, is today unfit for drinking, sanitation or even irrigation in these areas. The stretch between Tiruppur and the

[2] Structures built for irrigation i.e. dams and reservoirs

Orathupalayam dam (Fig. 1) consists of Industrial Wastelands. The Noyyal River is no longer seasonal in this part; it is perennial due to huge amounts of effluent water from mostly dyeing and bleaching industries in and downstream of Tiruppur. Over 3000 industries operate in Tiruppur out of which about 750 are engaged in dyeing and bleaching (Sivakumar, 2001) and the effluents from these flow into, and are stored in the Orathupalayam dam.

3.2. DEVELOPMENT OF TIRUPPUR AND THE ORATHUPALAYAM DAM

Tiruppur, traditionally a small urban centre, has become the centre of hosiery manufacturing in India. It began in the 1970s, when the production of knitted garments for the local and national market started on a small scale. In the middle of the 1980's capital accumulation and development of knowledge and skills enabled some of the larger units to start producing for the export market. In 1991, the liberalisation of the Indian economy began and export opportunities were welcomed by the central government. Within 10 years Tiruppur, became the "Knit City", "Cotton City" or "Dollar City" that presently produces the majority of India's total exports of hosiery garments. (Blomqvist, 1996)

Thousands of units are involved in spinning, knitting, bleaching, dyeing, printing embroidery and stitching. One of the characteristics of, and the explanations for, this little town's success in the hosiery market is the congregation of many small to mid-size units doing different phases in the production chain. (Blomqvist, 1996) A merchant for the domestic market, a direct exporter or an export merchant usually coordinates these networks of firms. They place orders or job work[3] in different steps of the production chain and the fabric moves from the knitting unit to the bleaching and dyeing unit and then to the printing unit and so on. (History of Tiruppur, 2004; Blomqvist, 1996)

Most of the industrialists in Tiruppur come from a modest agricultural background. From interviews, it became evident that these former farmers innovated the organisation of the industry. There are many ways in which they came to the industry and they all entered as small owners. As the market grew they created "sister" units, often managed by their relatives, expanding the industries in dispersed units within the city. (History of Tiruppur, 2004) The uniqueness of Tiruppur's work culture has made it difficult for the Indian textile giants to enter and capture a large market share, as the rules and norms governing manufacturing and job working are often informal and personalised (History of Tiruppur, 2004). The existence of innumerable small industrial units is also partly a result of a special economic policy intended to stimulate Small Scale Industries (Blomqvist, 1996).

For a visitor to Tiruppur, nothing about the city makes one believe that millions of dollars in foreign exchange are brought in each year. It seems to be a very poor city, with huge environmental problems. The state government and local municipal authorities have been too slow to cope with the rapid growth of the industries. In fact the environment in and around Tiruppur is deteriorating and the ecological balance has been lost because of industrialization (Blomqvist, 1996). The most polluting and water-demanding steps in the hosiery trade are bleaching and dyeing of fabrics and both these processes involve the use of many chemicals.

The Western method of industrialisation, with its use of toxic chemicals, has been adopted in a small-scale industrial sector where it is economically difficult to have a pollution

[3] Contracting of orders between different units in the production chain

control technology. The small enterprises have adopted western technologies, using toxic chemicals when, for example, dyeing clothes instead of, as has been done for centuries, using vegetable dyes. (Agarwal, 2002) Since clusters of these chemical- and water-demanding industries have developed in Tiruppur, serious waste problems have occurred.

Development of Orathupalayam Dam

In the 1980s there were only a small number of textile industries in the area around Tiruppur and they discharged their untreated effluents into the Noyyal River, but since the quantity released was small the effluents were somewhat diluted and naturally purified (PWD, 2003). At this time the Noyyal Orathupalayam Reservoir Project (NORP) started in order to utilize the heavy surplus of water in the Noyyal River during the monsoon season. This water would otherwise run straight into the Cauvery River. Since the plains along Noyyal River are very dry, people of Karur taluk had long demanded that a reservoir across the river should be built in order to use the floodwater (PWD 2003). The government formulated the NORP scheme in two stages and the construction of the Orathupalayam dam started in 1985, as part of the second stage, and was completed in 1992. By then, an increasing number of dyeing and bleaching units were established in Tiruppur about 20 km upstream of the dam (Table 1).

Table 1. Number of Bleaching and Dyeing Units in Tiruppur 1941 to 1994

Number of Bleaching and Dyeing units in Tiruppur	
1941	2
1951	15
1961	42
1971	67
1981	78
1986	99
1989	450
1992	518
1994	713

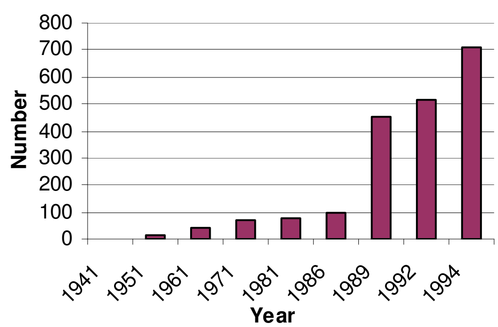

Figure 5. Histogram from Table 1

(Source: Blomqvist A., sid 139. Original Source: Development Plan for Tiruppur Town, 1990, Tiruppur Dyers' Association, and Kalaimany and Sathiah, 1994. The Figures only include members of either the Dyers' or Bleachers' Association)

The large environmental problems in Tiruppur came in the 1990's when the numbers of bleaching and dyeing units were more than 500. Up to 1997, virtually all effluents were let out into the Noyyal or its tributaries without any purification treatment. (MSE, 2002) After 1997 a number of Common Effluent Treatment Plants (CETPs) and Individual Effluent Treatment Plants (IETPs) were constructed (Section 3.7) but there are major problems with their functioning. Together, the industries discharge nearly 100 million litres per day of effluents, which affect the surface and groundwater quality in the region (MSE, 2002). It did not take long before the industrial effluents polluted the water in the Orathupalayam dam and the contamination is increasing year by year.

3.3. NOYYAL ORATHUPALAYAM RESERVOIR PROJECT (NORP)

The water resources in the Noyyal river basin are heavily utilized through many diversion channels and tanks but the NORP scheme was the first major reservoir project. The first scheme was sanctioned by the government in 1981 and the second in 1984. (Sivanappan, 2003)

First scheme

The first stage scheme was formulated to utilise the seepage/surplus water that drains into the Noyyal from the Lower Bhavani Project canal (LBP), which crosses the Noyyal River about 1 km downstream of Orathupalayam Hamlet (shown in Fig. 11). The LBP canal was constructed in 1953 and leads water from the Bhavani Sagar Reservoir in Bhavani river, located at a higher altitude in relation to Noyyal River Basin. Otherwise dry land in the Noyyal river basin received water from the LBP through seepage water flow to the Noyyal River. Excess water flows in Noyyal River whenever water is released in the LBP canal, usually several months per year. Investigations have shown that about 2760 Mega cubic feet or 78 450 m^3 of surplus water from LBP ayacut[4] lands ultimately flowed into the Cauvery each year. (NODR-folder)

After the LBP canal crosses Noyyal it goes up to Muthur, a distance of around 30 km. In Chinna Muthur village a barrage of the length 119 m was constructed across the river (Fig. 4), as per the first scheme, to utilise the excess water from the LBP. The seepage water is stored there and diverted through a 10 km long feeder canal to a reservoir called Athupalayam. The water is utilised to irrigate about 9625 acres of dry ayacut by excavating a 32.75 km long irrigation canal. (Sivanappan, 2003) An additional food grain production of 9305 metric tonnes was expected from these lands but due to pollution, the actual area cultivated is 6648 acres as estimated by the Water Resources Organisation for the period 1998-99 (MSE, 2002). The first scheme was completed in 1991 at a total cost of Rs. 1390 lakhs[5] (139 million rupees) (Sivanappan, 2003)

Second scheme

In the second stage the Orathupalayam reservoir was constructed by building a barrage across Noyyal, above the point where the LBP canal crosses the river. It was made to store floodwater from the Noyyal and proposed to directly irrigate 500 acres of dry ayacut in the Erode district through two head sluices located on the right and left side of the dam. Additionally the water was to irrigate 9875 acres of dry ayacut in Karur district by the extension of the Authupalayam main canal from 32.75 km to 60 km. It was planned to irrigate 10,375 acres in the future. (NODR folder) 10 000 metric tonnes of additional food grain production was supposed to come out of the irrigated lands. The actual land cultivated became, however, only 27% of the total ayacut area. Out of the 500 acres of direct ayacut, the actual area of cultivation during 1993-96 was very small and no irrigation water was released from 1996-97 to 1997-98. (MSE, 2002) The second stage was completed in 1991 at a cost of Rs. 1998 lakhs (199.8 million rupees). (Sivanappan, 2003)

Orathupalayam Reservoir

The reservoir consists of a 99.5 m long stone masonry dam and spillway with an earthen dam on both flanks. The total length of the reservoir is 2.19 km. (Sivanappan, 2003) It is built across the Noyyal River with Orathupalayam revenue village on the north side and Maravapalayam revenue village on the south side.

The floodwater stored in the reservoir can be discharged into the Noyyal River through a sluice built in the masonry dam and taken over the delta region to Muthur barrage 28 km downstream. From there, it can flow through a feeder canal to the Athupalayam Reservoir to irrigate 10 375 acres. (MSE, 2002) There are also two canals with sluices, one going

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[4] Area irrigated under a certain reservoir, tank or canal

[5] 1 Lakh is synonymous with 100000, i.e. one hundred thousand. A lakh is a unit in a traditional number system, still widely used in India.

northeast (left main canal) and one southeast (right main canal), for irrigation of the 500 acres of direct ayacut. The particulars of the dam are given in Table 2 below.

Table 2. Hydraulic particulars of the Orathupalayam Reservoir

Length of Reservoir	2290 m	**Left main canal**	
Capacity of Reservoir	17440 m3 (637Mcft)	Ayacut area	100 acres
Maximum water level	248 m	Length of canal	1.40 km
Maximum flood level	248 m	Sill level of Sluice	245.0
River Bed level	234 m	Taluk	Perundurai
Top Bund level	250,1 m	Village	Orathupalayam
Water spreading area	425 Ha	**Right main canal**	
Catchment area	2246 km2	Ayacut area	400 acres
Maximum Flood Discharge	2527 m3 ?	Length of Canal	1.86 km
Length of masonry dam	99.5	Sill level of Sluice	245.0 m
		Taluk	Kangayam
Number of river sluices	1	Village	Maravapalayam
Number of canal sluices	2		
Sill level of river sluice	236 m		
Sill level of Left main canal and Right main canal.	245 m		
Direct ayacut area of dam	500 acres		
Total ayacut area under Athupalayam extension Canal	9875 acres		

(Source: Information from Sivanappan 2003 and NODR folder)

The total cost of the two schemes was Rs 33.9 crores[6] (339 million rupees). About 20,000 acres of dry ayacut were supposed to benefit from seepage water, enriching underground water recharge. Industrial pollution from the Tiruppur region has, however, defeated the objective of the whole project. (MSE, 2002) The Irrigation Department of the Water Resources Organisation did not pay attention to the upstream discharge of industrial effluents which were likely to flow and accumulate in the Orathupalayam dam.

In the following sections, water and soil quality and standards will be discussed. A brief description of the common constituents of water and different parameters used to characterize and classify water for different purposes will be given. The composition of soil will be explained, as well as salt effects on soil and crops. This will give an understanding of the coming sections where the effects and consequences of the effluents from dyeing and bleaching industries are discussed.

3.4. WATER QUALITY AND STANDARDS

The chemical, biological, and physical characteristics of water determine its usefulness for household, agriculture and industrial purposes. The description below will be restricted to inorganic constituents and focus on the chemical water quality. BOD and COD will also be explained since they are used to describe the Noyyal river water in earlier studies. If human activity alters the natural water quality so that the water is no longer fit for its previous use, the water is said to be **polluted** or **contaminated** (Fetter, 2001).

[6] 1 crore is equal to 10 million. A crore is a unit in a traditional number system, still widely used in India.
1 crore = 100 lakh

3.4.1. Ions in water

In a typical water the major ions existing in solution are sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulphate (SO_4^{2-}), bicarbonate (HCO_3^{2-}) and carbonate (CO_3^{2-}). These ions are usually present in amounts greater than 5 mg/l (except for K^+ which can vary between 0.01 and 10 mg/l). Another major constituent is silica, which is usually considered to exist as the uncharged $H_4SiO_4^0$ species. Minor chemical species (0.01-10 mg/l) commonly occurring in water include NO_3^-, F^-, Br^-, Si^{2+}, Ba^{2+}, Fe^{2+}, Li^+, B^{3+}, PO_4^{3-}. (Hounslow, 1995) Trace elements such as arsenic, lead, cadmium and chromium may be present in amounts of usually < 0.1 mg/l but are important from a water-quality standpoint (Fetter, 2001).

3.4.2. Parameters for characterizing water

In addition to the ions mentioned, a variety of other chemical variables are often reported in order to characterise the water and assess its usefulness as potable, irrigation or industrial water. Some are based on analytical determinations and others are calculated values.

pH

pH is a standard variable and is a measure of the hydrogen ion concentration, or more correctly, activity. It indicates the degree of acidity. (Yadav & Khera, 1966)

Electrical conductivity (EC)

The amount of total soluble salts in a sample is generally expressed in terms of electrical conductivity since EC increases as the amount of soluble salts in a solution increases.
(Hounslow, 1995) EC is a good estimator of Total Dissolved Solids (TDS), since TDS in mg/l is proportional to EC in mhos. The relation is:

$$TDS\,(mg\,/\,l) = x \cdot EC\,(\mu mhos\,/\,cm) \qquad where \quad x = 0.55 to 0.76$$

For water with high EC values, it can be expressed as dS/m which is equivalent to mmhos/cm.

Solids in water

Solids can be both suspended and dissolved. Total dissolved solids (TDS) is usually used to characterise and classify water and can, as described above, be estimated by the EC value. TDS in a water sample includes all solid material in solution, whether ionized or not (David S & DeWiest R, 1966) but does not include suspended sediment, colloids or dissolved gases. If all dissolved solids were accurately determined by chemical tests, TDS would be the sum of these. The major constituents i.e. Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^{2-}, CO_3^{2-} constitute the bulk of the mineral matter contributing to TDS.

Hardness

Hardness in water is caused by dissolved calcium and to a lesser extent magnesium. It is usually expressed as the equivalent quantity of calcium carbonate. (WHO, 2nd ed.)
Groundwater usually has a greater hardness than surface water. (Hounslow, 1995)

Alkalinity and Acidity

Alkalinity and acidity are capacity values and are quantitative measurements of the capacity of a solution to react with acids and bases, respectively. The alkalinity of a solution is defined as the capacity of a solution to react with strong acid down to a reference pH value. Acidity is the analogous capacity of a solution to neutralize a strong base. (Hounslow,1995)

Sodium Adsorption Ratio (SAR)
SAR indicates the degree to which Na^+ in water replaces the electrostatically adsorbed Ca^{2+} and Mg^{2+} ions on negatively charged soil clay and organic matter surfaces (Hounslow, A 1995). SAR is used to classify irrigation water (3.4.4) and soil solutions (3.5.2.)

Residual Sodium Carbonate (RSC)
Carbonate and bicarbonate ions present in excess of calcium and magnesium ions in irrigation water may cause harmful effects on crops and are given as RSC (section 3.5.2.)

COD and BOD
Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) are often used to estimate the total quantity of organic matter present in water. COD is obtained by measuring the equivalent quantity of an oxidizing agent, commonly a permanganate or dichromate salt, necessary for the full oxidation of the organic constituents. BOD is a direct measure of the oxygen uptake in the microbiologically mediated oxidation of organic matter (Morgan & Werner, 1970). In other words, it measures the amount of oxygen consumed by an organic compound undergoing decomposition. (Hounslow, 1995)

3.4.3. Drinking water standards
A selected part, useful for this study, of the physical and chemical standards for drinking water prescribed by Indian Standards Institution (ISI) and the Indian Council of Medical Research (ICMR) is given in Table 3. The complete list of physical and chemical standards can be found in appendix 6. The WHO (World Health Organisation) guidelines for the same parameters and sodium follow.

Table 3. Standards of Drinking Water prescribed by ISI and ICMR

Parameter	ISI, Max Permissible level	ICMR, Highest Desirable Level	Maximum permissible level
PH	6.5 – 8-5	7.0 – 8.5	6.5 – 9.2
TDS (mg/l)	500	500	1500
Chloride (mg/l)	250	200	1000
Sulphate (mg/l)	150	200	400
Calcium (mg/l)	75	75	200
Magnesium (mg/l)	30	50	--

Reliable data on possible health effects associated with ingestion of high **TDS** in drinking water are not available, and no health-based guideline is proposed by WHO. The presence of high levels of TDS may, however, be objectionable to consumers. (WHO 2nd ed.). The palatability of water with a TDS level less than 600 mg/l is generally considered to be good. Drinking water becomes significantly unpalatable at TDS levels greater than 1200 mg/l. (WHO, 3rd ed.)

The WHO does not have a health-based guideline for **chloride** in drinking water. Chloride concentrations in excess of about 250 mg/l can, however, give rise to a detectable taste in water. Excessive Cl^- concentrations also increase the corrosion rates of metals which may lead to increased concentrations of metals in the water supply. (WHO, 2nd ed.) Consumers may become accustomed to low levels of chloride induced taste (WHO, 3rd ed.).

WHO does not have a health-based guideline for **sulphate** either, but because of gastrointestinal symptoms resulting from ingestion of drinking water containing high sulphate concentrations, it is recommended that authorities are notified if sulphate exceeds

500 mg/l (as sulphate). Sulphate my also cause noticeable taste and may contribute to corrosion of water distribution systems. (WHO, 2nd ed.)

Sodium salts (e.g. sodium chloride) are found in all drinking water. Concentrations of sodium in potable water are usually less than 20 mg/l, but can greatly exceed this value in some countries. No health-based guideline is proposed by WHO but concentrations in excess of 200 mg/l can give an unacceptable taste. (WHO, 2nd ed.)

According to WHO the degree of **hardness** (Ca^{2+} plus Mg^{2+}) may affect the acceptability of water to consumers, in terms of taste and scale deposition ($CaCO_3$). (WHO, 2nd ed.) The taste threshold for calcium ions is in the range of 100-300 mg/l, depending on the associated anion, and for magnesium it is probably lower. Hardness is usually indicated by precipitation of soap scum and the need for excess use of soap for cleaning purposes. (WHO, 3nd ed.)

3.4.4. Irrigation Water

The suitability of irrigation water depends on a) amount and nature of salts in the water, b) the soil to be irrigated, c) climatic conditions and d) the crop species. These conditions change from place to place and therefore the classification of irrigation water is based on the amount and nature of salts in the irrigation water. (Natarajan et al., 1988)

Irrigation waters are usually classified in terms of salinity hazard (estimated from EC or TDS) and sodium hazard (SAR), in order to determine its subsequent effects on soil. The classification with respect to SAR is based primarily on the physical effects on soil but sodium-sensitive plants may suffer injury as a result of sodium accumulation at lower levels (Natarajan et al., 1988).

TDS and SAR are used in the USDA[7] System for irrigation water (Fig. 6) (Richards, 1969). The salinity hazard (TDS) dividing points are 250, 750 and 2250 μmhos/cm, resulting in four classes:

<250	-Low-salinity water (C1)
250-750	-Medium-salinity water (C2)
750-2250	-High-salinity water (C3)
>2250	-Very high-salinity water (C4)

The sodium hazard is a function of both SAR and salinity and the dividing lines are:

$$SAR = 43.85 - 8.87 \log EC$$
$$SAR = 31.31 - 6.66 \log EC$$
$$SAR = 8.87 - 4.44 \log EC$$

The resulting four classes are:

S1	-Low-sodium water
S2	-Medium-sodium water
S3	-High-sodium water
S4	-Very high-sodium water

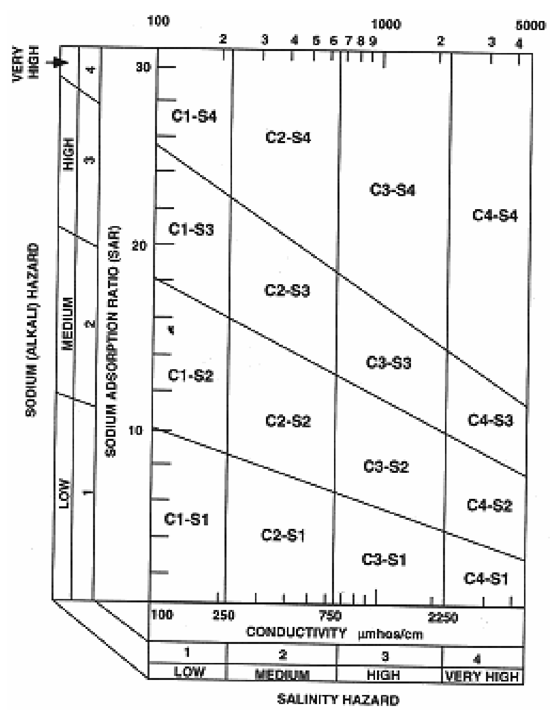


Figure 6. SAR-conductivity plot.(Richards, 1969)

[7] United States Department of Agriculture

The graph obtained from the different classes and calculations can be used to classify irrigation water. The water is classified as a combination between one out of C1, C2, C3 or C4 with one out of S1, S2, S3 or S4. More information about these classes can be found in appendix 5.

In Tamil Nadu, water intended for agricultural purposes is first analysed for pH and electrical conductivity (EC) with the ratings given in Tables 4 and 5.

If the water analysed has high concentrations of soluble salts and sodium, indicated by EC and pH, a detailed analysis for various cations and anions is made. The classification is then based on EC, pH, Na %, Cl, SAR and RSC. (Natarajan et al., 1988)

Table 4. Ratings on soil reaction (pH)

Rating	Status
Below 6.0	Acidic
6.0 to 8.4	Normal
8.5 to 8.9	Tending to alkaline
8.9 and above	Alkaline

Table 5. Ratings of EC

Rating	Status
Below 1.0	Normal
1.0-3.0	Critical
3.0 and above	Injurious

3.5. SOIL QUALITY AND STANDARDS

3.5.1. Soils and their composition

When describing a soil the mineralogy is of great importance in order to understand how the soil can interact when, for example, polluted irrigation water is added.

Physical and chemical weathering of the primary minerals results in the formation of secondary minerals. Secondary minerals are generally small particles, < 2 mm, with a surface area that, together with the organic material, is of major importance for the chemical reactivity in soil. Depending on what origin the secondary minerals have and the age of the soil, there are differences in the composition of secondary minerals although they can be divided into three different groups; layer silicate clays, oxides and non-crystalline aluminosilicates. The layer silicates are often dominating in soil and form minerals such as kaolinite, smectite, vermiculite and illite. (McBride, 1994)

Depending on how the different minerals are constructed, their chemical and physical properties vary. Differences in cation exchange capacity (CEC) between the minerals are a very significant feature. Smectite, for example, has a low specific surface area and CEC compared with illite and vermiculite. This is of importance when considering the soil nutrient status or the effect of adding irrigation water with high or low concentrations of, for example, sodium, Na^+. (McBride, 1994)

In the southern part of India one of the dominating soils is described as ‘Red Soil’. In some cases, the red soils could be classified as Alfisols, a soil type that was found in the area around the Orathupalayam dam according to earlier studies. The Red Soils contain a mixture of the secondary minerals, mainly kaolinite and illite. (Bhushana et al., 1987)

3.5.2. Salt-affected soils

Salts primarily originate from rocks as they weather into soil. The salts are carried downwards (leached) with the percolation water. Eventually they either precipitate or continue to be transported in solution. Ultimately they end up in the sea. Only in exceptional cases is a high salt content in soil directly related to the soil’s parent material. In such cases the salinity is called primary or residual. However, the most common cause of high soil salinity is salinisation, i.e. the accumulation of salts originating from an outside source (Lambert, 1983). There are many examples of salinisation caused by human activities; a common cause is irrigation with saline water in combination with poor drainage.

The occurrence of saline soils is much more prevalent in hot, dry climates than in temperate humid climates. In temperate climates there is usually enough excess water percolating through the soil to remove salts from the upper soil layers. Soil and drainage conditions are important since they largely determine the physical possibilities for leaching and removal of excess salts from the soil. (Lambert, 1983)

From a historical point of view, large areas in the semiarid part of the world have been wasted because of bad irrigation practices. When discussing salt-affected soils, the aspects considered are alkalinity, salinity and sodicity.

Alkalinity and Salinity

Alkalinity of water could be expressed as RSC; the Residual Sodium Carbonate value, defined according to equation 1.

$$RSC = \left[HCO_3^-\right] + 2\left[CO_3^{2-}\right] - 2\left[Ca^{2+} + Mg^{2+}\right] \qquad (1)$$

There is a potential alkalinity hazard if there is an excess of carbonate and bicarbonate ions compared with calcium and magnesium ions. If the RSC in irrigation water is above 2.5 $mmol_c/l$ the water is classified as hazardous and between 1.25 and 2.5 $mmol_c/l$ it is potentially hazardous. If the value is below 1.25 $mmol_c/l$ the water is classified as generally safe. The salinity of a soil is obtained by measuring the electrical conductivity. The EC-value is used for measuring the total concentration of dissolved salts (section 3.4.2.).

Sodicity

If a soil contains a large amount of exchangeable Na^+ the soil structure will often be poor. Swelling, surface crusting; sealing and erosion are some examples of the consequences connected with high concentrations of Na^+. To describe and measure the Na^+- concentration of a soil the term exchangeable sodium percentage, ESP is used. ESP defines to what extent Na^+- ions occupy the soil exchange sites in relation to the cations Ca^{2+}, Mg^{2+} and K^+. Often only Ca^{2+} and Mg^{2+} are considered since exchangeable K^+ is low in most soils. To describe the soil solution in terms of sodicity the term sodium adsorption ratio, SAR, is used. SAR is defined according to equation 2. (McBride 1994)

$$SAR = \frac{\left[Na^+\right]}{\sqrt{\left(\left[Ca^{2+}\right] + \left[Mg^{2+}\right] / 2\right)}} \qquad (2)$$

If all concentrations in equation 2 are given in $mmol_c/l$, ESP and SAR are found to be empirically related according to equation 3.

$$\frac{ESP}{100 - ESP} = 0.015 * SAR \qquad (3)$$

3.5.3. Consequences of salinisation

As a consequence of salinisation the structure of the soil often changes. If salinisation is caused by irrigation with saline water this change can be explained by the interactions between the soil and the ions in the irrigation water. The net result could be a destruction of the soil structure. The two principal effects of sodium are reduction in soil permeability and a hardening of the soil (David & DeWiest, 1966).

A reason for the destruction may be that when a high concentration of, for example, Na^+ is added to a soil the interlayer spacing in the clay minerals starts to collapse. The expansion can partly be explained in energy terms. When a salt such as NaCl is dissolved in water the activity and the free energy of water is lowered compared with pure water according to the equation:

$$\Delta G = RT \ln \frac{P}{P_0}$$

where ΔG is the change in free energy, R is the general gas constant, T the absolute temperature, P the partial pressure of water vapour above the surface of saline water and P_0 the partial pressure of water vapour above the surface of pure water. This means that when a dry soil is added a salt solution the free energy of the water in the clay is lower than the free energy in the salt solution. The result will be that water molecules diffuse from the solution to the clay and an expansion occurs, which is called osmotic swelling. If the concentration of salt in the solution increases, the opposite reaction occurs, the water moves out of the clay and as a consequence the interlayer spacing between the mineral sheets starts to collapse. (McBride 1994)

3.5.4. Crops and salinity

Salinity, sodicity and alkalinity are important aspects to consider when discussing salt-affected soils and plants. Based on the three aspects, a classification of the quality of the soil can be made (Table 6).

Table 6. Classification of soils according to EC, ESP and pH

Description	EC (dS/m)	ESP (%)	Typical pH	Structure
Saline	>4	<15	<8,5	Good
Sodic	<4	>15	>9,0	Poor
Saline-sodic	>4	>15	<8,5	Fair-good

If a soil is described as saline, plants may have difficulty in extracting water from the soil. This is related to **osmosis**. High ion concentrations in the soil solution lower the free energy of water and thereby the possibility for the plant to take up water. Another aspect that should be considered is **toxicity effects** connected to sodium and chloride and also the potential nutrient imbalances. A sodic soil, having an excess of Na^+, may be directly harmful to plants. A high alkalinity and thereby a high pH can also be indirectly harmful to plants. For instance, trivalent (Fe^{3+}) and copper (Cu^{2+}) will be less available. Molybdenum, on the other hand may occur in toxic concentrations (McBride, 1994)

Depending on the specific crop and its growth period the possibility to extract soil nutrients and water will differ. The tolerance to soluble salts may differ even between varieties of the same species. In Table 7 some crops that are grown in the area around the Orathupalayam dam are rated according to their salt tolerance. The ratings are T= tolerant, MT=moderately tolerant, MS= moderately sensitive and S= sensitive. (Bischoff, 2003)

Table 7. Crop tolerance to soluble salt (EC)

Crop	Latin name	Threshold (dS/m)	Rating
Maize	*Zea mays*	1.7	MS
Cotton	*Gossypium hirsutum*	7.7	T
Paddy rice	*Oryza sativa*	3.0 (soil water)	S
Sorghum	*Sorghum bicolor*	6.8	MT
Sugarcane	*Saccharum officinarum*	1.7	MS
Okra	*Abelmoschus esculentus*	-	S
Onion	*Allium cepa*	1.2	S

Many plants are very sensitive to salt stress, especially during germination and the early phase of growth. Soil fertility is one factor that could affect how plants can tolerate a high concentration of salts. Generally speaking, fertilization increases the plant tolerance towards salt stress, although if the addition of fertilizer is too high and the fertilizer is salt-based the addition might even contribute to soil salinity for a period. Factors such as a high temperature, low humidity and high wind speed will increase the evapotranspiration and thereby increase the vulnerability of the plant. (Bischoff 2003)

3.6. WATER AND CHEMICAL USE IN DYEING AND BLEACHING INDUSTRIES

Textile industries consume large quantities of water and produce large volumes of wastewater. The three major components of this industry are:

1. Yarn and Fabric Production (i.e. spinning and weaving)
2. Chemical Processing (i.e. scouring, bleaching, dyeing, finishing of fabrics)
3. Garments (i.e. manufacturing and finishing of garments)

Chemical processing and garment finishing involve highly effluent-generating processes and the effluents are water-based. (PWD, 2003) Both the huge volume of effluents and the high concentrations of chemicals in the effluents need to be considered when looking at the environmental effects of the industry.

3.6.1. Water Use

There are many different figures reported on how much water is discharged from the textile industries in Tiruppur but the figures range between 75 and 100 million litres per day. Most of the water is used in the dyeing and bleaching processes where the cloth is washed at least two or three times to remove excess chemicals (PWD, 2003). The quantity of water used to process one kilogram of hosiery fabric is on average 200-300 l and nearly 75-95 % is discharged as effluents containing organic and inorganic pollutants and colouring materials (Banat, 1996).

A market for water has been developed due to the high water demand in the industries and because of insufficient water resources and polluted water in and around Tiruppur. Some farmers are selling groundwater to the factories and can thereby earn more money than through farming. This has created a conflict between farmers who are selling and not selling water. The discharge of groundwater has led to a depletion of water level in many villages.

3.6.2. Use of Chemicals

Dyes and chemicals are fundamental parts of the textile industry. About 14 000 dyes and chemicals are used in the different processes, from cultivation to manufacturing, and a significant quantity of these are disposed of as liquid, solid and gaseous wastes, resulting in pollution of water, land and air. (PWD, 2003) In Tiruppur the most important chemicals in the dyeing and bleaching industries are NaOH, NClO, Na_2S, HCl and reactive dyes (Jacks et al. 1994) Common salt NaCl, is used in large amounts to fix dyes to fabric and the salt causes major problems, making surface and ground water brackish and hard (section 3.7.4) Other harmful substances, as mentioned above, are a number of dyes, many of which are based on benzidine compounds or heavy metals, both of which are toxic (Jacks et al. 1994). Some of the common chemicals used in textile manufacturing are given in Table 8 and a more specific list of harmful chemicals is found in Table 9.

Table 8. Some of the common chemical substances used in the textile manufacturing process in order of their pollution intensity (least harmful to most harmful)

Common Chemicals	Pollution Intensity
-Alkali compounds, oxidising agents, natural salts, mineral acids	Relatively harmless inorganic pollutant
-Organic acids, Starch sizes, Reducing agents, Vegetables oils, Fats and waxes, Biodegradable Surfactants	Readily biodegradable
-Fibres and polymeric impurities, Polyacrylate sizes, Dyes and Optical brighteners, synthetic polymer finishers, Silicons	Difficult to biodegrade
-Starch ethers, Esters, PVA sizes, Wool grease, Mineral oils, Anionic and non ionic softeners, Biodegradation resistant surfactants,	Increase BOD Difficult to biodegrade
-Chlorinated solvents & carriers, Cationic retarders & softeners, Biocide Sequestering agents, Heavy metal salts, Formaldehyde & M-Methylol reactants	Unsuitable for conventional biological treatment AOX problem Toxic.

Source: Information received from PWD, Coimbatore

Table 9. Harmful Chemicals used in Textile Industries in Tiruppur

Chemicals used in Indian textile industry	Hazards
a. Detergents: Non-ionic detergents based on nonyl-Phenol Ethoylates	Slow biodegradation, generates toxic metabolites highly poisonous to fish
b. Stain remover: Carries solvents like $CC1_4$	ozone depletion, ten times more potent than CFC
c. Oxalic acid used for rust stain removal (only harmful in high quantities but no information could be found on how much is used.)	toxic to aquatic organisms boosts COD
d. Sequestering agents: Polyphosphates like Trisodium, Polyphosphate, Sodium Hexameta phosphate	Banned in Europe, still used in India in water and house hold detergents
e. Printing gums: Preservative Pentachlorophenol is used in Europe & India only	Dermatitis, liver & kidney damage, carcinogenic banned
f. Fixing agent: Formaldehyde and Benzidine	harmful internationally banned
g. Bleaching: Chlorine bleaching	itching, harmful
h. Dyeing: Amino acid liberating groups	carcinogenic, internationally banned

Source: Information received from PWD, Coimbatore

Different steps in the textile processing and the chemicals used

Before the cloth is taken for bleaching, it is subjected to kier **boiling** to remove natural impurities, such as grease, wax, fats, etc. Chemicals used are caustic soda, soda ash, sodium silicate and sodium peroxide. The effluent water from this process is brown in colour and highly alkaline and high in both BOD and COD. (Azeez, 2001)

In Tiruppur, two types of **bleaching** are practised, hypochlorite and peroxide bleaching. The major chemicals used are sodium hypochlorite (NaClO) and acetic acid (CH_3COOH). When the cloth is bleached it is taken for mercerising, involving treatment of the cloth with cold caustic soda and washing with water, and is then taken for **dyeing**. (Azeez, 2001)

The industries use synthetic organic dyes like yarn dye, direct dye, basic dye, vat dye, sulphur dye, napthol dye, developed dye and reactive dye (PWD, 2003). In recent years, most of the dyes used are prepared from hydrocarbons such as benzedene, naphthalene, anthrocene, toluene and xylene and the amount of dyes used has been increasing steadily (Senthilnathan, 2001)

About 30 to 100 kg of common salt, an important ingredient in dyeing, is used for 100 kg of cloth and sodium phosphate (Na_3PO4) and sodium carbonate (Na_2CO_3) are also added to the dye bath for fixation. After dyeing, the cloth undergoes **soaping** which is a process where excess dye is removed. Dye-fixing agents such as Sandoz WEI and softening materials are also used. (Azeez, 2001)

More about Dyes

Textiles are generally made up of organic molecules, although the molecules vary greatly with respect to their physical and chemical nature. This results in every type of fibre requiring a specific dye, a fact that explains the large amount of dyes existing for colouring different materials. (Christie, 2001) Azo dyes and Reactive dyes are two examples of dyes that have been or still are used by the textile industries in the area in and around Tiruppur.

Azo dyes and pigments are the most common group used of chemical organic colorants. About 60-70 percent of the dyes used traditionally for colouring textiles are azo dyes (Christie, 2001). The dyes are used especially for cotton but also for silk, wool, viscose and synthetic fibres (KEMI, 2004). One typical feature of azo dyes is the azo linkage (-N=N-), most often with two aromatic groups connected to the nitrogen atoms (Christie, 2001). Azo dyes can be degraded chemically, by reductive cleavage or biologically, through the body's enzyme system, to aryl amines (aromatic amines). Aryl amines have in some cases been classified as carcinogenic; the compound aniline is a well-known example. Since most of the azo dyes are water soluble there is a risk that dyes will be absorbed by the body through skin contact. Some of the aryl amines are reported to cause allergic reactions with symptoms such as skin and eye irritation. Other effects that have been reported are toxicity effects on aquatic organisms. (KEMI, 2004)

Azo dyes can be used for the whole spectrum of colours but are commercially most important for colours such as red, orange and yellow. They are special because of their capability of providing colours with high intensity and with reasonable to very good resistance to, for example, light, heat and water. In comparison with other dyes, they are also relatively cheap. (Christie 2001).

The European Union has banned the use of azo dyes that could release carcinogenic aryl amines, for treatment of textiles and leather products. (KEMI, 2004) Also in India, azo dyes, which were widely used before, have been banned during recent years.

Reactive dyes have historically been used mostly for cellulose fibres but dyes for fibres of protein and polyamide have also been developed. When a reactive dye is added to a fibre a covalent bond is created between a carbon atom of the dye and an oxygen, nitrogen or sulphur atom of a hydroxyl, amino or thiol- group of the polymer. The strong covalent link between the dye and the textile results in a dye with long-lasting properties. Reactive dyes consist of four major components: a chromogen, a fibre reactive group, a water-soluble group and, in some cases, a bridging group between the chromogen and the fibre reactive group. A problem with reactive dyes is the occurrence of hydrolysis during the dyeing process, i.e. the dye reacts with a hydroxyl group instead of a fibre group. This results in a decrease of the efficiency of the dye and a need for washing the textile more carefully after dyeing to ensure a good fastness of the dye. Environmentally, this means that dyes that could have been used for textiles are instead included in the effluents, a situation that is favourable neither for the environment nor the economy of the dye industry. (Christie, 2001)

3.6.3. Pollution Load

For pollution load estimations both quantity and quality of effluents have to be considered. The Madras School of Economics has gathered industrial water consumption data as well as effluent quality data from Tamil Nadu Pollution Control Board (TNPCB) in order to estimate the pollution load (Fig. 7). The Figures are from 1980 to 2000 and the pollution load is estimated for TDS and chloride.

None of the industries had treatment plants until 1997 and therefore untreated effluent quality data were used from 1980 to 1997. Between 1998 and 1999 both untreated and treated effluent quality data were used. During 2000 only treated or partially treated effluents were included. (MSE, 2002) The pollution load therefore became lower but the TDS load is still very high.

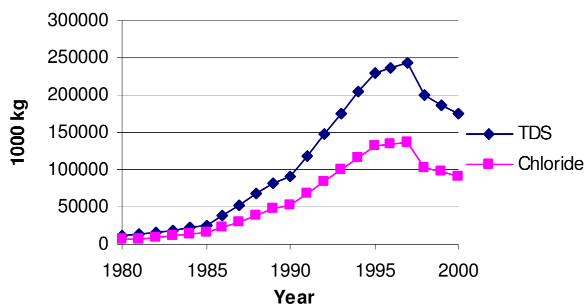


Figure 7. Pollution Load Generated by Textile Processing Units from 1980-2000 in Tiruppur
(Source: PCB Data, 2000. Computed by Madras School Economics)

3.7. EFFLUENT TREATMENT PLANTS AND CONTROL ORGANS

Effluents from the industries contaminate surface water, as well as soil and groundwater due to the presence of soluble solids, suspended solids, organic matter, heavy metals and toxic constituents. (Prabakaran 2001) This necessitates treatment of the discharged waste water. As mentioned above, no industries had treatment plants before 1997 but in recent years efforts have been made to treat the effluents from dyeing and bleaching industries in Tiruppur. Many individual industries have joined together to establish Common Effluent Treatment Plants (CETP) and other units treat their effluents in Individual Effluent Treatment Plants (IETP). There are eight CETPs in Tiruppur and they are all located near the bank of Noyyal River.

Pollution Control Board (PCB) and the Dyers' Association

To control water pollution from industries, the Water Act was passed in 1974 together with state Pollution Control Boards (PCB) for enforcement of the legislation. The state boards were given the responsibility to enforce the Water Act. In "Food and Fashion", A. Blomqvist (2000) argues that state boards are more exposed to local lobbyists than the central board and that this might affect the enforcement negatively, causing instability and corruption. The Water Act gives the state governments the right to exempt any area from the provision of the act and industries are therefore lobbying for exemptions.

The Tiruppur Dyers Association was formed in the same year as the PCB started working in Tiruppur. The association was formed in order to look after the interests of the Tiruppur dyers and the CETP-idea was negotiated between the two parties. The PCB wanted to implement the Polluter Pays Principle and the Dyers' Association eventually became an important institution which took large responsibility for the implementation of this principle through the CETP-project. (Blomqvist, 1996)

Treatment method

Most of the bleaching and dyeing industries use chemical treatment methods and specifically the **lime precipitation method** for their effluents. First lime ($Ca(OH)_2$) and then ferrous sulphate ($FeSO_4$) and a polyelectrolyte are added. A schematic diagram is showed in appendix 7.

Lime is added to the effluent to function as a precipitation agent. The lime is purchased in bags and the quality used contains about 60-90 % by weight of $Ca(OH)_2$. About 100 to 150 kg per day is used in one plant.

Ferrous sulphate $FeSO_4$ is then added to the lime for the coagulation. The average consumption of $FeSO_4$ is 50 to 75 kg per day and plant. Finally **polyelectrolyte** is added in drops as a flocculation agent, which brings the coagulated substances together as bulky flocks. Polyelectrolyte is also used for the sludge thickening in the centrifuge process.

To assess the optimum dosage needed for the treatment the **jar test** method is used. Normally this method is followed in regular intervals in both Common and Individual Effluent Treatment plants. (PWD, 2003)

3.8. QUALITY OF EFFLUENTS

Generally the CETP and IETP are functioning well according to the Pollution Control Board (PWD, 2003). In an industrial survey made by the PWD it was found that almost all the dyeing and bleaching industries have IETPs or are members of CETPs. There are, however, major problems with the method used and the functioning of many of the effluent treatment plants.

Quality of liquid effluents

The technology used, lime precipitation, can remove the colour to some extent and reduce BOD, COD and other chemical variables to a certain level but the TDS (Total Dissolved Solids) value cannot be reduced to an acceptable level. (PWD, 2003) When alum and lime are added, it does not reduce the concentration of soluble solids, thus TDS remains unchanged and Na^+ dominates if other ions are removed through precipitation. Ca^{2+}- and Mg^{2+}- ions become precipitated as carbonates and bicarbonates and NaCl, being highly soluble, becomes the major component in the effluent. (Prabarkaran, 2001) The general characteristics of treated water from CETPs are shown in Table 10 below. The standard set by the PCB is 2100 mg/l.

Table 10. Characteristics of the Waste Water Discharged by CETPs in Tiruppur

Parameters	Common Effluent Treatment Plant	
	Raw Effluent	Treated Effluent
pH	8.1	8.5
TSS (mg/l)	256	66
TDS (mg/l)	6272	5968
BOD (mg/l)	180	42
COD (mg/l)	450	162
Chloride (mg/l)	2939	2899
Sulphate (mg/l)	598	586

(Source: Information received from PWD, Coimbatore, 2003)

Effluents from the dyeing and bleaching industries contain part of the chemicals used for processing and treatment. Effluents vary widely in colour and are always turbid and highly alkaline. The coloured effluents will colour the water, which makes it aesthetically unacceptable, and in addition some dyes contain heavy metals and suspected carcinogenic compounds (Prabakaran, 2002).

Many studies have been made to analyse the effluent water and the values of the parameters vary, probably due to when (before or after 1997 and exact time) and where (closeness to source and CETP or IETP) the samples were collected (some are given in Table 11).

Table 11. Documented values/concentrations for effluent water

Variable	Measured value/concentration	Reference
EC (CETP)	10.8 dS/m	(Prabakaran 2002)
	8.5 – 13.9 dS/m	(Gupta & Jain 1992)
Chloride (CETP)	2639 mg/	(Senthilnathan, 2001)
Sodium (CETP)	600-3500 mg/l	(Aggarwal & Kumar 1990)
	719 mg/l	(Prabakaran 2002)

Reliable information about heavy metals in the effluents was hard to find and in the report by Azeez (2001) it is only said that traces of heavy metals such as Cu, Zn, Cr and Cd could be documented in effluents. Besides the salts and other inorganic chemicals, the textile wastes contain considerable amounts of oil and grease, up to 900 mg/l (Prabakaran, 2001).

Quality of solid waste - sludge

The chemical method also produces large quantities of solid waste in the form of sludge. The sludge contains unfixed dyes and various other chemicals used in the dyeing, bleaching and in the effluent treatment and may, if not properly disposed of or utilised, lead to environmental contamination. (Sivakumar, 2001) During a seminar on ecofriendly waste water technology in 2001 it was reported that the dewatered sludge was stored in the treatment unit premises and that there was a leakage of toxic metals and organic impurities causing pollution of groundwater and land. (Chandrasekaran, 2001) It is therefore essential to manage the sludge in a safe manner.

3.9. IMPACTS OF EFFLUENTS

The environmental impacts of the effluents are associated with degradation of:

- Surface water quality,
- Sediment and soil quality,
- Ground water quality and
- Aquatic life

3.9.1. Surface water

Release of untreated or (as today) treated effluents, albeit not to a sufficient degree, leads to serious changes in the physio-chemical characteristics of surface water. A number of studies have documented these changes, among them, a study reported by Senthilnathan (1998) and another by Sivakumar et al. (1996).

In 1998, Senthilnathan took surface water samples at five locations in Noyyal River; the first one was upstream of Tiruppur and the last one in the Orathupalayam dam. The water samples, except for the first and last sample were dark blue to black and had a pungent smell. It is mainly the unspent dyes that cause the colour. The colour impedes light penetration and thus affects the biological activity. Colour removal from effluents is a major environmental problem because the chemical treatment results in huge quantities of sludge (Senthilnathan, 2001). In general, the Ca, Mg, Na and K concentrations in the samples were well above the ISI level. The heavy metal concentrations in the river decreased in the order Mn>Fe>Zn>Cu although the levels were within the limit prescribed by ISI standards. (Senthilnathan, 1998)

P.A. Azeez (2001) summarises studies made in the late 1990's on the water quality in Noyyal river, downstream of the textile industries. In many places the alkalinity of the river water samples was about 800 mg/l and total hardness about 4000 mg/l. The water was very turbid because of the colloidal materials generated in the industrial units. The TS (Total solids) was above 10000 mg/l and TDS had reached almost the same level. The sodium concentration was very high and the concentration of chloride reached up to 4360 mg/l in some surface water samples. The concentration of potassium was low in comparison with other ions and ranged between 10 and 80 mg/l. BOD reached 150 mg/l and COD 1260 mg/l. The phosphate content, (mainly originating from detergents), reached around 5 mg/l and nitrite ranged from 0.01 to 0.26 mg/l. Overall Azeez reports that the surface water exceeded the ISI standards for drinking and irrigation purposes.

There have also been comprehensive studies of the entire Noyyal River in order to see the water quality changes along the whole course of the river. One of them is the PWD study on "Environmental Status of The River Noyyal Basin" (2001). Surface water samples were collected at 28 locations. The study shows that EC and TDS values were relatively low until the river reached Tiruppur, where the textile industries are situated. The TDS values were highest in the Tiruppur area and remained high up to the Orathupalayam dam. From there TDS decreased, since the water stagnated in the dam and was not often released and probably because the LBP-canal crosses the Noyyal river downstream of the Orathupalayam dam. The canal water has a diluting effect. The results of the study of the stretch from just outside Tiruppur to some distance after Orathupalayam are given in Table 12 and the change in EC is illustrated in Figure 8. Not only the river Noyyal but also a number of system tanks in the basin were affected (MSE, 2002).

Table 12. Physio-chemical parameters of the surface water for a part of Noyyal river, 2001

Station	pH	EC dS/m	DO mg/l	BOD mg/l	COD mg/l	TDS mg/l
Somanur	7.4	1.9	-	4	21	1615
Mangalam	7.8	2.6	-	14	37	2013
Andipalayam tank	7.9	3.6	6.2	28	46	4109
Tirupur area	8.7	8.8	-	62	501	10062
Tiupur tank	7.9	5.3	-	37	156	5536
Mannarai tank	8.4	8.9	-	62	508	7661
Mudalipalayam	8.4	8.6	-	48	411	7226
Anapalayam	7.9	8.1	-	37	322	7016
Kodumanal	7.8	6.6	-	31	289	5031
Orathupalayam	7.8	7.1	3.0	34	261	4908
Chinnamuthur	7.5	3.6	-	16	111	2719
Noyyal cross road	7.3	3.2	-	16	67	1928
Noyyal anicut	7.6	1.3	-	15	56	1619

(Source: Environmental Status Report of the River Noyyal Basin, Environmental Cell, PWD, 2001)

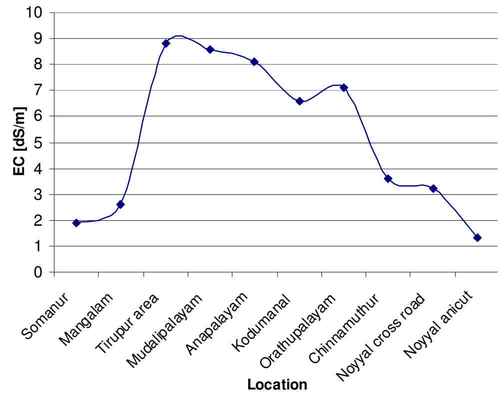


Figure 8. EC in surface water of Noyyal river from Somanur to Noyyal anicut

In a study by Prabakaran (2002), surface water samples were collected during June 2001 to May 2002 upstream and down stream of the Orathupalayam Dam. The mean EC values were 7.89 dS/m upstream and 8.21 dS/m downstream. Some samples were taken in the LBP-canal when there was water and the mean value during the months August to December was 0.155 dS/m.

3.9.2. Sediment and soil

The sediments in the river are affected by the industrial discharges. Dye materials, settled from the effluents, have changed the sediment colour since components in the sediment system adsorb the dyes and chemicals. (Azeez, 2001) This is also the case with terrestrial soil flooded by polluted river water or irrigated with this water. When the polluted water percolates through the soil profile, soil/sediment particles absorb dyes and other chemicals. There is also a salinisation and alkalinisation, causing an unsuitable environment for soil and sediment organisms (Azeez, 2001).

Studies on soil quality in the area around the Orathupalayam dam shows that most of the soils are naturally non-alkaline. However, as a consequence of the pollution, the soils have started to become increasingly alkaline. According to temporal studies, there has been an increase in both soil pH and EC. Other effects that have been noticed and described are, for example, a change in soil colour, structural changes and decreased crop yields. (Sankararaaj et al., 2002)

3.9.3. Ground water

Many studies have been made where well water samples have been collected around Tiruppur and along Noyyal up to the Orathupalayam Dam. (e.g. Senthilnathan & Azeez, 1999; Prakabaran, 2002)

In the study conducted by Prakabaran (2002), well water samples were also taken in some hamlets around the Orathupalayam dam. The results show that many wells have extremely high EC-values, those close to the dam having means above the interval 6 to 9 dS/m. In Orathupalayam hamlet, the maximum EC value was 9.56 dS/m in May and the minimum 8.22 dS/m in December.

A comprehensive study was made by the the Soil Survey and Land Use Organisation (SS&LUO) as part of the project study made by the Madras School of Economics during 2001 to 2002 to assess the environmental impact of industrial effluents in the whole Noyyal river basin. Both water (surface- and groundwater) and soil (surface and subsurface) were surveyed to investigate water and soil quality for agricultural use. The study covered a stretch of 5 to 6.5 km on either side of the river from Velliangiri to the confluence point with the Cauvery River, and was divided into four zones. Tiruppur and the Orathupalayam dam was the third zone. The water samples collected were characterised according to the Tamil Nadu system for irrigation water (Tables 4 & 5). Nearly 33 % (82 samples) indicated that it was not suitable to grow crops and 42% (106 samples) were in the critical category (1-3 dS/m). Around 23 % of the area (65 soil samples) was not used for cultivation but 53 % of the sub-surface samples indicated normal conditions.

3.9.4. Aquatic life

The Research Department of Zoology, Erode Arts College, conducted a biological study on the impacts of effluents in Noyyal River in connection with the study made by the Madras School of Economics (MSE, 2002). It was found that the Noyyal river was highly polluted from Sulur to the Orathupalayam dam and that the plankton species diversity was comparatively low in this part. There was a higher number of plankton and a higher plankton and fish diversity downstream of the dam because of the diluting effect of seepage water from the LBP canal. Indicators such as liver glycogen and blood glucose level in fish confirmed that the water in the dam is more toxic to fish than water further downstream.

The Fisheries Department started to develop fisheries in the Orathupalayam Dam in 1993 since the reservoir had a high potential for this activity. Up to 1996 there was increasing fish productivity, especially concerning Tilapia, a pollution resistant species, but in 1997 a mass fish mortality occurred in the reservoir. Floating dead fish could be seen near the dam site and posed a serious threat to human health. Several tonnes of dead fish were buried. The Public Works Department (PWD) requested the Fisheries Department to stop fishing in the dam and the Director of Fisheries in turn ordered the Regional office in Erode to stop the fishing activities in the Orathupalayam dam on 12th of March 1998. (MSE, 2002)

3.9.5. The problems with salt

Salt becomes a major problem because of the large number of industries. The Noyyal river is ephemeral and does not have the capacity to assimilate the huge pollution load. When the pollutants are not assimilated, accumulation occurs over time in the river bed, the tanks and in the Orathupalayam dam. Today, almost all dyeing and bleaching industries have treatment plants but, as discussed in the previous section, the method used does not remove the salts. The TDS and Cl^- values are still very high (Table 10).

Chloride is imported to an area both by natural processes and by human activities. The important sources of chloride are the following (Jacks et al., 1982):

- Wet and dry atmospheric deposition
- Common salt for domestic use
- Industrial chemicals
- Import of water via canals

During the years 1976-78 G. Jacks and V.P. Sharma carried out a detailed study to quantify the salinity problem in Noyyal and a tentative salt budget was made. All the above sources of Cl^- were estimated and also the export of Cl^- via runoff. The results for the entire Noyyal basin are given in Table 13 below. The use of chloride-containing chemicals was essentially restricted to textile industries.

Table 13. Chloride budget for the Noyyal river basin, 3500 km^2, Figures in kg Cl^-/km^2

		1976	1977	1978
Import	Wet. Dep.	358	468	544
	Dry Dep.	246	246	246
	Common salt	1467	1496	1526
	Ind. Chem.	235	235	235
	Water import	175	285	951
Export	Runoff	195	2343	3180

(Source: Jacks, G & Sharma, V.P, 1982)

Another study, with the aim of reassessing the situation in 1976, was made in 1992. A new salt budget was made, looking at the same imports of Cl^- . The result of this study was that there was a large increase in the human consumption of NaCl from 10 900 kg Cl^-/day in 1976 to 24 900 kg Cl^-/day in 1991. The population increase between the years was 15 %. (Kilhage & Magnusson, 1992). The most alarming result, however, was the large increase in the part of chloride imported from industries. In 1991 there were totally 600 units and only 15 had treatment plants. The calculations made in the two studies concerning textile industries cannot be readily compared, but in 1991 Cl^- from textile industries accounted for twice as much as the contribution from human and animal consumption of common salt. In 1976, the contribution of Cl^- from industries was much less than that from common salt.

Since 1991 the number of dyeing industries has increased even more. In 1997 there were around 866 units but because of pressure from the Tamil Nadu Pollution Control Board several units have closed down and in 2002 the number had decreased to 702 (MSE, 2002). The contribution of Cl^- from industries has therefore increased since 1991 and further aggravated the imbalance of the salt budget.

3.9.6. Problems with other chemicals used

There are many potentially dangerous chemicals involved in the textile industry (Tables 8 & 9). Some of these chemicals are known to become bio-accumulated (Azeez, 2001) and some are even carcinogenic. The dangers with azo dyes have already been discussed and azo dyes are today banned but they have been used for a long time and could possibly still be used in some industries. Heavy metals are found to be present only in negligible quantities but they may get accumulated in organisms especially “microscopical” organisms, and could then be transferred to higher trophic levels (Azeez, 2001).

No studies have been found where organic substances have been analysed in water samples from effluents, Noyyal river or well water. There might be potentially hazardous organic substances, and studies are needed in order to understand how or if these substances have, or will, affect the environment and people in a negative way.

The health risk due to toxic chemicals in drinking water differs from that caused by microbial contaminants. Few chemical constituents of water can lead to acute health problems except through massive accidental contamination. The problems associated with chemical constituents of drinking water arise primarily from their ability to cause adverse health effects after prolonged periods of exposure. Of particular concern are contaminants that have cumulative toxic properties, such as heavy metals, and substances that are carcinogenic. (Earthdaynetwork, 2004)

4. STUDY AREA

The Orathupalayam Dam lies on the border between Kangayam and Perundrai Taluks. Within each Taluk a number of revenue villages (Table 14 & Fig. 9) surround the dam and parts of these revenue villages have been studied. Within each village there are a number of hamlets, each with a cluster of houses.

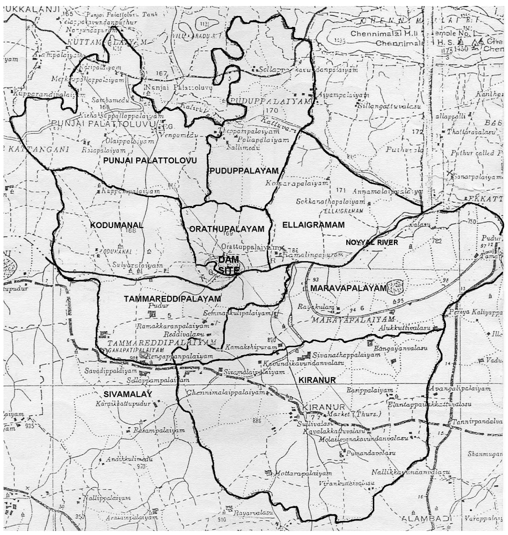


Figure 9. Study area with revenue villages

Table 14. Revenue villages in the study area

Revenue Village	Block	Taluk	District	State
Kodumanal	Chennimalay	Perundurai	Erode	TN*
Punjai Palattolovu	Chennimalay	Perundurai	Erode	TN
Orathupalayam	Chennimalay	Perundurai	Erode	TN
Pudupalayam	Chennimalay	Perundurai	Erode	TN
Ellaigraman	Chennimalay	Perundurai	Erode	TN
Tammareddipm.	Kangayam	Kangayam	Erode	TN
Sivamalay	Kangayam	Kangayam	Erode	TN
Maravapalayam	Kangayam	Kangayam	Erode	TN
Kiranur	Kangayam	Kangayam	Erode	TN

* Tamil Nadu

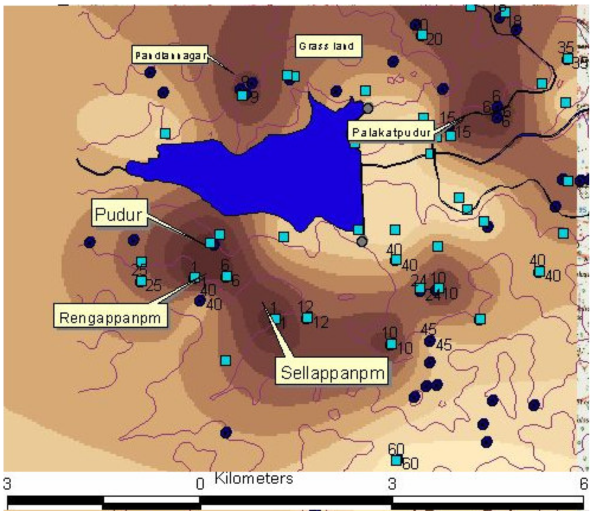
4.1. GEOLOGY

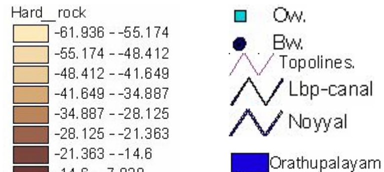
Erode district is situated in the part of India where the table-land of archaean rock, which constitutes the bedrock for the whole peninsula, reaches the land surface. The main rock type consists of primary and metamorphic granite and gneiss. Due to movement in the rock foundation, it is intersected by various fissure systems and the evolution and condition of these systems are crucial for groundwater deposits. (Gustavsson et al., 1970) The bed-rock of the two Taluks consists of mostly unclassified gneisses and this is the rock type in the study area. In Kangayam, the predominant mineral is Zircon and in Perundurai it is asbestos. (SSLUO, 1998)

The climate has affected the archaean rock in India for a long time, and as a result the upper layers have been transformed. Uppermost, there is a disintegrated layer of red soil and underneath a more or less transformed layer of decomposed rock, where weathering processes have affected and partially have decomposed the ground. The thickness of these layers is 1 to 15 m. (Gustavsson et al., 1970)

Figure 10. Locking down into an open well

Neither detailed information about the geology in the study area nor information about the locations of aquifers could be obtained from local governmental institutions. Knowledge of the thickness of the weathered zone might provide information about how water from the Orathupalayam dam could leach to surrounding aquifers. The weathered zone has a high water permeability. In order to find out the depth to solid rock, i.e. the thickness of the weathered zone, observations had to be made in the open wells (e.g. Fig. 10) in the study area[8]. An interpolation between the observation points was made in Surfer and taken into ArcView. A rough sketch of the depth to bed rock was obtained (Fig. 11 with figure text).





BWs (Bore wells) and OWs (Open wells) included in the study.

(in feet (ft)
1 ft = 0.305 m)

Figure 11. Depth to hard rock with numbers in feet

Figure text
The grid map shows that the bedrock is close to the surface south-west of the reservoir around Pudur to Sellappanpm. This is also easily observed since there is an open cast mine close to Rengappanpm. Also north of the dam the weathered zone is shallow which can be observed in Pandiannagar. East of the reservoir along the river bed the weathered zone is thick except for the area around Palakatpudur

Over a distance of about 2 km north of the barrier there were no open wells and no people lived there since it was dry grass land. Therefore no observations were made in this region and the map is most likely misleading in this part[9].

4.2. SOIL
In 2002 a study was performed around the Noyyal river basin in order to investigate the quality of soil and water for agricultural purposes. Some of the soil samples were collected in the Study Area around the Orathupalayam dam. According to the Indian soil classification system, five major soil types could be found in this area: Irugur, Vanapatti, Palladam, Tulukkanur, and Kallivalasu. (Sankaraaj et al. 2002) A description of each of these soil types is given below.

Irugur is a red to dark reddish brown soil, moderately deep and non-calcareous. The soil is well drained with a gravely texture and occurs in areas with an undulating topography. According to Soil Taxonomy the soil could be classified as an Inceptisol (Nilsson, 2004; Soil Survey Staff, 2003). Irigur can be found on the northern side of the dam.

Vanapatti is a dark brown, non-calcareous and well-drained soil. The texture is loamy and the soil often occurs in areas with an undulating topography. According to Soil Taxonomy, the soil could be classified as an Alfisol (Nilsson, 2004; Soil Survey Staff, 2003). Vanapatti has been described as occurring on the southern side of the Noyyal River.

[8] Sometimes it was very difficult to see the division line between hard rock and the weathered zone and sometimes there were mixed layers. At locations close to the reservoir the water level was above the weathered zone and local people had to be consulted.
[9] On a topographical map it said that there was sheer rock in this region and therefore the bed rock should be closer to the surface than figure 11 shows.

In the report of Sankaraaj et al. (2002), the soil types Irigur and Vannapatti were classified with respect to land capability, irrigability and soil productivity. The soils were classified as moderately good cultivable land with major limitations. Limitations for the two soil types could be erosion and high run-off, drought sensitivity or high alkalinity. Special countermeasures mentioned were erosion control, conservation irrigation, land reclamation and selection of suitable crops. Concerning irrigability, the soils could be classified as having severe limitations for sustained use under irrigation. Limitations could be a high gravel content and a shallow soil depth. Irigur was classified as either extremely poor or poor. Vannapatti was classified as average with a good potential for becoming a productive soil.

Palladam is described as a brown to dark yellowish brown calcareous soil. The soil is well drained, moderately deep, has a gravel texture, and occurs on land having an undulating topography. According to Soil Taxonomy, the soil could be classified as an Inceptisol (Nilsson, 2004; Soil Survey Staff, 2003). Palladam could be found mostly on the northern side of the Orathupalayam dam.

Tullukanur is a strong to dark brown, calcareous soil. It is moderately deep, well drained and occurs on gently sloping to undulating land. According to Soil Taxonomy, the soil could be classified as an Inceptisol (Nilsson, 2004; Soil Survey Staff, 2003). Tullukanur could be found mostly on the southern side of the Orathupalayam dam.

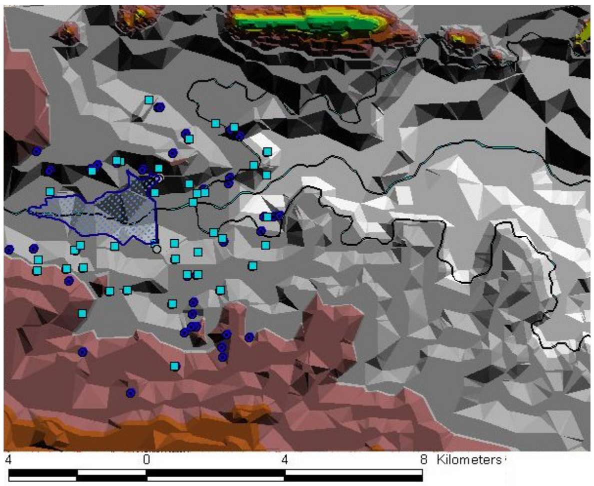
In the report by Sankaraaj et al. referred to above, the soil types Palladam and Tulukkanur were classified according to land capability, irrigability and productivity as moderately good cultivable land with major limitations. Limitations were their high $CaCO_3$ content, drought sensitivity and high alkalinity. Special needs for these soils were conservation irrigation, fertility management and land reclamation. Concerning irrigability, the soils could be classified as land with very severe limitations and of marginal value for sustained use under irrigation. Limitations were alkalinity, shallowness, calcareousness and depth. Palladam could be classified as an extremely poor soil with respect to productivity; moreover also the potential productivity was poor. Tulukkanur is also classified as a poor soil with respect to productivity, being regarded to have an “average” potential productivity.

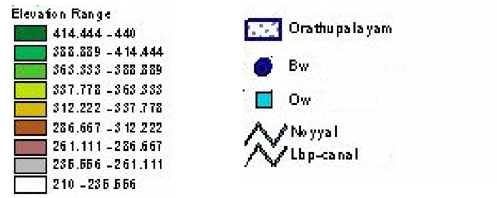
Kallivalasu is a dark greyish brown, non-calcareous soil. The soil is well-drained and very deep. It mainly occurs on river banks. According to Soil Taxonomy, the soil might be classified as an Inceptisol (Nilsson, 2004; Soil Survey Staff, 2003). Kallivalasu could be found close to the Orathupalayam dam and the Noyyal River.

Kallivalasu is regarded as a moderately good cultivable soil with major limitations. The limitations are a high content of $CaCO_3$ and its fluvial properties. Special needs for this soil type were fertility management, selection of crops and reclamation. Concerning irrigability, the soil could be classified as land that had severe limitations for sustainable use under irrigation. Limitations were again calcareousness, drainage and high alkalinity. Kallivalsu was classified as a poor soil regarding its productivity, but with an average production potential.

4.3. TOPOGRAPHY

The study area is an undulating plain with gentle slopes. The elevation ranges between 225 and about 300 m (SSLUO, 1998). A topographical map (scale 1:50 000) of the study area and its surroundings was imported to ArcView and the height lines were digitalised and made into a grid[10]. The grid was then converted to a tin[11], and a 3D illustration was obtained (Fig. 12). In order to study the topography near the Orathupalayam Dam more in detail another tin was made, which focused on the study area (Fig. 13). The figure texts give characteristic features. The topography is important for the water flow from the Orathupalayam dam.



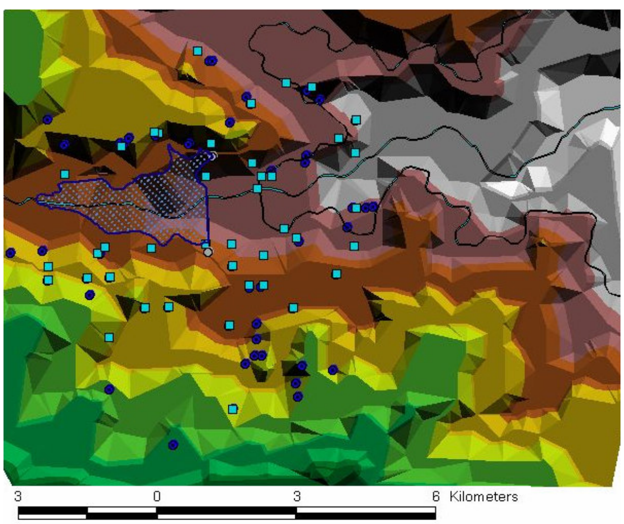


(in meters)

Figure text

The Orathupalayam Dam lies in a shallow valley with Chennimalay as the highest peak (about 450 m) on the north side. The flow pattern of the Noyyal river and the LBP canal can be seen. The LBP canal crosses Noyyal about 1050 m downstream of the dam barrier.

Figure 12. 3D map of Orathupalayam and its surroundings



(in meters)

Figure text

The barrier, which is about 2 km long, lies about 240 meters above sea level. The ground is gently sloping up to 260 m on the north side and slightly higher on the south side. The east side of the dam is lower lying and fairly flat and also southeast of the dam the ground is more flat.

Figure 13. 3D map with focus on the study area

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[10] A grid is an object that stores spatial data in a locational (or raster) data format in which space is partitioned into square cells, and each cell stores a numeric data value.

[11] A TIN (Triangulated Irregular Network) is an object used to represent a surface. TIN partitions a surface into a set of contiguous, non-overlapping, triangles. A height value is recorded for each triangle node. Heights between nodes can be interpolated thus allowing for the definition of a continuous surface.

4.4. CLIMATE AND RAINFALL

The climate in the plains of Noyyal river basin is “semiarid subtropical monsoonic”. (Sankararaaj et al., 2002)) The hot months are March, April and May with a maximum temperatures ranging from 35.5°C to 36.8°C and the cool months are November, December and January with minimum temperatures ranging from 23.9°C to 24.1°C. The mean annual temperature is 29.4°C. (SSLUO, 1998)

Since the study area is located in the eastern part of the Noyyal river basin, it is mostly influenced by the northeast monsoon (Table 15). In Kangayam 49 % of the rainwater comes during the northeast monsoon and in Perundurai the corresponding figure is 43%. The precipitation is unevenly distributed throughout the year and a distinct dry period, often completely lacking rainfall, occurs during January to March. (Gustavsson et al. 1970)

Table 15. Mean annual rainfall in Kangayam and Perundurai

TALUK	Mean annual rainfall	Southwest monsoon (Jun –Sep)		Northeast monsoon (Oct –Dec)		Winter (Jan –Feb)		Summer (Mar– May)	
	mm	mm	%	mm	%	mm	%	mm	%
Kangayam	484.80	111.40	22.98	237.40	48.97	19.50	4.02	116.50	24.03
Perundurai	726.30	242.30	33.50	309.90	42.85	24.30	3.36	149.80	20.71

(Source: SSLUO, 1998 (Erode Soil Atlas))

Besides these seasonal changes, the precipitation can vary a lot from year to year. Several years of drought often follow each other consecutively. (Gustavsson et al. 1970) The last three years have been very dry and the monsoon season this year (2003) gave a moderate rainfall. Large variations from year to year, together with the conditions where several dry years occur consecutively, have created great problems concerning water supply.

4.5. WATER RESOURCES

The whole plain and therefore also the study area consists of a distinct arid area that completely lacks lakes and other natural water storage magazines. Therefore, natural surface water storage hardly exists and water is a limiting factor. If the monsoon rain fails more than two years in succession, this area will definitely suffer a severe drought. Natural water storage is limited to the amount which the subsoil is capable of holding. (Gustavsson et al. 1970)

There is a manmade water storage magazine, the previously mentioned Orathupalayam Dam. Today, it stores mostly effluent water from the highly water consuming industries in Tiruppur. Except during the monsoon season, the water reaching the dam is effluent water. If no industries released effluents the Noyyal River would be a seasonal river but today the river always carries water between Tiruppur and the Orathupalayam Dam.

About 1 km downstream of Orathupalayam barrier the LBP (Lower Bhavani Project) canal, crosses the Noyyal River. When water is released in the LBP canal, seepage water flows into Noyyal and to aquifers along the canal. Wells near LBP are benefited by the seepage water and almost become full when LBP has water. For the past two years, i.e. 2001 and 2002, no water has been released into the LBP canal due to rain failure.

The water table is generally deep. Only in areas close to the dam, Noyyal River or the LBP canal (when it has water) is the groundwater level shallow. The soil does not contain groundwater in other areas and to reach groundwater one must go down into the bedrock.

There are a great number of wells in the villages studied, both open and bore wells. The open wells vary from a few meters close to Noyyal River to about 30 m for the deepest ones. The depth of bore wells ranges from 250 to about 900 feet (76 to 274 m). Open wells receive water from unconfined aquifers[12] or shallow confined aquifers[13] and bore wells receive water from deeper confined aquifers. Many open wells have dried out during the last few years and a great number of bore wells have very little water.

4.6. IRRIGATION

The type of irrigation mainly practised around the Orathupalayam dam is canal irrigation, but also drip irrigation is practised. In most cases, the irrigation water is pumped from open wells or, in the case of water scarcity, from bore wells to the canals surrounding the fields or to the drip irrigation system. The ways in which canals are constructed depend on what kinds of crops are grown. For sorghum cropping, the canals surround the fields while the canals in coconut fields are located between rows of trees. Farmers who have land under the Orathupalayam dam command area, use dam water for irrigation on some occasions.

4.7. LAND USE PATTERN

Table 16 shows the land use pattern for Kangayam and Perundurai Taluks. In Kangayam, fallow land constitutes the majority of the land followed by net area sown. For Perundurai, sown land accounts for the largest land area followed by fallow land. In both Kangayam and Perundurai there is very little forest, barren uncultivable land, cultivable waste land, permanent pasture and tree crops.

Table 16. Land Use Pattern

Land Use		Kangayam	Perundurai
Total geographical area (ha)		84.645	80.621
1. Forest	ha	3.76	1.069
	%	0.4	1.3
2. Barren and uncultivable land	ha	2.82	4.11
	%	0.3	0.5
3. Land put to non agricultural use	ha	9.086	11.189
	%	10.7	13.9
4. Cultivable waste	ha	68	17
	%	0.1	-
5. Permanent pastures and grazing lands	ha	10	23
	%	-	-
6. Miscellaneous tree crops and groves	ha	96	2
	%	0.1	-
7. Current fallows	ha	34.997	16.095
	%	41.9	20.0
8. Other fallow lands	ha	18.040	-
	%	21.3	-
9. Net area sown	ha	21.690	51.815
	%	25.7	64.3

(Source: SSLUO, 1998 (Erode Soil Atlas))

[12] Aquifers close to the land surface with continuous layers of material with the ability to transmit water are called **unconfined aquifers**. They have an upper boundary defined by the water Table.

[13] Groundwater below a layer of solid rock or clay is said to be in a **confined aquifer**. The rock or clay is called a **confining layer**. A well that goes through a confining layer is known as an **artesian well**.
The groundwater in confined aquifers is usually under pressure. This pressure causes water in an artesian well to rise above the aquifer level.

5. METHODS AND PROCEDURES

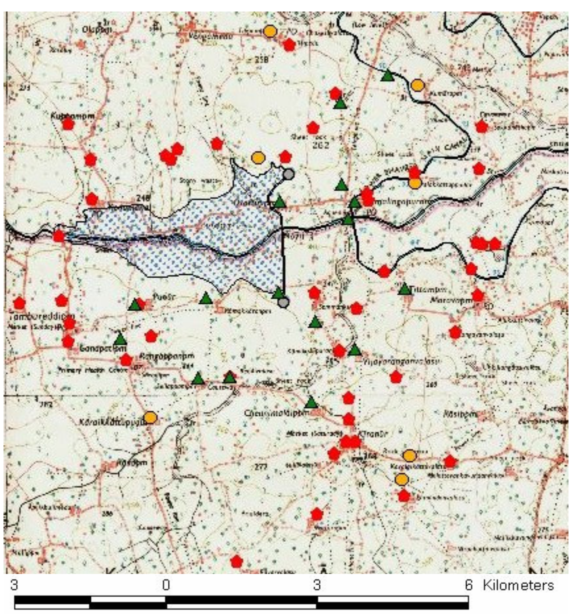
The following methods were used in order to determine the extent and impact of pollution on water, soil and people around the Orathupalayam Dam:

1. Water sampling
2. Soil sampling
3. Interviews
4. GPS-study
5. Geographical Information Systems (GIS), ArcView GIS 3.2 & ArcGIS
6. Surfer 7.0 for interpolations

5.1. WATER SAMPLING

The study was focused on ground water quality in wells around the Orathupalayam dam. The Noyyal river has a high electrical conductivity (EC) and high concentrations of Total Dissolved Solids (TDS) from Tiruppur to the Orathupalayam dam. Therefore these two parameters were used as indicators of pollution. The high EC level is mainly caused by the large amounts of sodium chloride used in the industries, and thus Cl^- and to some extent Na^+ ions will be good indicators of water being affected by the dam and, consequently the effluent water.

Groundwater samples were taken in bore wells and open wells, both common and private, around the dam. Some surface water samples were also taken. Inflowing and outflowing water from the dam was collected and samples were taken in the reservoir and in one canal leading from the dam. The samples were collected in three rounds (Fig. 14) in October and November 2003 (Table 17). In the first round, the collected samples were distributed within a circle with a radius of about 3 km with its centre at the barrier, in order to determine the major directions in which the pollutants had been spread. Heavy rain and thunder storms during the day of sampling unfortunately made it impossible to collect all the samples intended in the north and north-east directions.



Symbols

1: st round.shp

2: nd round.shp

3: rd round.shp

Table 17. Dates for water sampling

Round of sampling	Date, 2003
1	2nd and 3rd of October
2	13th and 14th of October
3	8th and 9th of November

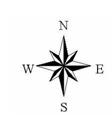


Figure 14. Water sampling locations

During the second round of water sampling the overall pattern of contaminated wells discerned from the first round was used as a reference. The whole area having groundwater affected by the dam was identified by asking people if their water had changed in quality since the dam was constructed. Water samples were taken in all directions around the dam where it was practically possible until people said they had good water, with no change in quality since the construction of Orathupalayam dam. Three wells were selected as reference wells, and samples were taken from these wells both in the first and second round in order to see if there was a change in the chemical composition. In the third round, only a complementary sampling was made with measurements of EC and pH as the only chemical variables. A number of questions were asked on two occasions at each well and can be found in appendix 8.

When analysing the results in interpolations all samples from the first and second rounds were used together since we wanted to discern the pollution pattern in the whole study area momentarily. This could be done after seeing that no major changes had occurred in the reference samples during the time between the sampling occasions. Some rain between the two rounds made the EC-value decrease somewhat. It was desirable but not possible due to the limited time for the study to take repeated samples in all wells.

No samples were taken far to the north or northeast due to the landscape being very dry grass land, so called “goats-land” and having no wells. In some locations many samples were taken close to each other. The reason was that people said that the wells had become salty, were naturally salty[14] or had good water within short distances.

5.1.1. Field procedures

The water samples were taken in new 1 litre white plastic bottles, which were rinsed carefully by filling them with water which was discarded before the actual water samples were taken. Before a well water sample was taken, the well water was pumped for some time, in order to make the sample representative of the ground water from which the well was fed. Samples were taken in both open- and bore wells.

Where possible samples, were taken from **open wells** after pumping for several minutes but many wells did not have electrical pumps and water was then collected with a bucket attached to a rope. The water level was measured in wells that had water and the thickness of the weathered zone was estimated where it was possible to observe in the open wells. Water from **bore wells** was collected either by using hand pumps, electrical pumps or via tanks.

5.1.2. Analytical work

The chemical analytical work was carried out at the Water Technology Centre, which belongs to the Tamil Nadu Agricultural University. The water samples were analysed for pH, EC and major cations and anions; Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Sulphate (SO_4^{2-}), Bicarbonate (HCO_3^{2-}) and Carbonate (CO_3^{2-}). Analytical methods for the different ions are shown in Table 18.

[14] Naturally salty, in this study, means that the water in the well have had salty water with high EC (>1dS/m), since the construction of the well without being affected by outside (anthropogenic) sources.

Table 18. Methods of analysis of well and surface water

No	Variable	Method	Reference
1	pH	Measured using a digital pH meter with a glass electrode.	
2	EC	Measured in terms of electrical resistance using a calibrated electrode.	
3	Carbonate (CO_3^{2-})	Titrating a known volume of water with standard sulphuric acid using phenolphthalein as an indicator.	Natarajan S et al 1988
4	Bicarbonate (HCO_3^-)	Determined with same method as carbonate but by using methyl orange as an indicator .	Natarajan S et al 1988
5	Chloride (Cl^-)	Precipitated as silver chloride by titration with standard silver nitrate solution using potassium chromate as the indicator.	Natarajan S et al 1988
6	Sulphate (SO_4^{2-})	Determined by the turbidity created by a precipitated colloidal barium sulphate suspension. Degree of turbidity measured with a turbidimeter.	Tandon HLS
7	Potassium (K^+)	Estimated by flame photometry. The intensity of emission is proportional to the concentration of potassium in the sample.	Natarajan S et al 1988
8	Sodium (Na^+)	Same as Potassium.	Natarajan S et al 1988
9	Calcium (Ca^{2+})	Determined by complexometric titration using ethylene diamine tetra acetic acid (EDTA).	Yadav BR & Khera MS
10	Magnesium (Mg^{2+})		

5.2. SOIL SAMPLING

The soil samples were collected from irrigated and non-irrigated fields at six different locations, (Fig. 15); Karikadu, Pudur, Thittampalayam, Orathupalayam, Ramalingapuram and Kamachipuram. The locations were selected with the aim to cover irrigated and non-irrigated fields in each location.

The samples from Kamachipuran were collected on the 2nd of October and the others on the 15th of November 2003. Until October very little rain had fallen in the area. Only 263 mm of rain had fallen between May and October (Table 20). In October and November, when the second round of samples were collected, some heavy rains occurred, especially two days before the sampling.

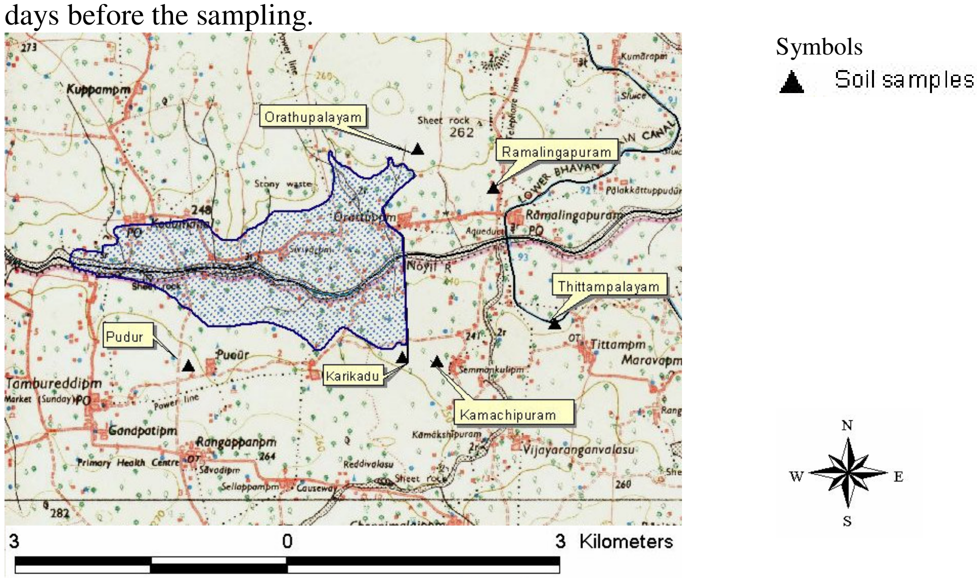


Figure 15. Soil sampling locations

5.2.1. Field procedures

Samples were taken from the surface soil (0-15 cm) and from the subsoil at (15-30 cm) depth. Surface litter was removed before sampling and was not included in the depth of the soil (Fig. 16). At each investigated field three spots were randomly selected for sampling. The soil from the three spots was mixed to obtain one bulk sample per field

Figure 16. Picture of soil by the time for sampling in Kamachipuram

If possible, soil was collected from both irrigated and non-irrigated areas. In Karikadu, samples were collected at two different spots in the same field. The difference between the spots was that one spot was closer to the irrigation channel. In Pudur, samples were collected close to the irrigation channel as well as from a non-irrigated field. At Thittampalayam, samples were collected only from an irrigated field, whereas at Ramalingapuram samples were collected both from an irrigated and a non-irrigated field. At Kamachipuram and Orathupalayam samples were collected from one field that was irrigated at the time of sampling, and another field that had been irrigated earlier but for the moment did not receive any irrigation.

5.2.2. Analytical work

The soil samples were air-dried outdoors in the shade for about 24 hours and thereafter sieved at 2 mm mesh size before analysis. Totally 22 samples were analysed for pH and EC as well as extractable Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-} and CO_3^{2-}. Due to analytical difficulties some samples were not analysed for Cl^{-}, HCO_3^{-} and CO_3^{2-}.

Figure 17. Filtering of soil samples (water samples behind)

Most of the soil samples were analysed at the Soil Science Department at TNAU, except for the anions Cl^{-}, HCO_3^{-}, and CO_3^{2-} which were analysed at the Water Technology Centre, TNAU. For the anion analyses, 20 g of air-dry soil was added to 100 ml distilled water and the soil suspensions were shaken for 2 hours. The soil suspensions were filtered (Fig.17) and the anions were analysed with the same methods as used for the water samples (Table 18).

For the analyses of extractable (exchangeable) cations 50 ml of ammonium acetate (1 M NH_4OAc) was added to 10 g of air-dry soil. The samples were kept at room temperature at about 20-30 ^oC for about 24 hours. The suspensions were then filtered through a filter, no 3, using ammonium acetate as an eluant. The filtrates were collected, made up to 250 ml with ammonium acetate (1 M) and analysed for the cations Ca^{2+}, Mg^{2+}, Na^+ and K^+. The analytical methods were the same as used for the water analyses.

5.3. INTERVIEWS AND VISITS

After we had collected the first round of water and soil samples we choose locations for the interviews. We wanted to cover both the southern and northern parts of the dam and interview people affected by the Orathupalayam Dam. Long in-depth interviews were held at 19 locations. The number of people who were interviewed varied depending on the situation. The selection of people was mostly done at same time as we entered the chosen area. Questions were formulated with the aim to understand how people had been and were presently affected by the dam and we therefore thought it important to interview people from all social groups including females, males, farmers, fishermen, agricultural labourers, industry workers and other local people. We tried to include old as well as young people.

The questions asked are shown in appendix 9. Complementary interviews were also made with the following people; engineers in charge of the data collection and regulation of water flow of the dam, leaders of the villagers' union and bleaching and dyeing industry owners.

The following governmental institutions were visited in order to receive maps, statistical data about the villages in the study area and information about earlier studies made on the effects of effluents from dyeing and bleaching industries:

- Pollution Control Board (PCB)
- Public Works Department (PWD)
- Thasildar office Kangayam and Perundurai
- Village Administrative Offices (VAO:s)
- Statistics office Erode

5.4. GPS-STUDY (Global Positioning System)

At each sampling point for water and soil the latitude and longitude was determined by a hand-held GPS apparatus. GPS coordinates were also taken along the Orathupalayam dam and LBP-canal in order to determine the extent of the reservoir and the path of the canal.

5.5. GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

Topographical maps of the study area were scanned, matched and imported into the computer programme ArcView 3.2. The GPS points with corresponding hamlet, chemical data and answers from questions asked at each well were put into a table and imported into ArcView. By using ArcView the reservoir and LBP could be drawn based on the GPS points and all the sampling points with their particulars could be located.

5.6. SURFER

Surfer 7.0, a grid-based graphic programme was used to interpolate three-dimensional data associated with the water samples, i.e. latitude, longitude and chemical variables into a regularly spaced grid. The grid was used to produce different types of maps. The method best suited for the wells in the study area was found to be Kriging, a geostatical gridding method that produces maps from irregularly spaced data and attempts to express trends suggested by the data.

6. THE ORATHUPALAYAM DAM FROM CONSTRUCTION TO TODAY –RESULTS AND DISCUSSION

6.1. CONSTRUCTION AND COVERAGE OF THE ORATHUPALAYAM DAM

We visited the dam on the 10th of October 2003 and the engineer working at the barrier informed us that the construction of the dam was completed in 1992 and from then on water started to accumulate in the reservoir. During construction a gap was left for the river flow and no stagnation of water occurred.

Another man working with the maintenance of the dam told us that sand from the Noyyal river basin was used to build the barrier. Sand was taken upstream and downstream for about 6-7 km in each direction. Broken rocks were also taken from places close by. When there was not sufficient building material, material was brought from other places. The barrier was built with a bend on the north side of the river in order to save the hamlet Orathupalayam.

Local people told us that the government bought land from farmers in order to create the reservoir, since a lot of land was to be inundated as the water accumulated. The area of the reservoir as of the 9th of November 2003 was 3.98 km^2 (980 acres), calculated in ArcView based on the GPS points taken around the dam (Fig. 18). The length was about 3.59 km in the east-west direction and 2.17 km at its widest point in the north-south direction. The extent of the water spreading followed the altitude of 250 m above sea level (Fig.18). The water level of the reservoir was therefore somewhat below 250 m.

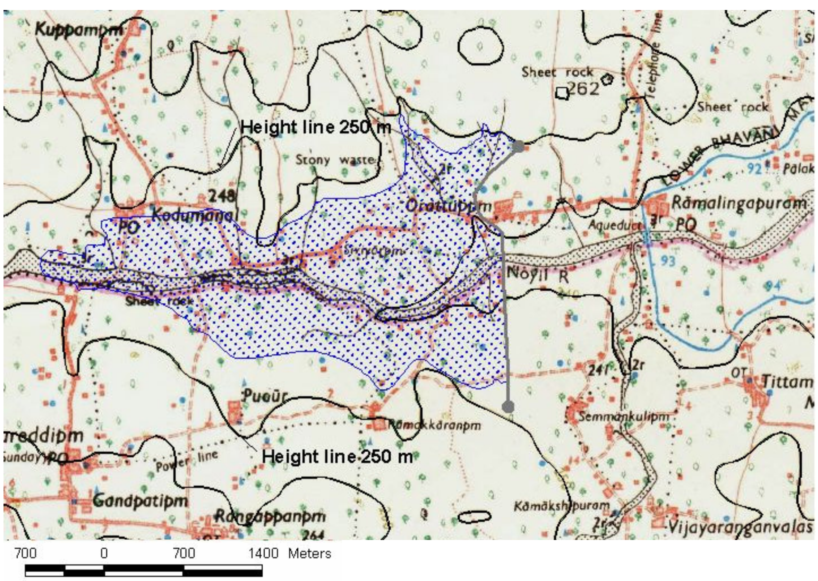


Figure 18. Extent of the Orathupalayam Reservoir, 9th of October 2003

The reservoir has an area of about 4 km^2 and a capacity of 17 440 m^3, which means that a huge quantity of polluted water is stored and stagnated. The water level normally fluctuates between 10 and 11 m the engineer informed us. This means that the water level has risen by about 10 m since the river was dammed (the river used to have very little or no water except after heavy rains).

6.2. WATER FLOW TO AND FROM THE DAM

According to the engineer, water was released into the canals and the main sluice during the first four years 1992-1996, but was then found unsuitable for irrigation. Farmers who live down stream of the Orathupalayam dam refused to have water released for irrigation and farmers under the dam command area did not want water released into the canals.

The main sluice is now open only if the reservoir reaches its maximum capacity, which is 40 ft (12 m) of water, the engineer told us. Water is let out into the canals during October and January but only if the farmers request so. We observed, however, that there is always water leaking from the main sluice.

There is a log book kept at the barrier. The book contains hydrological data which are collected daily by the engineer. The sluice was last opened two years ago, when the water level reached 40 ft (12 m), and 750cft/s of water (21.2 m^3/s) was released for some days. Water was also going to be released during this monsoon season (2003) since the water level on the day of our visit was 36 ft and more rain was expected. Water had also been released 3, 4, 5 and 6 years ago, the dam engineer informed us. The amount of water being released varied; sometimes it was up to 2000 cft/ s (56.6 m^3/s). If it is needed, the sluice is opened during the months with the highest rainfall, which are October and November.

On a later visit to the dam, the engineer told us that water had been released right after our first visit. The amount corresponded to 500 cft/s (14.2 m^3/s) from the 16th through the 19th of October and 250 cft/s (7.1 m^3/s) from the 20th through the 22nd of October. There had been heavy rains which had started on the 16th. Water had also been released in the left main canal on request of some farmers.

The inflow varied a lot from day to day depending on the rain but also on how much effluent water that had been released from the industries. Inflow was only documented in the log-book when there was an increase in the dam water level. It was apparent that the water level rose in periods of 4-6 days with an inflow of 3 – 160 cft/s (0.085 – 4.5 m^3/s) and in-between there was a zero inflow. (log book, 2003) When the inflow was recorded as zero the amount coming in equalled the amount of water that had leached. Inflow during the first half of October 2003, which is one of the monsoon months, is shown in Table 19.

Table 19. Rainfall and inflow to the Orathupalayam Dam

Date, 2003	Rain (mm)	Inflow (cft/s)	Inflow (m^3/s)
01-10	0	0	0
02-10	8	0	0
03-10	2	66	1.87
04-10	59	104	2.94
05-10	0	80	2.265
06-10	8	26	0.74
07-10	0	0	0
08-10	0	0	0
09-10	0	0	0
10-10	0	0	0
11-10	0	0	0
12-10	0	0	0
13-10	107	136	3.85
14-10	0	160	4.53
15-10	0	96	2.72

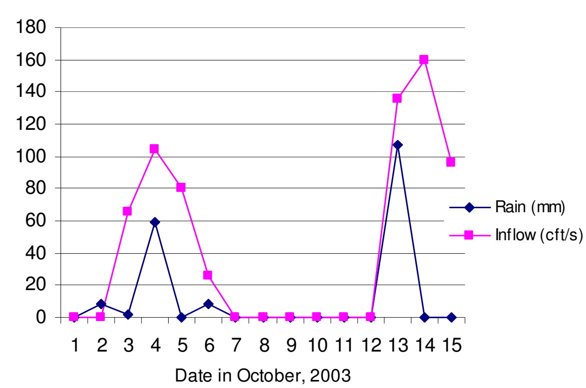


Figure 19. Inflow and rain covariation in the Orathupalayam Dam during first half of October, 2003

A family who lived on the bank of the Noyyal River upstream of the Orathupalayam dam told us that the water flow varied a lot. This was also the case during the dry season when there was no rain. Also the colour of the water changed. The incoming water was usually blackish. They thought they could see a pattern with increasing flow during weekends. Moreover, they believed the factories let out more effluents when there was rain. We speculated that this had to do with a smaller likelihood of having their effluent water tested at weekends and with the diluting effect of the rain.

Rainfall and release into the main sluice and left canal for the period May to November was also taken from the log book (Table 20). By comparing observations of days with rain and rainfall registration in the log-book, we realised that rainfall was recorded in the log-book the day after the rain occurred and was estimated as the increase in water level in the dam.

Table 20. Rainfall and release of water in the Orathupalayam Dam from May to November, 2003

Date, 2003	Rain (mm)	Release in main sluice (cft/s)	Release in left canal (cft/s)	Date, 2003	Rain (mm)	Release in main sluice (cft/s)	Release in left canal (cft/s)
05-05	21	-	-	06-10	8	-	-
14-05	59	-	-	13-10	107	-	-
24-05	9	-	-	16-10	21	500 (14.16 m^3/s)	-
28-05	9	-	-	19-10	8	500	-
29-06	12	-	-	20-10	48	250 (7.08 m^3/s)	-
10-07	4	-	-	21-10	-	250	-
16-07	5	-	-	22-10	-	250	-
31-07	4	-	-	31-10	15	-	-
01-08	20	-	-	2-11	2	-	-
06-08	16	-	-	3-11	2	-	-
13-08	16	-	-	5-11	-	-	2 (0.057 m^3/s)
15-08	39	-	-	6-11	3	-	2
29-09	30	-	-	7-11	4	-	2
02-10	8	-	-	8-11	3	-	2
03-10	2	-	-	9-11	5	-	2
04-10	59	-	-	10-11	33	-	-

Analysis and Discussion

It can be seen from figure 19 that the inflow increased in connection with a rain event, but did not quite follow the pattern of rainfall. During the 3rd of October the inflow increased substantially although there had been no heavy rain. This leads to the conclusion that a lot of effluent water must have been released. The same amount of rainfall on the 6th did not lead to an increase in inflow. A longer observation period would be needed in order to determine the pattern of inflow and its covariation with rainfall and release of effluents.

One lesson learnt from this study, which could be useful for future work in this part of the Noyyal River, is that it might be worthwhile to collect samples on a number of occasions in order to catch the actual situation with daily monthly and seasonal variations in water flow and water quality. Moreover, it is a good idea to ask people who live by the river if the river has comparatively high or low flow at the time of sampling and if the colour of the water is “natural” or if it might be influenced by dyes.

7. EFFECTS OF THE ORATHUPALAYAM DAM ON WATER –RESULTS AND DISCUSSION

Water is stored and stagnated in the Orathupalayam dam and we studied the effects of this stagnation of water both on the quantity and quality of groundwater. Interviews and water samples were used in this assessment.

7.1. QUANTITY OF WATER

By asking people if the water level in a particular open well had risen after the accumulation of water in the reservoir, it could be concluded whether there was an exchange between the surface water in the reservoir and the groundwater in the surrounding areas or not.

An illustration and estimation of this was done by making a classification of the answers (Table 21) and an interpolation between the wells with change in water level (0, 1 or 2) as the z-value (Fig. 20), leading to three categories of areas (Table 22). Wells given the number 2 have had an increase in water level of about 9 to 15 m (30-50 ft).

Table 21. Classification of answers

Did the water level in the Open well change?	
0	No
1	Little
2	A lot

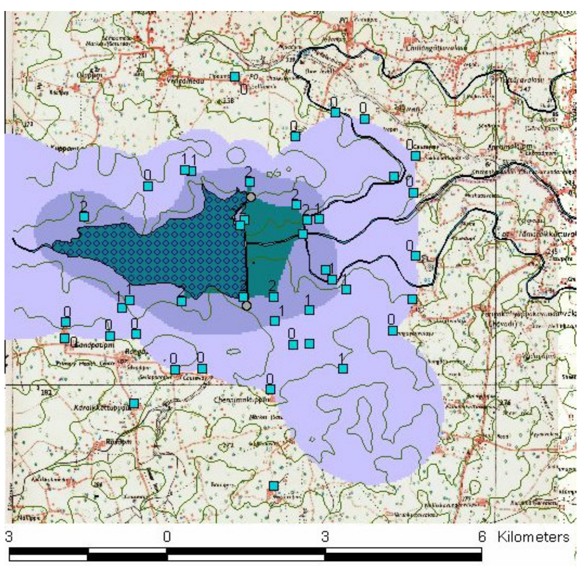
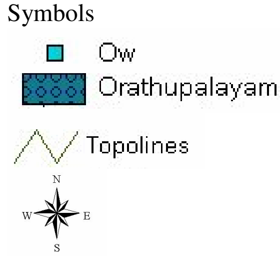


Figure 20. Change in water level in open wells with numbers corresponding to the classification obtained in the interviews

Table 22. Categories

Category	Colour	Explanation
0 - 1	Light	Potential increase of water
1 - 2	Medium	Small to large increase of water
2 -	Dark	Large increase of water

Symbols



In the darkest part (Fig. 20) the water level[15] in the open wells had increased by more than 9 m. This was mostly in the eastern direction along the riverbed (following the topography Fig. 13). The open wells in this region had their water tables[16] in the weathered zone, i.e. hard rock was more deeply located than the actual water level. In the middle section a small increase had been noted and some wells in this region had their water tables below the

[15] Water level – the surface of water. In open wells it is measured as the distance from ground level to the surface of water.

[16] Water Table- (1) the surface of a groundwater body at which water is at atmospheric pressure, (2) the upper surface of the saturated zone that determines the water level in a well in an unconfined aquifer.

weathered zone. However, also in this region most wells had their water tables above the weathered zone. In the most light-coloured part there was a potential increase of the water level with the coloured boundary being an absolute limit.

By asking local people how much water they had in their wells and by classifying the answers according to Table 23 a visual picture of the water resource pattern as of October 2003 could be obtained. This was done for open and bore wells separately (Fig. 21).

From the water resource pattern for **open wells** in October 2003 it could be seen that there was plenty of water in the wells close to the reservoir, but scarcity of water further away. In many wells in the higher areas and in areas with a thin layer of weathered material there was no water at all. This pattern followed the grid map of thickness to hard rock quite well. There is a misleading pattern 2 km north of the barrier where there is dry land grass land. There is less water in this area than Fig. 21 shows.

Bore wells had more water in some directions around the reservoir, especially to the south-east and northeast (Fig. 21). Many wells (both bore and open wells) in the higher regions had very little water during October 2003 since there had been little rain so far during the rainy season and rain failure during the last two to three years.

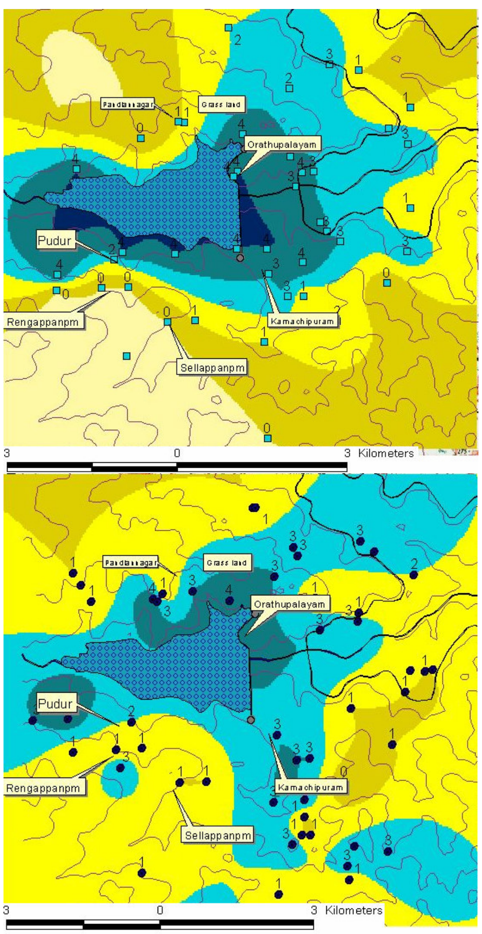
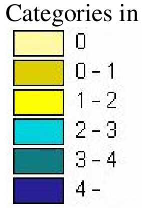


Figure 21. Water resource pattern in OW above and BW below, Oct 2003

Table 23. Classification of answers about quantity of water in open- and bore wells

How much water in well?	
0	No water
1	Scarcity
2	Little
3	Enough
4	Plenty

Categories in Figure 21 a and b



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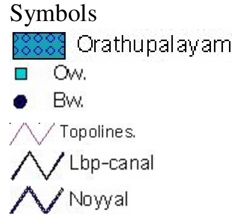


Ow and Bw have labels corresponding to answers in Table 23.

The water level was measured in open wells that contained water on the day of sampling. Wells situated close to the dam had water levels close to the surface and wells further away and on higher elevations (Fig. 13) had deeper water levels in the open wells, or even no water at all. This pattern clearly followed the grid map of thickness to hard rock, which should be expected.

Analysis and Discussion

The grid map, which shows the changes in water level, could only be made for open wells, because it was not possible for people to observe changes in bore wells in an easy manner. Some data points had to be added just north of the barrier since there were no open wells in this dry region. It was assumed that the water level would not have risen in this region and zero values were therefore added to hopefully get a more realistic picture.

Unconfined aquifers were fed by seepage water from the reservoir since the water table had risen in wells within the weathered (permeable) zone (Fig. 20). This could happen because the water level in the dam was higher than the groundwater table which is a quite common phenomenon in arid areas. The water level rose about 10 m when water accumulated in the reservoir and stagnation occurred. Surface water from the reservoir also percolated to deeper confined aquifers through fissures in solid rock since water level changes had been observed in wells with water levels below the weathered zone. Another piece of evidence was that a farmer who lived in Kamachipuram, about 750 m from the reservoir shore south-east of the barrier, said that his bore well (250 ft, 76 m deep) had had an increase in water level after the dam was built. This was also the case in Pallakadu, about 1 km from the reservoir shore, south-west of the barrier.

The normal condition in these dry areas is to have no unconfined aquifers and to reach ground water one must go down to the bedrock. However the area close to the Orathupalayam reservoir had groundwater close to the surface. Apart from water being released into the canals and the main sluice as well as water leakage, the water in the reservoir either evaporated or was fed to the groundwater, thus recharging the surrounding aquifers, both the unconfined and confined ones. (Fig. 22)

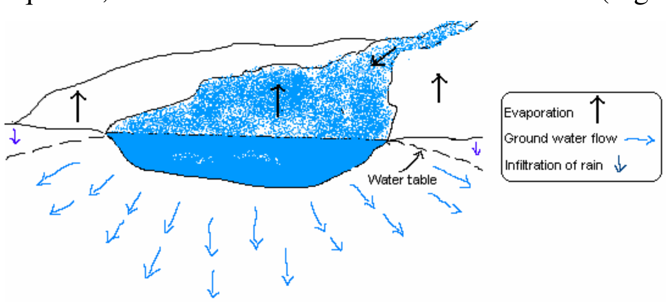


Figure 22. Illustration of seepage from the Orathupalayam dam (not to scale)

The LBP Canal usually recharged the wells in its vicinity and the wells close by became full. Due to rain failure during the last few years there had been no water in the LBP for the past two years. Therefore there was less water in these wells as of September to November 2003 than before. From the information received about the wells and from the grid maps, it was evident that there was an uneven distribution of water in the study area and that there was a problem with scarcity of water in the upper regions. If the water in the Orathupalayam dam had not been polluted this problem would have been solved but now the pollution further aggravated the problem of scarcity.

7.2. QUALITY OF WATER

The quality of water as of October and November 2003 was studied through interviews as well as water sampling and chemical analysis. In order to understand how the groundwater around the dam had become affected over time and for what purposes the water was used, well-owners were interviewed.

7.2.1. Interviews

Local people in the area said they first noticed a change in the quality of their well water because the taste was different. They could taste that the water had become salty and some said it had a bitter or “chemical” taste. After some time they also noticed effects on soil and crops (Section 8). Some people also observed that it took longer than previously to boil the water and that rice got a different, more yellowish colour after cooking.

At each well, the owner (private wells) or the users (common wells) were asked if the well water had changed in quality since the Orathupalayam dam was built and if so, how many years after the construction this had happened (Fig. 23 a & b). They were also asked for their opinion about the quality of the water and the answers could be good, slightly salty, salty, bitter or naturally salty (Fig. 24 & Table 24)

a) b)

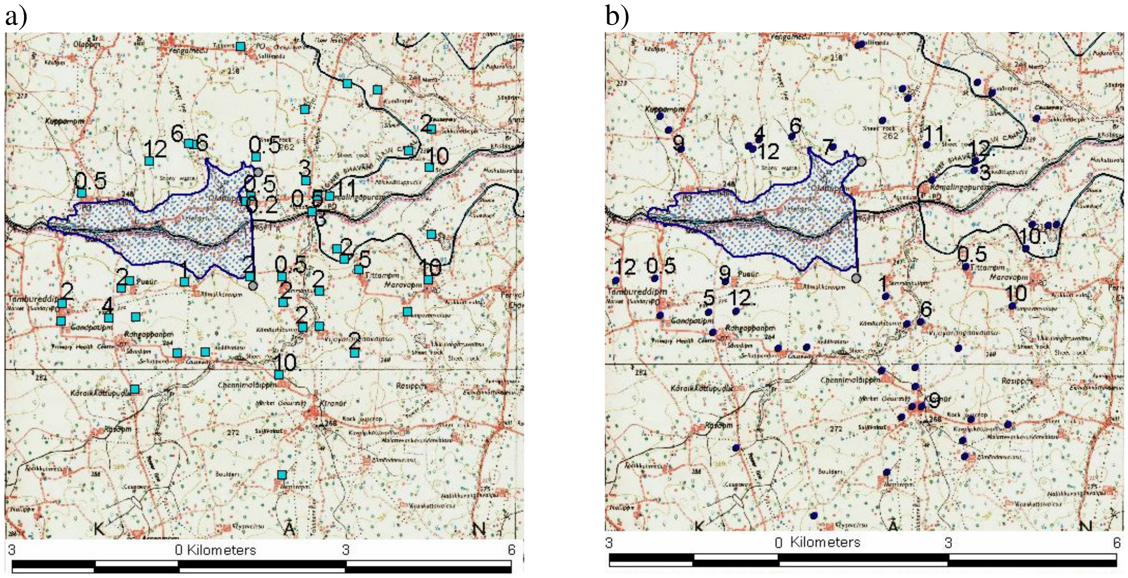


Figure 23. Wells with labels showing after how many years they became affected a) Open wells, b) Bore Wells

For the open wells that were situated close to, and at the same height as, the dam or beneath it, it took less than a year before the water quality had changed. This happened mostly in the eastern part. Increasing numbers of open wells became affected as the years passed by. It took a longer time before the wells on the northern side were affected and the water of some wells had not changed in quality until quite recently. The wells to the far north or south of the dam had not changed their water quality at all. The latter wells (Fig. 24) were considered to have good water (G) or naturally salty water (N).

An important point noticed was that wells close to the LBP, especially on the eastern side, took longer to become affected and some wells only changed their water quality when water was no longer released into the LBP-canal, which happened in 2001. People, who lived in areas benefited by seepage from the LBP had noticed that their wells had recently become affected. They were earlier “on the safe side” of the dam but now the water that came from the Orathupalayam dam was no longer diluted. For most of the wells affected, people said the quality was deteriorating year by year.

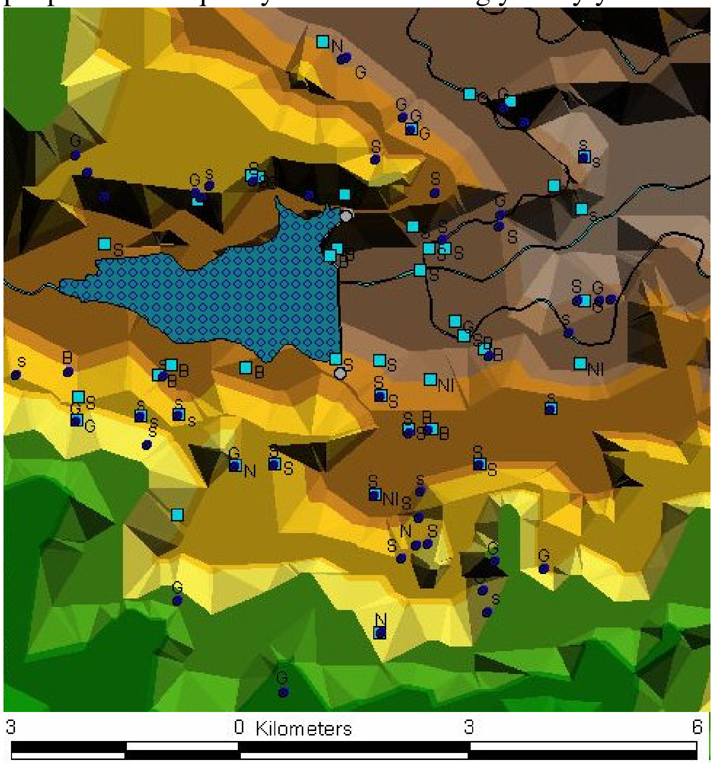
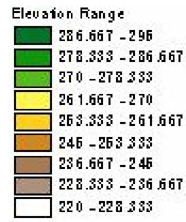


Figure 24. 3D map of open wells and bore wells with labels showing opinions about water quality

Table 24. Classification of answers about the quality of water in wells

Quality of well water, Labels in map	
G	Good
s	Slightly salty
S	Salty
B	Salty and bitter
N	Naturally salty,
NI	Naturally salty but increasing



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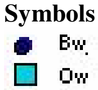

BW have labels above and OW on the right side of the symbol

In Fig. 24 it is possible to see a spatial pattern in water quality. Many people who had wells close to the reservoir said that the water had become bitter and salty and that there had been a change in water colour. It was “chemical water” they said. Some wells had naturally salty water we were told, and most of these wells were located south-east of the dam. In some naturally salty wells the saltiness had increased since the dam was constructed.

Analysis and Discussion

Since many wells were drilled after the construction of the dam it was difficult to know if the water had changed at that particular location and at that particular depth. Another complicating factor was the occurrence of naturally salty water in the area. Water in the bore wells could vary in quality even though the BWs seemed to be very close to each other as judged from a map. The depths varied and the water could therefore come from different aquifers.

For open wells close to the dam, it took less than a year for the water quality to change and these wells were the same as those in which the water table had risen when water had accumulated in the dam (Fig. 20). Wells that only had a slight increase in the amount of water took some years to become affected. Often it took longer for bore wells to become affected compared with open wells in the same area, but this was not always the case.

East and west of the Orathupalayam dam, along the Noyyal river, the groundwater might have been influenced both by the river water and seepage water from the dam. It is difficult to determine how far in the eastern and the western direction it was the stagnation of water in the dam that affected the groundwater.

7.2.2. Water samples

Complete data tables with concentrations in $mmol_c/l$ and mg/l are found in appendices 1 and 2 together with maps showing the locations of the corresponding samples with sample-numbers as labels. There are more open wells located close to the dam and more bore wells further away.

All water samples had a pH greater than 7. The open wells had EC-values ranging from 0.75 to 17.04 dS/m with most values in the interval 5-9 dS/m and bore wells varied between 0.57 and the extreme value 18.3 dS/m with most values (85%) in the interval 1-3 dS/m. One open well, not thought to have been affected by seepage water from the Orathupalayam dam, was no. 16 in Kosuvankattuthottam. This well had not changed its water quality according to the well owner. The water had an EC value of 0.93 dS/m and a pH of 7.77. Moreover, two bore wells (nos. 52 and 60) situated in Kovalakattuvalasu and Rayavalasu, respectively, were not thought to have been affected by the dam water, according to the users. The EC values were 0.78 and 0.57, and the pH values were 7.49 and 7.8. The water in these wells was used for all purposes.

Three wells were selected as reference wells, and samples were taken from these wells both at the first and second round of water sampling (Table 25). As shown in Table 20, there were two days of heavy rain in between the rounds of sampling, i.e. 59 mm (which fell between 3rd and 4th of October) and 107 mm (between 13th and 14th). There was a decrease in EC in the three wells from the first to the second round.

Table 25. Three reference sampling points for the first and second round of sampling

No.	OW/BW	pH	EC dS/m	CO3 $mmol_c/l$	HCO3 $mmol_c/l$	Cl $mmol_c/l$	S04 $mmol_c/l$	Ca $mmol_c/l$	Mg $mmol_c/l$	Na $mmol_c/l$	K $mmol_c/l$	SAR	TDS (mg/l)
8*	Bw	8.14	4.33	0.8	8.4	33.2	1.79	3.44	7.26	29.76	0.36	12.86	2775
Ref.8	Bw	8.17	4.00	0.8	8.0	31.00	1.39	1.60	8.59	33.73	0.30	14.94	2564
10**	Bw	7.97	4.44	0	5.2	34.8	1.60	13.28	12.95	13.37	0.13	3.69	2846
Ref.10	Bw	7.82	3.74	0.40	4.60	32.0	1.30	11.0	12.83	15.51	0.08	4.49	2397
15***	Ow	7.22	7.97	0	5.0	76.4	1.05	32.72	17,2	19.00	0.36	3.92	5109
Ref.15	Ow	7.47	7.50	0.8	3.0	78.0	1.13	33.90	21.41	20.89	0.18	3.97	4808

* 8. Chennimalaypalayam. Common well
** 10. Thittampalayam. Common well
*** 15. Ramalingapuram. Private well

EC and also the Cl^- and to some extent the Na^+ concentration were good indicators of pollution coming from the dyeing and bleaching industries. This was verified by looking closer at the water samples collected from the inlet and in the dam water. These samples had high EC values (6.4 and 7.89 dS/m) and high Cl^- and Na^+ concentrations, which were well above irrigation standards. However, according to the interviews there were wells with naturally high EC values in the study area. The results are first presented in three parts and an analysis and discussion part follows.

Interpolations of EC and pH

Interpolations, using the Surfer programme, were made for EC and pH values, measured in open- and bore wells, which were located with GPS. The pH was lower in the groundwater around the dam and Noyyal River and was higher further away but with some patches of high pH close to the LBP canal (Fig. 25). Water with pH above 8.4 is close to alkaline conditions and pH above 8.9 is alkaline according to the Tamil Nadu classification of irrigation water. Some locations are marked in Fig. 25 for guidance.

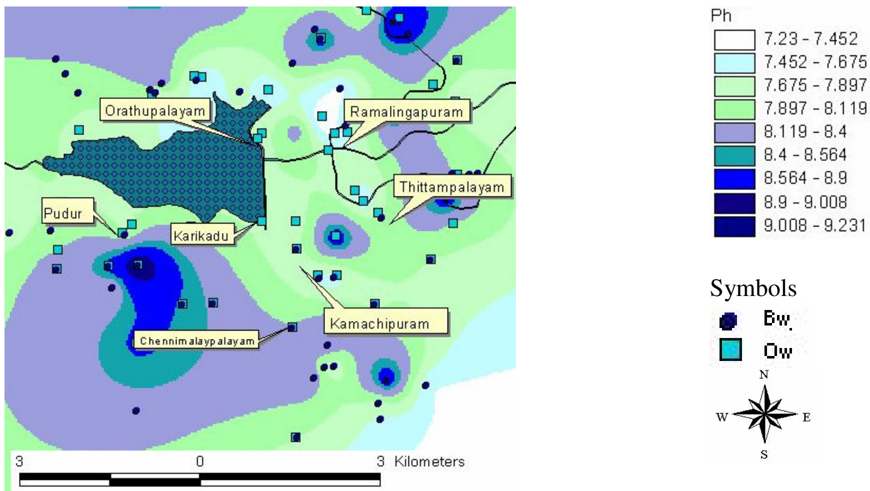

Figure 25. Interpolation of pH in open wells and bore wells

In order to determine if and how far the pollution from the dam had been spread the EC interpolation was used (Fig. 26). Outside the coloured area, the interpolation indicated an EC-value of less than 1 dS/m, which is normal according to the Tamil Nadu system.

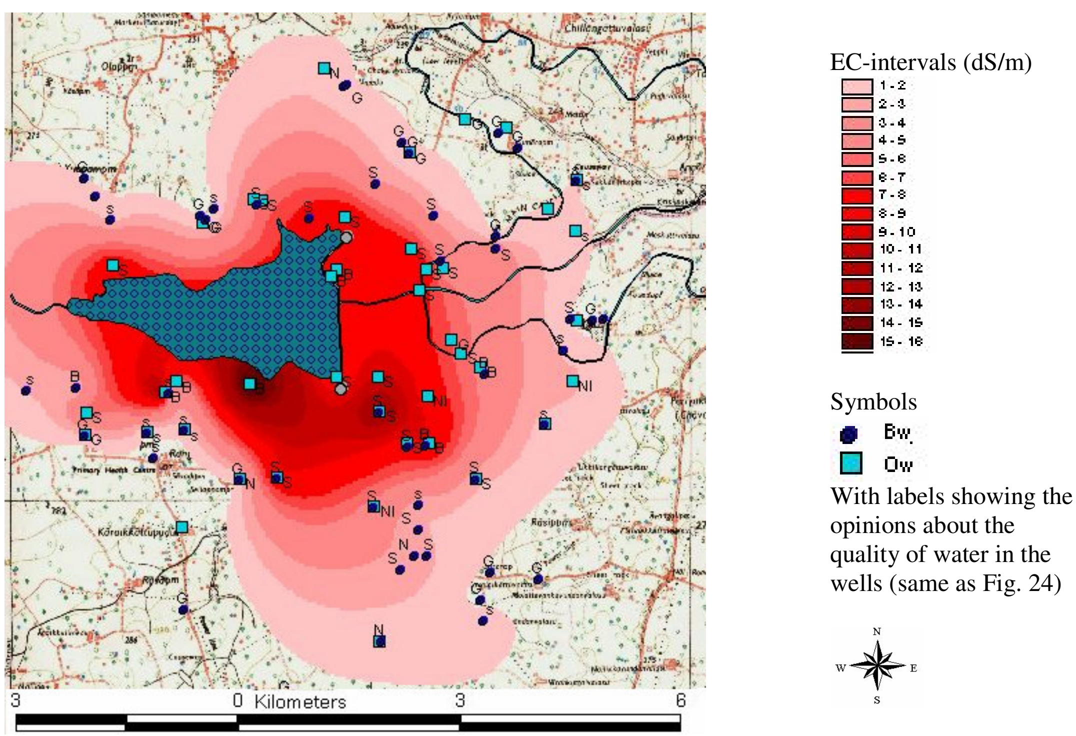

Figure 26. Interpolation of EC-values in dS/m in open and bore wells.

A pattern could be noticed where high EC-values were associated with the dam. There were high EC values in well water close to the dam with the extremes just south of the reservoir. Since EC could be used as an indicator of pollution it could be seen that the pollution had been spread all around the dam but more so in the eastern and south-eastern directions. As in the maps of bedrock and water resources, Fig. 26 is most likely misleading to the north of the barrier where there are no wells.

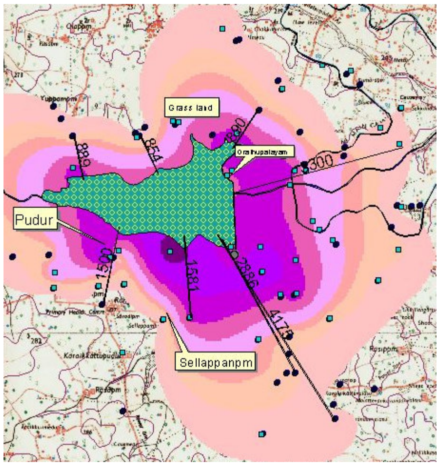

Figure 27. Measured distances

Distances to the outermost wells known to be salty were measured in ArcView (Fig. 27). The furthest distance was about 4.2 km in the south-east direction. Many wells had higher EC values than the dam, especially those wells that were located on the south side of the reservoir.

The measured EC-values and the opinions about water quality showed a good correspondence. When EC was greater than 1 dS/m people thought that the water had a slightly salty taste. If EC increased to more than 2 dS/m the water was said to have a salty taste.

Bar diagrams

Bar diagrams were made to determine which anions and cations accounted for most of the increasing EC values. The data were stratified into three categories, (1) all wells (OW + BW), (2) open wells (OW) and (3) bore wells (BW). In the first category, the samples were divided into EC-intervals of 1 dS/m (Fig. 28).

There was a wide range in EC values, from 0.57 to 17.04 or even 18.3 dS/m. The figure above each bar shows the number of samples within each interval. Most wells had EC values between 1 and 3 dS/m.

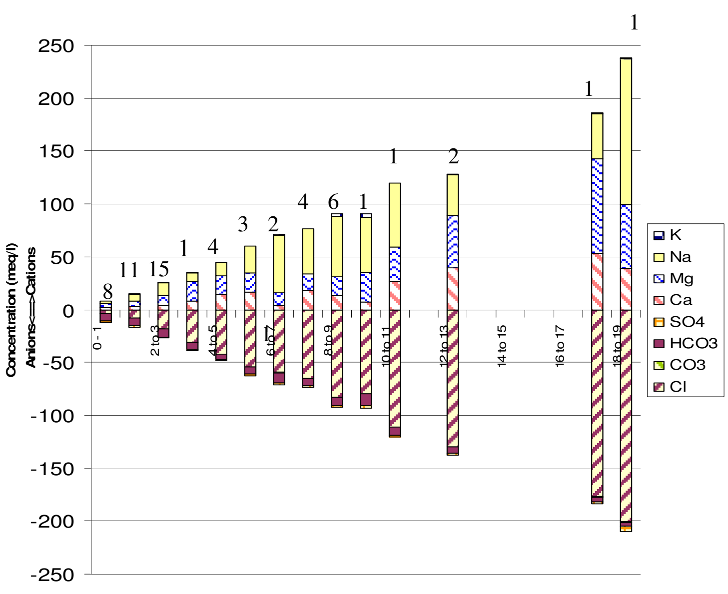

Figure 28. Major ionic constituents in OWs and BWs within different EC- intervals

Among the anions, Cl^- accounted for most of the relative increase in concentration as EC increased. The Cl^- concentration was positively correlated with EC and 98 % of the variation in EC could be explained by the Cl^- concentration alone ($R^2 = 0.979$). Among the cations, Na^+, Mg^{2+} and Ca^{2+} were positively correlated with EC. The corresponding R^2 values were 0.708, 0.763, and 0.710, respectively. It could be noticed that the increase in Cl^- with increasing EC was greater than the increase in Na^+. The K^+ concentration was high in some samples, but was not statistically related to the EC values. Sulphate did not increase with increasing EC and the relative amount was low in samples having high EC values. The bicarbonate concentration decreased both in absolute and relative terms as EC increased, whereas the CO_3^{2-} concentration was low or zero in all samples.

For open wells individual samples correspond to specific bars (Fig. 29). In this diagram water samples from inflow, canal and dam water are also included, which enables a comparison of surface water with open well water with respect to major ionic constituents.

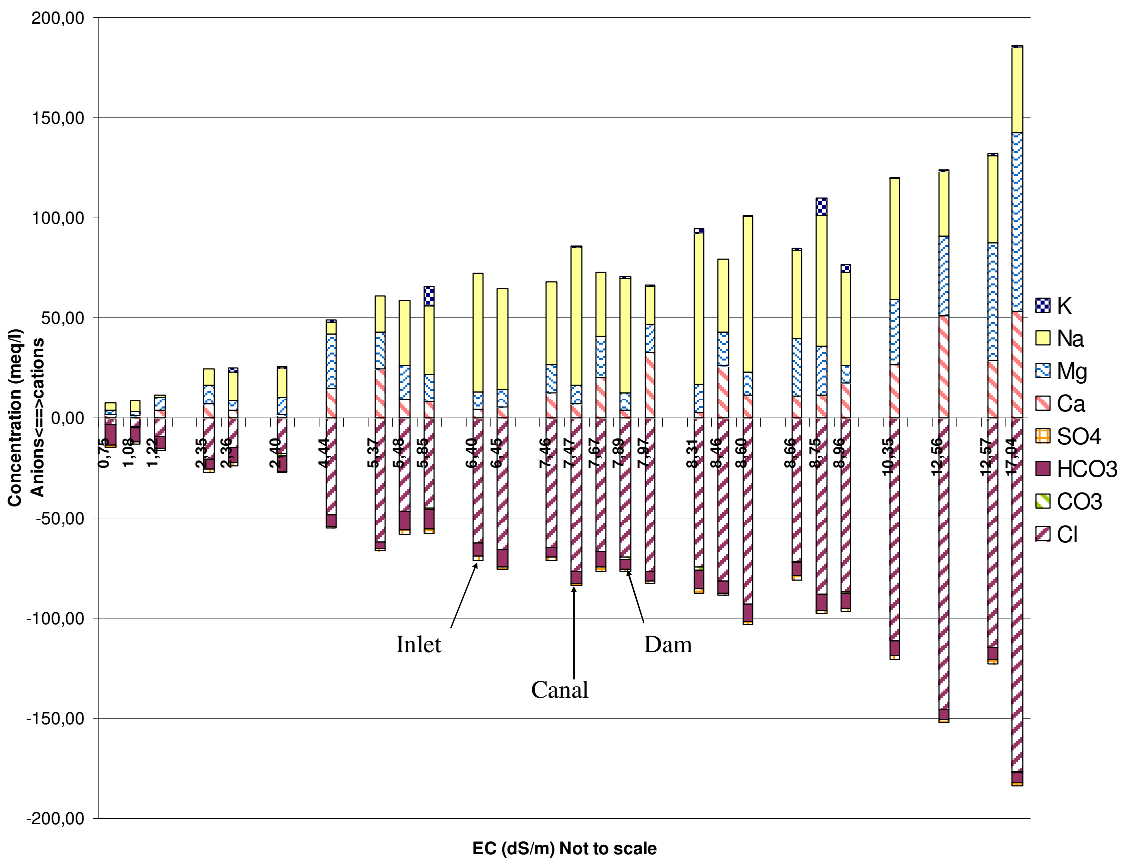

Figure 29. Major ionic constituents in open wells, inflow-, canal- and dam water

The surface water had comparatively low concentrations of Mg^{2+} and Ca^{2+} and a high concentration of Na^+ compared with well water samples within the same EC-range. The diagram shows the same trends as in Fig. 28 but illustrates the variability in Na^+, Ca^{2+} and Mg^{2+} concentrations between the samples. Also, it can be seen that Cl^- increased more rapidly than either Na^+ or Mg^{2+}. There were some samples that had high K^+ concentrations.

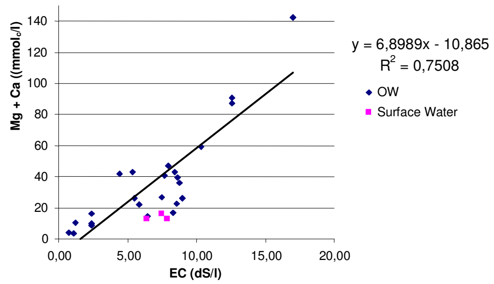

Figure 30. Sum of Mg and Ca as a function of EC. (mmol$_c$/l equals meq/l)

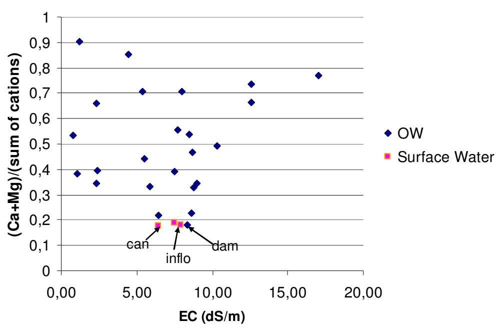

Figure 31. Percentage of Mg and Ca as a function of EC

The (Mg^{2+} + Ca^{2+}) concentration increased as EC increased (Fig. 30) but the (Mg^{2+} + Ca^{2+}) concentration as a percentage of the total cation concentration did not show any statistical relationship with EC (Fig. 31). The same surface water samples were included in the two figures. These samples had low Ca^{2+} and Mg^{2+}concentrations. There were well waters having the same relation between the percentage of Ca and Mg as the surface water.

The third category (BWs) showed a wide range spread in EC but a majority (85 %) of the samples had values between 1 and 3 dS/m. The bar diagram (Fig. 32), shows samples in this range and the same pattern is apparent here as in the previous diagrams. Sulphate was quantitatively more important in this EC-range but the concentration did not change much throughout the EC range. There was a gradual relative decrease of bicarbonate and an absolute and relative increase of chloride as EC increased.

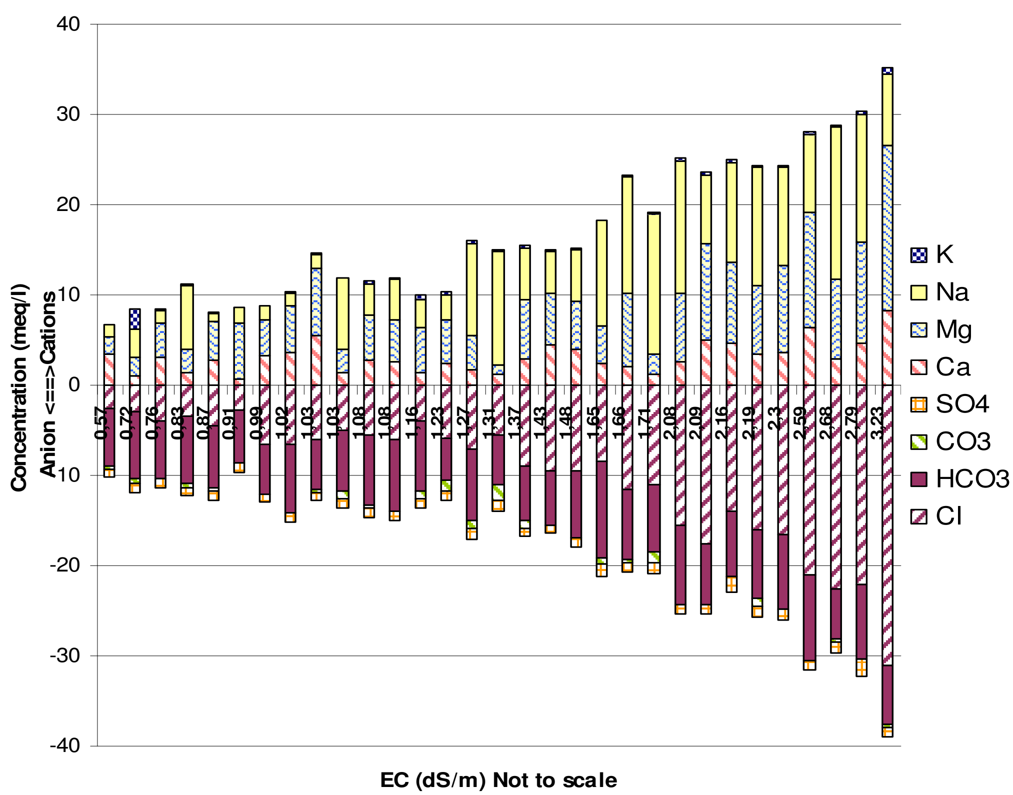

Figure 32. Major constituents in bore wells having EC between 1 and 3 dS/m

Correlations - cations and chloride

In order to see if there were any correlations between different ions in the water samples, plots including Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- were made. Table 26 shows the R^2-values for regression lines including the different sets of ions divided into the three categories, all wells (BW + OW), only bore wells (BW) and only open wells (OW).

Table 26. R^2- values for regression lines

1BW & OW	R^2 N*=62	2 BW	R^2 N=38	3 OW	R^2 N =24
Cl-Ca	**0.7692**	Cl-Ca	0.274	Cl-Ca	**0.729**
Cl-Mg	**0.7692**	Cl-Mg	**0.6699**	Cl-Mg	**0.6687**
Cl-Na	**0.669**	Cl-Na	**0.7646**	Cl-Na	0.3918
Cl-K	-	Cl-K	-	Cl-K	-
Ca-Mg	**0.7073**	Ca-Mg	0.3802	Ca-Mg	**0.6193**
Ca-Na	0.23	Ca-Na	0.0592	Ca-Na	-
Ca-K	-	Ca-K	-	Ca-K	-
Mg-Na	0.3359	Mg-Na	0.331	Mg-Na	-
Mg-K	-	Mg-K	-	Mg-K	-
Na-K	-	Na-K		Na-K	-

*N= number of samples

For BW & OW together, there were statistically significant relationships for Cl^- versus either Ca^{2+}, Mg^{2+} or Na^+. There was also a statistically significant relationship for Ca^{2+} versus Mg^{2+} but none of these cations showed any relationship with Na^+. The regression lines which have the highest R^2-values are shown in Fig. 33. Inflow-, canal and dam water data (not included in the regressions) are also plotted for a comparison.

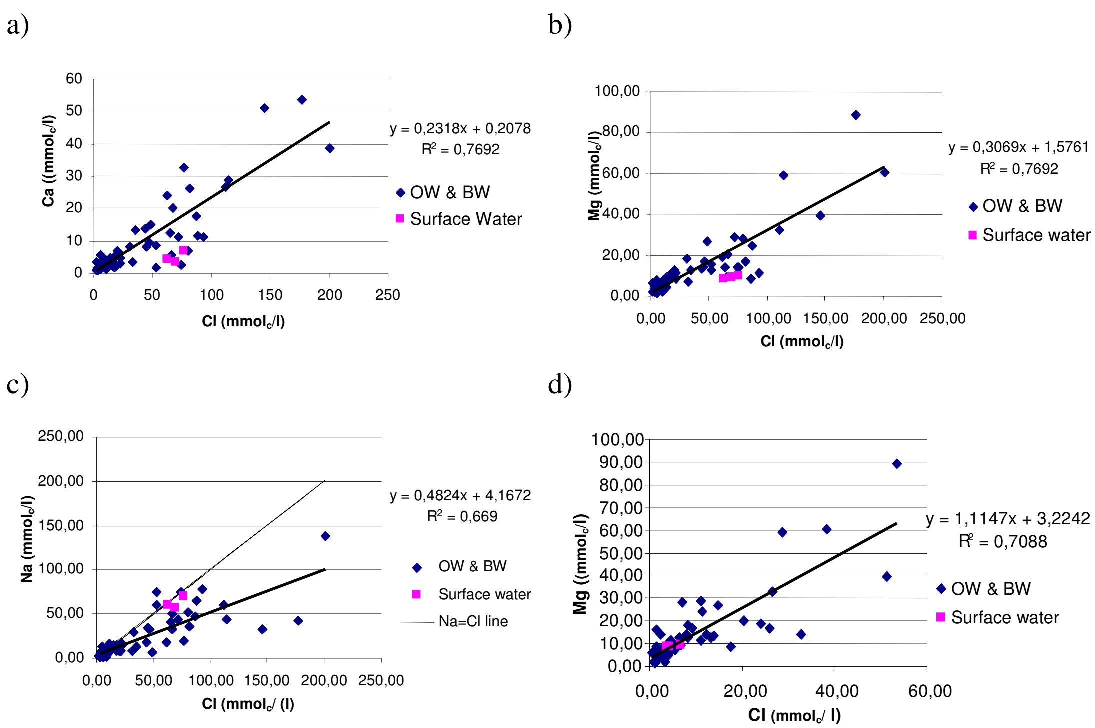

Figure 33. Linear regressions for OW & BW and surface water (inflow- canal- and dam water) a) Ca/Cl b) Mg/Cl c) Na/Cl including a 1:1 (Na = Cl) line, d) Mg/Cl

Concerning the BW samples, there were significant linear relationships for Cl^- versus Mg^{2+} or Cl^- versus Na^+. Concerning the OW samples there were statistically significant relationships for Cl^- versus Ca^{2+} or Mg^{2+}, as well as for Mg^{2+} versus Ca^{2+}.

Interpolations of cation and chloride distribution

In order to get a visual picture of the chloride and cation spatial pattern in the study area, interpolations were made in Surfer (Fig. 34 a,b,c,d,e). Also EC was included for comparison.

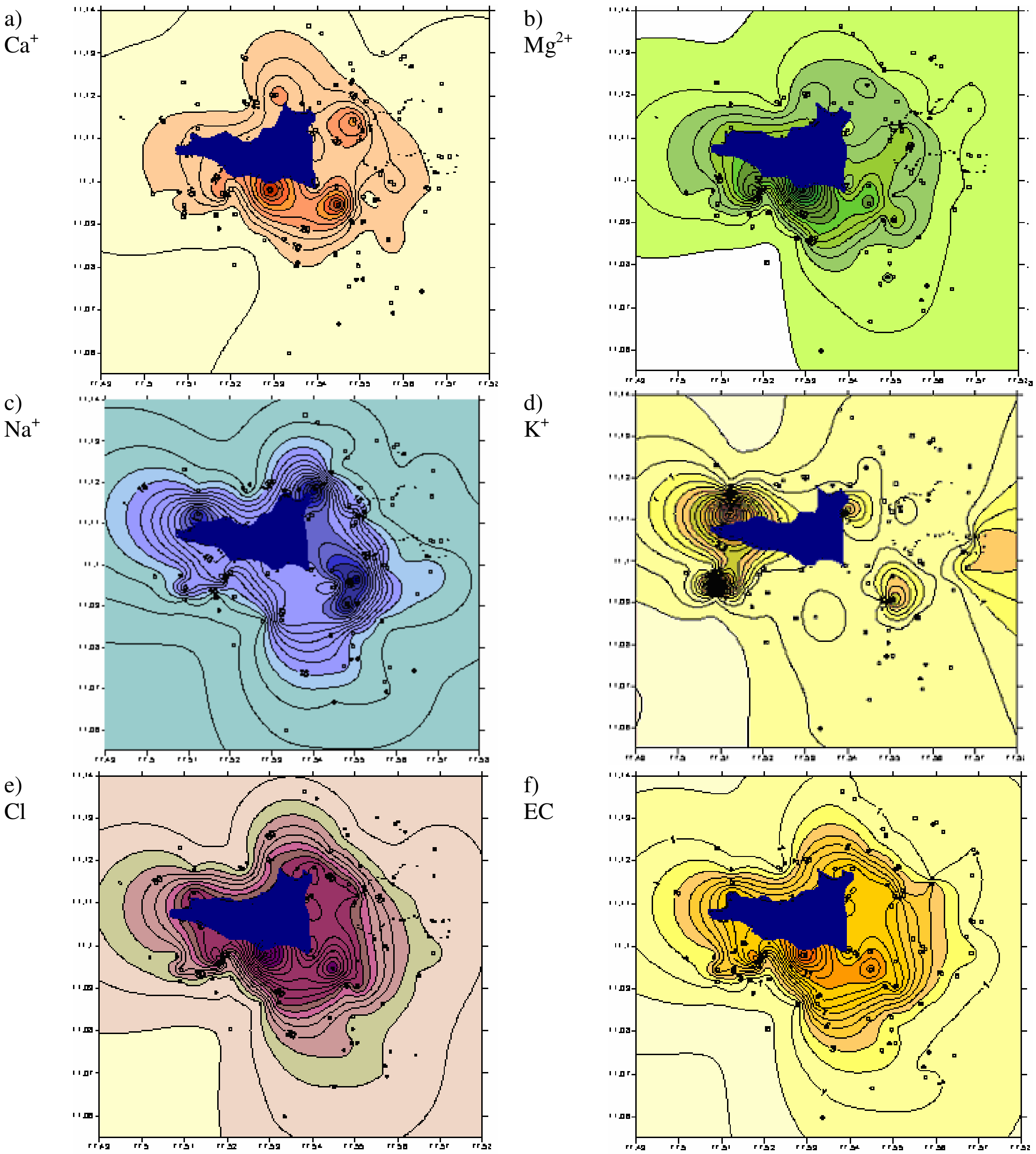

Figure 34. Interpolations for a) Ca^+ b) Mg^{2+} both with10 $mmol_c/l$ between isolines c) Na^+, with 5 $mmol_c/l$ between isolines d) K^+, with 0.5 $mmol_c/l$ between isolines and e) Cl^-, with 10 $mmol_c/l$ between isolines with outermost isoline equal to zero for all ions, f) EC, with 1dS/m between isolines.

It is obvious that high concentrations of all ions, except for $K^{+,}$ were associated with the dam. Very similar patterns could be seen for EC and Cl^-, with the highest values south of the reservoir. Also the isolines of Na^+ showed an analogous pattern as that of EC and Cl^- but the highest values were more concentrated towards the east. Ca^{2+} and Mg^{2+} had similar isolines. As for EC and Cl^-, the highest values were found south of the reservoir. The pattern of K^+ concentrations did not have any similarities with the other ions and did not seem to be associated with the dam.

Analysis and discussion of water samples and water quality

Two wells were not included in the interpolations. One of them was the bore well no. 56 because of its extremely high EC-value (18.3 dS/m). Neither was it included in the correlations made. This well was treated separately since wells close by had a good water quality (EC < 1 dS/m). Number 56 was drilled one month before the sample was taken. It was strange to note its extreme EC value since there were bore wells nearby, e.g. number 58, which had a good water quality. However, no. 56 was deeper (650 ft) than no. 58, whose depth was 380 ft. The water in well 56 might have been affected by old stagnant water but was most likely also affected by the dam since it was of the Na^+-Cl^- type rather than the Ca^{2+}-Cl^- type.

The other well excluded was the open well in Thippanpalayam, (no. 72), because it was naturally salty and had not changed since the dam was constructed. If it was included it would give a false estimate of the pollution spreading north of the barrier since there were no open wells in this direction until Thippanpalayam.

The spatial pattern obtained by the EC interpolation followed the topography quite well, with plumes of high EC in low lying areas, i.e. in the east and south-east. There was, however, a plume towards the north that was not expected since this is a higher region (Fig. 13). The reason was that no samples could be taken in this part and the interpolation model used the EC values available close to the dam and then "jumped" to bore wells about 2 km to the north and calculated a gradual decrease in EC. EC probably decreased more rapidly as judged from the topographical map.

There were high EC-values in many wells, especially south of the reservoir. An accumulation of ions had occurred in these wells. Well no. 4 is one example with an EC value of 17.04 dS/m. The water was only used for irrigation of coconut once a week which means that the water turnover in the well was low. This might theoretically lead to an accumulation of ions in the well. Water evaporates and the salt stays in the well water.

The wells which were not considered to be affected by polluted water still had EC-values above 0.5 dS/m. According to the USDA system, EC > 0.5 dS/m implies medium salinity, and EC > 0.75 dS/m implies high salinity water. The comparatively high values could be explained by natural causes, or in some locations perhaps by leakage from agricultural activities (e.g. Mg^{2+} + Ca^{2}). The wells might also be slightly affected by the dam since a slight increase in EC might be difficult to recognize just by tasting the water, which was the way by which people first noticed a change in water quality. It must be stressed, however, that there was good correspondence between measured EC-values and opinions about water quality. People knew their water very well. Open well no. 16, which had an EC value of 0.93 dS/m, had good water according to the farmer but might potentially have been or become affected by the dam since the area was quite low-lying and situated on the east side of the dam. The well was also benefited by seepage water from LBP whenever the canal contained water.

- **Cation-anion balances and analytical uncertainties**

The electrical charge balance was not satisfactory in many of the samples, which is illustrated in appendix 4 as the percentage difference between cations and anions on a mol_c basis. Often the Σanions was greater than Σcations. One important reason for the dominance of anions was probably the fact that CO_3^{2-} and HCO_3^{2-} were analysed some days before the analysis of Ca^{2+} and Mg^{2+}. During the time that elapsed between the analyses $CaCO_3$ could have been precipitated and the documented concentration of Ca^{2+}might therefore be too low. We may assume that carbonic acid is the only important acid in the dam and well water. Since all water samples had a pH roughly between 7 and 9, HCO_3^- was supposed to be the dominating anion in the carbonic acid system. The precipitation of $CaCO_3$ could then be explained by the following chemical reactions:

$$Ca^{2+} + 2HCO_3^- \Leftrightarrow CaCO_3(s) + H_2CO_3 \qquad (1)$$

$$H_2CO_3 \Leftrightarrow CO_2 + H_2O \qquad (2)$$

If 1 and 2 are combined, we get;

$$\mathbf{Ca^{2+} + 2HCO_3^- \Leftrightarrow CaCO_3(s) + CO_2 + H_2O \qquad (3)}$$

We may also assume that the water was initially oversaturated with respect to the partial pressure of CO_2 in the free atmosphere at the time of sampling, and that the air temperature in the lab was higher than the original water temperature (the samples were not kept cool after sampling). The CO_2 -concentration at equilibrium will then be considerably lower than at the time of sampling, which means that reaction 3 will be forced towards the right and $CaCO_3$ will precipitate. The cation/anion imbalance could also be explained by errors associated with the separate chemical analyses.

Some analytical data were uncertain, especially the SO_4^{2-} data and some were difficult to carry out. The analyses found to be the most difficult ones to carry out were the acid/base titrations of CO_3^{2-} and HCO_3^{2-} and the precipitation titration of Cl^- especially for water samples that had high EC-values. All titrations of one particular ion were made by the same person and in the same manner, which should make it possible to compare the samples among themselves although systematic errors might lead to generally too high or too low absolute concentrations. The cation analyses were probably more accurate than the analyses of the anions although the Ca^{2+} concentration could be too low, as discussed above. We focussed on the cations in the data analysis. Chloride was still included, however, since it is an important ion, the concentration gradient of which, seemed to indicate the spreading of pollutants from the bleaching and dyeing industries. It should be stressed that there was a significant correlation between EC and Cl^-. Yet one has to keep in mind the discussion above concerning analytical errors.

- **Cation and chloride concentration in the water samples**

The concentrations of Na^+ and Cl^- often balance each other in rainwater. Also in our surface water samples Na^+ and Cl^- balanced each other quite well. This can be seen in Fig. 33 c where the surface water samples are close to the 1:1 line. The same figure shows that most well water samples fall below the 1:1 line, i.e. the Cl^- concentration tends to be greater than that of Na^+. However, there were some well water samples that showed a balance between Na^+ and Cl^- and these samples tended to have low EC values, ≤ 1 dS/m, or stay in direct contact with the water in the reservoir. The latter was valid for OWs nos. 3, 13, 26 and 27 (with EC values of 7.46, 8.96, 8.60 and 6.45 dS/m respectively). These wells were situated on the east side of the reservoir close to the barrier and had an ionic composition that was similar to the ionic composition of the dam water (Fig. 29). Two wells on the south side of the reservoir, nos. 4 and 7 with EC values of 17.04 and 12.56 dS/m, fell well below the 1:1 line for Na^+ versus Cl^- (Fig 33 c). These samples had high concentrations of Ca^{2+} and Mg^{2+} instead of Na^+.

Calcium and Mg^{2+} both increased in absolute terms when EC increased but Ca^{2+} and Mg^{2+} might not have their sources in the dam water since the surface water had a lower concentration of these ions and a higher concentration of Na^+. The high concentrations of $Ca^{2+}$and Mg^{2+} in many wells might be due to a cation exchange with Na^+ and therefore be an indirect effect of the spreading of pollutants from the dam.

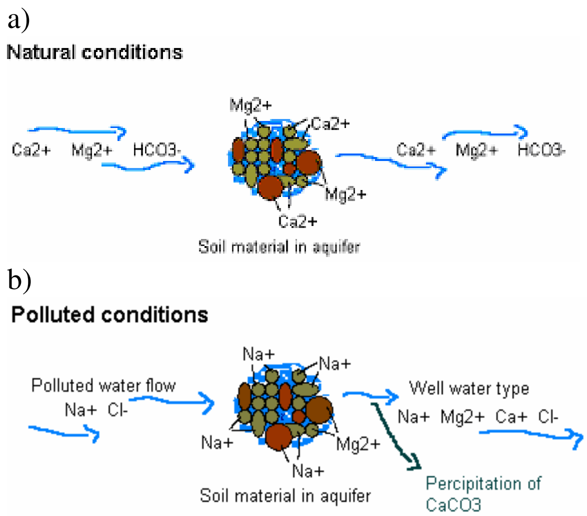

Figure 35. Illustration of cation exchange on soil material under **a**) natural and **b**) polluted conditions.
Source: made in Paint from sketch by Gunnar Jacks

There was a dominance of Mg^{2+} compared with Ca^{2+} in many samples, which might be due to precipitation of $CaCO_3$ in the aquifers and in the samples between analyses.

Fig. 35 a and b illustrate what happens under natural versus polluted conditions when water in aquifers interacts with the soil material. Under natural conditions groundwater is dominated by Ca^{2+}, Mg^{2+} and HCO_3^- but the polluted water from the Orathupalayam dam was dominated by Na^+ and Cl^-. A cation exchange occurs on the soil particles leading to more Mg^{2+} and Ca^{2+} in the well water and an eventual precipitation of $CaCO_3$.

Consequently, sodium could not be used as a good indicator of the spreading of pollutants even though high Na^+ concentrations were observed in the polluted water. Chloride, however, showed a strong correlation with EC and its relative concentration increased when EC increased. Chloride could therefore be used as an indicator of the spreading of polluted water from the Orathupalayam dam.

7.2.3. Drinking water classification

In Table 3 standards are shown for four of the ions that were included in the study. The water samples could therefore be compared with these standards in order to have an idea about their quality as drinking water. The standards for the four ions, Cl^-, SO_4^{2-}, Ca^{2+} and Mg^{2+} are 250 mg/l, 150 mg/l, 75 mg/l and 30 mg/l.

All **surface water** samples had high Mg^{2+} concentration, about 3 times the limit for drinking water, but the Ca^{2+} concentrations were below the standard in dam, canal and inflow water. The Mg^{2+} concentrations in **wells** were also high, even in wells with low EC (around 1 dS/m), e.g. bore wells nos. 2 and 6 on the south side of the reservoir and 14, 23, 31-33 on the north side. The only wells below the standard for Mg^{2+} were the open wells 12 and 16 (close to LBP) and the bore wells 40 (Rengappanpm), 54 (Maravapm close to LBP), and 60 (Rayavalasu). These wells also had Cl^-, Ca^{2+} and SO_4^{2-} concentrations that were below the limit.

All **open wells** except nos. 12, 16 and 57 had higher Cl^-, Mg^{2+} and Ca^{2+} than the ISI standard and most wells were well above the limit with Cl^- concentrations of more than 4000 mg/l close to the reservoir. The three wells were all situated close to the LBP canal and the water was used for drinking. Number 12 was built just one year before the sample was taken and was closest to the reservoir. Also the water in well no. 64 (Pallanthottam) was used for drinking although Cl^- was somewhat above and Mg^{2+} well above the standard. The water in some open wells was used as drinking water for animals, i.e. wells 3, 5, 9, 15 and 61. All these wells had Cl^- concentrations well above or just below 2000 mg/l and should therefore not be used for drinking.

Many **bore wells** had concentrations of Cl^- and Mg^{2+} above the standard. The water in some of these was used as drinking water (wells 19, 32, 37, 43, 44, 47-49, 54 and 55). Two wells also had Ca^{2+} concentrations above the standard (wells 48 and 49). In several bore wells the Mg^{2+} concentration, but not the Cl^- concentration, was above the limit (wells 2, 6, 14, 22, 23, 31-33, 42, 50 and 63). The SO_4^{2-} concentration was below the standard in all samples except for open well number 64.

It is quite alarming that bore well 8 in Chennimalaypalayam was used for drinking purposes since the TDS in the water sample was as high as 2775 mg/l and WHO states that drinking water becomes significantly unpalatable at TDS levels greater than 1200 mg/l.

Almost all open wells and many bore wells were unsuitable for drinking purposes. Many wells, especially the open wells close to the reservoir, were also unsuitable for washing clothes and bathing (meaning personal hygiene). People using the water for bathing got skin irritations and the soap did not lather because of high water hardness.

7.2.4. Irrigation classification of water samples

All water samples were classified according to the USDA and Tamil Nadu system for irrigation water (appendix 5). Water uses and an explanation of the different classification systems are also included in the same appendix.

The majority (84 %) of the samples from **open wells** fell into the C4 category (EC>2.25 dS/m) and most samples were well above that limit. These waters were therefore not suitable for irrigation under ordinary conditions. As for the sodium hazard, there was more variation with samples falling into all classes (S1-S4). S1 and S2 are low and medium sodium waters respectively, and can be used on almost all soils with respect to sodium hazard but high salinity could cause a salinity hazard. Many of the low sodium waters had a high salinity hazard. According to the Tamil Nadu system, 74 % of the OW samples were in the injurious category (EC > 3.0 dS/m) and not suitable for irrigation, 17 % were in the critical category and only two OWs had normal EC values(< 1 dS/m).

Figure 36. Open well in Vingerrengavalasu. Salt crystals can be seen on the sides

Most of the OWs were used for irrigation, however, mainly for coconut trees. The OWs with normal or critical ratings are situated close to the LBP canal. Open wells with low sodium hazard were also situated close to LBP but also three wells south of the reservoir (nos. 7, 4 and 1) had low sodium water.

The majority (60 %) of the samples from **bore wells** fell into the C3 category (0.75 dS/m <EC< 2.25 dS/m). These wells thus had high salinity water that could not be used on soils with restricted drainage and plants with good salt tolerance had to be selected. About 30 % of the BWs had very high salinity water and a few (6 %) had medium salinity. Most bore well water was low or medium sodium water (S1 & S2) but a few wells had high or very high (S3 & S4) values and these were situated south of the dam. According to the Tamil Nadu system, 23 % of the samples had an injurious rating with respect to EC (>3 dS/m), 59 % were critical and 20 % were normal. The BWs with injurious irrigation water were situated to the east of the dam following the slopes towards the east. Fig. 26 showed the pattern of EC around the dam. The whole coloured area had EC-values above 1 dS/m. This is above normal according to the Tamil Nadu system.

Most OWs had water with a high salinity in terms of EC or TDS, but not all of these water samples were high sodium waters. Since the sodium hazard is based on the SAR value, which is a measure of the degree to which sodium in irrigation water replaces the adsorbed calcium and magnesium ions on the soil particles, a high sodium water has a large amount of Na^+ compared with Ca^{2+} + Mg^{2+}. The reason for high or low sodium hazard could be explained in the same way as high or low relative concentration of Na^+ compared with Ca^{2+} and Mg^{2+}.

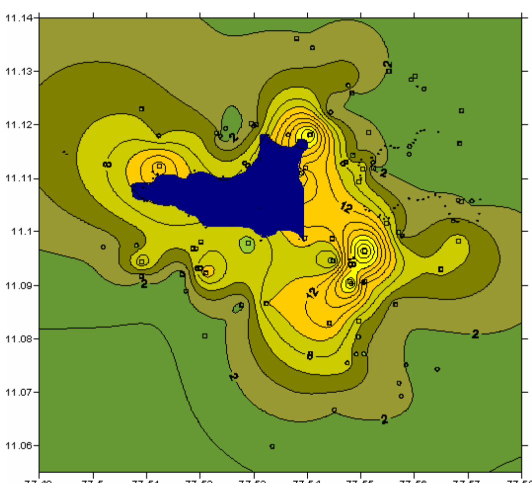

Figure 37. Interpolation for SAR with 2 units between the isolines.

The high sodium waters were directly connected with the dam water, e.g. nos. 3, 13 and 27, and low sodium water had gone through a change where Na^+ was replaced by Mg^{2+} and Ca^{2+} (Fig. 35). To illustrate the SAR variations around the dam an interpolation was made in surfer (Fig. 37). It can be noticed that the pattern is similar to the isoline pattern for Na^+ (Fig. 34 c), which is natural since SAR is directly related to the concentration of Na^+. There were high concentrations of Mg^{2+} and Ca^{2+} south of the dam which make the SAR value lower there although the EC values were extremely high.

The OWs with a low sodium hazard (low SAR) albeit with a high salinity hazard could perhaps cause less damage to the physical structure of the soil. The absolute concentrations of Na^+ were, however, high in most OWs and this could cause sodium toxicity to crops.
The salinity in the OWs, except for the ones located close to the LBP canal, was very high and for this reason the water should not be used for irrigation. The reason why most OWs were still used for irrigation was that there was no other alternative for the farmers.

The **surface water** samples were all in the C4-S4 category which means “very high salinity water”, not suitable for irrigation and “very high sodium water”, generally not good for irrigation purposes except at low or medium salinity. Water from Orathupalayam dam and Noyyal River should, therefore, not be used for irrigation purposes. The surface water samples had high SAR values since the sodium concentration was high. Well water had lower SAR values except for wells in close connection to the dam water.

7.2.5. Overall conclusions and discussion about the water situation

The long-distance spreading of pollution to groundwater was due to the **stagnation** of water in the Orathupalayam dam. Flowing water in the Noyyal river did not infiltrate to groundwater to the same extent as when the river water was dammed, when the water level rises and when water is stagnated for a long period of time. Because of the continuous discharge of effluents and the damming of these in the Orathupalayam dam, not even monsoon flows that are almost free of pollution can be used, and open and bore wells around the dam have turned brackish. The rainfall over the area only marginally dilutes the pollution. Well water close to, and surface water from, the river was formerly used for irrigation but due to the high amounts of salt it can no longer be used for other purposes than irrigation of some coconut trees, which can cope with high concentrations of salt.

The synthesis of the chemical analyses (especially the EC-interpolation) and the interviews made at the sampling locations strongly indicate that many hamlets have become affected by polluted water from the Orathupalayam dam, which originates from the textile industries. In Table 27 the hamlets that were included in the study and found to be affected are listed. Villages listed as affected had wells with water that had changed in quality and turned salty, after the construction of the dam and had EC values above 1 dS/m. Most wells close to the dam, had EC-values in the injurious category according to the Tamil Nadu system for irrigation water, i.e. EC>3 dS/m.

Table 27. Hamlets affected by polluted water judged from chemical analyses and spatial interpolations

Revenue village	**Affected Hamlets**	**Potentially affected hamlets**	**Risk zones, judged from 3D map (Fig. 13)**
Tammareddipm	Pudur, Tammareddipm. Pudur, Pallakadu, Thangamman Kovil, Ramakkanpm., Reddivalasu & parts of Rengappanpm. (south of the road).	Ganapathypm.	
Sivamalay		Savaipm., Karaikattupudur[1]	
Maravapm.	Karikadu, Semmankulipm. Kamachipuram, Kamachipuram Colony, Thittampm., Vingerrengavalasu, Meenaksithottam(BW no. 56)[2] & parts of Maravapalayam		Towards the east, following the river bed if no dilution effect from released water in the LBP.
Kiranur	Sellappanpm., Chennimalaypm., Kiranur[3], Vakkanang kattu thottam (no. 51)	Sullivalasu[3], Rangayavalasu[4](no. 55)	Further in the direction of Rangayavalasu and possibly Sullivalasu.
Ellaigramam	Ramalingapuram, Ramalingapuram Colony, Palakatpudur (no. 71)	Sakkanathapm.(no. 31), Pallanthotam (no. 64)	Further towards the east and northeast in the direction of no. 16, no. 31 and no. 64. Possibly all the way towards Komanapalayam (no. 68)
Orathupalayam	Orathupalayam, Onakaradu,		
Kodumanal	Kodumanal, parts of Pandiannagar,		

1. The open well had an extremely high EC value, but the local people said the well was naturally salty.
2. Other wells close to no. 56 still had good quality water.
3. There was naturally salty water in some wells in the area around Kiranur, Sullivalasu and Pumandavalasu hamlets. It is therefore difficult to determine the cause of the salinity in the wells in this region but judged from the 3D map made (Fig. 13), it seems possible that the ground water could flow in this direction from the dam.
4. Salty since dam construction but increasing

It does not look likely, judged form the 3D map (fig. 13) that the pollution would spread much more, straight south or north of the dam, since these areas belong to the higher regions, unless there are fissure systems in the bed rock going in these directions from the dam.

The reasons for the observed pattern of the spreading of polluted dam water, using EC as an indicator, seemed to be:

- Elevation in relation to the dam (topography)
- Distance from the dam
- Depth to bedrock in the area
- Closeness to the LBP-canal

Aquifers are less vulnerable to anthropogenic pollution than surface water bodies, as the aquifers are naturally protected by the soil and underlying confining strata. However, as a result of a usually large storage capacity and long residence time when aquifers do become polluted contamination is persistent and difficult to reverse. It is therefore hard to say how long it would take for the contaminated aquifers around the Orathupalayam dam to recover if polluted water was no longer stored in the dam. In some wells, especially south of the dam, the EC-values were even higher than in the dam.

8. EFFECTS OF THE ORATHUPALAYAM DAM ON SOIL & CROPS –RESULTS AND DISCUSSION

The effects of using irrigation water from the Orathupalayam dam or from wells affected by the dam were studied through soil analysis and interviews.

8.1. INTERVIEWS AND OBSERVATION AT SOIL SAMPLING SITES

In-depth interviews and soil sampling were performed at six different locations around the Orathupalayam dam (Fig. 15). Interviews were also held with other farmers than with those who owned the farms where we collected the soil samples.

Karikadu is situated very close to the southern part of the Orathupalayam dam. The family members whom we interviewed had moved to the area because of the dam. Two years after the construction of the dam the family noticed a decrease in crop yield and after 6 years sorghum would not even germinate after irrigation. Four to six years after the construction of the dam a noticeable change in soil quality was noticed. At the time of the interview the farmer described the soil as porous with salt crystals. The family had an open well with a water level similar to that of the dam. They irrigated coconut trees with water from the right main canal and also had some rain-fed land where they grew sorghum. Before the salt effects had occurred they also grew cotton and other crops. The samples that were collected from the upper part of the irrigated soil could be described as red and sandy, and containing roots and weathered material. Below 15 cm, the soil was harder and had a higher frequency of weathered material. We suggest that the soil belongs to the Irigur-series.

Pudur is a small village situated southwest of the Orathupalayam dam. The family, whom we interviewed, had some irrigated land where they grew coconut and also had some rain-fed land where they grew sorghum and had grass land for the cattle. The water used for irrigation came from a bore well. One year after the construction of the dam the first change in crop yield was noticed. Before the bore well became contaminated, the family grew cotton, tobacco, onion, chilli, mulberry and banana. The farmer described the irrigated soil as porous and white. The whole sampled profile of the irrigated soil could be described as a brown loamy soil with few roots and a good water-holding capacity. We suggest that the soil belongs to the Vanapatti series. The soil was irrigated about a week before sampling. The upper part of the non-irrigated soil was brown, porous and sandy. In the lower part the soil became harder and weathered material occurred more frequently.

Thittampalayam is situated southeast of the Orathupalayam dam. The farmer grew coconut and sorghum on irrigated fields. The land was irrigated with water from an open well and it became affected three to four years ago when water stopped being released in the LBP. At the time of the sampling, the farmer said the soil had a higher viscosity than before the irrigation water was contaminated. Salt crystals were found on the soil surface. We suggest that the soil belongs to the Tulukkanur series. The irrigated soil was dark brown and rather massive. It had a high water-holding capacity and was classified as a fertile soil with good structure. No weathered material could be found in the sampled profile.

Orathupalayam village is situated north of the Orathupalayam dam. The farmer used a bore well to irrigate his coconut field from small canals. The water in the bore well became contaminated four months after the construction of the dam. The farmer said that the irrigated soil was white and porous. One year after the construction of the dam the yield of the irrigated fields started to decline and about four years ago the farmer stopped irrigating some land since the crop did not even germinate when it had been irrigated. Soil samples were collected from the land that was presently irrigated and the land that had been irrigated before and now was slowly recovering. The upper 15 cm of the irrigated soil was red/black and loamy and had a high frequency of roots. The soil was irrigated eight days before the sampling. The lower part of the soil was more aggregated and had some small stones. The non-irrigated soil was red/brown and had a high frequency of weathered material and stones below 15 cm. We suggest that both the irrigated and the non- irrigated soil belong to the Vanapatti series.

Ramalingapuram is situated northeast of the contaminated dam, close to the Noyyal River. The interviewed farmer had both irrigated coconut fields and non-irrigated fields where he mostly grew sorghum. The land was under the dam command area and water from the irrigation canals was used for irrigation for three years after the construction of the dam. Then it was noticed that the water was affected. At the time of the interview the farmer used water from an open well for irrigation. One year after the construction of the dam the farmer received good yields when using this irrigation water. Crops such as tarmaric, tobacco, ginger leaf and cotton were cultivated. About five years after the construction of the dam even sorghum could not germinate after irrigation with contaminated water. The farmer described the irrigated soil as sticky after rain and hard and porous during the dry season. The upper 15 cm of the irrigated soil was porous and brown-red with a high frequency of roots and small stones. Below 15 cm the soil was hard and contained some stones and weathered material. The land was irrigated one day before sampling. The upper part of the non-irrigated soil was porous, red-brown and sandy with a high frequency of roots and some weathered material. Below 15 cm the soil was hard, and consisted mostly of weathered material. We suggest that the soil belongs to the Irigur series both on the irrigated and non-irrigated land.

The village **Kamichipuram** is situated south east of the dam. The land was under the dam command area and the water became affected about two years after the construction of the dam. The farmer could use the canal water for two years and received good yields and the crops grown were cotton, tarmaric, tobacco and onion. Successively, the yield started to decline and by the time of the interview even the irrigated coconut trees had started to decrease in size and the tender coconuts had a somewhat salty taste. Drip irrigation from an open well was now used for the coconut trees. The irrigated soil was described as porous with a crust of salt. Soil samples were also collected from a nearby field that was not irrigated at present. This field was situated close to an irrigation canal and had been irrigated with water from the canal for some years after the construction of the dam. At the time of soil sampling the land was fallow, but should there be enough rain, the growing of crops such as sorghum, horse gram and cowpea was planned. The upper part of the irrigated soil, 0-15 cm, was red- brown, porous and sandy with a high frequency of roots. Below 15 cm the soil was hard and aggregated with $CaCO_3$- noodles. The upper 15 cm of the non-irrigated soil consisted of a red sandy material, which contained roots and small stones. Below 15 cm the soil was hard and fragile and had Ca CO_3- noodles. We suggest that both soils (irrigated and nonirrigated) belong to the Palladam series.

8.2. SOIL SAMPLES- Results and discussion

According to Table 28 & 29 none of the soils was saline, sodic or saline-sodic because the EC-values were too low. In all cases EC was below 4 dS/m. However, the majority of the soils were collected after some heavy rainfall that probably had diluted the soil water to some extent. The EC-values of the irrigation water were invariably much higher than the EC values of the soil. The soil pH-values were high and ranged between 8.5 and 9. Mg^{2+} was mostly the dominating cation. The concentration was high compared with the concentration of Ca^{2+}. Unfortunately, very few samples were analysed for the CO_3^{2-}, HCO_3^- and Cl^- content, but these few samples showed that the soil did not contain any large amounts of either CO_3^{2-} or HCO_3^-.The Cl^- content was mostly higher in the irrigated soils compared with the non-irrigated soils. As was earlier mentioned, the analyses of CO_3^{2-}, HCO_3^- and Cl^- were rather difficult and therefore these results should not be regarded as absolute values.

Table 28. Surface soil samples, 0-15 cm I= Irrigated, NI= Non irrigated, EC* = Irrigation water

Hamlet	I/NI	pH	EC dS/m	EC* dS/m	Ca $cmol_c/kg$	Mg $cmol_c/kg$	Na $cmol_c/kg$	K $cmol_c/kg$	CO_3 $cmol_c/kg$	HCO_3 $cmol_c/kg$	Cl $comi_c/kg$
Karikadu	I	8.97	0.09	7.46	2.50	6.00	0.92	0.40			
Karikadu	I	9.04	0.16	7.46	1.50	5.70	1.17	0.33			
Pudur	I	8.25	2.68	12.57	9.25	29.70	11.74	0.88	0.0	0.5	4.9
Pudur	NI	8.73	0.09	12.57	3.75	9.75	12.07	0.42	0.0	1.0	1.0
Thittampalayam	I	8.92	0.51	5.48	4.50	43.65	3.12	0.71			
Orathupalayam	I	9.46	0.72	8.6	3.00	7.95	5.00	0.47			
Orathupalayam	NI	9.20	0.18	8.6	3.75	4.20	1.57	0.85			
Ramalingapuram	I	9.07	0.13	7.79	3.75	13.50	0.97	0.51			
Ramalingapuram	NI	8.57	0.08	7.79	4.50	6.30	0.89	0.40			
Kamachipuram	I	8.59	0.23	12.56	4.50	22.20	1.22	0.37	0.0	1.0	1.0
Kamachipuram	NI	8.61	0.09	12.56	4.00	4.05	11.09	0.37	0.0	1.1	0.7

Table 29. Subsurface soil samples, 15-30 cm I=Irrigated, NI=Non irrigated, EC*= Irrigation water

Hamlet	I/NI	pH	EC dS/m	EC* dS/m	Ca $cmol_c/kg$	Mg $cmol_c/kg$	Na $cmol_c/kg$	K $cmol_c/kg$	CO3 $cmol_c/kg$	HCO_3 $cmol_c/kg$	Cl $comi_c/kg$
Karikadu	I	8.74	0.22	7.46	2.25	6.15	2.02	0.52			
Karikadu	I	8.33	0.44	7.46	2.75	6.00	12.83	0.44			
Pudur	I	8.29	2.29	12.57	8.50	26.10	12.17	0.69	0.0	0.9	3.9
Pudur	NI	8.74	0.09	12.57	2.50	14.40	0.74	0.30	0.0	1.0	1.4
Thittampalayam	I	8.68	0.78	5.48	3.50	32.70	3.59	0.58	0.2	1.2	1.5
Orathupalayam	I	9.09	0.91	8.6	3.00	18.15	2.93	0.40			
Orathupalayam	NI	9.13	0.15	8.6	4.00	2.40	1.52	0.56			
Ramalingapuram	I	8.97	0.13	7.79	6.75	14.25	0.82	0.39			
Ramalingapuram	NI	8.79	0.10	7.79	5.25	15.90	0.89	0.37	0.0	1.1	1.2
Kamachipuram	I	8.57	0.33	12.56	3.50	19.50	1.52	0.37	0.0	1.0	1.2
Kamachipuram	NI	8.66	0.12	12.56	4.50	27.60	11.63	0.37	0.4	0.8	1.6

EC- values

The irrigated soils had higher EC-values than the non-irrigated soils. The soil sample that was collected at Pudur had a very high value compared with the other samples. The reason for the high values was probably that the samples were collected very close to the irrigation channel and thereby they were not fully representative. Therefore, they were not included in the calculations shown in Fig. 38 and 39.

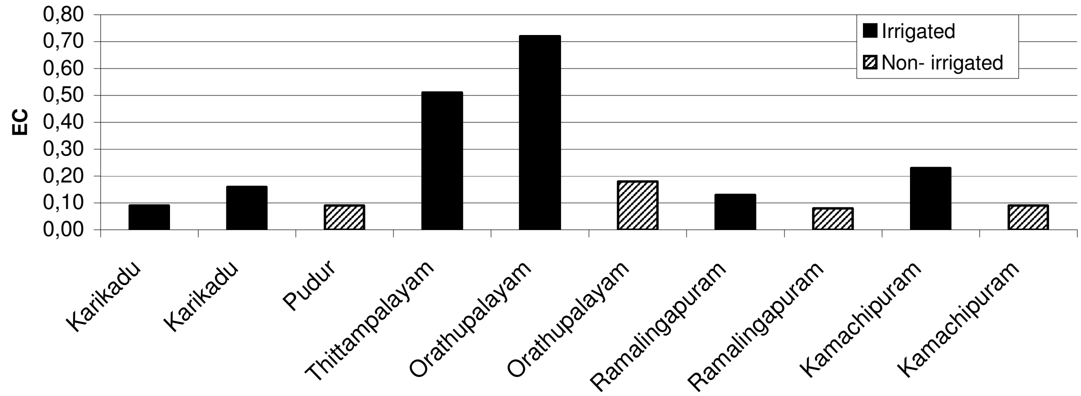

Figure 38. Description of EC-values in topsoils, 0-15 cm

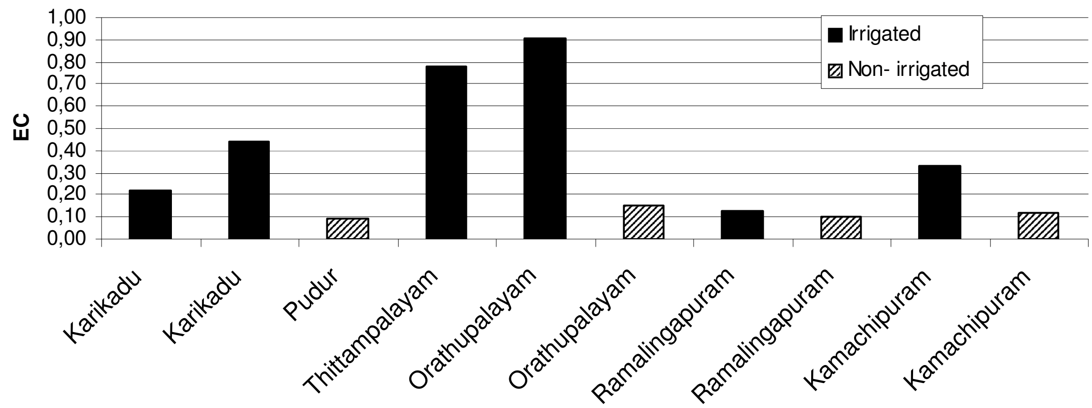

Figure 39. Description of EC-values in subsoils, 15-30 cm

Correlations

The most strongly significant linear relationships were found for EC versus the Na^+ content (Fig. 40). Two sampling spots which had deviating values were omitted: Concerning the upper horizon the omitted points represented the non-irrigated fields at Pudur and Kamachipuram and concerning the lower horizon they represented one of the irrigated spots at Karikadu and the non-irrigated field at Kamachipuram. The excluded values are marked with a ring in Figures 40a and 40b. The coefficient of determination was 0.98 in the upper horizon and 0.95 in the lower horizon. When comparing the EC-value of the irrigation water and the cation contents of the soil, no direct correlation could be found, but since the soil samples are very few it is difficult to comment on this.

a) b)

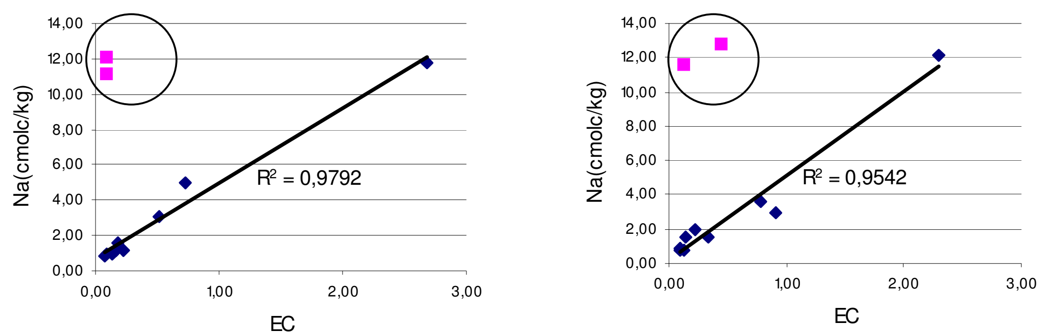

Figure 40. a) Correlation of Na and EC, 0-15 cm, b) Correlation of Na and EC, 15-30 cm

Cations and ESP

Depending on the locations of the soil samples, the extractable cations varied a lot. When looking only at the cation contents, the highest values were found at the locations Pudur, Thittampalayam and Kamachipuram (Table 30). Common features for all three locations were that the soils were brown and loamy, they had a finer texture than the other soils and probably also a higher CEC. The ESP values of the irrigated soils with a finer texture tended to be rather low. This was rather noticeable at Thittampalayam and Kamachipuram.

Table 30. Total cations and ESP, 0-15 cm and 15-30 cm, I=Irrigated, NI=Non-irrigated

Hamlet	I/NI	Cations 0-15 cm cmol$_c$/kg	ESP 0-15 cm (%)	Cations 15-30 cm cmol$_c$/kg	ESP 15-30 cm (%)
Karikadu	I	9.8	9.41	10.9	18.48
Karikadu	I	8.7	13.48	22.0	58.25
Pudur	I	51.6	22.76	47.5	25.65
Pudur	NI	26.0	46.43	17.9	4.12
Thittampalayam	I	52.0	6.00	40.4	8.89
Orathupalayam	I	16.4	30.44	24.5	11.98
Orathupalayam	NI	10.4	15.10	8.5	17.93
Ramalingapuram	I	18.7	5.16	22.2	3.67
Ramalingapuram	NI	12.1	7.37	22.4	3.98
Kamachipuram	I	28.3	4.30	24.9	6.11
Kamachipuram	NI	19.5	56.85	44.1	26.38

8.3. OVERALL CONCLUSIONS AND DISCUSSION ON SOIL AND CROPS

Farmers who had land close to the dam said that they could use the water for irrigation during the first year after the dam construction. Some farmers could also use their land after the second year, but then the yield started to decrease. Moreover, they said that the seeds did not germinate any more when they continued to use the water for irrigation.

Our collected soil samples could only give an indication of the situation around the dam. The crops grown in the area close to the dam were mostly coconut trees and sorghum. The coconut trees were usually irrigated and the sorghum crops were rain-fed. Just after the dam was built the farmers managed to grow many different crops, such as cotton, tarmaric, onion and sugarcane (Fig. 41) but some years after the construction of the dam the negative effects started to become obvious, and were noticed as inhibited germination and growth as well as a deterioration of the soil structure. After some years, not even the rather tolerant sorghum could germinate after irrigation with contaminated water. The soil became white, porous and fragile.

The farmers who were benefited by the LBP-canal did not observe the negative effects as early as the farmers who lived closer to the dam. However, the LBP canal has now been dry for some years, a situation which has led to a spreading of the pollutants to these areas as well.

For some of the farmers who had previously irrigated their land with contaminated water and then stopped the irrigation, a positive change in the soil quality was indicated after quite many years of fallow. By the time of our interviews the dominating crops grown by the affected farmers were coconut and sorghum.

TIME	**Before the dam**	**Construction of the dam** **1992**	**Present**
PLANTS	Mostly rain fed crops, except for the areas benefited by the LBP- canal	Tarmaric Cotton Onion Tobacco Rice Sugarcane Coconuts Sorghum	Sorgum Coconuts

Figure 41. Schematic description of the change in crops in the investigated area.

9. EFFECTS OF THE ORATHUPALAYAM DAM ON PEOPLE –RESULTS AND DISCUSSION

The release of more or less untreated effluents from the textile industries in Tiruppur and the stagnation of the effluents in the Orathupalayam dam had resulted in a terrible situation for the people who lived close to the dam. Through the in-depth interviews, we learned how people were affected, what help they had received and what they thought of the future for people in general and for different groups of people.

9.1. STRUGGLE FOR WATER

In each revenue village in the study area there were a number of hamlets affected by the dam, and they had to receive, bring or buy drinking water from other places (Table 31). Pollution and scarce water supply in the upper regions created a critical and complex water situation. Many people went several kilometres by bike in order to collect water for drinking and in some cases also for washing clothes and bathing (personal hygiene). At some locations the government had arranged pipelines from wells with good quality water but that was not the case for all villages and at the time of the study the wells from which the pipelines were fed did not have sufficient water for all hamlets they were meant to support. For example, the pipelines made from two BWs in Maravapalayam close to the LBP (no. 58 and another one close by), did not bring sufficient amounts of water.

Table 31. Source of drinking water, a summary

Revenue village	Source of drinking water for hamlets affected by the Orathupalayam dam
Tammareddipm	Affected hamlets either brought water from BW no. 2 in Rengappanpm in case of scarcity which was the case at the time of the interviews. Before that they received water through a pipeline from BW 58 close to the LBP canal in Maravapm. Some people also brought water from a BW in Sellappanpm.
Maravapalayam	Some people in the affected hamlets bought water from Chennimalay. A couple of years ago they used to receive water from the BW 58. Many people had to buy water in this village, e.g. Semmankulipm., Karikadu and Kamachipuram.
Kiranur	Affected hamlets bring water from wells with good water within Kiranur
Ellaigramman	Affected people in the village bring water from wells with good water within Ellaigramman or receive water through a pipeline from Kumarapm as in Ramalingapuram hamlet.
Orathupalayam	Some affected hamlets used to receive water through the pipeline from Kumarapm but because of scarcity many people now brought water from the common BW in Pandiannagar (no. 21) or from Thippanpm. A new BW had been drilled in Onakaradu (no. 34) but the water was soon found to have a salty taste and could not be used for drinking.
Kodumanal	Some affected hamlets brought water from BWs with good water within the village, i.e. from the Pandiannagar common well or Kuppanpm.

Figure 42. Women washing in Noyyal river close to the Orathupalayam barrier

People in many hamlets had to buy water and some people bought water for all purposes whereas most people could not afford buying water for washing and bathing. As always, the poorest people were the ones most severely affected. Women could be seen washing in the river water (Fig. 42) and even in the dam. There was no other way, they said, since they could not bring enough water from other places for all purposes and could not afford buying water.

People complained that it was very difficult to wash clothes in the polluted water since the soap did not lather and dirt was not removed.

Figure 43. Men fetching water in Maravapm.

Many new wells had been drilled in the upper regions to reach good water for the affected people but some wells did not supply sufficient amounts of water and others reached bad water, probably due to contamination from the dam. Many bore wells with good water in the upper regions were drying out in October 2003.

Some people in the upper regions even had to fetch water from wells close to the dam for washing purposes e.g. in Ganapathypalayam they had a pipeline from Thangamman Kovil which carried high EC-water. For the people living in the affected areas around the Orathupalayam dam every day was a struggle for receiving fresh water.

9.2. HEALTH

All people interviewed in the in-depth interviews said their skin was itching after taking bath in their well water (or in dam or river water) and that they got allergic diseases (Fig. 44). Their skin and hair got sticky and some people also said they had lost hair from washing in the polluted water. They stopped drinking the water as soon as they got diarrhoea.

Everybody expressed their worries about the health effects of being in contact with the water. They had not received any information about the analyses made on the water in their area and knew nothing of the health effects other than what they had experienced themselves.


Figure 44. Picture of woman with skin irritation

9.3. STRUGGLE FOR COMPENSATION

The only help that the affected people, farmers and non-farmers, had received from the government was the construction of some new bore wells and at some places new pipelines. People who owned land that became inundated when water accumulated in the dam received some money from the government. One farmer mentioned that he received 3600 rupees per acre (1 Rupee = 0.018 Euro). A man who had had a house on land which was now under water, did not receive any compensation because he did not own the land on where his house was standing. The land belonged to the government.

In order to receive compensation for lost land and water resources some people had individually filed cases. Others had gone together in the hamlet and filed a common case or were planning to file a case. People, who did not own land, had only complained to the

VAOs (Village Administrative Offices) or the district Collector in Erode. No-one had heard anything or received any compensation as of October 2003, even if people had filed cases two years earlier.

An investigation had been made by farmers residing around Orathupalayam dam and close to Noyyal river up- and downstream of the dam. They went together and collected information about how much land that was affected as a consequence of the contaminated water (Gounder, 2003).

Governmental investigations had also been done by the VAOs in order to describe the quality of the wells in the area. During November 2003 a meeting was held where all the VAOs both on the southern and northern side of the dam came together and discussed the situation. Governmental people from the Collector's office in Erode had visited some of the places that were affected together with a judge. According to the farmers, the judge's aim was to review the situation and decide about compensation. During the autumn of 2003 a rather extensive investigation was also made by Anna University, Chennai, on the initiative of the Indian government in order to describe the situation around the dam. No information could be retrieved about the results of the investigations.

9.4. WORRIES ABOUT THE FUTURE

Most of the interviewed people felt that if nothing happened in the near future they would have to abandon the area. When we asked what help people would like to have, most of the people mentioned economic compensation and clean water. Suggestions of what could be done to change the situation were to release or clean the water in the dam and stop releasing contaminated effluent water from the industries in and around Tiruppur.

People were worried about the whole situation partly because of their lack of knowledge. They did not know exactly what the water they had been using or still used contained, neither if they would receive any economic compensation for their lost land. For some people, compensation would mean that they would have the possibility to move while others saw the compensation as chance to stay. Since they did not know whether the water in the dam would be released or be kept in the dam, they did not know if the pollution would contaminate the remaining new wells that still could be used. The people felt they lived in a situation where the future was totally uncertain and that they suffered of something they had absolutely no responsibility for.

A rather common worry among the affected people was that the government officials were corrupted. Complaints were made that the control organ PCB worked for the interests of the industries instead of protecting the environment and the people. Other complaints were that the industries did not follow the rules for releasing effluent water and that they still let out untreated effluents.

9.5. MIGRATION

At the time of the construction of the dam the feelings of people in the area around Orathupalayam were very optimistic. People looked forward to receive a better farming situation as a result of the dam and people moved to the area from nearby villages. But very shortly after the construction, the negative effects started to become evident. The immigration of people to the area changed to a migration from the area. As a consequence of the pollution many people decided to move to work in textile industries or other industries in the surrounding areas, e.g. tanneries, rice mills and coconut oil factories in Tiruppur, Chennimalay and Kangayam. For many people, there was no other option but to stay. Even if they wanted to sell their land they were not able to do so. Many had also started to commute to work in industries.

9.6. FARMERS

Farmers were particularly affected by the pollution through irrigation with dam water or contaminated well water. The only constraint before the construction of the reservoir was the availability of water. Effects on soil and crops were discussed in section 7. The farmers could no longer exist on farming and could only grow rain-fed crops in fields where they had not used polluted water for irrigation. Many had been forced to change profession and started to commute to nearby cities to work in industries. We were told by many farmers who had walked in the fields while irrigating with polluted water that they had got skin irritations on their legs. One man also showed us the skin irritations he had. Many farmers had animals that were also affected by the contaminated water.

The farmers in the affected hamlets said that they had to decrease the number of animals. The reason for this was that it was not possible to grow enough feed for them and/or the farmers had to buy water or collect water far away from the farm. Some farmers also explained that they had to change animal species, e.g. cattle to goats.

Some farmers still let the animals drink the contaminated water, which was sometimes mixed with good quality water, but in some cases the farmers complained that the animals often had diarrhoea. They also had a decrease in milk production or produced milk with a salty taste. Some farmers told us that a higher frequency of pregnant cows got stillborn calves. The appearance of the animals had also changed. The goats, for example, looked very unhealthy since they had started to loose their skin. The goats also gave birth to comparatively small kids and had colds more frequently than before the contamination. Some farmers also claimed that the animals would become sterile if they were to drink the water. One farmer, who lived close to the dam and still let the animals drink the contaminated water, explained that the animals received some medicine to be able to drink the water; unfortunately the name of the medicine was not known to him. Those farmers that still gave the contaminated water to the animals and had not yet seen any negative effects, as yet expressed their worries about what would happen to the animals in the near future.

9.7. AGRICULTURAL LABOURERS

For people who did not own land but worked for farmers as labourers, the pollution had resulted in unemployment. On the farms where they used to work, not as many labourers were needed anymore since less land was cultivated and many fields had to be left as fallow or gave poor yields. This was a reality in the village of Ramalingapuram Colony where the grownup members of the 40 families almost all worked or had been working as agricultural labourers. The water scarcity due to rain failure during the recent years, and no water in the LBP canal, had further added to the difficult situation.

Figure 45. Villagers gathered around the bore well in Ramalingapuram Colony

The bore well in the village (Fig. 45) was affected by the contamination and could not be used for drinking. Instead the villagers had to bike kilometres away to fetch water. They used the bore well for washing and bathing but it was not sufficient and they therefore had to go to the river downstream of the dam to wash clothes. A lady showed the result of being in contact with the contaminated water too much. She had very visible skin irritations.

The villagers explained that they had gone to the VAO in Ramalingapuram and to the Collector in Erode in order to raise their complaints but so far nothing had happened and they felt that no one listened to them.

9.8. FISHERMEN -Fish and fishing in the Orathupalayam dam

We interviewed two men who were fishing in the Orathupalayam dam. They told us that some people living close to the Orathupalayam dam still use the dam for fishing. At the time of the interview, only one type of fish (Tilapia) could be caught in the dam and that fish did not usually weigh more than 25 g. One of the men, who had moved to the dam to earn a living as a fisherman, told us that he caught 30-40 kg of fish daily just after the dam was constructed but now the daily catch was only 3-4 kg. A man in Kodumanal told us that fishermen lost the hair on their hands from fishing in the dam.

The fish was sold to Erode and Chennimalai and was also used for their own consumption. Before leaving India we were informed that a study was going to be carried out in order to investigate the quality of the fish. The fish may have negative health effects.

10. VISITS TO TEXTILE INDUSTRIES IN TIRUPPUR

To get a better picture of the reasons for the contamination in the area around the Orathupalayam dam we decided to visit two textile industries, one in the central part of the town Tiruppur and the other just outside the town. The people at the industry inside Tiruppur were aware of and had accepted our visit, whereas the people at the industry outside the town were not aware of our visit in advance. As a result, we could not, watch how the actual dyeing was performed in the industry outside the town. We could only talk to the owners and look at their cleaning system for the effluent water.

The industry just outside Tiruppur was a complete export company with its customers mainly in USA, Canada and Europe. The factory was 15 years old and had totally 1000 employees, 250 of whom worked with the dyeing process. The water consumption in the factory was about 400 000 L per day and the water was brought with lorries from farmers about 20 km away from the factory. The effluent amount was as a maximum 200 000 L per day and was first treated in the treatment plant of the factory before being released into the Noyyal river. The owners could envisage that they might reuse the water in the future but for the moment the effluent water released was not clean enough for reuse, although some of the effluent water was presently used as irrigation water for crops such as eucalyptus, coconut and casuarinas. The factory belonged to the certification system ISO 9002. The rules for belonging to this system were, for example, that the number of working hours should be 8, and that only standard dyes should be used in the process. A local person from the Pollution Control Board (PCB) was responsible for controlling that the certification rules were followed. The import countries that bought the products from the industry did not control that the certification rules were followed, only the PCB performed the control.

The other factory we visited was situated just on the banks of the river Noyyal, in the centre of Tiruppur. The industry worked through an Indian agent, so to whom their products were sold was not known to the company. Bleaching and dyeing were mainly performed in the industry. The starting material was natural white cotton. Before dyeing, bleaching of all cotton material with H_2O_2 had to be performed. After the bleaching the dyes were added. The dyes were so-called bifunctional dyes. After dyeing, the colours were fixed with NaCl and Na_2CO_3. pH should be above 12 and the temperature 60°C. The company had rather recently invested in new machines that were more efficient concerning both the use of dyes and water. They were certified according to the system ISO 9001/9002. To be able to run the industry steam was used as an energy source. The water used for the production was brought with lorries from farmers about 20 km from the industry. Every day about 200 000 L of effluent water were produced. The industry had its own treatment plant and also a laboratory where they controlled the quality of the effluent water. When asked why they did not use natural dyes, the answer was that it was too expensive and that it did not work to dye dark colours with natural dyes. The industry is planning to start using reverse osmosis as a new treatment method for the effluent water. However, the economy for new investments is not so good since world prices for textiles have decreased. The general comment was that Azo dyes were prohibited and were not used any more.

11. SUMMARY OF THE MAIN RESULTS

The construction of the Orathupalayam dam in combination with the increase of textile industries in Tiruppur has resulted in devastating consequences for the people and the environment around the dam. The main results of the study are summarized below:

- Water in the reservoir was fed to the groundwater, thus recharging the surrounding aquifers, both unconfined and confined. The water level in wells close to the reservoir, especially downstream the barrier, rose 9-15 m.
- A pattern could be noticed where high EC-values were associated with the dam. The pollution had spread all around the dam but more so in the eastern and south-eastern directions (> 4 km). In many wells the EC-values were higher than in the dam.
- It took less than a year for wells close the dam to become affected and more wells became contaminated depending on 1) distance from the dam, 2) elevation to the dam, 3) depth to the bedrock and 4) closeness to the LBP-canal. For most of the affected wells, people said the water quality was deteriorating each year.
- Wells close to the LBP took longer time to become affected and some wells only changed their water quality when water was no longer released into the canal.
- A pattern was noticed where high concentrations of Cl^- and the cations analysed (except for K^+) were associated with the dam. The relative concentration of Na^+ was higher in dam- and river water compared with well water (except for wells in direct contact with the dam water).
- High $Ca^{2+}$and Mg^{2+} concentrations in the wells could be due to a cation exchange with Na^+ and therefore be an indirect effect of the spreading of pollutants.
- Almost all open wells and many of the bore wells were unsuitable for drinking purposes. Many wells, especially the open wells close to the reservoir, were also unsuitable for washing and bathing. People experienced itching and skin irritations and some had lost their hair after washing their heads. Soap did not lather due to the high water hardness.
- Pollution and scarce water supply in the upper regions created a critical and complex water situation where people had to fetch water many kilometres away.
- The poorest people were the ones most severely affected.
- The salinity in the OWs and some BWs, except the ones located close to the LBP canal, was very high and the water should not be used for irrigation. The dam and river water samples had high SAR values and had EC- values between 6-7 dS/m and should not be used for irrigation either.
- Soils that had been irrigated with contaminated water became impossible to cultivate. The structure of the soil changed and became fragile and porous with salt crystals. The only crop that could possibly grow in the soil was coconut.
- Land that was left as fallow after it had been irrigated with contaminated water was found to slowly recover and become possible to cultivate again after some years.
- Farmers had to decrease the number of animals and also change the type of animals, e.g. from cows to goats. Animals that still drank the contaminated water had poor health: mainly diarrhoea and an increased number of still-born calves.
- Agricultural labourers lost their working opportunities due to the pollution.
- Some people still fished in the dam, although the daily catch was very small.
- Many people had moved from the affected hamlets and started to work in textile industries, coconut mills and tanneries in nearby cities.

12. ACTIONS NEEDED AND SUGGESTIONS FOR THE FUTURE

As of November 2003 the local people paid a large part of the externalities of the polluting activities of the textile industries in terms of lost agricultural land, water resources, fishing and working opportunities. These problems have been caused by the high salt concentration in the effluents but it is unclear whether other substances have caused or might cause harmful effects to the environment, people and animals.

12.1. ACTIONS NEEDED FOR THE AFFECTED PEOPLE

12.1.1. Immediate actions

- The government (Tamil Nadu Water Supply and Drainage Board, TNWSDB) need to provide **free and safe drinking water** for all affected people.
- No one should have to use either the dam water or river water upstream or some distance downstream of the Orathupalayam dam or the affected wells for washing and bathing.
- Cattle and goats also need safe drinking water.
- **Compensation** to farmers for lost agricultural land: the areal extent of affected land has already been estimated by a farmer's organisation. Other affected people, who should have a possibility to receive compensation are:
    - Agricultural labourers for their lost working opportunities
    - Fishermen, fishing in the Noyyal river and the dam
    - People who have been forced to move from the contaminated area
- Governmental institutions need to listen to the affected people and give them **information** about what is happening in the process of compensation and provision of safe drinking water.
- Connections between diseases and the polluted water need to be investigated more thoroughly and information about this has to reach the affected people.
- Local people need to get updated information about the quality of their water.

12.1.2. Medium term actions

- A better **funtioning of the Effluent Treatment Plants**, CETPs and IETPs, including treatment of TDS (Total Dissolved Solids).
- A **plan for the future** of the Orathupalayam Dam. The water cannot be left standing as it does today. The pollution situation needs to be investigated more in detail in order to decide the best possible solution for how to treat the water. Inorganic and organic chemicals in the polluted water and sediments should be looked for and included in a monitoring programme. It needs to be assessed what substances in the effluents are water soluble and thus could be transported and which ones are more likely to stay in the sediments close to the point of discharge. Sediments may have to be removed and cleaned. Industries should fund the cleaning up of the Orathupalayam Dam.
- People should have the opportunity to receive free **health care**. A health programme could be created that monitors the health of the affected people and notices if any specific complaints occur in the area.
- **Organize all affected people**- not only the farmers but also the landless people. This is needed to put more pressure on and have a dialogue with governmental agencies, industries and importers. A problem with this might be that people are afraid of organising themselves since the industrial activities are a major source of employment and income. Today, quite many people in the area around the Orathupalayam dam are dependent on the textile industry for their income and are therefore afraid of losing their jobs because of protests against the industries. This threat must be prevented by governmental agencies.
- **Rain water harvesting** could be started in the area around the dam in order to utilise more of the highly variable rainfall.

12.2. SUGGESTIONS

12.2.1. Regional and National Level

Compensation needs to be given to people affected by the industries both in the past and at present. Control of the pollution and better management of the limited water resources is needed for the future.

Suggestions for Bleaching and Dyeing Industries

- Decrease the discharge of TDS by:
    - Adding **desalinisation devices** such as reverse osmosis to CETPs and IETPs.
    - **Clean technology/production**.
        - Use less water, i.e. apply a water saving technology, implying a recycling of water/effluents.
        - Use less chemicals.
        - Use more environmentally friendly chemicals e.g. natural dyes.
- Proper handling and adequate **financial investment** for the above.
- The industries need to organise themselves and start to work out a plan for giving compensation to affected people downstream and to fund working CETPs.
- Better operations of CETPs, which is a good treatment concept for clusters of small enterprises. Industries should pay in relation to their size, e.g. how much effluents they release or the turnover of the company.
- **Research** on cleaner production and treatment methods for textile industries.
- Research on environmental effects of the chemicals used in all production steps.

Suggestions for the Pollution Control Board (PCB) and the PWD

- **Economic instruments** to encourage reduced water consumption by the industries and reduced discharge of effluents. It should be more expensive to buy than to recycle water. The unsustainable practice of transporting groundwater to the industries and the ensuing release of effluents into the Noyyal river needs to be changed.
- **Administrative capacity** to the PCB. Resources are needed for enforcement of the effluent water quality standards in the environmental legislation. The PCB needs to be more consistent in its restrictions and have a stricter policy.
- Effluent standards need to be set not only at the point of discharge (in effluents), as today, but also for natural waters, i.e. the Noyyal river. The pollution load that can be released from all the industries must be less than the **carrying capacity** of the Noyyal river. The cumulative effects due to clusters of industries can thereby be handled.
- Integrated Water and Land Resources Management (**IWLRM**) for the whole of Noyyal River Basin.
    - Upstream/Downstream thinking. Activities upstream affect water quality and quantity and also sediment and soil quality downstream.
    - Cooperation between different governmental agencies in the water sector, i.e. agencies for drinking water supply, agriculture and irrigation, aquatic ecosystems, fisheries, and industries. The Water Resources organisation, TNWSDB and PCB need to work together and have a better dialogue with industries and also exchange information and data with universities and research stations.
    - New institutions may be needed to integrate and negotiate between the different water users on a basin (watershed) level. Flows in the basin, users and impacts need to be identified, shared and compromised on by all the stakeholders.
    - Empowerment of local people to participate in the water and land resources management.
    - Continuous publication of reliable data on water quality and quantity in the Noyyal river basin needs to be done. The data should be kept in a computer database.
    - Environmental flows both in terms of quantity and quality need to be assessed for the Noyyal river and its tributaries.
    - Environmental Impact Assessments (EIA) have to be made for future development plans of the Noyyal River Basin.
- Incentives to increase **water harvesting** in the villages around the dam.

12.2.2. International Level

A large part of the textiles in the dyeing and bleaching factories is exported to Europe and North America. It is cheaper to produce, bleach and dye clothes in India where the labour cost is much less and the environmental laws are weaker. However, through their imports the importing countries are exporting the huge environmental problems involved in this trade. The foreign buyers and consumers should therefore take responsibility for the unsustainable impact of the textile industry.

- **Foreign buyers** need to put pressure on the Tiruppur textile producers for cleaner production and also be willing to pay for necessary research and investment.
- **Awareness** should be raised among consumers concerning the effects of textile industries on environment and people. If a demand for "clean clothes" would be raised this could put pressure on both importers and producers for cleaner production.

In order to make foreign buyers from different countries more willing to pay for cleaner production, international laws are needed to overcome competitive advantages.

- **Environmental governance and laws** for industrial water pollution need to be **harmonised** between countries.
- A **Multilateral Environmental Agreement** (MEA) is needed in the trade of textiles (clothes). International laws for cleaner production including enforcement of working effluent treatment plants, recycling, use of least harmful chemicals and effluents being below the maximum concentration standards for receiving waters.
- An effective international **compliance system** is needed for the enforcement of the MEA.
- **Trade penalties** might be needed to enforce the international environmental laws.

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APPENDIX 1

Maps with numbers showing water sample locations, one for bore wells (Fig. 1) and one for open wells (Fig. 2) with corresponding location descriptions (Table 1).

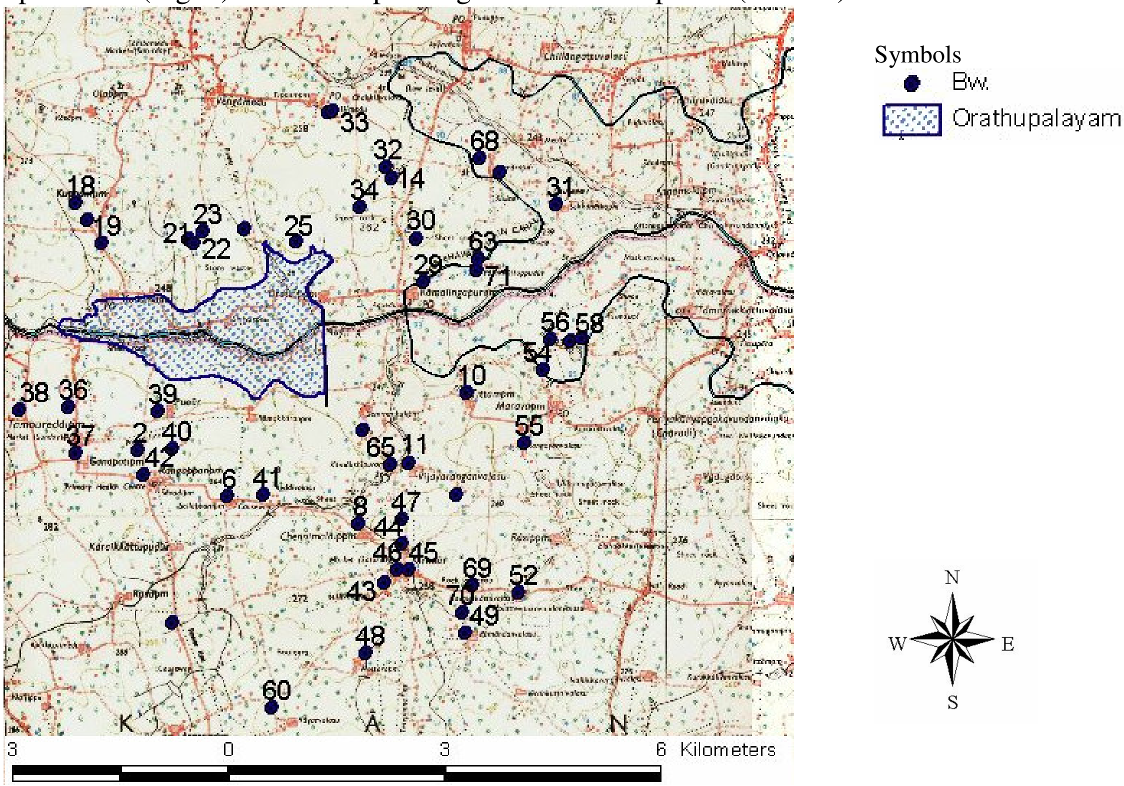


Figure 1. Map with bore wells with corresponding numbers

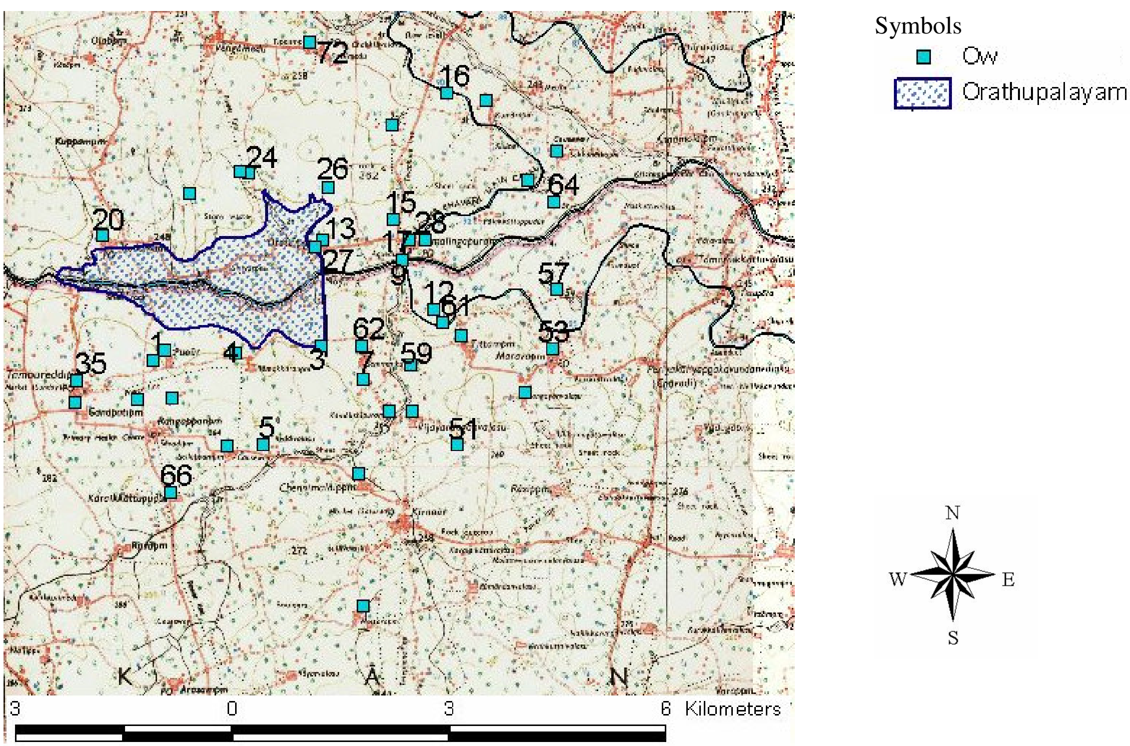


Figure 2. Map with open wells with corresponding numbers

Table 1. Location description of each sampling number

No	OW/BW	Location		No	OW/BW	Location
1	Ow	Pudur, PW		37	Bw	Ganapathypalayam, CW
2	Bw	Rengappanpalayam, CW		38	Bw	Ganapathypalayam, CW
3	Ow	Karikadu, PW		39	Bw	Pudur, CW
4	Ow	Ramakkanpalayam, PW		40	Bw	Rengappanpalayam, PW
5	Ow	Reddivalasu, CW		41	Bw	Reddivalasu, PW
6	Bw	Sellappanpalayam, CW		42	Bw	Savadipalayam, CW
7	Ow	Kamachipuram, CW		43	Bw	Sullivalasu, CW
8	Bw	Chennimalaypalayam, CW		44	Bw	Kiranur, CW
9	Ow	By Noyyal and LBP, PW		45	Bw	South-east of Kiranur, CW
10	Bw	Thittampalayam, CW		46	Bw	South of Kiranur, CW
11	Bw	Vingerrengavalasu, CW		47	Bw	South of Kamacipuram Colony, PW
12	Ow	South of Noyyal. east of LBP, PW		48	Bw	Mottarapalayam, CW
13	Ow	Orathupalayam, CW		49	Bw	Pumandanvalasu, CW
14	Bw	Velaikattuthotam, PW		50	Bw	Pumandanvalasu, CW, no GPS point
15	Ow	Ramalingapuram(west LBP), PW		51	Ow	Vakkanang kattu thottam, PW
16	Ow	Kosuvankatuthotam, PW		52	Bw	Kovalakattuvalasu, CW
17	Ow	Ramalingapuram(east LBP), CW		53	Ow	Maravapalayam, CW
18	Bw	Kuppanpalayam, CW		54	Bw	Maravapalayam, CW
19	Bw	Kuppanpalayam, CW		55	Bw	Rangajevalasu, CW
20	Ow	Kodumanal, CW		56	Bw	Meenaksithottam, PW
21	Bw	Pandiannagar, CW		57	Ow	Meenaksithottam, PW
22	Bw	Pandiannagar, PW		58	Bw	Meenaksithottam, CW
23	Bw	Pandiannagar- weavery, PW		59	Ow	B/w Thittampm & Vingerrengavalasu, PW
24	Ow	b/w Kodumanal and Orathupm, PW		60	Bw	Rayavalasu, CW
25	Bw	Orathupalayam, on the hill, PW		61	Ow	Thittampalayam, PW
26	OW to BW	West of Orathupalayam, OW-BW		62	Ow	Semmankulipalayam, PW
27	Ow	Orathupalayam, close to barrier,PW		63	Bw	Palakatpudur, CW
28	Ow	East of LBP, north of Noyyal, PW		64	Ow	Pallanthotam, PW
29	Bw	North of number 11, PW		65	Bw	Kamachipuram Colony, CW
30	Bw	Ramalingapuram colony, CW		66	Ow	Karaikattupudur, CW
31	Bw	Sakkanathapalayam, CW		67	Bw	West of Orathupalayam, PW, No GPS point
32	Bw	B/w Thippanpm and Orathupm,CW		68	Bw	Komanapalayam, CW
33	Bw	Thippanpalayam, CW		69	Bw	Pumandanvalasu, CW
34	Bw	Onakaradu, CW		70	Bw	Pumandanvalasu, CW
35	Ow	Thammareddipalayam Pudur, CW		71	Bw	Palakatpudur, CW
36	Bw	Pallakadu, CW		72	Ow	Thippanpalayam, CW

CW: Common well
PW: Private well

APPENDIX 2

Table 1. Results from chemical analyses of water samples in $mmol_c/l$

	BW/ OW	pH	EC (dS/m)	TDS (mg/l)	SAR	Cl^- ($mmol_c/l$*)	SO_4^{2-} ($mmol_c/l$)	Ca^{2+} ($mmol_c/l$)	Mg^{2+} ($mmol_c/l$)	Na^+ ($mmol_c/l$)	K^+ ($mmol_c/l$)	CO_3^{2-} ($mmol_c/l$)	HCO_3^- ($mmol_c/l$)
R.I 02 Oct & 03 Oct 2003													
1	Ow	7.96	12.57	8057.4	6.58	114.6	2.33	28.64	58.82	43.53	0.87	0.00	6.00
2	Bw	8.65	0.91	583.3	0.90	2.8	0.96	0.72	6.16	1.68	0.13	0.80	5.80
3	Ow	7.85	7.46	4781.9	11.32	64.8	1.45	12.24	14.37	41.30	0.24	0.00	4.80
4	Ow	8.06	17.04	10922.6	5.07	176.6	2.16	53.52	88.97	42.78	0.48	0.80	4.40
5	Ow	8.36	8.66	5551.1	9.95	72	2.44	11.04	28.58	44.28	1.00	0.40	6.20
6	Bw	8.52	1.23	788.4	1.44	5.8	0.99	2.48	4.82	2.75	0.24	1.20	4.80
7	Ow	7.81	12.56	8051.0	4.79	145.6	1.27	51.20	39.63	32.31	0.74	0.00	5.20
8	Bw	8.14	4.33	2775.5	12.86	33.2	1.79	3.44	7.26	29.76	0.36	0.80	8.40
9	Ow	7.83	7.67	4916.5	7.18	66.8	1.99	20.32	20.21	32.31	0.24	0.00	7.60
10	Bw	7.97	4.44	2846.0	3.69	34.8	1.60	13.28	12.95	13.37	0.13	0.00	5.20
11	Bw	7.55	9.5	6089.5	12.47	80	2.42	7.04	27.95	52.17	3.95	0.00	10.60
12	Ow	8.82	1.08	692.3	4.17	4.2	0.93	1.28	2.05	5.38	0.01	0.80	7.00
13	Ow	7.78	8.96	5743.4	12.85	87	1.61	17.60	8.68	46.58	3.76	0.40	7.60
14	Bw	8.7	1.16	743.6	1.81	4	0.94	1.44	4.89	3.23	0.36	0.80	7.80
15	Ow	7.22	7.97	5108.8	3.92	76.4	1.05	32.72	14.21	19.00	0.36	0.00	5.00
16	Ow	7.77	0.93	596.1	0.58	5.2	0.91	3.36	1.66	0.92	0.13	0.00	7.20
17	Ow	7.33	8.46	5422.9	7.84	81.6	1.34	26.08	16.82	36.33	0.24	0.00	5.80
Dam	S	8.76	7.89	5057.5	22.79	69.6	1.39	3.60	9.00	57.20	0.74	1.20	4.60
R.II 13 Oct & 14 Oct 2003													
18	Bw	8.13	1.03	660.23	5.58	5.00	1.00	1.40	2.57	7.86	0.08	0.80	6.80
19	Bw	7.94	1.66	1064.06	5.77	11.50	1.02	2.00	8.09	12.96	0.18	0.40	7.80
20	Ow	7.87	8.75	5608.75	15.43	88.00	2.09	11.40	24.47	65.36	8.75	0.00	8.00
21	Bw	8.06	0.83	532.03	5.07	3.50	0.97	1.40	2.57	7.13	0.08	0.40	7.40
22	Bw	7.70	0.99	634.59	0.80	6.50	0.89	3.20	4.05	1.52	0.08	0.00	5.60
23	Bw	8.27	1.03	660.23	0.60	6.00	0.89	5.60	7.40	1.52	0.18	0.40	5.20
24	Ow	7.52	5.37	3442.17	3.81	62.00	0.97	24.20	18.95	17.71	0.18	0.00	3.40
25	Bw	7.89	7.78	4986.98									
26	ow-bw	7.42	8.60	5512.60	23.09	93.00	1.44	11.20	11.55	77.87	0.30	0.00	8.80
27	Ow	7.69	6.45	4134.45	18.76	66.00	1.16	5.40	8.88	50.13	0.43	0.00	8.40
28	Ow	7.50	4.44	2846.04	1.33	48.50	0.96	14.90	26.84	6.08	1.04	0.00	5.60
29	Bw	7.80	4.27	2737.07	5.05	44.00	1.30	13.80	13.32	18.60	0.72	0.00	3.80
30	Bw	7.39	2.59	1660.19	2.78	21.00	0.89	6.40	12.73	8.61	0.30	0.00	9.60
31	Bw	7.96	1.02	653.82	0.73	6.50	1.08	3.70	5.03	1.52	0.18	0.00	7.60
32	Bw	8.36	1.27	814.07	6.09	7.00	1.30	1.70	3.85	10.14	0.30	0.80	8.00
33	Bw	7.65	1.08	692.28	2.32	6.00	1.06	2.60	4.64	4.41	0.18	0.00	8.00
34	Bw	8.17	3.23	2070.43	2.16	31.00	0.94	8.20	18.36	7.86	0.72	0.40	6.60
35	Ow	8.13	5.85	3749.85	10.17	45.00	2.00	8.00	14.01	33.73	10.17	0.40	10.20
36	Bw	7.98	2.16	1384.56	4.18	14.00	1.81	4.60	9.08	10.93	0.43	0.00	7.20
37	Bw	8.32	1.37	878.17	2.64	9.00	0.98	3.00	6.41	5.73	0.30	0.80	6.00
38	Bw	7.79	2.09	1339.69	2.67	17.50	1.01	5.00	10.76	7.50	0.30	0.00	6.80
39	Bw	7.91	2.08	1333.28	6.49	15.50	1.02	2.60	7.60	14.65	0.30	0.00	8.80
40	Bw	9.26	1.31	839.71	11.74	5.50	1.29	1.20	1.09	12.55	0.08	1.60	5.60
41	Bw	8.89	6.24	3999.84	20.11	53.00	2.40	1.60	15.79	59.31	0.43	1.60	9.20

42	Bw	8.16	1.08	692.28	1.76	5.50	0.90	2.80	4.93	3.47	0.30	0.40	7.80
43	Bw	8.28	2.68	1717.88	6.93	22.50	1.22	3.00	8.78	16.82	0.18	0.40	5.60
44	Bw	8.33	2.19	1403.79	5.50	16.00	1.23	3.40	7.70	12.96	0.30	0.80	7.60
45	Bw	7.73	2.30	1474.30	4.24	16.50	1.13	3.60	9.67	10.93	0.18	0.00	8.40
46	Bw	7.85	2.79	1788.39	5.05	22.00	1.83	4.60	11.25	14.22	0.30	0.00	8.40
47	Bw	8.32	2.40	1538.40	6.71	18.00	0.85	1.70	8.39	15.08	0.30	0.80	7.60
48	Bw	7.90	1.43	916.63	2.10	9.50	0.86	4.40	5.72	4.73	0.08	0.00	6.00
49	Bw	7.65	1.48	948.68	2.65	9.50	1.11	4.00	5.33	5.73	0.08	0.00	7.40
50	Bw	8.44	0.98	628.18	2.12	5.50	0.83	2.10	4.24	3.77	0.08	0.80	10.40
51	Ow	7.86	2.35	1506.35	2.90	20.50	1.28	6.80	9.37	8.23	0.18	0.00	5.20
52	Bw	7.49	0.76	487.16	0.70	4.00	1.03	3.10	3.85	1.30	0.14	0.00	6.40
53	Ow	8.04	2.36	1512.76	6.88	14.50	1.44	4.00	4.54	14.22	2.10	0.40	8.00
54	Bw	8.81	1.71	1096.11	11.77	11.00	1.31	1.20	2.27	15.51	0.09	1.20	7.40
55	Bw	7.89	1.65	1057.65	6.49	8.50	1.24	2.40	4.14	11.74	0.08	0.80	10.60
56	Bw	8.14	18.30	11730.3	19.61	201.00	4.96	38.50	60.69	138.12	0.88	0.80	3.00
57	Ow	8.02	0.75	480.75	2.43	3.00	1.22	1.70	2.37	3.47	0.09	0.40	10.00
58	Bw	8.05	0.72	461.52	1.45	3.00	1.07	2.10	2.96	2.31	0.12	0.40	7.40
59	Ow	8.85	8.31	5326.71	25.91	74.50	2.37	2.60	14.31	75.33	2.10	1.60	9.00
60	Bw	7.80	0.57	365.37	0.78	2.50	0.92	3.40	1.97	1.28	0.08	0.40	6.40
61	Ow	7.50	5.48	3512.68	9.05	47.00	1.83	9.40	16.68	32.69	0.18	0.00	9.20
62	Ow	7.72	10.35	6634.35	11.13	111.50	2.17	26.60	32.57	60.51	0.18	0.00	7.20
63	Bw	8.03	0.87	557.67	0.43	4.50	1.04	2.80	4.34	0.82	0.21	0.40	6.80
64	Ow	7.81	1.22	782.02	0.45	9.00	1.12	3.90	6.61	1.04	0.08	0.40	6.00
65	Bw	7.67	7.67	4916.47	23.07	52.50	4.25	8.50	12.83	75.33	0.43	0.40	8.80
Inflow	S	7.92	6.40	4102.40	23.46	62.50	1.95	4.40	8.39	59.31	0.43	0.00	6.60
Dam	S	8.79	6.84	4384.44	27.39	68.00	1.80	3.00	8.39	65.36	0.45	0.80	4.80
Canal	S	8.28	7.47	4788.27	24.14	76.50	0.96	6.80	9.57	69.06	0.57	0.40	5.60
Outflow	S	7.98	6.86	4397.26	24.44	69.00	1.34	4.60	9.18	64.14	0.43	0.40	7.80
R10	Bw	7.82	3.74	2397.34	4.49	32.00	1.30	11.00	12.83	15.51	0.08	0.40	4.60
R8	Bw	8.17	4.00	2564.00	14.94	31.00	1.39	1.60	8.59	33.73	0.30	0.80	8.00
R15	Ow	7.47	7.50	4808.00	3.97	78.00	1.13	33.90	21.41	20.89	0.18	0.00	5.20
R III 09 Nov 2003													
66	Ow	8.63	10.82										
67	Bw	8.2	8.29										
68	Bw	9.0	0.90										
69	Bw	8.83	0.93										
70	Bw	8.79	0.66										
71	Bw	8.55	4.21										
72	Ow	8.81	1.70										

*Note: $mmol_c$/l equals meq/l

APPENDIX 3

Table 1. Results from chemical analyses of water samples in mg/l

	pH	EC (dS/m)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)
R I 02 Oct & 03 Oct 2003										
1	7.96	12.57	4062.91	111.87	573.95	714.96	1000.77	33.98	0.00	366.10
2	8.65	0.91	99.27	46.01	14.43	74.86	38.51	4.91	24.00	353.89
3	7.85	7.46	2297.35	69.46	245.29	174.66	949.61	9.46	0.00	292.88
4	8.06	17.04	6261.00	103.58	1072.54	1081.56	983.57	18.91	24.00	268.47
5	8.36	8.66	2552.62	117.06	221.24	347.41	1018.11	39.25	12.00	378.30
6	8.52	1.23	205.63	47.36	49.70	58.54	63.32	9.46	36.00	292.88
7	7.81	12.56	5161.96	60.92	1026.05	481.76	742.90	28.84	0.00	317.28
8	8.14	4.33	1177.04	86.01	68.94	88.29	684.19	14.12	24.00	512.53
9	7.83	7.67	2368.26	95.76	407.21	245.68	742.90	9.46	0.00	463.72
10	7.97	4.44	1233.76	76.98	266.13	157.39	307.28	4.91	0.00	317.28
11	7.55	9.5	2836.24	116.14	141.08	339.73	1199.42	154.61	0.00	646.77
12	8.82	1.08	148.90	44.84	25.65	24.95	123.72	0.49	24.00	427.11
13	7.78	8.96	3084.41	77.41	352.70	105.57	1070.99	147.17	12.00	463.72
14	8.7	1.16	141.81	44.96	28.86	59.50	74.24	14.12	24.00	475.92
15	7.22	7.97	2708.61	50.54	655.71	172.74	436.77	14.12	0.00	305.08
16	7.77	0.93	184.36	43.75	67.33	20.15	21.26	4.91	0.00	439.32
17	7.33	8.46	2892.96	64.22	522.64	204.41	835.28	9.46	0.00	353.89
Dam	8.76	7.89	2467.53	66.73	72.14	109.40	1315.13	28.84	36.00	280.67
R II 13 Oct & 14 Oct. 2003										
18	8.13	1.03	177.27	48.14	28.06	31.19	180.77	2.96	24.00	414.91
19	7.94	1.66	407.71	49.09	40.08	98.37	298.07	7.09	12.00	475.92
20	7.87	8.75	3119.86	100.25	228.46	297.50	1502.77	342.22	0.00	488.13
21	8.06	0.83	124.09	46.36	28.06	31.19	164.03	2.96	12.00	451.52
22	7.70	0.99	230.44	42.64	64.13	49.18	34.97	2.96	0.00	341.69
23	8.27	1.03	212.72	42.88	112.22	89.97	34.97	7.09	12.00	317.28
24	7.52	5.37	2198.09	46.44	484.97	230.32	407.07	7.09	0.00	207.45
25	7.89	7.78								
26	7.42	8.60	3297.13	69.15	224.45	140.35	1790.35	11.81	0.00	536.94
27	7.69	6.45	2339.90	55.75	108.22	107.96	1152.57	16.97	0.00	512.53
28	7.50	4.44	1719.47	46.19	298.60	326.29	139.67	40.61	0.00	341.69
29	7.80	4.27	1559.93	62.49	276.55	161.95	427.72	28.27	0.00	231.86
30	7.39	2.59	744.51	42.93	128.26	154.75	197.89	11.81	0.00	585.75
31	7.96	1.02	230.44	51.93	74.15	61.18	34.97	7.09	0.00	463.72
32	8.36	1.27	248.17	62.68	34.07	46.78	233.19	11.81	24.00	488.13
33	7.65	1.08	212.72	50.77	52.10	56.38	101.28	7.09	0.00	488.13
34	8.17	3.23	1099.04	45.05	164.33	223.13	180.77	28.27	12.00	402.71
35	8.13	5.85	1595.39	96.19	160.32	170.34	775.39	397.79	12.00	622.36
36	7.98	2.16	496.34	86.99	92.18	110.36	251.34	16.97	0.00	439.32
37	8.32	1.37	319.08	47.08	60.12	77.97	131.76	11.81	24.00	366.10
38	7.79	2.09	620.43	48.34	100.20	130.76	172.35	11.81	0.00	414.91
39	7.91	2.08	549.52	49.06	52.10	92.37	336.77	11.81	0.00	536.94
40	9.26	1.31	194.99	61.95	24.05	13.20	288.57	2.96	48.01	341.69
41	8.89	6.24	1879.01	115.15	32.06	191.94	1363.61	16.97	48.01	561.35
42	8.16	1.08	194.99	43.35	56.11	59.98	79.74	11.81	12.00	475.92

43	8.28	2.68	797.69	58.68	60.12	106.76	386.67	7.09	12.00	341.69
44	8.33	2.19	567.25	58.89	68.14	93.57	298.07	11.81	24.00	463.72
45	7.73	2.30	584.97	54.43	72.14	117.56	251.34	7.09	0.00	512.53
46	7.85	2.79	779.97	87.68	92.18	136.76	326.99	11.81	0.00	512.53
47	8.32	2.40	638.15	40.62	34.07	101.97	346.62	11.81	24.00	463.72
48	7.90	1.43	336.80	41.46	88.18	69.58	108.72	2.96	0.00	366.10
49	7.65	1.48	336.80	53.28	80.16	64.78	131.76	2.96	0.00	451.52
50	8.44	0.98	194.99	40.08	42.08	51.58	86.78	2.96	24.00	634.57
51	7.86	2.35	726.79	61.70	136.27	113.96	189.29	7.09	0.00	317.28
52	7.49	0.76	141.81	49.23	62.12	46.78	29.81	5.38	0.00	390.50
53	8.04	2.36	514.07	69.16	80.16	55.18	326.99	82.16	12.00	488.13
54	8.81	1.71	389.98	62.79	24.05	27.59	356.53	3.43	36.00	451.52
55	7.89	1.65	301.35	59.68	48.10	50.38	269.80	2.96	24.00	646.77
56	8.14	18.30	7126.05	238.07	771.54	737.76	3175.57	34.33	24.00	183.05
57	8.02	0.75	106.36	58.70	34.07	28.79	79.74	3.43	12.00	610.16
58	8.05	0.72	106.36	51.57	42.08	35.99	53.10	4.71	12.00	451.52
59	8.85	8.31	2641.25	113.79	52.10	173.94	1731.89	82.16	48.01	549.14
60	7.80	0.57	88.63	44.28	68.14	23.99	29.35	2.96	12.00	390.50
61	7.50	5.48	1666.29	87.68	188.38	202.73	751.56	7.09	0.00	561.35
62	7.72	10.35	3953.01	104.03	533.06	395.87	1391.18	7.09	0.00	439.32
63	8.03	0.87	159.54	49.96	56.11	52.78	18.88	8.22	12.00	414.91
64	7.81	1.22	319.08	53.96	78.16	80.37	23.98	2.96	12.00	366.10
65	7.67	7.67	1861.28	203.89	170.34	155.95	1731.89	16.97	12.00	536.94
Inflow	7.92	6.40	2215.81	93.85	88.18	101.97	1363.61	16.97	0.00	402.71
Dam	8.79	6.84	2410.80	86.26	60.12	101.97	1502.77	17.73	24.00	292.88
Canal	8.28	7.47	2712.15	45.91	136.27	116.36	1587.78	22.47	12.00	341.69
Outflow	7.98	6.86	2446.26	64.55	92.18	111.56	1474.68	16.97	12.00	475.92
R10	7.82	3.74	1134.50	62.52	220.44	155.95	356.53	2.96	12.00	280.67
R8	8.17	4.00	1099.04	66.56	32.06	104.37	775.39	11.81	24.00	488.13
R15	7.47	7.50	2765.33	54.43	679.36	260.31	480.39	7.09	0.00	317.28
R III 09 Nov 2003										
66	8.63	10.82								
67	8.2	8.29								
68	9.0	0.90								
69	8.83	0.93								
70	8.79	0.66								
71	8.55	4.21								
72	8.81	1.70								

APPENDIX 4

Table 1. Percentage difference between cations and anions (ion balance) in water samples

	BW/ OW	EC (dS/m)	Cl^- ($mmol_c/l$*)	SO_4^{2-} ($mmol_c/l$)	Ca^{2+} ($mmol_c/l$)	Mg^{2+} ($mmol_c/l$)	Na^+ ($mmol_c/l$)	K^+ ($mmol_c/l$)	CO_3^{2-} ($mmol_c/l$)	HCO_3^- ($mmol_c/l$)	**Ion balance** $\left(\frac{Cations - Anions}{\sum(Cations + Anions)/2}\right) \cdot 100$ (%)
1	Ow	12.57	114.6	2.33	28.64	58.82	43.53	0.87	0.00	6.00	7.0
2	Bw	0.91	2.8	0.96	0.72	6.16	1.68	0.13	0.80	5.80	-17.6
3	Ow	7.46	64.8	1.45	12.24	14.37	41.30	0.24	0.00	4.80	-4.2
4	Ow	17.04	176.6	2.16	53.52	88.97	42.78	0.48	0.80	4.40	1.0
5	Ow	8.66	72	2.44	11.04	28.58	44.28	1.00	0.40	6.20	4.7
6	Bw	1.23	5.8	0.99	2.48	4.82	2.75	0.24	1.20	4.80	-21.6
7	Ow	12.56	145.6	1.27	51.20	39.63	32.31	0.74	0.00	5.20	-20.4
8	Bw	4.33	33.2	1.79	3.44	7.26	29.76	0.36	0.80	8.40	-7.9
9	Ow	7.67	66.8	1.99	20.32	20.21	32.31	0.24	0.00	7.60	-4.4
10	Bw	4.44	34.8	1.60	13.28	12.95	13.37	0.13	0.00	5.20	-4.6
11	Bw	9.5	80	2.42	7.04	27.95	52.17	3.95	0.00	10.60	-2.1
12	Ow	1.08	4.2	0.93	1.28	2.05	5.38	0.01	0.80	7.00	-38.8
13	Ow	8.96	87	1.61	17.60	8.68	46.58	3.76	0.40	7.60	-23.1
14	Bw	1.16	4	0.94	1.44	4.89	3.23	0.36	0.80	7.80	-30.8
15	Ow	7.97	76.4	1.05	32.72	14.21	19.00	0.36	0.00	5.00	-21.7
16	Ow	0.93	5.2	0.91	3.36	1.66	0.92	0.13	0.00	4.90	-58.7
17	Ow	8.46	81.6	1.34	26.08	16.82	36.33	0.24	0.00	5.80	-11.0
Dam	S	7.89	69.6	1.39	3.60	9.00	57.20	0.74	1.20	4.60	-8.5
18	Bw	1.03	5.00	1.00	1.40	2.57	7.86	0.08	0.80	6.80	-0.8
19	Bw	1.66	11.50	1.02	2.00	8.09	12.96	0.18	0.40	7.80	20.5
20	Ow	8.75	88.00	2.09	11.40	24.47	65.36	8.75	0.00	8.00	16.4
21	Bw	0.83	3.50	0.97	1.40	2.57	7.13	0.08	0.40	7.40	-0.8
22	Bw	0.99	6.50	0.89	3.20	4.05	1.52	0.08	0.00	5.60	-14.1
23	Bw	1.03	6.00	0.89	5.60	7.40	1.52	0.18	0.40	5.20	41.1
24	Ow	5.37	62.00	0.97	24.20	18.95	17.71	0.18	0.00	3.40	-7.5
25	Bw	7.78									
26	ow-bw	8.60	93.00	1.44	11.20	11.55	77.87	0.30	0.00	8.80	3.3
27	Ow	6.45	66.00	1.16	5.40	8.88	50.13	0.43	0.00	8.40	-13.7
28	Ow	4.44	48.50	0.96	14.90	26.84	6.08	1.04	0.00	5.60	-7.5
29	Bw	4.27	44.00	1.30	13.80	13.32	18.60	0.72	0.00	3.80	-2.7
30	Bw	2.59	21.00	0.89	6.40	12.73	8.61	0.30	0.00	9.60	6.4
31	Bw	1.02	6.50	1.08	3.70	5.03	1.52	0.18	0.00	7.60	-6.9
32	Bw	1.27	7.00	1.30	1.70	3.85	10.14	0.30	0.80	8.00	0.6
33	Bw	1.08	6.00	1.06	2.60	4.64	4.41	0.18	0.00	8.00	-15.8
34	Bw	3.23	31.00	0.94	8.20	18.36	7.86	0.72	0.40	6.60	-1.1
35	Ow	5.85	45.00	2.00	8.00	14.01	33.73	10.17	0.40	10.20	22.5
36	Bw	2.16	14.00	1.81	4.60	9.08	10.93	0.43	0.00	7.20	21.4
37	Bw	1.37	9.00	0.98	3.00	6.41	5.73	0.30	0.80	6.00	7.2
38	Bw	2.09	17.50	1.01	5.00	10.76	7.50	0.30	0.00	6.80	4.6
39	Bw	2.08	15.50	1.02	2.60	7.60	14.65	0.30	0.00	8.80	7.5
40	Bw	1.31	5.50	1.29	1.20	1.09	12.55	0.08	1.60	5.60	12.3
41	Bw	6.24	53.00	2.40	1.60	15.79	59.31	0.43	1.60	9.20	17.7
42	Bw	1.08	5.50	0.90	2.80	4.93	3.47	0.30	0.40	7.80	-0.8
43	Bw	2.68	22.50	1.22	3.00	8.78	16.82	0.18	0.40	5.60	2.3
44	Bw	2.19	16.00	1.23	3.40	7.70	12.96	0.30	0.80	7.60	6.5
45	Bw	2.30	16.50	1.13	3.60	9.67	10.93	0.18	0.00	8.40	6.6

46	Bw	2.79	22.00	1.83	4.60	11.25	14.22	0.30	0.00	8.40	5.9
47	Bw	2.40	18.00	0.85	1.70	8.39	15.08	0.30	0.80	7.60	2.5
48	Bw	1.43	9.50	0.86	4.40	5.72	4.73	0.08	0.00	6.00	-9.2
49	Bw	1.48	9.50	1.11	4.00	5.33	5.73	0.08	0.00	7.40	-14.0
50	Bw	0.98	5.50	0.83	2.10	4.24	3.77	0.08	0.80	10.40	-25.2
51	Ow	2.35	20.50	1.28	6.80	9.37	8.23	0.18	0.00	5.20	1.7
52	Bw	0.76	4.00	1.03	3.10	3.85	1.30	0.14	0.00	6.40	-7.4
53	Ow	2.36	14.50	1.44	4.00	4.54	14.22	2.10	0.40	8.00	16.2
54	Bw	1.71	11.00	1.31	1.20	2.27	15.51	0.09	1.20	7.40	-4.3
55	Bw	1.65	8.50	1.24	2.40	4.14	11.74	0.08	0.80	10.60	-5.2
56	Bw	18.30	201.00	4.96	38.50	60.69	138.12	0.88	0.80	3.00	13.6
57	Ow	0.75	3.00	1.22	1.70	2.37	3.47	0.09	0.40	10.00	-32.9
58	Bw	0.72	3.00	1.07	2.10	2.96	2.31	0.12	0.40	7.40	-40.3
59	Ow	8.31	74.50	2.37	2.60	14.31	75.33	2.10	1.60	9.00	8.7
60	Bw	0.57	2.50	0.92	3.40	1.97	1.28	0.08	0.40	6.40	-29.2
61	Ow	5.48	47.00	1.83	9.40	16.68	32.69	0.18	0.00	9.20	11.0
62	Ow	10.35	111.50	2.17	26.60	32.57	60.51	0.18	0.00	7.20	3.6
63	Bw	0.87	4.50	1.04	2.80	4.34	0.82	0.21	0.40	6.80	-23.4
64	Ow	1.22	9.00	1.12	3.90	6.61	1.04	0.08	0.40	6.00	-19.4
65	Bw	7.67	52.50	4.25	8.50	12.83	75.33	0.43	0.40	8.80	45.4
Inflow	S	6.40	62.50	1.95	4.40	8.39	59.31	0.43	0.00	6.60	2.9
Dam	S	6.84	68.00	1.80	3.00	8.39	65.36	0.45	0.80	4.80	2.4
Canal	S	7.47	76.50	0.96	6.80	9.57	69.06	0.57	0.40	5.60	4.9
Outflow	S	6.86	69.00	1.34	4.60	9.18	64.14	0.43	0.40	7.80	3.1
R10	Bw	3.74	32.00	1.30	11.00	12.83	15.51	0.08	0.40	4.60	6.6
R8	Bw	4.00	31.00	1.39	1.60	8.59	33.73	0.30	0.80	8.00	15.2
R15	Ow	7.50	78.00	1.13	33.90	21.41	20.89	0.18	0.00	5.20	-8.2

*Note: $mmol_c$/l equals meq/l

APPENDIX 5

All water samples were classified according to the USDA and Tamil Nadu systems for irrigation water. The explanations for the different letters in the two systems and for “Water uses” follow in Tables 2-6.

Table 1. Classification of water samples for irrigation

	BW/ OW	pH	EC (dS/m)	TDS (mg/l)	SAR	**USDA system**	**Tamil Nadu System**		**Water uses**			
R I							pH	EC	D	W	B	I
1	Ow	7.96	12.57	8057.4	6.58	C4-S2	N	I		Y		Y
2	Bw	8.65	0.91	583.3	0.90	C3-S1	TA	N	Y	Y	Y	
3	Ow	7.85	7.46	4781.9	11.32	C4-S3	N	I	An	S	S	Y
4	Ow	8.06	17.04	10922.6	5.07	C4-S2	N	I		S	S	Y
5	Ow	8.36	8.66	5551.1	9.95	C4-S3	N	I	An	Y	Y	
6	Bw	8.52	1.23	788.4	1.44	C3-S1	TA	C	Y	Y	Y	
7	Ow	7.81	12.56	8051.0	4.79	C4-S2	N	I		S	S	Y
8	Bw	8.14	4.33	2775.5	12.86	C4-S4	N	I	Y	S	S	Y
9	Ow	7.83	7.67	4916.5	7.18	C4-S2	N	I	An			
10	Bw	7.97	4.44	2846.0	3.69	C4-S2	N	I				
11	Bw	7.55	9.5	6089.5	12.47	C4-S4	N	I		Y	Y	
12	Ow	8.82	1.08	692.3	4.17	C3-S1	TA	C	Y	Y	Y	Y
13	Ow	7.78	8.96	5743.4	12.85	C4-S4	N	I				
14	Bw	8.7	1.16	743.6	1.81	C3-S1	TA	C	Y	Y	Y	Y
15	Ow	7.22	7.97	5108.8	3.92	C4-S2	N	I	An	S	S	Y
16	Ow	7.77	0.93	596.1	0.58	C3-S1	N	N	Y	Y	Y	Y
17	Ow	7.33	8.46	5422.9	7.84	C4-S2	N	I				
Dam	S	8.76	7.89	5057.5	22.79	C4-S4	TA	I		S		Y
B II												
18	Bw	8.13	1.03	660.23	5.58	C3-S1	N	C	Y	Y	Y	
19	Bw	7.94	1.66	1064.06	5.77	C3-S2	N	C	Y	Y	Y	
20	Ow	7.87	8.75	5608.75	15.43	C4-S4	N	I		S		Y
21	Bw	8.06	0.83	532.03	5.07	C3-S1	N	N	Y	Y	Y	
22	Bw	7.70	0.99	634.59	0.80	C3-S1	N	N	Y	Y	Y	Y
23	Bw	8.27	1.03	660.23	0.60	C3-S1	N	C		Y	Y	
24	Ow	7.52	5.37	3442.17	3.81	C4-S2	N	I				Y
25	Bw	7.89	7.78	4986.98			N	I		Y	Y	Y
26	ow-bw	7.42	8.60	5512.60	23.09	C4-S4	N	I				Y
27	Ow	7.69	6.45	4134.45	18.76	C4-S4	N	I		S	S	
28	Ow	7.50	4.44	2846.04	1.33	C4-S1	N	I		Y	Y	Y
29	Bw	7.80	4.27	2737.07	5.05	C4-S2	N	I		Y	Y	Y
30	Bw	7.39	2.59	1660.19	2.78	C4-S1	N	C		Y	Y	
31	Bw	7.96	1.02	653.82	0.73	C2-S1	N	C	Y	Y	Y	
32	Bw	8.36	1.27	814.07	6.09	C3-S2	N	C	Y	Y	Y	
33	Bw	7.65	1.08	692.28	2.32	C3-S1	N	C	Y			
34	Bw	8.17	3.23	2070.43	2.16	C4-S1	N	I		Y	Y	
35	Ow	8.13	5.85	3749.85	10.17	C4-S3	N	I		Y		
36	Bw	7.98	2.16	1384.56	4.18	C3-S1	N	C		Y	Y	
37	Bw	8.32	1.37	878.17	2.64	C3-S1	N	C	Y			

38	Bw	7.79	2.09	1339.69	2.67	C3-S1	N	C	An	Y	Y	
39	Bw	7.91	2.08	1333.28	6.49	C3-S2	N	C	An	Y	Y	
40	Bw	9.26	1.31	839.71	11.74	C3-S2	A	C	Y	Y	Y	Y
41	Bw	8.89	6.24	3999.84	20.11	C4-S4	TA	I	An	Y	Y	Y
42	Bw	8.16	1.08	692.28	1.76	C3-S1	N	C	Y	Y	Y	
43	Bw	8.28	2.68	1717.88	6.93	C4-S2	N	C	S	Y	Y	
44	Bw	8.33	2.19	1403.79	5.50	C3-S2	N	C	Y	Y	Y	
45	Bw	7.73	2.30	1474.30	4.24	C4-S1	N	C		Y	Y	
46	Bw	7.85	2.79	1788.39	5.05	C4-S2	N	C		Y	Y	
47	Bw	8.32	2.40	1538.40	6.71	C4-S2	N	C	Y	Y	Y	
48	Bw	7.90	1.43	916.63	2.10	C3-S1	N	C	Y	Y	Y	
49	Bw	7.65	1.48	948.68	2.65	C3-S1	N	C	Y	Y	Y	
50	Bw	8.44	0.98	628.18	2.12	C3-S1	TA	N	-	-	-	-
51	Ow	7.86	2.35	1506.35	2.90	C4-S1	N	C		Y	Y	Y
52	Bw	7.49	0.76	487.16	0.70	C3-S1	N	N	Y	Y	Y	
53	Ow	8.04	2.36	1512.76	6.88	C4-S2	N	C		Y	Y	
54	Bw	8.81	1.71	1096.11	11.77	C3-S3	TA	C	Y			
55	Bw	7.89	1.65	1057.65	6.49	C3-S2	N	C	Y	Y	Y	
56	Bw	8.14	18.30	11730.3	19.61	C4-S4	N	I				Y
57	Ow	8.02	0.75	480.75	2.43	C2-S1	N	N	Y	Y	Y	
58	Bw	8.05	0.72	461.52	1.45	C2-S1	N	N	Y			
59	Ow	8.85	8.31	5326.71	25.91	C4-S4	TA	I				Y
60	Bw	7.80	0.57	365.37	0.78	C2-S1	N	N	Y	Y	Y	
61	Ow	7.50	5.48	3512.68	9.05	C4-S3	N	I	An	Y	Y	Y
62	Ow	7.72	10.35	6634.35	11.13	C4-S3	N	I		Y	Y	Y
63	Bw	8.03	0.87	557.67	0.43	C3-S1	N	N	Y	Y	Y	
64	Ow	7.81	1.22	782.02	0.45	C3-S1	N	C	Y	Y	Y	Y
65	Bw	7.67	7.67	4916.47	23.07	C4-S4	N	I		Y	Y	
Inflow	S	7.92	6.40	4102.40	23.46	C4-S4	N	I		S	S	
Dam	S	8.79	6.84	4384.44	27.39	C4-S4	N	I		S		Y
Canal	S	8.28	7.47	4788.27	24.14	C4-S4	N	I		S	S	Y
Outflow	S	7.98	6.86	4397.26	24.44	C4-S4	N	I		S	S	Y
R1		7.82	3.74	2397.34	4.49							
R2		8.17	4.00	2564.00	14.94							
R3		7.47	7.30	4679.30	3.97							

USDA system for classification of irrigation water

Table 2. USDA quality rating for irrigation water

	C	S
1	LOW SALINITY WATER (C1) can be used for irrigation with most crops on most soils.	LOW SODIUM WATER (S1) can be used for irrigation on almost all soils with little danger of harmful levels of exchangeable sodium.
2	MEDIUM SALINITY WATER (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases.	MEDIUM SODIUM WATER (S1) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity. It may be used on coarse textured or organic soils with good permeability.
3	HIGH-SALINITY WATER (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required. Plants with good salt tolerance should be selected.	HIGH SODIUM WATER (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management with good drainage, high leaching and organic matter. Amendments may not be feasible with waters of very high salinity.
4	VERY HIGH SALINITY WATER (C4) is not suitable for irrigation under ordinary conditions. It may be used occasionally but the soil must be permeable, drainage adequate, irrigation applied in excess. Very salt-tolerant crops should be grown.	VERY HIGH SODIUM WATER (S4) is generally not good for irrigation purposes except at low and perhaps medium salinity.

If the soil is calcareous sufficient calcium may dissolve to decrease the sodium hazard. This should be taken into account in the use of C1-S3, C1-S4 waters. For calcareous soils with high pH or for non-calcareous soils, the sodium status of water in classes C1-S3, C1-S4 and C2-S4 may be improved by adding gypsum to the water. Also for C2-S3 and C3-S2 may this be beneficial.

Tamil Nadu Classification of Irrigation Water

Table 3. Ratings on soil reaction (pH)

Rating	Status	Designation
Below 6.0	Acidic	A
6.0 to 8.4	Normal	N
8.4 to 8.9	Tending to alkaline	TA
8.9 and above	Alkaline	A

Table 4. Ratings of EC

Rating	Status	Designation
Below 1.0	Normal	N
1.0-3.0	Critical	C
3.0 and above	Injurious	I

Classification for water use. based on interviews

Table 5. Categories of water use

Category	Designation
Drinking	D
Washing	W
Personal hygiene	B
Irrigation	I

Table 6. Designation for answers about water use

Status	Designation
Yes	Y
Some people only	S
Animals	An

APPENDIX 6

Quality Criteria of Drinking Water
Prescribed by Indian Standards Institution and Indian Council of Medical Research
Prescribed by ISI (IS:10500-1989) Prescribed by ICMR

Standards of Bacterioloogical Quality

i) Water in Distribution System
   - a) Throughout year, 95% of samples should not contain any coliform organisms in 100 ml.
   - b) No sample should contain E. coli in 100 ml.
   - c) No sample should contain more than 10 coliform organisms per 100 ml; and
   - d) Coliform organisms should not be detectable in 100 ml of any two consecutive samples.

ii) Unpiped water supplies

Where it is impracticable to supply water to consumers through a piped distribution network and where untreated sources, such as wells, boreholes and springs which may not be naturally pure, have to be used, the requirements for piped supplies may not be attainable. In such circumstances disinfection is most desirable and considerable reliance has to be placed on sanitary inspection and not exclusively on the results of bacteriological examination.

C. Standards of Physical & Chemical Quality

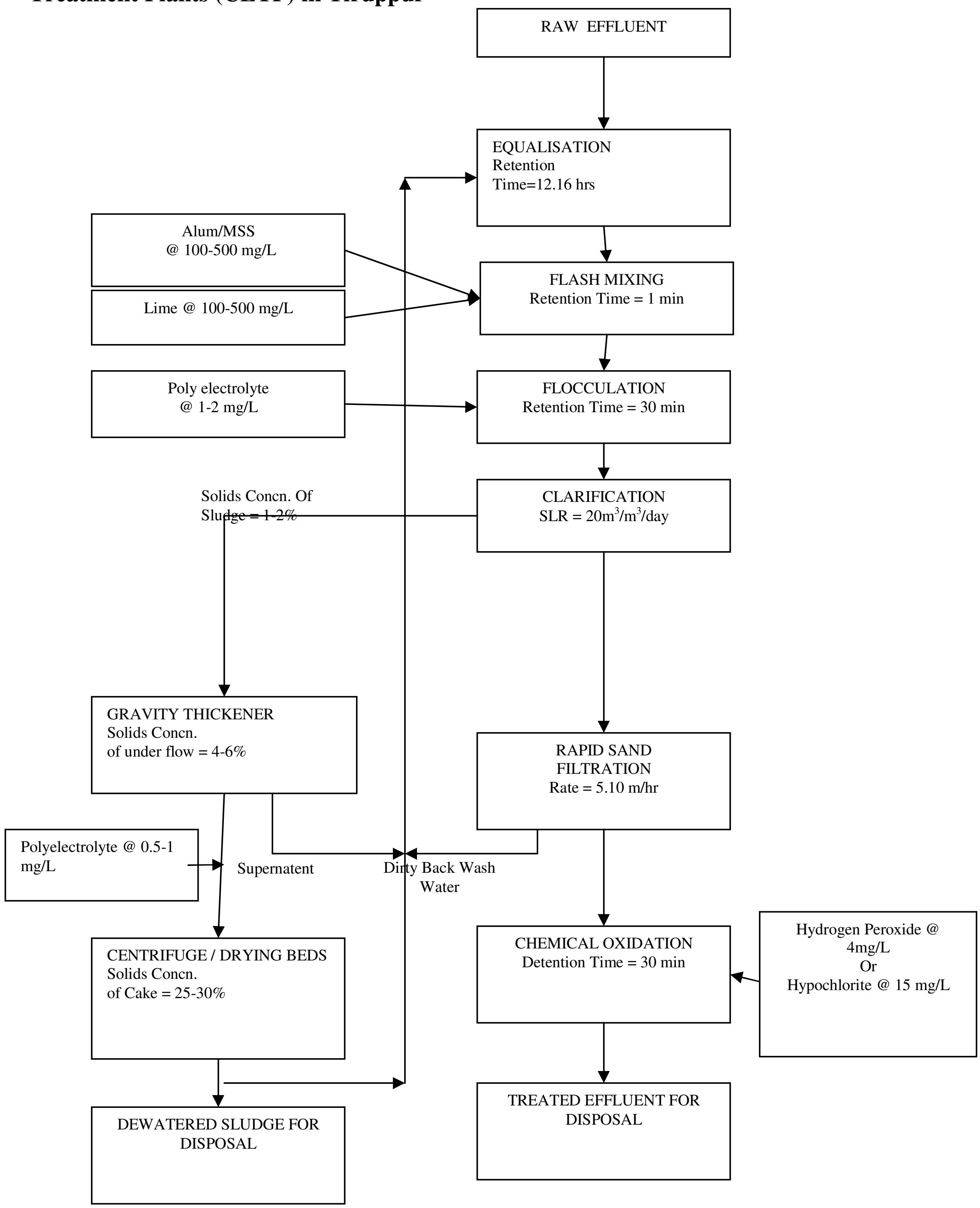
Sl. No.	Substance or Characteristic	Prescribed by ISI Requirement (Desirable Limit) Max. Permissible level	Prescribed by ICMR Highest Desirable Level	Maximum Permissible level
(1)	(2)	(3)	(4)	(5)
1.	Colour. Hazen Units	10	5 units	25 units
2.	Odour	Unobjectionable	Unobjectionable	Unobjectionable
3.	Agreeable	Unobjectionable	Unobjectionable	Unobjectionable
4.	Turbidity	10 NTU	5JTU	25 JTU
5.	Dissolved solid, mg/l	500	500	1500*
6.	pH value	6.5 to 8.5	7.0 to 8.5	6.5 to 9.2
7.	Total hardness (as $CaCO_3$), mg/l	300	300	600
8.	Calcium (as Ca), mg/l	75	75	200
9.	Magnesium (as Mg), mg/l	30	Not more than 50 mg/I, if there are 200 mg/l sulfates; if there is less sulphate, magnesium up to 100 mg/I, may be allowed at the rate of 1 mg/Img, for every 4 mg/I decrease in sulfates	

10.	Copper (as Cu), mg/l	0.05	0.05	1.5
11.	Iron (as Fe), mg/1	0.3	0.1	1.0
12.	Manganese(as Mn),mg/1	0.1	0.1	0.5
13.	Chlorides (as Cl), mg/l	250	200	1000
14.	Sulfate (as SO4), mg/l	150	200	400
15.	Nitrate (as NO3), mg/l	45	20	**
16.	Fluride (as F), mg/I	0.6 to 1.2	1.0***	1.5
17.	Phenolic Compounds (as C6H5OH), mg/I	0.001	0.001	0.002
18.	Mercury (as Hg), mg/l.	0.001	--	0.001
19.	Cadmium(as Cd), mg/l	0.01	--	0.01
20.	Selenium (as Se), mg/l	0.01	--	0.01
21.	Arsenic (as As), mg/l	0.05	--	0.05
22.	Cyanide(as CN), mg/l.	0.05	--	0.05
23.	Lead (as Pb), mg/1.	0.10	--	0.10
24.	Zinc (as Zn), mg/l	5	--	--
25.	Anionic detergents (as MBAS), mg/l	0.2	--	--
26.	Chromium (as Cr6+), mg/1	0.05	--	--
27.	Polynuclear aromatic hydrocarbons (as PAH), mg/1	-	--	--
28.	Mineral oil, mg/1	0.01	--	--
29.	ResiduaL free Chlorine, mg/1.Min.	0.2	--	--
30.	Pesticides	Absent	--	--
31.	Radio-active materials:		--	
	a) Alpha emitters uc**** per ml. Max	10-8	--	3 pci/l*****
	b) Beta emitters uc per ml. Max	10-7	--	30 pci/1

*Dissolved solids reliable up to 3000 mg/1 in case where alternate sources are not available within reach.
** More information is required to prescribe a value but in no circumstances should the level exceed 100 mg NO3
*** The presence of fluoride in drinking water in excess of 1.0 mg/1, gives rise to dental fluorosis (mottling of varying degrees of severity in children. When present in high concentrations, fluorides may eventually cause endemic cumulative fluorosis with resultant skeletal damage in children and adults
**** uc – micro Curie
***** pCi – 'Picocurie'- unit of radio-active disintegration, also known as micro microcuric equivalent to disintegrations per second

APPENDIX 7

Schematic diagram showing Treatment method followed in Common Effluent Treatment Plants (CETP) in Tiruppur



APPENDIX 8

Questionnaire for open wells and bore wells

The following questions were asked at each open well and bore well:

1. Is it a private or common well?
2. Time since construction?
3. Depth of the well?
4. Water level? (the water level was measured in the open wells but could only be estimated concerning some bore wells)
5. Has there been a change in water level after the construction of the Orathupalayam Dam? If so, how much increase or decrease?
6. What is your opinion about the quality of the well water today? (good, slightly salty, salty or bitter)
7. Has the quality of the water changed? If so, when and how?
8. What is the well water used for?
    - Drinking
    - Washing clothes and personal hygiene
    - Irrigation
9. Is there plenty, enough, scarcity or severe scarcity of water in the well?
10. How much is the well used? By how many families?
11. What is the source of drinking water (in the hamlet or farmers' houses)?

APPENDIX 9

Questionnaire for in-depth interviews

Name and Occupation:
Family:

Number of people:
Sex:
Occupations:

Water Quality

Have you noticed any changes in the water quality and if so when and how?

What type of water do you use for drinking, personal hygiene, washing and for cattle, since when?

Has the water level in the Open and Bore wells changed since the construction of the dam?

If there has been a change in the water quality, have there been constructions of new wells?

Has there been any construction of new wells due to rain failure?

Diseases

Has there been an increase of any specific diseases since the construction of the dam?

Specific questions to farmers

What types of crops do you grow at present and how has your crop pattern changed due to the dam?

Do you use irrigation, if so what crops do you irrigate and what type of irrigation is used?

Do you have any rainfed land, if so what type of crops do you grow?

Do you have any cattle, if so what type of cattle and how many? Has the number of animals changed during the last years and if so why?

If there has been a change in the water quality how did you first notice the change?

Has there been any damage to the crops, since when?

Has there been decrease in yield, since when?

Has there been any effect on the germination, since when?

Has there been any change in the soil quality, since when?
How, describe?

Migration

Have people in your family/hamlet moved away because of the pollution?

How many?
Where have they moved to?
What is their occupation now?

Compensation

Have you received any help from the government?

Have you received any help from NGOs?

Have there been any studies in your hamlet concerning the pollution?

What has been done in your hamlet to raise this question?

Future

How do you picture the future?

What kind of help would you like to receive?

In your opinion, what should be done to change the situation?