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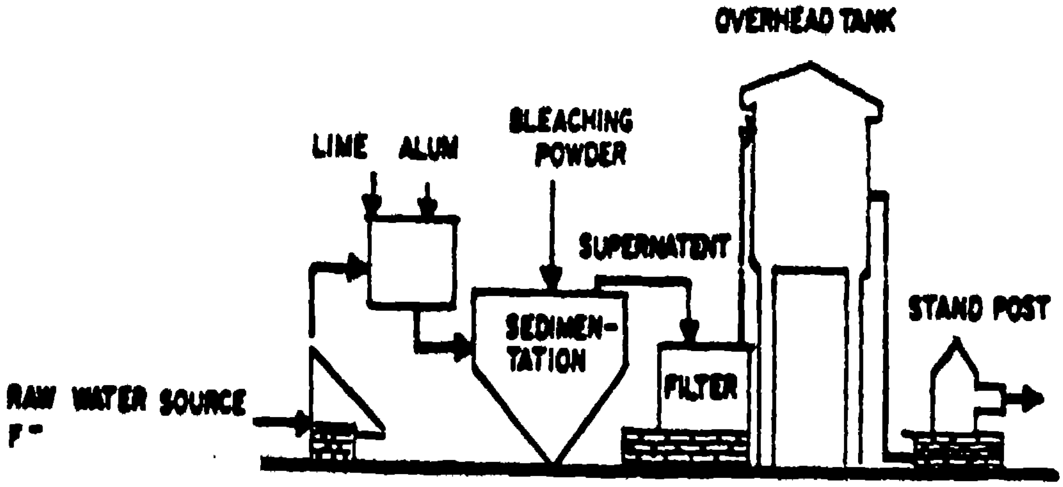

Application of Defluoridation Plants for Rural Water Supply in North Gujarat (India)

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Application of defluoridation plants for rural water supply in North Gujarat (India)

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ABSTRACT

The programme for providing clear and safe drinking water to rural areas is in the forefront among the development programmes of Gujarat state (India). But providing safe drinking water to 23.4 million persons residing in 18,114 villages is really a challenging task for Gujarat Water Supply & Sewerage Board (GWSSB). It is challenging too because of depletion of groundwater, ingress of salinity and occurrence of high contents of fluoride and nitrate in the groundwater.

Excessive fluoride content in drinking water causes dental, skeletal and non skeletal fluorosis and the diseases caused by fluoride are incurable. In North Gujarat, where groundwater contains more than the permissible limit of fluoride, safe drinking water with a fluoride content less than 1.5 mg/l can be supplied by: i) installation of defluoridation plants or ii) through comprehensive water supply scheme based on distant perennial surface water source (CWSS).

This study was aimed to select the best suitable option out of the two alternatives mentioned above. Therefore literature was studied for occurrence of fluoride in groundwater, health related aspects of fluoride and available fluoride removal technologies. Tests for removal of fluoride through coagulation and adsorption were performed at IHE laboratory, for studying removal efficiencies in an ideal situation. Determination of fluoride concentrations were done using different methods for finding the most appropriate procedure. Field study was also carried out in Mehsana district of North Gujarat to evaluate the performance of existing defluoridation plants based on the Nalgonda process. Feasibility of applying defluoridation plants in an adjacent district (the Sabarkantha district) was examined by comparing all aspects of defluoridation plant scheme and comprehensive water supply scheme. GWSSB officials, village leaders and plant operators were consulted to obtain their views regarding the selection as well as the operation and maintenance aspects of installed water supply facilities.

The study reveals that defluoridation of groundwater based on Nalgonda process should be seen as immediate solution before implementing water supplies based on surface water source. Movable defluoridation plants are found most suitable for the worst affected villages, as considerable implementation time is required for CWSS. Double quantity of iron chloride is required for obtaining same fluoride removal efficiency as with aluminium salts used as coagulant. The SPADNS method gave lower values while ion selective electrode gave higher values with iron chloride as coagulant. Results were comparable for both methods when aluminium salts were used as coagulant. In adsorption tests only phosphatic compounds were found effective in removal of fluoride.

List of Abbreviations

AA	Activated Alumina
CGWB	Central Ground Water Board
CWSS	Comprehensive Water Supply Scheme
DFP	Defluoridation Plant
DL	District Laboratory
EC	Electrical Conductivity
GEB	Gujarat Electricity Board
GJTI	Gujarat Jalseva Training Institute
GOG	Government of Gujarat
GOI	Government of India
GWSSB	Gujarat Water Supply and Sewerage Board
HD II	Hatharva Dobhada CWSS Stage II
HDPE	High Density Poly Ethylene
HWS	Head Works Site
IDA	International Development Agency
ISE	Ion Selective Electrode
LD	Lalpur Davad CWSS
LPCD	Liters Per Capita Day
M	Moles per litre
MLD	Million Litres Per Day
MPHW	Multi Purpose Health Worker
NEERI	National Environmental Engineering Research Institute
NGO	Non Governmental Organisation
NIDC	National Industrial Development Corporation
O & M	Operation and Maintenance
PRL	Physical Research Institute
RCC	Reinforced Cement Concrete
RGNDWM	Rajiv Gandhi National Drinking Water Mission
R & D	Research and Development
RWS	Rural Water Supply
SAC	Space Application Centre
SDB	Sludge Drying Bed
TDS	Total Dissolved Solids
TISAB	Total Ionic Strength Adjustment Buffer
TM	Technology Mission

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CHAPTER 1
INTRODUCTION

Importance of water

Water is elixir of life, in fact, we can not think of life without water. If the most serious problem of the day is food, the same would be water by the turn of the century. The importance of water can very well be appreciated in case the issue is properly analyzed as below.

- 75% of the earth's total area is covered by water.
- 97.2% is in seas as a salt water.
- 1.8% tapped as ice in polar caps.
- 1% is available as surface and underground water and,
- 0.01% of this 1% available in economically unexploitable underground water layers.

It would be interesting to note that this remaining 0.39% of water will however be sufficient to cater the drinking water need of the whole world, having population of about 5800 million at the rate of 200 lpcd for 40,000 years. However the catch is attributable to uneven and unequal geographic distribution of water.

Water is a primary source of life and sustains all human activities such as agriculture, industries, energy etc. As the structure of society becomes more complex, water quality requirements, wastes produced, management processes and environment impact there of becomes greater in complexity and magnitude.

The changing relationship

In recent times, the relationship between man and water has been fast changing. It is no more the same as it used to be in the historical past. Increase in population has been resulting into over exploitation of available water resources and deterioration of water quality. Because of the chemical age, growth of industry and urbanisation, pollution of water is increasing continuously.

On the other hand man's capacity to manage and handle water has also been changing fast and favourable. The present technology has enabled man to treat water to the required quality standards. And it has made management of water quite a thrilling experience and a complex job. The importance of environmental engineering is at present quite different from what it was a generation before. The future of various societies will greatly depend on how efficiently and skilfully they manage the quantity and quality of water.

Fluoride contamination

However, fluoride is well known as a substance effective in the prevention of dental caries, clearly harmful effects of fluorides even at 1 ppm level, are serious and widely recognised. The intake of excessive amount of fluoride causes pathological changes in the teeth, also in the skeleton eventually causing permanent disability. Usually the cause of fluorosis lies in the use of drinking water that has a fluoride content in excess of 1.5 ppm. Thus the standard for fluoride in drinking water has been specified in India at 1.5 mg/l.

According to the WHO report *Fluorine and fluorides* (WHO, 1984) approximately 25 million people in 8700 villages in India drink water with a fluoride content more than 1.5 mg/l. This population is suffering from varying grades of fluorosis, and majority of them are leading a vegetative existence as there is apparently no cure for the disease.

Fluoride in drinking water far exceeds the standard mentioned above in North Gujarat region of western India and fluoride intoxication has become there a serious threat to public health. The severity of the problem is scientifically acknowledged, and justifies the implementation of measures to solve the fluorosis problem.

Background

Gujarat has a very peculiar geological & geohydrological situation. The total geographical area of the state is 195,984 sq.km. Nearly 35,463 sq.km.(18.09%) of this area is covered by alluvial deposits, 109,894 sq.km.(56.13%) by hard rock formation, 34,962 sq.km.(17.83%) area consists of saline zone, and 15,575 sq.km.(7.95%) are sandstone and lime stone deposits. The groundwater table has been continuously depleting due to poor recharge.

The work of implementation of rural water supply and sanitation programme as well as development and regulation of drinking water sector in the state of Gujarat is entrusted to GWS&SB (Gujarat Water Supply and Sewerage Board). Gujarat has 18,114 villages covering total population of 23.48 million and 255 towns having urban population of 10.6 million.

Rural water supply in N.Gujarat comprises the use of both surface and groundwater. The comprehensive water supply schemes (CWSS) are based on surface water.The villages of state are mainly dependent on groundwater for their drinking water supply.

The groundwater quality has deteriorated due to the presence of excess fluoride, chloride and nitrate. A survey recently carried out in Gujarat revealed that 2413 villages (13.3%) out of total 18,114 villages are affected by excessive fluorides. The population affected is 3.4 million (14.48%) out of total 42.6 million, where the fluoride content in groundwater ranges from 2.0 mg/l to 8.5 mg/l.

In 14 villages in the district of Mehsana defluoridation of groundwater by coagulation with alum takes place. For these villages with more than 500 people, a small distribution network has been constructed, whereas in small villages only one single standpost at the plant is present.

Out of the total 2413 fluoride affected villages, at present only 14 villages have been covered under defluoridation plants and 350 more villages are proposed to be covered under plant installations as well. However, majority of the affected villages are supposed to be supplied by comprehensive water supply schemes using surface water, free of fluoride, as resource. These schemes require huge investment cost. The total anticipated cost for providing potable water to fluoride affected villages has been valued at Rs. 2500 million (US $ 75 million).

Problem identification

Because of its consequence in terms of health damage, fluoride problem should be solved to prevent and reduce fluorosis. It requires fast and socio-economically feasible means to improve the drinking water quality.

Most defluoridation plants (DFPs) are complicated and expensive. They require a certain level of technological skill and chemicals, and are presumed not suitable for rural areas as these plants have to be maintained by the community.

The centralised water distribution system based on surface water is expensive as well, because formulation, approval and implementation of schemes are time consuming. However, in comparing both alternatives installation of defluoridation plant (DFP) as package plant can be seen as readily available solution for individual village and may be economical too.

The DFPs in the villages are designed and constructed under the supervision of GWS&SB. On temporary basis these plants are operated by an operator paid and trained by GWS&SB. It is the policy of GWS&SB to let the community be involved and be responsible for operation and maintenance.

Aims and Objectives

The aims of the study are to investigate the desirability and possibility to introduce DFPs as package plants in rural areas where at this moment fluoride contaminated water is consumed and secondly to investigate the willingness and capability of villagers to daily operate and maintain these plants.

As a representative pilot area, Idar taluka is selected which is situated in the district of Sabarkantha in N.Gujarat. This district has a maximum number of fluoride affected villages and several CWSSs are planned to be implemented.

Objectives can be mentioned as :

* Studying the various consequences of the presence of fluoride in water, as well as the various removal techniques particularly the fluoride removal by coagulation.

* Studying the various aspects of current defluoridation plants in terms of: performance, ability to reduce fluoride, cost, level of applicability (municipal, community), experience gained with applied defluoridation methods, suitability considering operation & maintenance (o & m) and socio-economic points of view, needed skills etc.

* Comparing CWSS and DFPs on basis of water quality, cost, expected life span and rehabilation and upgrading capacity.

* Identifying inexpensive and effective means suitable for villagers to be able to take over the daily o & m of DFPs.

* Identifying/assessing the local training needs, to be catered by GJTI (Gujarat Jalsewa Training Institute), a department of GWS&SB, as well as kinds of involvement of GWS&SB could also be considered.

* Providing guidelines for selection of fluoride removal technology, and o & m of same particularly in rural areas.

* Examining the role of GWSSB to work as facilitator for smooth running of such DFPs.

Methodology

Review of presently practised defluoridation methods on basis of choice of technology, cost, o & m, and social aspects. For this purpose data are collected regarding:

* the area in the district of Mehsana where the 14 DFPs are functioning,

* the pilot area Idar taluka, where the outcome of this study could serve as a basis for further decision making, and

* the existing surface water schemes (CWSS).

In order to assess the performance of the DFP's they were visited while the quality of raw water and treated water was examined. Quality parameters as pH, turbidity, F^-, alkalinity and residual aluminium were measured at local laboratories and at the IHE afterwards. In addition a study is made how those plants are operated and maintained. Plant details are given in annex 6.

The possibility of applying DFP's in Idar taluka also depends on local groundwater quality and quantity. Important information is the groundwater quality from Mehsana district and the pilot area.

Information is gathered from administrative head offices for water sector regulation on the problem of fluoride content in water, GWS&SB sub division offices and field officers, plant operators, panchayats, primary health centres etc.

To judge if villagers are able to operate the DFP (or even to take them over) , their education level, income and other socio-economic aspects have also been assessed with the help of questionnaire (annex 14).

Possibilities to train villagers was discussed with GJTI and people involved. Besides of technical aspects, training of operators in administration etc. is needed too. The willingness of villagers to be responsible for o & m of the DFP in future is investigated too.

Expected results

To come forward with a judgement about the best technical and organisational solution to supply people with water that meets the standard for fluoride. What is "best" is determined on basis of criteria as investment cost, o & m, needed time for implementation, need for skilled personnel, opportunities for communities to participate etc.
One of the outcomes could be a proposal to render temporally some DFP based water supply schemes to villagers as a kind of test case.

CHAPTER 2
LITERATURE REVIEW

2.1 Fluorine and its properties

Fluorine, the most electro-negative of all elements, has not only notable chemical qualities but also physiological properties of great interest and importance to human health and well-being. The chemical activity of the fluoride ion makes it physiologically more active than any other elemental ion. With low concentration of fluoride ion enzymatic processes may be either inhibited or stimulated, and interactions with other organic or inorganic body components may occur that are of great importance for human physiology.

Fluorine(F_2) is a greenish diatomic gas. Its atomic number is 9, electronic configuration 2, 7 ($1s^2$, $2s^2p^5$) and atomic weight is 19. The great reactivity of the element is in part attributable to the weakness of F-F bond in the fluorine molecule. Its ionisation potential, 401 kcal/g-atom, combined with dissociation energy, leads to the standard heat of formation of gaseous F^+ ion of 420 kcal/g-atom. Thus even solvated cationic species are unlikely and no evidence for a positive oxidation state of fluorine.

Fluorine compounds are essential of two main types, ionic and covalent, in both of which fluorine has a complete octet. Many fluorides and oxides are ionic with similar formulae and crystal structure, for example CaO and NaF. Covalent fluorides of many elements exists, and in view of the high electro-negativity of fluorine such bonds have considerable ionic character. Fluorine shows the lowest affinity towards oxygen due to its electro-negativity.An important feature in the formation of fluorides is that in reaction with fluorine, the elements usually give the highest known or maximum oxidation state (Bulusu *et al*, 1979).

Fluorine combines directly at ordinary or elevated temperatures with all elements other than oxygen and nitrogen and therefore reacts vigorously with most organic compounds. Fluoride ions have a strong tendency to form complexes with heavy metal ions in aqueous solutions, e.g., FeF_6^{3-}, AlF_6^{3-}, MnF_5^{2-}, MnF_3, ZrF_6^{2-}, and ThF_6^{2-}. The toxic potential of inorganic fluorides is mainly associated with this behaviour and formation of insoluble fluorides (WHO, 1984).

2.2 Sources of fluoride

Fluorine is so highly reactive that it is never encountered in its elemental gaseous state except in some industrial processes. It is the 13th most abundant element in the earth's crust. Three most common sources of fluorine are minerals fluorspar, or calcium fluoride (CaF_2), the aluminium compound cryolite (Na_3AlF_6), and apatite, a calcium phosphate complex ($3Ca_3(PO_4)_2.Ca(F,OH,Cl)_2$), but in most soils it is associated with micas and other clay minerals (WHO, 1984).

As fluorspar is found in sedimentary rocks(limestone and sandstone) and as cryolite in igneous rocks(granite). In igneous rocks (including volcanic rocks), the fluorine is mostly bound in micas and amphiboles (up to 80%) and to a lesser extent in apatite (up to 20 %). However in basalt all fluorine can be obtained in apatite.

A great part of fluorine in volcanic rocks is not in the mineral structure, but bound at the mineral surface as a result of impossibility for the gases to escape completely. In general alkalic rocks contain more fluorine than ultramafic rocks.

In carbonate sedimentary rocks, fluorine is present as fluorite. Clastic sediments have higher fluorine concentrations as the fluorine is concentrated in micas and illites in clay fractions (TNO, 1992).These fluoride minerals are nearly insoluble in water. Hence fluorides will be present in groundwaters only when conditions favour their solution.

Fluoride bearing minerals are in abundance in India. Therefore water is contaminated with fluoride. The Geological Survey of India has brought out considerable data which reveals that Fluorite, Topaz Apatite and Rock Phosphate, and Phosphatic nodules, Phosphorite are wide spread in India and contain high percentages of fluoride. As a result of the rich mineral content, fluoride leaches out and contaminates water and the soil (RGNDWM, 1993).

2.3 Fluoride contamination in drinking water

The natural fluoride content of water in different area varies according to the source of the water (surface or subterranean), the geological formation of the area, the amount of rainfall, and the quantity of evaporation (Waldbott, 1979).

Some fluoride compounds in the earth's upper crust are fairly soluble in water. Thus, fluoride is present in both surface and groundwater. The natural concentration of fluoride in ground water depends on such factors as the geological, chemical and physical characteristics of water supplying area, the consistency of the soil, the porosity of rocks, the pH and the temperature, the complexing action of other elements, and the depth of wells (WHO, 1984). Owing to these factors, the fluoride concentration in groundwater fluctuates within wide limits, e.g., from < 1 to 25 mg or more per litre. In some areas of the world, e.g., India, Kenya and South Africa, levels can be much higher than 25 mg/l (WHO, 1970).

The presence of fluorine bearing minerals and gases is essential for the occurrence of fluoride in water. The ultimate concentration of fluoride, however, depends also on climatological and geochemical condition of the region. The formation of fluoride rich waters was discussed in detail by Griffioen (1986). A summary is given in figure 2.1.

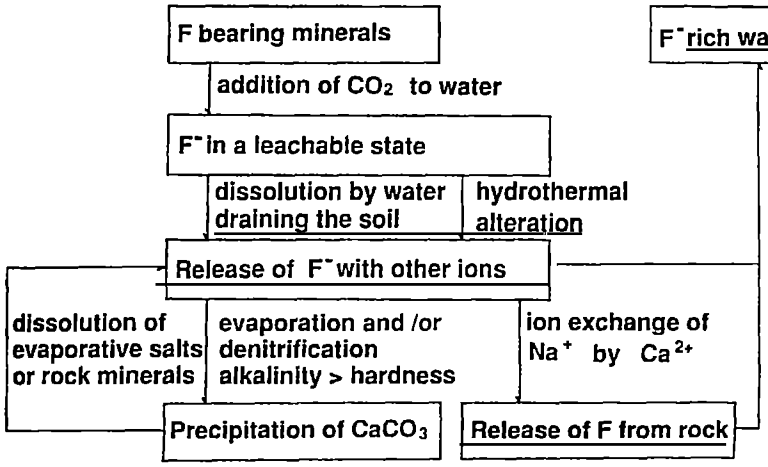

Figure 2.1 Formation of fluoride rich water (Source: TNO, 1992)

In the areas with fluoride containing geological formations, the groundwater, through its direct contact with fluoride minerals, usually has a higher fluoride content than near by surface water sources. Groundwater from bore holes, wells, and springs may have varying and/or fluctuating fluoride content, ranging between 0.1 and > 100 mg/l, depending on several influences such as :

- shallow ground water usually has a lower fluoride content during rainy season than during dry season, because of dilution by infiltrating rain water,

- deep ground water has more or less constant fluoride content,

- groundwater may show variation in fluoride content depending on the presence of fluoride containing formations at different depths.

2.3.1 Fluoride contamination in drinking water in India

Occurrence of fluoride bearing water have been reported in Andhra Pradesh, Rajasthan, Gujarat, Punjab, Haryana, Maharastra, Tamil Nadu, Karnataka, Madhya Pradesh and Uttar Pradesh.

The survey conducted under Technology Mission by Government of India, has identified 8,700 villages in India having excessive fluoride in water affecting more than 25 million people. The total number of states declared endemic for fluorosis in India are 15. The endemic states are shown in Fig.2.2. With the available information on prevalence of the disease, the states have been graded as:

Category I • Less than 30% of districts affected
Category II •• 30-50% districts affected
Category III ••• 50-100% districts affected
Δ disease not detected yet

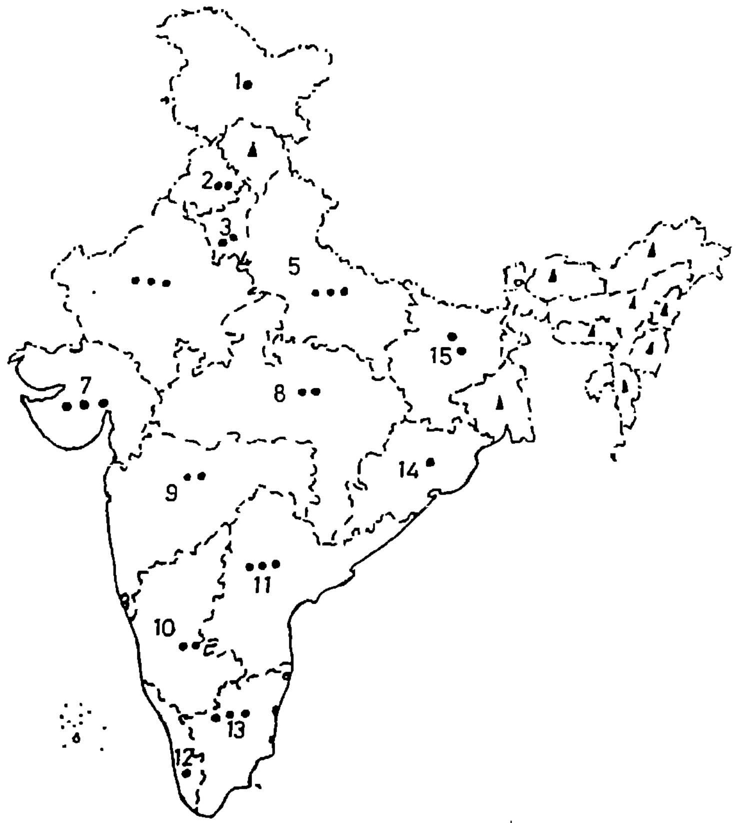

Figure 2.2 Map of India showing endemic states for fluorosis (Source: RGNDWM, 1993)

Legend:

1.	Jammu & Kasmir	•	2.	Punjab	••
3.	Haryana	••	4.	Delhi	•
5.	Uttar Pradesh	•••	6.	Rajasthan	•••
7.	Gujarat	•••	8.	Madhya Pradesh	••
9.	Maharasrta	••	10.	Karnataka	••
11.	Andhra Pradesh	•••	12.	Kerala	•
13.	Tamil Nadu	•••	14.	Orrisa	•
15.	Bihar	••	Disease not detected yet		Δ

2.3.2 Fluoride contamination in drinking water in Gujarat

In Gujarat the total number of villages having very high content of fluoride in local water sources are 2,413 (out of total number of 18,114 villages). In Mehsana and Sabarkantha districts of North Gujarat the number of villages identified with high fluoride content are 447 and 310 respectively (Technology Mission Cell, 1994)

For the first time in the state, in the district of Amreli in Saurastra region, high content of fluoride was found in the villages of Liliya and Lathi talukas. In 1976-77, GWSSB prepared a scheme based on fluoride free surface water source covering 37 villages of these talukas. This was implemented under assistance of The Netherlands Government.

The survey conducted under Rajiv Gandhi National Drinking Water Mission (RGNDWM) has revealed very striking and serious situation the prevalence of the spread of excessive content of fluoride in drinking water sources of as many as 2413 villages of 18 districts of Gujarat (Technology Mission Cell, 1994). Details are given in table.

Table 2.3 Numbers of fluoride affected villages in Gujarat State

Sr.No.	Name of district	No. of villages affected
1	Ahmedabad	173
2	Junagadh	48
3	Rajkot	15
4	Surendranagar	41
5	Amreli	70
6	Bhavnagar	75
7	Jamnagar	11
8	Gandhinagar	20
9	Sabarkantha	310
10	Banaskantha	386
11	Kachchh	4
12	Mehsana	447
13	Baroda	261
14	Kheda	178
15	Bharuch	26
16	Surat	23
17	Pnchmahal	311
18	Valsad	14
	Total	2413

2.4 Health related aspects of fluoride

The role of fluoride in animal or human metabolism is not known with certainty. From the information available it is clear that a certain quantity of fluorine is essential for formation of caries resistant dental enamel and for normal process of mineralisation in hard tissues. The element is metabolised from both electrovalent and covalent compounds. Low fluoride concentration stabilises the skeletal system by increasing the size of apatite crystals and reducing their solubility. The great affinity of fluoride for calcium phosphate is perhaps the most important aspect from physiological point of view and it results in its accumulation in all tissues exhibiting physiological or pathological calcification (Bulusu *et al*, 1979).

Table 2.4 Concentration of fluoride and biological effects

Concentration of fluoride mg/l	Medium	Effects
0.002	Air	Injury to vegetation
1	Water	Dental caries reduction
2 or more	Water	Mottled enamel
8	Water	10% Osteosclerosis
50	Food and water	Thyroid changes
100	Food and water	Growth retardation
120	Food and water	Kidney changes

About 95% of fluoride in the body is deposited in hard tissues and it continues to be deposited in calcified structures even after other bone constituents (Ca, P, Mg, CO_3, and citrate) have reached a steady state. Age is also important factor in deciding to what extent fluorine is incorporated into the skeleton. A pattern similar to that in bone is followed in the fluoride concentration in teeth. It is clear that physiology of human skeleton is adversely affected by fluorides. (WHO, 1970).

'Fluorosis' caused by intake of fluoride was used for the first time in 1930 by two Danish scientists Miller and Gadejinashan to describe the disease of osteosclerosis.

2.4.1 Mechanism of fluoride poisoning

Once fluoride enters the body either through the blood vessels in mouth or through the gastrointestinal route, it reaches the various organs and tissues in the body. Fluoride being an electronegative element and having negative charge is attracted by positively charged ions like calcium (Ca^{2+}). Bones and teeth having highest amount of calcium in the body, attract maximum amount of fluoride which is deposited as calcium fluoroapatite crystals. At the same time, from certain areas (location) in bones or teeth, the unbound calcium is lost (RGNDWM, 1993).

2.4.2 Effect on dental enamel

A condition, now known as dental fluorosis or mottled enamel, was described by Eager in 1901 among the emigrants from Italy. The term mottled enamel was first introduced by Black *et al* who described the disease in detail (Black and McKay, 1916). The permanent teeth are particularly affected, though it occasionally affects primary teeth too. It was in 1931 that direct relationship between mottled enamel and fluoride content of water was established. (Smith *et al*, 1931).

In India, a disease similar to mottled enamel was first reported by Viswanathan to prevalent in human beings in Madras Presidency in 1933. Mahajan (1934) reported a similar disease in cattle in certain part of old Hydrabad state. However, Shrott (1937) was the first to identify the disease as 'fluorosis'. Subsequent to this findings, cases of fluorosis were reported from several other parts of the country.

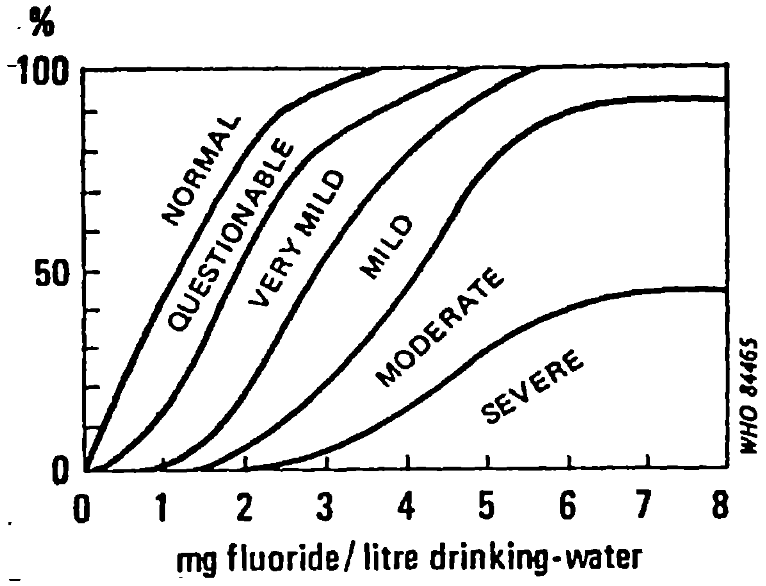

Figure 2.5 Distribution of dental fluorosis at different levels of fluoride in drinking water according to results published by Dean (1942). (Source: WHO, 1984)

The assessment of dental fluorosis is particularly important in areas where the natural fluoride content of water supply is high. The oldest and most widely used index for assessment is the one recommended by Dean (Dean index), (1934). This index, as shown in fig.2.5, contains six categories; normal, questionable, very mild, mild, moderate and severe (WHO, 1987).

In extensive studies, Dean and co-workers related the appearance and severity of dental fluorosis to different fluoride levels in drinking water with the aid of a special classification and weighing of the severity of the lesions.

Normal:

The enamel presents the usual translucent semivitriform type of structure. The surface is smooth, glossy and usually of pale, creamy white colour.

Questionable:

The enamel discloses slight aberrations from translucency of normal enamel, ranging from a few white flecks to occasional white spots, with a tendency to form horizontal striations. This classification is used where definite diagnosis of the mildest form of fluorosis is not warranted but classification of 'normal' is not justified.

Very mild:

Small, opaque, paper white areas scattered irregularly over tooth but involving less than about 25% of the tooth surface. Frequently included in this classification are teeth showing not more than 1-2 mm of white opacity at the tip of the cups of premolon or second molars.

Mild:

The white opaque areas in the enamel of teeth are more extensive, but still involve less than 50% of tooth.

Moderate:

All enamel surfaces of teeth are affected, and surface subject to attrition show marked wear. Brown stain is frequently a disfiguring feature.

Severe:

All enamel surfaces are affected and hypoplasia is so marked that the general form of tooth may be affected. The major diagnostic sign of this classification is discrete or confluent pitting. Brown stains are wide spread and teeth often present a corroded appearance.

Very mild fluorosis is only detectable by only close examination of dried teeth and in good light. Mild fluorosis is more easily recognised by trained examiner. In general, both very mild and mild fluorosis remain undetected by the layman.

As a consequence of higher water consumption, the frequency and severity of dental fluorosis increase with increasing mean temperature .

2.4.3 Skeletal fluorosis

Elevated intake of fluoride over prolonged periods of time may result in skeletal fluorosis, i.e., an accumulation of fluoride in the skeletal tissues associated with pathological bone formation. This disease was first discovered in Copenhagen in 1931 during a routine examination of cryolite workers (WHO, 1984).

Skeletal Fluorosis not easily recognisable until the disease has developed to an advanced stage. Excessive quantities when deposited in the skeleton, it is more in cancellous bone compared to cortical bone. Changes in bone will then be revealed through radiographs. Maximum ill effects of fluoride are detected in the neck, spine, knee, pelvic and shoulder joints. It also affects small joints of the hands and feet. Calcification of certain ligaments is usually associated with atleast 10 mg/l of fluoride in drinking water, which renders difficult movement of joints.

Skeletal fluorosis with severe radiological and clinical manifestation connected with drinking water containing fluoride in excess of 10 mg/l was reported in 1937 from Madras in India by Pandit *et al.* (1940). On the basis of extensive epidemiological survey, Singh & Jolly (1970) stated that crippling fluorosis was result of continuous daily intake of 20-80 mg fluoride for 10-20 years (WHO, 1984).

2.5 Control of fluorosis

2.5.1 Control of fluorosis in India

The government of India has set up a Rajiv Gandhi National Drinking Water Mission on drinking water and related water management in august 1986 for providing adequate quantity of water of acceptable quality and sustained availability on long term basis.

The RGNDWM took cognizance of the problems of drinking water in rural areas. As drinking water is collected from bore wells, open wells, ponds, rivers and lakes, the contamination with chemicals, living organisms and total unawareness of the health problems associated with drinking polluted/contaminated water was wide spread. Facility for drinking water quality in rural areas then either did not exit/ or not within easy reach of the common man (RGNDWM, 1993).

The Rajiv Gandhi National Drinking Water Mission was lunched with following objectives:

- Cover all 'No source' problem habitations
- Supply 40 lpcd in all areas for human beings and additional 30 lpcd in desert areas for cattle within accessible reach
- Evolve cost effective appropriate technology to solve specific problem
- Take conservation measures for sustained supply of water
- Improve performance and cost effectiveness of ongoing programmes
- Create awareness on use of safe drinking water
- Promote community participation.

Mini missions

The concept of Mini-mission is a district based integrated project covering major aspects of rural water supply to attain sustainable water supply on long term basis with close involvement of community and NGO's in the implementation, O & M and health education and solution to specific problem of excess fluoride, iron, brackishness etc. It aims at adopting appropriate technology and such other techno-scientific inputs as scientific source finding for sustainable and safe water supply. The objective is to develop a model in the fifty five Mini Mission districts selected in different part of the country which have unique problems the tackling of which gives an experience which is replicable elsewhere.

Sub-missions

RGNDWM recognised the need to concentrate on certain specific problems which were area specific and at the same time needed to be tackled on a national scale because each of these problems existed in several states. The following sub-mission areas were identified:

- Sub-mission on Control of Fluorosis
- Sub-mission on Iron removal
- Sub-mission on Removal of salinity and brackishness
- Sub-mission on Guineaworm eradication
- Sub-mission on Source finding

The sub-mission 'Control of Fluorosis' unlike other Sub-missions is dealing with a serious crippling health problem 'Fluorosis', its control and prevention.

The implementation strategies involve professionals and grass root level workers from both Health and Public Health Engineering Sectors, besides Administrators from State/District /Taluk/and Village level.

The Sub-mission activities commenced in rural areas from April 1987, on a well structured plan of action which is phased out on the following objectives:

Phase I	To up date and create awareness on fluoride action on body tissues and on the disease 'Fluorosis'.
Phase II	To conduct a health and water quality survey from house to house in all affected villages, taluks, districts and states.
Phase III	To introduce ameliorative and preventive measures for prevention and control of Fluorosis.

This efforts are aimed to achieve the overall goals of the sub-mission as under:

1. To provide safe water (with less than 1.5 ppm of fluoride)

2. To control and prevent fluorosis and fluoride toxicity manifestations and promote health in endemic areas for fluorosis.

2.5.2 Control of fluorosis in Gujarat

The GWSSB action programme (1994-97) to cover all fluoride affected villages is as under.

Table 2.6 Planning to cover fluoride affected villages

Sr. No.	Programme	No. of villages	
1	Total villages identified as fluoride affected	2413	
2	Villages already covered under different water supply schemes	557	
3	Villages remaining to be covered		1856
4	Villages to be covered through proposed World Bank aided projects	309	
5	Villages to be covered through Netherlands assisted projects	195	
6	Villages to be covered fund from Govt.of India under Sub-mission on control of fluorosis		1351

2.6 Fluoride removal technologies

Most defluoridation methods are complicated and expensive as they require certain level of technological skill and chemicals. Several methods have been suggested from time to time for removing excessive fluorides. These may be divided into two basic types, those based upon an exchange process or adsorption, and those based upon the addition of chemicals to water during treatment. (HASKONING, 1994)

The materials used in contact beds include processed bone, natural or synthetic calcium phosphate, hydroxy apatite, magnesia, activated alumina, activated carbons and ion exchangers. Chemical treatment methods include the use of lime either alone or with magnesium salts, and aluminium salts either alone or in combination with a coagulant aids. Other methods include the addition to fluoride water of materials like magnesia, calcium phosphate, bentonite, fuller's earth, bentonite and diatomaceous earth, mixing and their separation form water by settling and/or filtration. All these methods suffer from one or more of the draw-backs of high initial cost, lack of selectivity for fluorides, poor fluoride removal capacity, separation problem, complicated or expensive regeneration.

2.6.1 Precipitation processes

Precipitation processes are based on addition of chemicals (and possibly coagulant aids) and the subsequent formation of insoluble fluoride compounds. Common characteristics of the precipitation processes are large amount of chemicals involved, amount of sludge produced, optimal pH control for the process and residuals in the final water.

Examples of the precipitation processes are:

- excessive lime softening (lime process)
- alum and lime addition (Nalgonda process)
- aluminium sulphate addition (alum process)
- Addition of a phosphate and calcium mixture (Andco process)

Lime process

Fluoride ions present in water are absorbed on and coprecipitates with magnesium hydroxide, following the addition of lime. The amount of fluoride removed is proportional to the quantity of magnesium present in the water. If the magnesium concentration is too low, lime is used to form fluorite (CaF_2).

$$F_{res} = F_{init} - (0.07F_{init} * \sqrt{Mg})$$

Total of 45-65 mg/l Mg^{2+} has to be added to realise a 1 mg/l reduction in fluoride. This method is suitable for waters relatively low in fluoride (< 3-4 mg/l) that require softening.

In this process, the water must be treated to a caustic alkalinity of 30 mg/l, a pH of 10.5 or above and as a such recarbonation is necessary. Magnesia and calcinated magnesite is also used for fluoride removal from water and the fluoride removal capacity is reported to be better at higher temperatures.

Alum and lime addition (Nalgonda process)

Nalgonda process involves the addition of aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation and filtration and disinfection. Aluminium salts may be added as aluminium sulphate or aluminium chloride or combination of these two. The dose of aluminium salt increases with increase in the fluoride and alkalinity levels of the raw water.

Careful control of pH is required in the process to complete coagulation. The amount of alum required depends on alkalinity, pH and fluoride content of the water to be treated. The Higher the alkalinity and fluoride content of raw water, the more alum is needed. The optimal pH for removal is 6.5. Draw-back of this method are large amount of alum needed to remove 1 mg/l of fluoride, careful control of pH, risk of residual aluminium in final water and production and disposal of sludge.

Nalgonda technique of defluoridation is described in detail in para 2.7.

Andco process

In this sophisticated process phosphate-calcium mixture is added to form an insoluble fluorapatite compound. Lowering of fluoride concentration below 1 mg/l is possible.

$$NaF + 3H_3PO_4 + \frac{1}{2} CaCl_2 + 4\frac{1}{2} Ca(OH)_2 \rightleftarrows Ca_5(PO_4)_3F + NaCl + 9H_2O$$

Consumption of chemical is low and amount of sludge produced is also reduced. The facilities for Andco processes are supplied by Andco Environmental Processes Inc., U.S.A. as package plants.

Alum process

In this process aluminium sulphate is added to the water to form an insoluble aluminium fluoride complex, to be removed through sedimentation and filtration. It is possible to lower the fluoride concentration below 1 mg/l through this process, but it requires large amount of alum. To lower the fluoride concentration from 3.6 mg/l to 1.5 mg/l, 250 mg/l alum is required and for further lowering to 1.0 mg/l will need 134 mg/l of alum.

As calcium and magnesium ions interfere with the process it is suitable for soft waters. The fluoride removal capacity can be increased by addition of coagulant aids like activated silica or clays.

The quantity of alum needed and sludge produced is relatively large in this process also high sulphate concentration is reported in final water.

Other precipitation processes like addition of polyaluminium chloride, calcium chloride, gypsum and fluorite, magnesite and dolomite are tested in laboratory, but not widely applied in the field.

2.6.2 Adsorption and Ion Exchange

Most of the fluoride removal methods are based on adsorption and ion exchange, which include removal with aluminium and calcium phosphates (processed bone, bone charcoal, activated alumina, activated carbons, and florex).

Upto 95% removal of fluoride can be realised with adsorption and ion exchange processes. Both require careful process control and safe handling of chemicals. The disposal of regeneration waste is a problem with all ion exchange processes and results in high overall cost for operation and maintenance.

Activated alumina

Activated Alumina (AA) is a special form of acid treated alum. Its affinity for fluoride is very high and it Al_2O_3 (AA) acts as an ion exchanger and is highly selective for fluoride ions. AA is easily available and it is used in contact beds. The fluoride adsorption capacity increases with decrease in particle size. AA is especially suitable for water containing sulphates, chlorides and carbonates. The fluoride uptake capacity is affected by chloride or sulphate ions present in raw water.

Process efficiency depends on pH, alkalinity, AA size and initial fluoride concentration. But the most important factor affecting the fluoride exchange of alumina is the alkalinity of influent water. In low pH and low alkalinity water, alum tends to give up the hydroxyl (OH^-) group to neutralise acidity and thus providing additional sites for fluoride. Better results are achieved in water low in alkalinity.

After breakthrough the contact bed needs regeneration, which consists of three steps. First backwash to remove trapped suspended materials, break up the packed bed and re distribute the media. Secondly regeneration with NaOH solution and the third step is neutralisation to bring the bed back to an acidic condition.

Even problems with process control, operation and maintenance also occur. Clogging of bed is the main problem. Fouling problems are caused by suspended solids and metal hydroxides during loading and regeneration and by insufficient silicate removal during regeneration with caustic soda. Waste produced during backwash is high in pH and fluoride. Care and safety is required in handling concentrated acid and caustic soda.

Phosphatic compounds

Phosphatic compounds include several bone formulations, synthetic tri-calcium phosphate and a mixture of calcium phosphate and hydroxy-apatite. Adsorption/ion exchange methods normally involves passage of water through a contact bed. During operation fluoride removal capacity will decrease and after some time the bed needs to be regenerated. The regeneration process is similar to activated alumina regeneration.

All removal methods rely on high affinity bone has for fluorides. The active component in bone is tri-calcium phosphate (apatite), that has anion-exchange properties. During fluoride removal the carbonate in bone (n $Ca_3(PO_4)\cdot CaCO_3$) is replaced by F^- to form insoluble fluoro apatite.

During regeneration with sodium hydroxide, hydroxide apatite is formed. Excess sodium hydroxide is neutralised through rinsing with acid. Hydroxy apatite then becomes the exchange material and the hydroxy radical is replaced by fluoride.

- Processed bone

Bones are degreased, dried and pulverised to 40-60 mesh size. The powder is carbonized at 1380-1740°F. The product contains tri-calcium phosphate and has a capacity to remove 1,000-1,500 mg of F^- per litre of medium. After saturation with fluorides, it can be recalcinated at around 750°F under restricted air supply to restore the adsorbing capacity of char.Alternatively, the bed may be regenerated by sodium hydroxide solution.

- Bone charcoal

Bone char is produced from natural animal or fish bone which is degreased, dried and pulverised and than charred to remove all organics, and graded for fineness. The fluoride removal capacity of the media is 1,000 mg F^- per litre of media.

• Activated carbon

Most of the carbons prepared from different carbonaceous sources showed fluoride removal capacity after alum impregnation. Granulated activated charcoal, pretreated with aluminium sulphate solution, can remove fluoride from water. In removal process, fluorides form a complex compound with aluminium ions. There is adsorption at the surface of activated charcoal of both free and bound fluoride ions by the products of hydrolysis of aluminium sulphate.

The adsorption of fluorides by granular activated carbon is intensified in an acidic medium. This medium can be regenerated with a solution of aluminium sulphate. During the treatment of water the concentration of SO_4^{2-} and Al^{3+} ions in the water increases but remains below 100 mg/l and 0.2 mg/l respectively.

• Synthetic tri-calcium phosphate

The product is prepared by reacting phosphoric acid with lime. It has a capacity to remove 700 mg of F^- per litre. The medium is regenerated with 1% sodium hydroxide solution, followed by mild acid rinse.

• Florex

Florex is trade name for a mixture of tri-calcium phosphate and hydroxy apatite. The fluoride removal capacity of medium is 600 mg F^- per litre and is regenerated with 1.5 % sodium hydroxide solution.

Ion Exchange Resins

Strong base exchange resins remove fluorides either on hydroxyl cycle or chloride cycle along with anions. Since the proportional quantity of fluorides as compared to other anions is very small, the effective capacity of such resins works out quite low. There are no known commercial resins which are selective for fluoride only. Some inorganic ion exchangers also exchange fluoride for chloride.

Cation exchange resins impregnated with alum solution have been found to act as defluoridating agents. They can be used after treatment with alum solution for defluoridation.

Synthetic resins are most effective when the ratio F/total anions in raw water is high. But most waters show a low F/total anions ratio. An additional disadvantage is that the ion exchange process almost completely de-ionises high fluoride waters.

Other Adsorption and Ion exchange materials

- Defluoron 1

This medium is prepared by treating dried saw dust with concentrated sulphuric acid, washed with sodium carbonate or sodium chloride, followed by 1% aluminium sulphate. Adsorption and ion exchange takes place in the medium, which can be regenerated with 1% alum. The medium is reported to have poor hydraulic properties and high attritional losses.

- Defluoron 2

This material consists of sulphonated carbonaceous material which is loaded with aluminium ions. Regeneration is carried out with commercial aluminium sulphate solution.

Other adsorption and ion exchange compounds include activated bauxite, superphosphate, clays and natural adsorbents, coconut shell, zeolites, Zeocarb 225, Tulsion, Carbion, Agrion O-100, filter carbon, shell sand, Perlites, Filton, Hustad Marmor N2 and N5, and plant carbon etc. Adsorption and filtration of water through a filter bed of these material remove fluoride through ion exchange. The removal capacity of these material are tested in laboratory, and Very little information is available in the literature.

2.6.3 Electrocoagulation

The initial process of electric coagulation is an electrolytic one. Usually aluminium plates are used as electrodes in fluoride removal process. Fluoroaluminium complexes are formed resulting in removal of fluoride from treated water. This method is capable of reducing fluoride concentration to the WHO recommended level.

2.6.4 Membrane processes

Two types of membrane processes are available for the removal of fluoride. Characteristics of membrane processes are total demineralisation of water, pretreatment, high energy consumption, low chemical consumption and concentrated brine production.

- Reverse osmosis

In reverse osmosis the water is forced through a membrane under pressure. Pre-treatment is required for sediment removal and if necessary activated carbon filter for removal of chlorine. Purified water filters through the membrane while the impurities remain behind. The process is effective in removing ions from water including fluoride. High operational costs are involved because of high energy consumption and waste disposal. Without pre-treatment membranes need to be replaced every year else every 3-5 years.

• Electro-dialysis

In electro-dialysis impurities are electrically removed from the water. Here the water does not pass through the membrane, but the ions migrate through ion selective membranes by a direct current electric field. Two types of membranes one permeable to anions and one permeable to cations are used in electro-dialysis.

Electro-dialysis is not ion selective and will remove all ions except OH^-. It is very effective in removal of fluoride. No chemicals are required for standard operation. Water recovery varies between 80-95%, and up to 99% of all salts are removed.

2.7 Defluoridation of water using Nalgonda process

After extensively testing since 1961, many materials and processes including activated alumina, NEERI has evolved an economical and simple method for removal of fluoride which is referred to as Nalgonda process. The method has been used with success in several areas in India.

Nalgonda process involves addition of aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection. Aluminium salt may be added as aluminium sulphate or aluminium chloride or combination of these two. The selection of either aluminium sulphate or aluminum chloride also depends on sulphate and chloride contents of the raw water to avoid exceeding their permissible limits.

Aluminium salt is only responsible for removal of fluoride from water. Apparently this method can be used to lower fluoride concentrations till below 1 mg/l, even though this is hard to achieve when fluoride concentrations are high.

The dose of aluminium salt increases with increase in the fluoride and alkalinity levels of the raw water. The dose of lime is empirically $1/20^{th}$ that of the dose of aluminium salt. Lime facilitates forming dense flocs for rapid setting. Bleaching powder is added to the raw water at the rate of 3 mg/l for disinfection.

Approximate doses of alum required to meet the acceptable limit (1.0 mg F/l) in water at various fluoride and alkalinity levels are given in the Table 2.8. Flow diagram of plant is given in figure 2.7 (RGNDWM, 1993).

2.7.1 Salient features of Nalgonda process

The salient features are:

- No regeneration of media.
- No handling of caustic acids and alkalies.
- Readily available chemicals used in conventional municipal water treatment are only required.
- Adaptable to domestic use.
- Flexible upto several thousands m^3/d.
- Applicable in batch as well as in continuous operation to suit needs.
- Simplicity of design, construction, operation and maintenance.
- Local skills could be readily employed.
- Highly efficient removal of fluorides form 1.5 to 20 mg F/l to desirable levels.
- Simultaneous removal of colour, odour, turbidity, bacteria and organic contaminant.
- Normally, associated alkalinity ensures fluoride removal efficiency.
- Sludge generated is convertible to alum for use elsewhere.
- Little wastage of water and least disposal problem.
- Needs minimum of mechanical and electrical equipment.
- No energy, except muscle power for domestic equipment.
- Provides defluoridated water of uniform acceptable quality.

2.7.2 When to adopt the Nalgonda process

Absence of acceptable, alternate low fluoride source within transportable distance.

Total dissolved solids are below 1500 mg/l; desalination may be necessary when the total dissolved solids exceeds 1500 mg/l, the cause for rejection limit in the absence of alternate source.

Total hardness is below 600 mg/l, the cause for rejection limit in the absence of alternate source. Hardness does not interfere in the defluoridation.

Hardness > 200 mg/l and < 600 mg/l require precipitation softening, and > 600 mg/l becomes a cause for rejection or adoption of desalination. Between 200 mg/l and 600 mg/l hardness, precipitation softening techniques supplement Nalogonda process and, such waters are to be dealt individually on merits.

Alkalinity of the water to be treated must be sufficient to ensure complete hydrolysis of alum added to and to retain a minimum residual alkalinity of 1 to 2 meq/L in the treated water to achieve treated water pH between 6.5 and 8.5.

Raw water fluorides ranging from 1.5 to 20 mg F/l.

The Nalgonda process is a simple and economical process which can be adapted by a common man. It can be adapted at domestic as well as at community level. Both fill and draw and continuous operation systems can be installed for defluoridation of water for community water supply. Nalgonda process is effective even when the dissolved solids are above 1500 mg/l and hardness above 600 mg/l.

2.7.3 Description of defluoridation by Nalgonda process

Nalgonda process is a combination of several unit operations and process incorporating rapid mixing, chemical interaction, flocculation, sedimentation, filtration, disinfection and sludge concentration to recover water and aluminum salts.

Rapid Mix

Provides thorough mixing of alkali, aluminium salts and bleaching powder with the water. The chemicals are added just when the water enters the system.

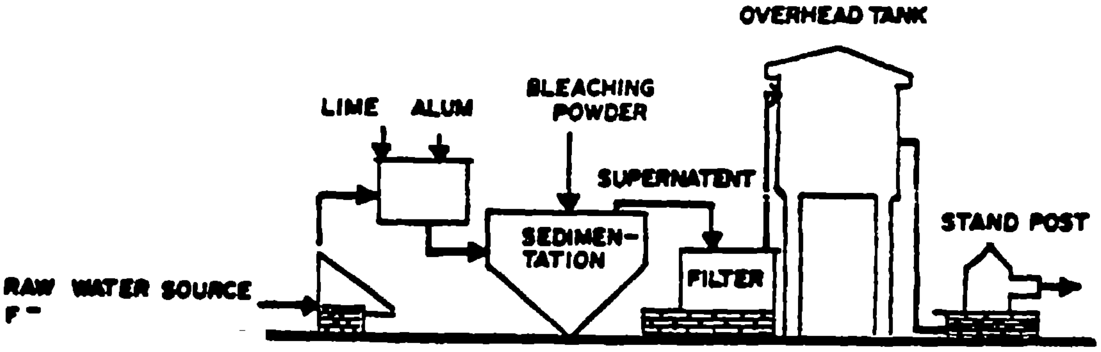

Figure 2.7 Layout plan of Nalgonda process

Flocculation

Flocculators provide subsequent gentle agitation before entry to the sedimentation tank. The flocculation period permits close contact between the, fluoride in water and polyalumenic species formed in the system. The interaction between fluoride and aluminium species attains equilibrium.

The chemical reaction involving fluorides and aluminium species is complex. It is a combination of polyhydroxy aluminium species complexation with fluorides and their adsorption on polymeric aluminium hydroxides (floc). Besides fluorides, turbidity, colour, odour, pesticides and organics are also removed. The bacterial load is also reduced significantly. All these are by adsorption on the floc.

Lime or sodium carbonate ensures adequate alkalinity for effective hydrolysis of aluminium salts, so that residual aluminium does not remain in the treated water. Simultaneous disinfection is achieved with bleaching powder and also keeps the system free from undesirable biological growths.

Table 2.8 Approximate alum dose (mg/l) required to obtain acceptable limit (1 mg F/l) of fluoride in water at various alkalinity and fluoride levels (Source: RGNDWM, 1993)

Test water fluorides, (mg F/l)	Test water alkalinity, (mg $CaCO_3$/l)							
	125	200	300	400	500	600	800	1000
2	145	220	275	310	350	405	470	520
3	220	300	350	405	510	520	585	765
4	*	400	415	470	560	600	690	935
5	*	*	510	600	690	715	885	1010
6	*	*	610	715	780	935	1065	1210
8	*	*	*	*	990	1120	1300	1430
10	*	*	*	*	*	*	1510	1690

* To be treated after increasing the alkalinity with lime or sodium carbonate.

Sedimentation

Permits settleable floc loaded with fluorides, turbidity, bacteria, and other impurities to be deposited and thus reduces concentration of suspended solids that must be removed by filters. Sedimentation theory is complex and of little avail, because floc is not uniform and hence its basic sedimentation properties cannot be given quantitative values and because the influence of eddy currants cannot be predicted. Hence, various factors which influence sedimentation in relation to design and operation rely largely on experience.

Filtration

Rapid gravity sand filters are suggested to receive coagulated and settled water. In these filters unsettled gelatinous floc is retained. Residual fluorides and bacteria are absorbed on the gelatinous floc retained on the filter bed.

Disinfection and Distribution

The filtered water collected in the storage water tank is rechlorinated with bleaching powder before distribution.

2.7.4 Application of Nalgonda process

Based on the volume of water to be treated, the process can be applied at the following levels:

i Domestic for individual houses
ii Fill and draw for small communities
iii Fill and draw type for rural water supply schemes
iv Continuous flow type for larger water supply schemes.

Domestic defluoridation

Defluoridation at domestic level can be carried out in a container (bucket) of 60 L capacity with a tap 3-5 cm above the bottom of the container for the withdrawal of treated water after precipitation and settling. The raw water taken in the container, is mixed with adequate amount of aluminium sulphate solution (alum).

Lime or sodium carbonate and bleaching powder are dosed depending upon its alkalinity and fluoride content. Alum solution is added first and mixed well with water. Lime or sodium carbonate solution is then added and the water is stirred slowly for 20 minutes and allowed to settle for nearly one hour before withdrawal. The supernatant which contains permissible amount of fluoride is withdrawn through the tap for consumption. The settled sludge is discarded.

Table 2.9 Approximate volume of alum solution (millilitre) required to be added in 40 litres test water to obtain acceptable limit (1.0 mgF/l) of fluoride in water at various alkalinity and fluoride levels (Source: RGNDWM, 1993).

Test water fluorides, (mg F/l)	Test water alkalinity, (mg $CaCO_3$/l)							
	125	200	300	400	500	600	800	1000
2	60	90	110	125	140	160	190	210
3	90	120	140	160	205	210	235	310
4	*	160	165	190	225	240	275	375
5	*	*	205	240	275	290	355	405
6	*	*	245	285	315	375	425	485
8	*	*	*	*	395	450	520	570
10	*	*	*	*	*	*	605	675

Fill and draw defluoridation plant for small community

This is also a batch method for communities upto 200 population. The plant comprises a hopper-bottom cylindrical tank with a depth of 2 m equipped with a hand operated or power driven stirring mechanism (Fig.2.10). Raw water is pumped or poured into the tank and the required amounts of alum, lime or sodium carbonate and bleaching powder added with stirring. The contents are stirred slowly for ten minutes and allowed to settle for two hours. The defluoridated supernatant water is withdrawn and supplied through standposts. The settled sludge is discarded.

With a raw water pump of adequate capacity the entire operation is completed in 2-3 hours and a number of batches of defluoridated water can be obtained in a day.

The accessories needed are a few and these are easily available (these include 16 L buckets for dissolving alum, preparation of lime slurry or sodium carbonate solution, bleaching powder and a weighing balance).

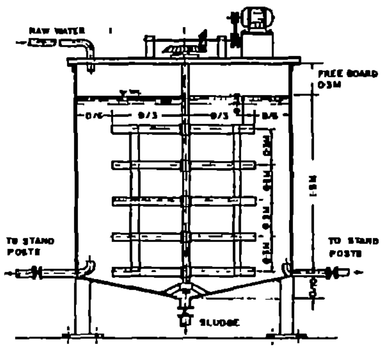

Figure 2.10 Fill and Draw Defluoridation Plant for Small Community

The plant can be located in the open with precautions to cover the motor.
Semi-skilled labour can perform the function independently.

Fill and draw type plant for rural water supply

Fill-and-draw defluoridation plant technology based on the Nalogonda process is designed for removal of excess fluoride from water, at rural water supply.

The scheme comprises of tanks of 10 M^3 capacity each, a sump well and an over head reservoir. A system with two units in parallel for treating water for 1500 population at the rate of 40 lpcd is shown in figure 2.11. The raw water is pumped into the units and treated by Nalgonda process. The treated water collected in sump is pumped to an overhead tank, from where it is supplied through standpost.

Components of Fill-and-Draw Defluoridation Plant

reactor (reaction-cum-sedimentation tank equipped with power driven agitator assembly).
sump well
sludge drying beds
elevated service reservoir
electric panel room
chemical store house

Design considerations

The plant capacities are based on one to four operations in each reactor per day, subject to availability of electricity.

Each reactor will be of 10, 20, or 30 m^3 capacity.

The capacity of raw water pump will be sufficient to fill up the reactors within an hour.

The defluoridated water from the sump well will be pumped to the elevated service reservoir and distributed by gravity through standposts and house connections.

The capacity of the sump well will be equal to the total capacity of the reactor(s).

The capacity of the elevated service reservoir will be half of the volume of the sump well.

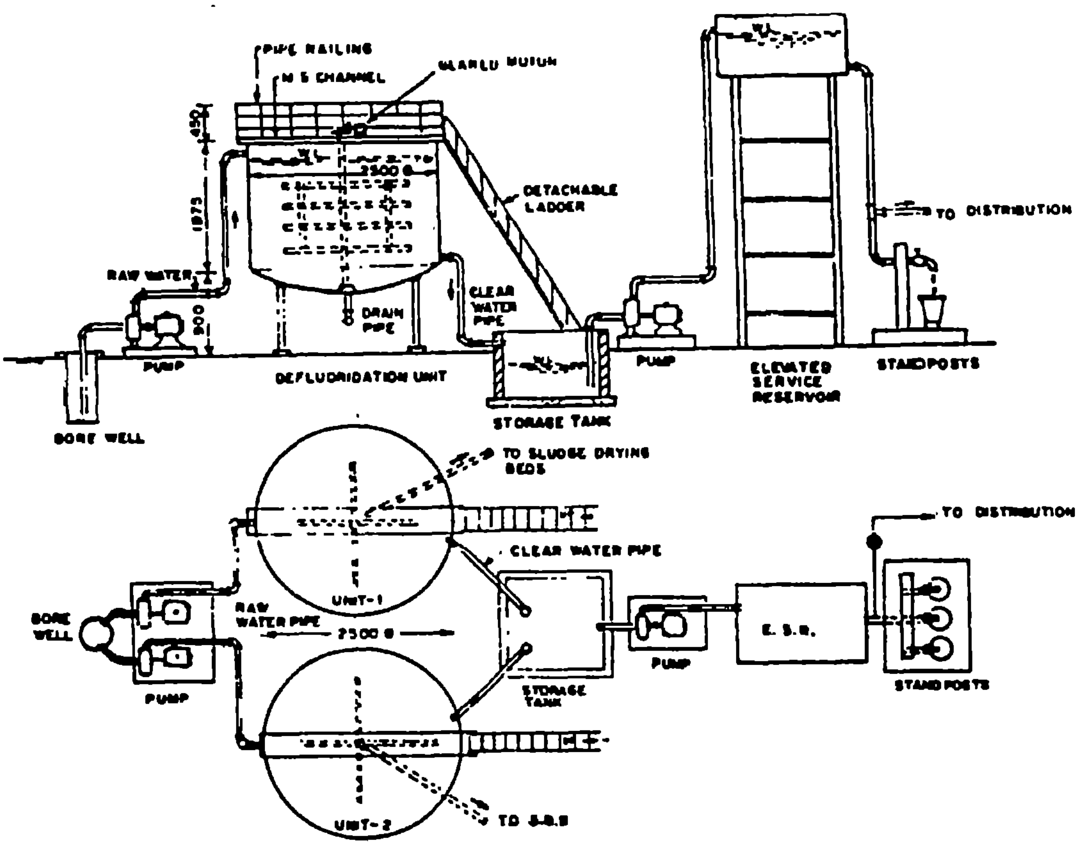

Figure 2.11 Fill and draw defluoridation plant for rural water supply

Continuous flow system for larger water supply

The scheme intends to treat the raw water for villages and includes channel mixture, pebble bed flocculator, sedimentation tank and constant rate sand filters. The design of entire water facilities are available for 500, 1000, 2000, and 5000 population. The scheme is gravity operated except the filling the of overhead tank and delivery from treated water sump.

Channel mixture is provided for mixing lime slurry or sodium carbonate solution and aluminium salts with the raw water. Pebble bed flocculation is used in place of conventional flocculator in order to avoid the dependence on electric power supply. The scheme envisages power supply for two hours each during morning and evening for filling the overhead tank and for supply of treated water.

CHAPTER 3
HYDROGEOLOGY IN GUJARAT

Gujarat has a very peculiar geological and geohydrological situation.The total geographical area of Gujarat State is 1,95,984 km^2. Nearly 35,463 km^2. of this area is covered by alluvium deposits, 1,09,894 km^2 by hard rock formation and 34,962 km^2 area consists of saline soils.

3.1 Geohydrology of Gujarat

Geohydrologically Gujarat State can be divided into three groups:

i) Alluvium area,
ii) Soft rock area and
iii) Hard rock areas

Alluvium areas

North-East area of Gujarat is formed of thick alluvium consisting of alternative beds of sands and clays. Banaskantha, Mehsana, Ahmedabad, Kheda, Baroda and Broach Districts. are formed of thick alluvium which is developed mainly by deep tubewells.

In this alluvium areas, upper strata are highly saline and yield unpotable water while lower strata yield potable water.

Part of the area of Kachchh and Banaskantha Districts are lying adjacent to the little Rann(desert) of Kachchh are highly saline. Similarly, the whole coastal strip composed of sandy strata is highly affected by sea water intrusion and has become saline. Hence this area is not suitable for ground water development.

Soft Rock Areas

In parts of Sabarkantha, Surendranagar and Kachchh, sandstone formations are exposed. In these areas, groundwater development has taken place through deep tubewells and dug wells. Because of less permeability of these soft rocks than alluvium, yield of water is comparatively less.

Hard Rock Areas

The whole of Saurashtra area and eastern fringe of Gujarat State as well as part of South Gujarat is formed of hard rock so called deccan trap, granites and phyllite etc. In such areas ground water development has taken place through bores and dug wells. Deep tube wells are not feasible in these areas due to hard and massive nature of trap rocks.

3.2 Groundwater problems

There are number of problems encountered in the field of providing adequate quantity of potable water for water supply needs of rural & urban population of Gujarat State.

The main problems encountered are as following:

1. Problem of providing adequate quantity of potable water in rural and urban areas situated in hard rock regions.

2. Problems of providing potable water in salinity affected hard rock areas.

3. Problem of providing adequate quantity of potable water in coastal areas of Saurashtra and Kachchh.

4. Problem of providing adequate quantity of potable water in the adjoining areas of the little Rann of Kachchh.

5. Problem of declining water levels in North Gujarat Region

6. Problem of water logging in the Mahi Right Bank Canal command areas in Kheda Dist.

7. Problem of occurrence of high fluoride and high Nitrate in ground water.

8. Problem of providing adequate quantity of water in the hilly areas like Dangs District.

9. Occurrence of droughts.

Gujarat is mainly dependent on the South-West monsoon and many areas in northern Gujarat and Saurastra-Kachchh region are prone to drought conditions. The groundwater recharge is very limited due to the absence of perennial rivers except the Narmada and Tapti river in South Gujarat and Mahi river in Central Gujarat.

3.3 Quality of groundwater

The variation in quality of groundwater in Gujarat state is a very complex phenomenon as it is controlled by not only the normal coastal salinity ingress, but is also influenced by inherent salinity of marine formation and a structural feature. It is further aided by the over exploitation of groundwater in the adjoining coastal plains.

Regarding the confined aquifer, below 100 to 200 metres depth, the groundwater is essentially brackish with electrical conductivity value (EC) of groundwater always higher than 1500 micromhos/cm at 25°C, in the alluvial and semi consolidated formations. Basaltic terrains consist of consolidated rocks with confined aquifers, have yielded ground water with EC values less than 1000 micromhos/cm.

In fresh groundwater areas, presence of fluoride has created problems in domestic water supply. The fluoride problem is more pronounced in the basaltic terrains. Basalt is known to be one of the source rocks of fluoride mineralisation. The fluoride content of groundwater in all the aquifers down to depth of 100 m is found in almost all the Mehsana district. The concentration of fluoride varies from 2 to 9 ppm. The source of fluoride is the fluoride containing alluvial formations, which are derived from the weathering and erosion of fluoride rich basalts and carbonative rocks in hilly areas towards east and northwest of Meshana. Areas yielding fluoride rich groundwater are shown in figure 3.1.

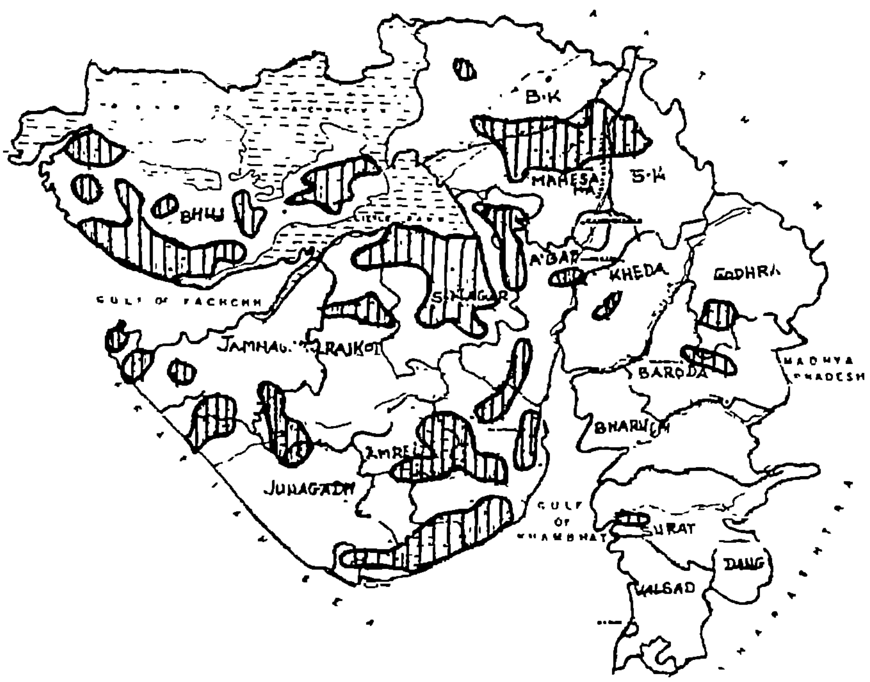

Figure 3.1 Map of Gujarat showing distribution of fluoride in groundwater

CHAPTER 4
WATER SECTOR ORGANISATION

Gujarat Water Supply and Sewerage Board (GWSSB) has been established in 1979 as a Statutory Board for development and proper regulation of the drinking water sector in the State. The Department of Water Supply under the Health and Family Welfare Department of the State Government guides, oversees and looks after the activities of the Board as a Government administrative authority.

4.1 Objectives and Activities of GWSSB

Objectives

The main objectives of the GWSSB could be summarised as:

i To provide safe and adequate drinking water on sustainable basis to the community.

ii To maintain sanitary conditions so as to promote health and well being of the people by preventing water borne diseases.

Activities

The main activities of the Board are explained as under.

i Rural water supply ("No Source Schemes")

To identify a no source village, to accord priority, to develop a safe water source and infrastructure, to put it into commissioning and finally to hand over to respective Panchayat for its operation and maintenance.

Depending upon the size of population concerned and the presence of local water sources, water supply facilities are planned as follows:

* Where population is less than 500 people, simple well or hand pumps are installed.

* For villages having population more than 500 people, small piped water supply schemes are installed.

* Where local source is not feasible (due to quality or quantity), water is supplied through comprehensive water supply schemes (CWSS). Maintenance of such schemes is handled by GWSSB. The GWSSB has developed 279 CWSS covering 2590 villages.

ii Urban works

Sewerage facilities are developed in urban areas on behalf of the local self government on "As and When" basis, where the State Government extend 60 % grant provided the local body contribute 40 % share. ("As and When" means when the funds are available with the state government)

iii Rural sanitation

Low cost sanitation scheme is operated by the GWSSB for providing household latrine facilities in rural areas. About 85 % subsidy is provided for these scheme by the government. A large number of NGOs are involved in motivation and construction of latrines.

iv Augmentation of Rural schemes

Rural water supply schemes once developed, when prove inadequate or become defunct the GWSSB rejuvenates or augments them.

v Scarcity programme

Since the state is prone to draughts, the Board faces challenging task of providing water to scarcity hit villages. Sometime water is supplied through tankers also.

vi R & D activities

The GWSSB takes up certain R & D activities to solve complex problem of water and adopt new technologies. The desalination and defluoridation plants in saline and excessive fluoride areas are example of such activities. GWSSB also intends to take up some R & D projects on alternative sources of energy such as solar power, biogas generation and wind energy as well as water harvesting structures and water recharging etc.

vii Training activities

With a view to make services more effective, efficient and economic, the Board has set up a well equipped training institute (Gujarat Jalseva Training Institute) to develop trained manpower.

viii Water quality monitoring

Emphasis is also laid on testing and monitoring water quality. Different types of laboratories and coverage of districts are as under.

Central laboratory Gandhinagar	(4 districts)
Regional laboratory Vadodara	(5 districts)
Sub Regional laboratory 2 Nos.	(3 districts)
District laboratories, 5 Nos.	(7 districts)

4.2 Organisational setup

The Board consists of 12 members including the Chairman and the Member Secretary. The Chairman and Member Secretary are appointed by the State Government and they work full time. The Department of Finance, Urban Development and Family Welfare are also represented by an official member, one each from the concerned department. Three non-official members have been appointed from amongst the elected heads of the Local Bodies. Four members are appointed by the State Government who are experts in economics, development, planning and engineering. Organisational structure of GWSSB is shown in figure 4.1.

The Member Secretary is the Chief Executive Officer of the Board.

For administrative convenience, the GWSSB has divided the State into three zones as ;

i) Zone-I (7 Districts of South Gujarat)
ii) Zone-II (6 Districts of North Gujarat)
iii) Zone-II (6 Districts of Saurashtra & Kachchh)

Each zone is headed by one Chief Engineer (Civil). Each district has one Executive Engineer (Civil) responsible for implementation and maintenance of the Rural Water Supply Programme and also other water supply activities in this district. Some of the districts where the magnitude of work is more have more than one Executive Engineer of the Civil wing. One Superintending Engineer (Civil) heads a Circle with two or more districts under his control. These Superintending Engineers work as controlling, monitoring and supervising officers and are responsible to the Chief Engineer in charge of the zone.

The Rural Water Supply Programme also involves use of support services like mechanical and electrical engineering, geology and geo-hydrology and project formulation and design. Each district has a Mechanical Executive Engineer who looks after all the drilling, mechanical and electrical activities pertaining to the water supply programme of the district in close liaison and co-ordination with the Executive Engineer in charge of the civil division. The Mechanical Executive Engineer has Geologists working under him for identification, selection and finalisation of water sources.

Three Mechanical Circles headed by Superintending Engineer (Mechanical) have been working at Rajkot, Ahmedabad and Baroda i.e. one each for the Saurashtra and Kachchh, North Gujarat and South Gujarat Zone. One Chief Engineer (Mechanical) working in the head office of the Board looks after planning, co-ordination and monitoring the activities of the Mechanical Divisions in the State. Like-wise, a Superintending Geo-hydrologist in the Board's head office has been made in charge of the planning, controlling and monitoring of the geological/geo-hydrological activities which are utmost essential for planning and selection of water sources for the Rural Water Supply Programme.

For identification of villages under the "No Source" category, surveys and investigation and for project formulation function in the Rural Water Supply programme, separate project divisions and circles have been working under the control of each zone.

A separate Chief Engineer is in charge of the implementation of the projects being financed by the IDA (International Development Agency) of the World Bank with supporting structure consisting of Superintending Engineers and Executive Engineers.

For implementation of the programme under Technology Mission in rural areas, the Superintending Engineers working at Jamnagar, Valsad and Kachchh have been designated as Executive Directors. This is because, the districts of Kachchh, Jamnagar and Dangs have been identified as Mini Mission Districts.

A State level source finding committee has also been constituted for approval of the selected sources with a view to attract the technological inputs from organisations like Central Ground Water Board (CGWB), Space Applications Centre (SAC) and National Environmental Engineering Research Institute (NEERI).

Implementation of 3 comprehensive water supply scheme covering 195 villages and 3 towns were completed by the end of March '93, with Bilateral aid of the government of The Netherlands, at an estimated cost of Rs.402 Million (US $ 13 Million).

4.3 <u>O & M activities</u>

The GWSSB is engaged in design, construction and O & M of water supply and sewerage schemes. Being an engineering organisation much attention has been given to the design and construction of new schemes. O&M has received little attention and where possible GWSSB has left it to the local bodies.

GWSSB only serves a very small portion of the total population in Gujarat. Individual schemes are handed over to the local bodies for o & m, whereas CWSS are maintained by GWSSB. In all schemes where the Board is responsible for O&M, the population served just exceeds 5 million persons, which is only 13% of total population in the state of Gujarat. The rural population served is estimated at 3.9 million persons, while in urban areas the Board supplies water to 1.3 million persons.

The total O&M costs are around Rs.240 million (out of total budget of Rs.2,000 million), while overall recovery is only Rs.17.1 million or 7%. In rural village and comprehensive water supply schemes together the O&M costs are Rs.176.2 million, with 1% recovery rate (Rs.1.7 million). In urban centres the total costs are around Rs.63.9 million and recovery is 24% or Rs.15.3 million.

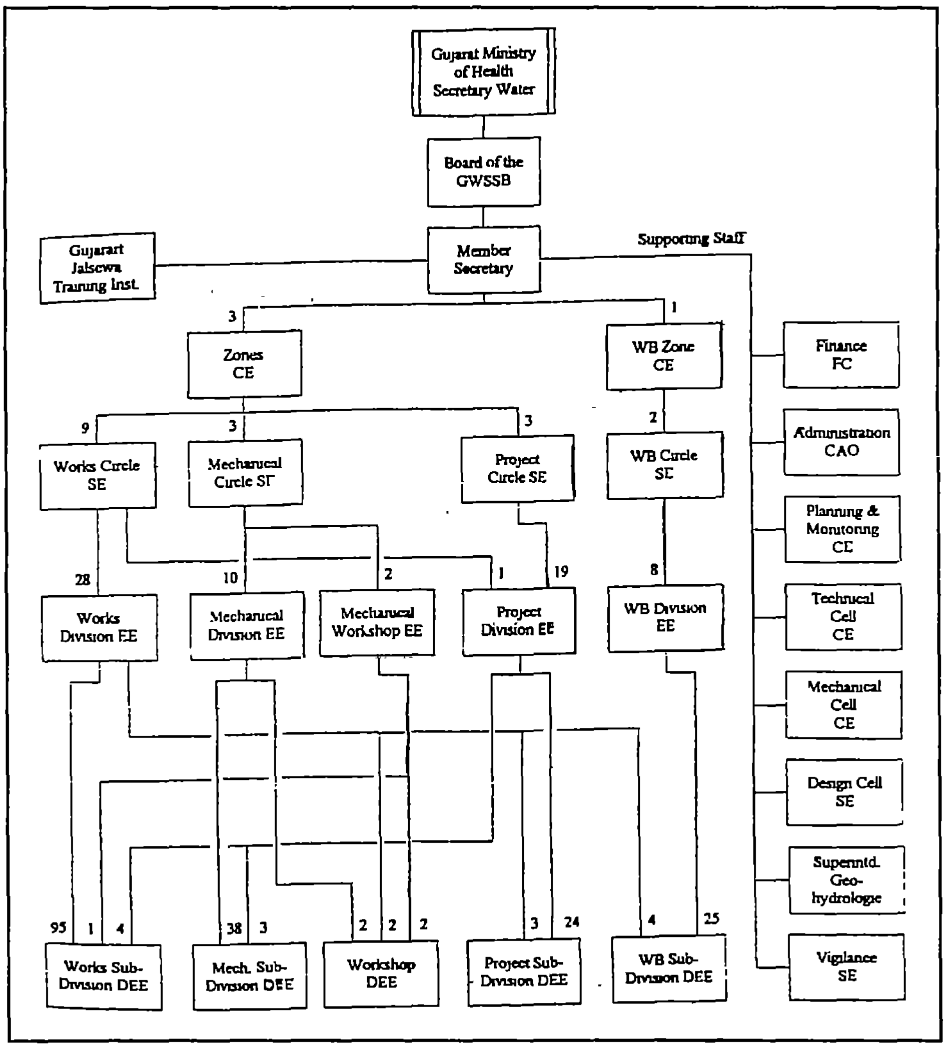

Figure 4.1 Organisational structure of GWSSB

CHAPTER 5
METHODOLOGY

5.1 Introduction

Government of India has set up a Technology Mission on drinking water in villages and related water management to provide safe drinking water to rural population. Under the mission activities, water quality assessment in various parts of country were under taken. The Gujarat Water Supply and Sewerage Board (GWSSB) also under took water quality assessment and identified problem parameters in existing water sources in villages in the state. Fluoride was one of the parameters, identified in many parts of the state.

Gujarat is one of the worst affected state in the country due to excessive fluoride in drinking water. The district of Mehsana and Sabarkantha in particular in North Gujarat are having the severe problem of fluorosis. As per the latest information as many as 447 and 310 villages in Mehsana and Sabarkantha district respectively are threatened with this scourge.

The fluorosis prevention programme in endemic areas includes, as remedial measure two possibilities:

- to provide safe water from alternative source. This is possible if a dependable source is available in the vicinity for a village or implementation of comprehensive water supply scheme based on assured distant water source for group of villages, and

- to remove fluoride from local source by installation of defluoridation plants based on Nalgonda process using fill and draw type schemes.

5.2 Field Situation

After confirming excess fluoride, the 14 villages were selected for installation of defluoridation plants in Mehsana district based on Nalgonda process. Technical expertise were made available through National Environmental Engineering Institute (NEERI) and National Industrial Development Corporation (NIDC). The comprehensive water supply scheme (CWSS) covering as many as 550 villages is submitted to World Bank for financial assistance, covering 309 fluoride affected villages of Mehsana district.

Where as in Sabarkantha district a CWSS was implemented covering 16 fluoride affected villages out of total 24 villages covered, based on river bed infiltration wells as source of fluoride free water.

These plants are evaluated to verify their performance under field conditions and also techno-economic and operational feasibility were studied in the project area (Mehsana district). Study is carried out to check replicability of the fluoride removal technology in the pilot area (Idar taluka of Sabarkantha district). Map of the Gujarat showing these areas is given in annex 1.

Project area

Mehsana is one of the 19 districts of the state of Gujarat and is located in North region of the state. East and west boarders of Mehsana district are lined by the boarders of Sabarkantha district and desert of Kachchh. The total area of district is 9027 sq.km. The district is divided in 11 talukas and has 1099 villages and 11 towns.

Out of these 11 talukas, some of villages in Kheralu, Siddhpur, Patan, Chanasma and Visnagar taluka have groundwater sources containing high fluoride concentration.

The main source for supply in Mehsana district is groundwater. Incidently, the district is very potential in the agricultural activities and this has led to over exploitation of groundwater, resulting into depletion and deterioration of groundwater sources. It is reported that every year groundwater level in Mehsana district goes down by 1.5 to 4 meter. Before 25 years ago, it was around 25 to 30 m, which has depleted today upto about 130-200 m from local ground level. Based on Gujarat Water Resources Development Corporation (GWRDC) reports, in Mehsana district the unconfined and confined aquifer deplete by 2.8 and 6.2 m/yr respectively. As the level of groundwater goes down, the fluoride concentration in water increases. This aggravates the problem of drinking water supply as time goes on.

Out of total 447 fluoride affected villages 14 are covered under defluoridation plants and 309 are proposed to be covered by comprehensive water supply scheme with the aid from World Bank.

Pilot area

Sabarkantha is located in North Gujarat comprising of 10 talukas. Out of these 10 taluka, Idar taluka is selected for studying the applicability of defluoridation plants. Idar taluka is having 200 villages, out of total 1360 villages present in the entire district.

Agriculture is the main occupation of people. Due to a few dams, and canals based irrigation system, exploitation of groundwater is less compared to that of Mehsana district. According to GWRDC, depletion of groundwater in unconfined and confined aquifers are 1.61 and 0.69 m/yr respectively.

The recent survey under technology mission (TM) has identified 310 fluoride affected villages in the Sabarkantha district. 91 affected villages (out of total 200 villages) are located in Idar taluka only.
The number of villages having non potable water quality is given in annex 2.

Fluoride content in groundwater was even detected prior to TM survey in Idar taluka and a CWSS (Jalia-Umedgadh) was approved in February '90 to cover 16 fluoride affected villages of West Idar. Now it is under testing and commissioning stage. TM and GWSSB has organised awareness camp regarding fluorosis in '89 in the district.

Recently 11 defluoridation plants approved under TM, covering 10,008 people (1991) at an estimated cost of Rs.4.0 million. Details are presented in annex 3.

5.3 Approach and Strategy

The solution to fluorosis problem as seen in Gujarat by GWSSB is consisting of two options as mentioned in 5.1. For analyzing and comparing both these options following factors are considered:

i) Cost comparison

This involves,

- i) Comparison of capital costs, and
- ii) Comparison of running charges. The annual cost of water is capitalised for the life of the alternative system in question.
- iii) The final total of the capital cost plus the capitalised cost of o & m which represents the economical viability of the system.

A annex 4 and 5 give the details of investment and o&m costs for new CWSSs and DFPs planned for implementation in pilot area.

ii) Amortization or interest rate

The cost of money is very much dependent on the prevailing market rate of interest. The normal GWSSB practice is to work out the annual burden on any scheme by working out following costs in addition to other o & m costs.

- a) Annual rate of interest, and
- b) Annual depreciation

The higher cost between the two is added to other annual running costs. The details of depreciation costs for CWSS and DFP are shown in annex 4 and 5.

iii) Government's liability (Physical and Financial)

a) Depending on Government's annual plans and priorities and as per the provisions made in budget allocation, the size and shape of a project may have to be chosen/restricted. This is more true in case of CWSS where a number of villages (from 2 to 100 or more) are to be served water from a common source and by a common system.

b) GWSSB has decided to bear the running cost of all DFPs in the state because:

- the plants require adequate technical expertise which is lacking with most of the rural local bodies,
- the plants produce costly water and local bodies can not afford the cost,
- the plants are yet under R&D field application stage.

Over 2413 villages face the problem of fluorosis in Gujarat and need potable water supply, but there are some limits upto which GOG (Govt. of Gujarat) can assure financial liability. GWSSB has to depend on external financial support.

iv) Raw water quality

The concentration as well diversity of specific impurities of raw water dictates the nature of treatment mechanism required for water purification. The more the complexity the more shall be the capital and running cost.

v) Availability of local material, equipment, expertise and energy

This aspect is self evident. Over and above, reducing the capital cost it self, it also makes o & m smooth and simple as well as economical, because for repairs/ replacement one is not dependent on distant external agency.

vi) Impact of inflation

Less the time taken in perceiving, planning, formulating, designing, estimating and implementing a project, less is the impact of inflation on the cost.

vii) Safe yield uncertainties

An alternative which may be a bit costlier but, it gives more safe yield of water may have to be opted against option that is cheaper but, whose yield may be uncertain.

viii) Beneficiary's acceptability

Day by day this aspect is gaining importance in democratic set up. If 10 lpcd of water is unexpectable by the beneficiaries from a DFP, we may have to give 40 lpcd of water through it though the cost economics dictate otherwise.

To minimise the operational cost, if only the quantity of water required for drinking purpose (10 lpcd) is treated and supplied through DFPs, and rest of the supplies are provided untreated beneficiaries may not agree as they have to manage two different storage system at house hold level. Moreover, in such system water also requires to be supplied to times during the day.

ix) Modular design

An alternative that has more in built flexibility to take up and satisfy additional water demands, by addition of suitable modules, at the minimum of additional cost will always be economically preferable.

x) Load factor consideration

Load factor considerations relate to percent utilisation of project. GWSSB projects normally assume atleast 90% load factor, but in practice, they are usually run at 40% to 70% only. For example, one DFP of capacity 1 m^3/hr can produce 24 m^3 of product water. In field, because of non availability of power it operates for 10-12 hours a day only. The load factor = 1/24*12*100 = 50%.

xi) Land requirement and availability

This aspect becomes crucial when comparing alternative proposal and when private land, specially land under irrigation, has to be acquired, for construction of head works and other civil structures specially under CWSS.

xii) Life of component

While working out capitalised cost of running charges, the proposal that has shorter life of its components, usually proves uneconomical because of effect of inflation when replaced in future.

Over and above all these points following points are also considered.

xiii) Availability of spares, equipments
xiv) Design, implementation and O&M complexities
xv) Waste disposal
xvi) More predictable and controllable water quality

To compare the cost for providing potable water to a village, it is selected where the DFP is to be installed and also the same village is included in proposed CWSS. Out of the total 11 villages selected for installation of DFP in pilot area, 6 are to be covered by proposed CWSS later on, as shown in annex 3.

Field work

Project area:

The information related to above aspects for selecting most suitable option is gathered from field as well as from office staff with help of questionnaire given in annex 14, and from office literature.

For studying DFPs in Mehsana district, the GWSSB Division and Sub Division Offices in charge of DFPs were contacted and made aware of study objectives. The plan to visit and study the plant when it is operating was worked out with sub divisional officer (Deputy Executive Engineer). Operation of plant depends on availability of power in that particular village. Usually power is available for 12 hours a day, but timings change every fortnight. First half of the month if it is from noon to midnight, while during the second half it would be midnight to noon. As the office record did not contain any information of power availability at DFPs, 3 plant visit per week were decided.

Neither the operator nor local body persons were informed about these visits. Concerned plant officer in charge (Assistant Engineer) from office was accompanying me to village and was helpful in introducing me to operator and village leaders. As the visits were arranged without prior intimation reliable data were obtained from plant operators and village council.

All the meetings were held at plant site. After formal discussion on water supply situation in the village prior to installation of plant, the operator was asked to tell about daily operations performed to keep plant functioning and about the duties he and two helpers (GWSSB employees), have to perform. Design aspects of plants were studied with help of TM guidelines on plant design.

Sarpanch (Head of village panchayat) and members of village Panchayat, and other committee members who were present there were invited for discussion. To create their interest they were first informed about fluorosis and importance of water quality and with its relation to health, after which they participated actively. During the discussion information regarding awareness, beliefs, expectations, tax collection and revenue generation activities, organisation of village society, political and religious influence etc. were gathered from them. Later, local health worker was contacted for knowing health sector activities in fluorosis control programme. Most of the villages were not having Primary Health Centre (PHC), only visited weekly/fortnightly by Multi Purpose Health Worker (MPHW). It was not possible to know what they do in some of the villages.

Water samples from plant were taken for raw as well as treated water. Various log books were maintained at plant showing power and chemical consumption, water quantity delivered to village, and attendance of operator and helpers. These registers were studied for the information it contain. As the officers were interested in getting log book signed by a village leader, assessment was done to know whether it can be useful for monitoring and evaluating plant performance, and satisfaction of villagers with treated water quality.

Second visit to the same village planned according to availability of power to observe the plant functioning. Lateron back at office, same day the dose of chemicals, according to NEERI's recommendation was worked out and operator was informed to add chemicals accordingly on the day of next visit. He was informed by a special messenger or by post depending upon the time available till next visit. This was done so as the water quality reports are not kept at plant site, for first two visits afterwards it was collected well in advance from office prior to visit.

The collected samples were sent to the District Laboratory at Mehsana for chemical analysis. Each plant was visited two times and some of them three times due to non availability of concerned person or electricity.

Pilot area:

The information about planning to cover fluoride affected villages in pilot area is collected from the office of the Executive Engineer, GWSSB divisional office at Himatnagar (Sabarkantha), and TM Cell of GWSSB head office. Regarding information about new

CWSSs planned to be implemented in the pilot was collected from Himatnagar and Idar offices.

Out of the 11 villages identified for plant installation, recently approved under TM, 6 villages are found also included in CWSS. These were selected to study acceptability of technology. What system they would prefer was known by discussion with Village Panchayat members and representative from villages, which includes farmers, teacher, group leaders etc.

These visits were done for 5 villages in pilot area, and was not accompanied by any field office staff. Evening time was selected for such visits to be sure of presence of Sarpanch (Head of village panchayat) and other concerned personnel. Their views for preferring particular system were brought out during discussion based on O&M, reliability, time required for implementation, cost recovery, and acceptability.

5.3.1 Method of operating DFP

The DFPs installed in Mehsana district are operated and maintained by GWSSB. Method of operating DFP is briefly described as under. Details of these DFPs are given in annex 6.

First of all the reactor is filled to the capacity with raw water from source by pumping. The raw water is having varying fluoride concentration at each plant ranging from 2.62 to 7.0 ppm (annex 6). To reduce this to acceptable limit, NEERI and NIDC have suggested alum and lime dose after conducting jar test for the plants installed by them during testing and commissioning of particular DFP, considering fluoride concentration and natural alkalinity of water. Alum solution (10% w/v) is prepared taking 10% excess alum to account for scaling factor. Lime solution is also prepared as $1/10^{th}$ of alum dose.

Now, stirring operation (20 rpm) starts in reactor with agitator assembly driven by electric motor and reduction gear mounted on the reactor. The quantity of alum solution is prepared is added in the reactor. After 5 minutes of stirring, lime solution is added with specified quantity of bleaching powder. Stirring is continued for 15-20 minutes, during the flocculation phase in which flocs are build up. Flocs are allowed to settle for 2-4 hours afterwards.

The settled water is drawn to underground storage sump, from where it is lifted to an elevated reservoir for distribution to village through standposts and house connections.

The settled sludge in reactor bottom is withdrawn by gravity flow and put on the sludge drying beds. Thus one cycle completes and unit is available for second cycle.

During field visit 11 plants were under operation and 3 plants were under either construction or commissioning stage. The plant operating then, followed the dose of alum as prescribed by installing agency. Water samples of raw and treated water were collected from these plants during visit, and were analyzed at District Laboratory of GWSSB at Mehsana using the SPADNS method. Results are presented in annex 7.

Later, considering raw water alkalinity, the dose of alum and lime were prescribed based on NEERI guidelines as per table 2.8. The samples of treated water were analyzed for fluoride at GJTI laboratory, Gandhinagar and for residual aluminium at Physical Research Laboratory (PRL), Ahmedabad. The GJTI central laboratory or any other laboratory under GWSSB is not equipped with an Atomic Absorbacnce Spectrometer to determine Al^{3+} in water samples.

5.3.2 Design considerations for DFP

For evaluation of design of existing DFP, following standards are considered:

Design aspects for reactor:

Material for fabrication	HDPE, Ferrocement,RCC
Shape	Cylindrical with dished bottom, inlet pipe, outlet pipe sludge drain, manhole for inspection and adding chemicals, and agitator assembly.
Capacity of reactor	10, 20, or 30 m^3
Settling time	2 to 4 hours
Other aspects	Each reactor needs 4-6 hours for complete operation. Each reactor can be operated upto 4 times daily. The number of operation depends on duration of power supply in the village.

Design aspect of Agitator assembly

The agitator assembly consists of mild steel agitator with anti corrosive epoxy coating, reduction gear box with output speed of 20 rpm, vertical downward shaft with ball bearing housing, flanged coupling and directly coupled to totally enclosed fan cooled induction motor of specified rating, 3 phase, 50 Hz, 1440 RPM with $415 \pm 6\%$ voltage fluctuation.

Material of paddles	Mild steel
Width of paddles	1/3 dia. of reactor

Shaft diameter	50 mm for 10 m^3 reactor 75 mm for 20 m^3 reactor 100 mm for 30 m^3 reactor
Type of mixture	Vane type
Material of vane	Mild steel
Type of mounting	Vertical flanged mounted type

Gear box

Input speed	1440 RPM
Output speed	20 RPM
Reduction	72:1 with vertical downward shaft
Rating of motor	3 HP for 10 m^3 reactor 5 HP for 20 m^3 reactor 7.5 HP for 30 m^3 reactor

Dimensions for other components of DFP like sump well, elevated service reservoir, sludge drying beds, raw water pumps, chemical store house and pump room are also specified by TM for different capacity of DFP, but it depends on availability of land at plant site.

5.3.3 Comprehensive Water Supply Schemes (CWSS)

Any CWSS covers number of villages with water from distant perennial source. Usually these sources are located in downstream of a dam as river bed infiltration well. Depending upon the requirement of water to serve the ultimate stage population (population at end of design period of 30 years), and considering yield from source, it is equipped with suitable capacity of pumps. The pumping hours are according to availability of electricity.

Water quality is checked before constructing sources by analyzing water samples of surrounding field wells and also by drilling trial boreholes at source site.

Pumping main connects source and head works site (HWS) , and carries pumped water from well to underground sump at HWS. CWSS is designed with only one pumping main to ease o & m and save consumption of energy. HWS is selected on elevated ground to cover maximum possible villages and reduce the height of elevated service reservoir. Quarters for operator, pumproom, chlorinator room, and generator room are the other civil structure constructed at HWS. At HWS water is again pumped into elevated service reservoir from under ground sump for distribution to covered villages through gravity fed dead end pipe network system. Prior to supply to gravity main water is chlorinated by injecting chlorine into outlet pipe of elevated service reservoir.

Depending on the size of scheme, number of villages covered, local geographical features and hydraulic condition of pipeline, a CWSS may consist of more than one boosting stations. All such boosting stations will have similar structures like HWS.

All the villages covered under any CWSS receives water in a ground level or elevated cistern located in the village. The quantity of water delivered to village is at the rate of 40 lpcd. Distribution of water within the village is controlled and maintained by village panchayat.

Supplies upto bulk supply point is operated and maintained by GWSSB. The beneficiary villages have to pay for water at the rate of Rs.14 per capita per year. The collection of charges and paying to GWSSB is village panchayat's responsibility. Billing may be monthly/quarterly/yearly. The same rate is applicable for village covered under a DFP.

Details of new CWSSs planned in pilot area of Idar taluka of Sabarkantha district is briefly described as follows.

Hatharva-Dobhada stage II CWSS:

The Hatharva-Dobhada stage II CWSS is approved recently to provide potable water supplies to 42 villages of Idar taluka. Out of these 42 villages, 16 villages have fluoride concentration of 1.5-6.05 mg/l in existing water sources. Where as 22 villages the nitrate content is more than 45 mg/l and 8 villages have bacteriological contamination in groundwater sources. Table showing water quality parameter of included villages is given in annex 9.

The scheme is based on 4 infiltration well in river bed. This CWSS is designed for a supply of 60 lpcd. Total estimated cost of scheme is Rs.50.86 million ('93-'94). The population served at present and end of design period shall be 45,187 and 69,757 respectively. Salient feature of scheme is given in annex 4a.

Lalpur-Davad CWSS:

Lalpur-Davad CWSS covers 27 villages out of which 20 villages are affected with excess fluoride in drinking water sources ranging from 2.28 to 6.40 mg/l. Source for the scheme is 4 nos of river bed in filtration wells. Water quality in terms of F^- contamination of included villages is shown in annex 10.

Cost of the scheme is Rs.52.15 million. Water demand for the covered villages at 60 lpcd will be 3.37 MLD and 5.05 MLD at for present population of 56,220 and design population of 84,241 respectively. Salient feature of scheme is given in annex 4b.

5.4 Removal experiments

To get acquainted with working of a DFP, laboratory scale removal experiments were carried out at IHE laboratory. as per the dose of alum prescribed by NEERI (Table 2.8). Determination of fluoride in raw and treated water is practised using SPADNS and Ion Selective Electrode (ISE) method.

5.4.1 Measurement of fluoride in water

Among the methods suggested for determination of fluoride ion in water, the colorimetric method (SPADNS) and ion selective electrode method are the most satisfactory and applicable to variety of samples. Because all colorimetric methods are subject to errors due to presence of interfering ions, it may be necessary to distil the sample before making the fluoride estimation. Addition of prescribed buffer frees the electrode method from interference caused by such relatively common ions as aluminium, hexametaphosphate, and orthophosphate which adversely affect the colorimetric methods. However, unknown samples and samples containing fluoroborate ions (BF_4^-) must be subject to preliminary distillation step in either of the methods.

At IHE laboratory both SPADNS and ISE methods were used for measurement of fluoride.

- **SPADNS method**

Principle:

Under acidic condition fluorides (HF) react with zirconium SPADNS solution and the 'Lake' (Colour of SPADNS reagent) gets bleached due to formation of ZrF^{2-}. Since bleaching is a function of fluoride ions, it is directly proportional to the concentration of F^-. It obeys Beers law in a reverse manner.

Interference:

Alkalinity 5000 mg/l, aluminium 0.1 mg/l, chlorides 7000 mg/l, iron 10 mg/l, PO_4^{3-} 16 mg/l, SO_4^{2-}, 200 mg/l, and hexametaphosphate 1.0 mg/l interfere in bleaching action. In presence of interfering radicals distillation of sample is recommended.

Apparatus:

- Distillation apparatus.
- Colorimeter for use at 570 nm.
- Nessler's tubes, cap. 100 ml.

Reagents:

- Sulphuric acid, H_2SO_4, Concentrated.
- Silver sulphate Ag_2SO_4 crystals.
- SPADNS solution: Dissolve 958 mg SPADNS and dilute to 500 ml.
- Zirconyl acid reagent: Dissolve 133 mg $ZrOCl_2 \cdot 8H_2O$ in 25 ml water. Add 350 ml conc. HCl and dilute to 500 ml.
- Mix equal volumes of SPADNS solution and Zirconyl acid reagent to produce a single reagent. Protect from direct light.
- Reference solution: Add 10 ml SPADNS solution to 100 ml distilled water. Dilute to 7 ml conc. HCl to 10 ml and add diluted SPADNS solution.
- Sodium arsenite solution: Dissolve 5.0 g $NaAsO_2$ and dilute to 1000 ml.
- Stock F^- solution: Dissolve 221.0 mg anhydrous NaF and dilute to 1000 ml. 1ml = 100 $\mu g F^-$
- Standard F^-: Dilute stock solution 10 times to obtain 1ml = 10 μg F^-.

Procedure:

Prepare standard curve in the range 0.0 to 1.40 mg/l by diluting appropriate volume of standard F solution to 50 ml in Nessler's tubes.

Add 10.0 ml mixed reagent prepared as above to all the samples, mix well and read optical density of bleached colour at 570 nm using reference solution for setting zero absorbance. Plot concentration vs % transmission or absorbance.

If sample contains residual chlorine, remove it by adding 1 drop (0.05 ml) $NaAsO_2$ solution per 0.1 mg Cl_2 and mix. $NaAsO_2$ concentration should not exceed 1300 mg/l to avoid error due to $NaAsO_2$. Take suitable aliquot and dilute it to 50 ml.

Add 10 ml acid Zirconyl-SPADNS reagent; mix well and read % transmission or absorbance.

Take suitable aliquots of sample either direct or after distillation, in Nessler's tubes. Follow the steps above.

Calculate the mg fluoride present in the sample using standard curve.

For the experiments carried out at IHE laboratory, AccuVac brand SPADNS fluoride reagent ampules (Cat. No. 25060-25) were used, and distillation of samples was not done as the model water was prepared using demineralised water. As per the procedure prescribed by manufacturer, 50 ml of sample was taken in a 100 ml beaker and tip of ampule containing SPADNS reagent was broken in upside down position, due to vacuum action it suck the content of sample and mixed with reagent. This is transferred to standard square bottles and absorbance was measured using spectrophotometer at 580 nm. Using standards of 0.0 to 1.40 mg/l fluoride content, calibration curve is prepared and shown in annex 13a. Similarly absorbance for all samples were measured and concentration of fluoride is obtained from graph.

Preliminary distillation:

Place 400 ml distilled water in the distilling flask and carefully add 200 ml concentrated H_2SO_4. Swirl until the flask contents are homogenous, add 25 to 30 glass beads and connect the apparatus. Begin heating slowly at first and then rapidly until the temperature of flask reaches exactly 180°C. Discard the distillate. This process removes fluoride contamination and adjusts the acid water ratio for subsequent distillations.

After cooling the acid mixture remaining after above step or previous distillation to 120°C or below, add 300 ml of sample, mix thoroughly, and distil as before until the temperature reaches 180°C. Do not heat above 180°C to prevent sulphate carryover.

add Ag_2SO_4 to distilling flask at the rate of 5 mg/mg Cl when high chloride samples are distilled. Use the sulphuric acid solution in the flask repeatedly until contamination from the samples accumulate to such an extent that the recovery is affected or interference appear in the distillate. After the distillation of high fluoride samples, flush the still with 300 ml distilled water and combine the two fluoride distillates. after periods of inactivity, similarly flush the still, discard the distillate.

- **Ion selective electrode method**

Principle:

The fluoride sensitive electrode is of the solid state type, consisting of a lanthanum fluoride crystal: in use it forms a cell in combination with a reference electrode, normally the calomel electrode. The crystal contacts the sample solution at one face and an internal reference solution at the other. A potential is established by the presence of fluoride ions across the crystal which is measured by device called ion meter or by any modern pH meter having an expanded millivolt scale.

The fluoride ion selective electrode can be used to measure the activity or concentration of fluoride in aqueous sample by use of an appropriate calibration curve. However, fluoride activity depends on the total ionic strength of the sample. The electrode does not respond to bound or complexed fluoride. Addition of a buffer solution of high total ionic strength containing a chelate to complex aluminium preferentially overcomes these difficulties.

Interference:

Polyvalent cations such as Al (Ill), Fe (Ill) and Si (IV) will complex fluoride ions. However, the addition of CDTA (Cyclohexylene diamine tetra acetic acid) preferentially will complex concentrations of aluminium up to 5 mg/l. Hydrogen ion forms complex with fluoride while hydroxide ion interferes with electrode response. By adjusting the pH in between 5 to 8 no interference occurs.

Apparatus:

- pH meter for measuring mV or
- Ion meter (field/laboratory model) or pH/mV meter for precision laboratory measurements.
- Reference electrode (calomel electrode)
- Fluoride sensitive electrode.
- Magnetic stirrer
- Plastic lab wares (Samples and standards should always be stored in plastic containers as fluoride reacts with glass)

Reagents:

- Standard fluoride solution prepared as directed in SPADNS method

- Total ionic strength adjustment buffer (TISAB)

Place approximately 500 ml distilled water in 1 L beaker; add 57 ml glacial acetic acid, 58 gm NaCl and 4.0 gm 1,2 cyclohexylene diamine tetra acetic acid. Stir to dissolve. Place beaker in a cool water bath and add slowly 6 N NaOH (About 125 ml) with stirring, until pH is between 5 and 5.5 Transfer to a 1 L volumetric flask and make up the volume to the mark.

At IHE laboratory TISAB was prepared as prescribed by manufacturer of ISE. Used TISAB components and their concentration were as under:

1 M potassium nitrate (KNO_3)
0.21 M potassium hydroxide (KOH)
0.01 M DCTA (trans-1,2-diaminocyclohexane-N,N,N',N'-tetraacetic acid)
0.30 M potassium hydrogen phthalate (KOOC-C_6H_4-COOH)
DCTA was left out as sample dose not comprise complexing metals.

Procedure:

For connecting the electrode to meter and for further operation of the instrument follow the instruction manual supplied by the manufacturer.

Check the electrode slope with the ion meter (59.16 mV for monovalent ions and 29.58 mV for divalent ions at 25°C)

Take 50 ml of each 1 ppm and 10 ppm fluoride standard. Add 50 ml. TISAB (or 5 ml if conc. TISAB is used) and calibrate the instrument.

Transfer 50 ml of sample to a 150 ml plastic beaker. Add TISAB as mentioned in step above.

Rinse electrode, blot dry and place in the sample. Stir thoroughly and note down the steady reading on the meter.

Recalibrate every 2 hours.

Direct measurement is a simple procedure for measuring a large number of samples. The temperature of samples and standards should be the same and the ionic strength of standards and samples should be made the same by addition of TISAB to all solutions.

Direct measurement results can be verified by a known addition procedure. The known addition procedure involves adding a standard of known concentration to a sample solution. From the change in electrode potential before and after addition, the original sample concentration is determined.

The calibration curve was first prepared by measuring the mV on titroprocessor for standards containing fluoride ion concentration from 0.1 to 10 mg/l. 50 ml of TISAB was added to 50 ml of standard solution, and by lowering the ISE (ISE25F) and reference electrode while applying constant stirring speed, stable reading was recorded. Calibration curve is shown in annex 13b.

5.4.2 Measurement of Alkalinity

Alkalinity of water samples were measured by titration with standard solution of 0.1 N HCl and using Methyl Orange as indicator. Initially all the apparatus were cleaned with distilled water. After shaking sample properly 100 ml of it was taken into 250 ml conical flask. Then 2-3 drops of Methyl Orange indicator were added to produce a solution with a yellowish colour. Titration was carried out with 0.1 N HCl giving an end point with orange colour.

Calculation of alkalinity:

M Alkalinity (as $CaCO_3$) = B*N*50,000/ml of sample

Where, B = Total ml of titrant to reach the end point
N = Normality of acid

5.4.3 Measurement of conductivity

The conductivity of water samples were measured with help of a conductivity meter. Initially the meter was adjusted for proper range of conductance. The conductivity cell was thoroughly rinsed with sample and was immersed in the beaker of sample then. Corresponding conductance was measured.

5.4.4 Measurement of pH

Standardised handy pH meter was used for pH measurements. After placing the electrode in the sample, pH of sample was recorded from digital display. Every time electrode was washed with distilled water for subsequent measurements.

5.5 Jar test or coagulation experiment

Principle:

In water treatment processes, particles and suspended matter are removed from the raw water through sedimentation and filtration. Chemical coagulation is the most important unit operation for the removal of turbidity, as colloidal particles cannot be removed directly by sedimentation.

It is because of their small size, ranging from 1 to 100 μm, that colloidal particles cannot be removed by sedimentation; the required settling times are too large. Moreover, colloidal particles have a negative surface charge, resulting from i) surface reactions (pH dependent hydrolysis of acid and amine groups), ii) lattice imperfections and iii) adsorption of various ions onto the surface. This negative surface charge causes particle repulsion, preventing colloids from agglomeration and formation of larger particles, which would settle down more easily. Due to these combined factors as small particle size and (negative) surface charge, colloidal suspensions are very stable.

To remove such ions, the colloidal suspension has therefore to be destabilized by neutralizing the negative surface charge on the colloidal particles. This is achieved through the addition of coagulants, which are positively charged species. Subsequently, agglomeration flocculation of the destabilized particles will take place; resulting in the formation of larger, easily settleable flocs. These flocs are then removed from the water through sedimentation and/or filtration. In water treatment processes, the destabilization and agglomeration steps together are often referred to as the coagulation process.

Coagulants can be metal salts, aluminium and ferrous sulphate and ferric sulphate, or (organic) poly electrolytes, such as activated silica. The most common coagulants in water treatment are however aluminum sulphate (alum) and iron sulphate. The coagulation mechanism for fluoride removal by means of metal coagulants is discussed in the following section.

Destabilization or Coagulation Mechanism:

Destabilization of the colloids consists of neutralization of the (negative) surface charge, which is achieved through adsorption of positively charged ions. Iron and aluminum ions (Fe^{3+} and Al^{3+}) are therefore very effective coagulants, because of their capacity to form (positively charged) complexes in water.

After dissolution of the aluminium or iron salt, step wise hydrolysis of the hydrated metal ions will occur, resulting in the production of $H+$ and various metal hydroxide products; first there is a rapid formation of metal monomers; in a subsequent, but slower reaction, hydroxy metal polymers, such as $Al_7(OH)_{17}^{4+}$, are generated and finally (poorly soluble) metal hydroxides ($Al(OH)_3$, or $Fe(OH)_3$) are produced. The metal monomers and hydroxy metal polymers are present for a relative short time only, subsequent reactions occur, resulting in the formation of less active coagulant species. The hydrolytical reactions of the weakly acid hydrated aluminium and iron ions are similar. The products of these hydrolytical reactions are strongly affected by the pH.

The chemical and physical aspects of the coagulation process are complex; the actual mechanism of destabilization or charge neutralization depends on the active coagulant species in solution. Three different mechanisms can therefore be distinguished as:

i) Adsorption with charge neutralization:

Adsorption of metal monomers neutralizes colloidal surface charge. Coagulant overdosage causes restabilization through charge reversal, as more than one positive metal hydroxy monomer adsorbs onto the same colloid, resulting in a net positive surface charge: a new, stable, colloidal suspension of positively charged colloids is thereby formed.

ii) Adsorption with bridge formation

Adsorption of metal hydroxy polymers onto several colloids, thereby forming bridges between these adsorbed colloids. Coagulant overdosage causes restabilization through charge reversal, as in this case excess adsorption by hydroxy metal polymers onto one colloid will take place, resulting in a net positive charge.

iii) Enmeshment or 'Sweep floc' coagulation

At high coagulant dosage, formation of insoluble metal hydroxides takes place and the colloids are incorporated into the growing hydroxide flocs and subsequently removed from solution. Overdosage will not result in restabilization.

The pH and the coagulant dosage are the most important parameters in coagulation, but raw water alkalinity and turbidity also affect the coagulation process.

i) Effect of alkalinity on coagulation

The hydrolysis of the hydrated metal ion results in the formation of H^+ and therefore in a pH decrease, thereby directly affecting the coagulation process. The water alkalinity (or bicarbonate presence) can counteract the pH decrease to some extent, the pH of the coagulated water is thereby less affected.

ii) Effect of turbidity on coagulation

Water with low turbidity may even need a higher coagulant dosage than water with high turbidity. This is due to the fact that water with low turbidity contains only a limited number of nuclei which can serve as a base for particle growth. In water treatment practice, the turbidity of raw water is therefore sometimes artificially increased through the addition of coagulant aids, such as kaolinite.

Coagulation is a non-stoichiometric process and it is therefore not possible to calculate the optimum pH and optimum dosage for a given water quality, these parameters have to be determined experimentally, which is done in the Jar Test.

5.5.1 Jar Test

The jar test is a laboratory procedure to determine the optimum combination of coagulant dosage and pH for a given raw water. The test is carried out in a series of beakers (or jars), which are simultaneously and uniformly stirred. In order to determine removal of fluoride at different coagulant dose of alum for varying fluoride concentration as prescribed by NEERI, different amounts of coagulant are added to each beaker filled with model water at a uniform pH. The following steps are carried out in the Jar Test.

Demineralised water of 10 l quantity was prepared to the required alkalinity by adding $NaHCO_3$, and each beaker was filled with one litre of model water using measuring cylinder.

For achieving different concentration of fluoride required quantity of fluoride stock solution was added to each beaker. The stock solution is prepared by taking 221 mg NaF and diluting to 1000 ml to obtain 1 ml=100 μg F^-.

Coagulant doses were prepared by diluting $Al_2(SO_4)_3 \cdot 18H_2O$ (Alum) or $FeCl_3 \cdot 6H_2O$, in measuring tubes.

Alkalinity of model water was determined by titration, using 0.1M HCl and Methyl Orange.

pH and EC were measured for each beaker, and were labelled showing initial pH value, fluoride concentration and coagulant dose, before placing into mixing equipment.

Required quantity of coagulant were added to each beaker, while stirring vigorously at 200 rpm. Coagulants were added as quickly as possible to ensure intense and immediate contact. After addition, rapid mixing was continued for 30 seconds more.

Stirrer was turned to 15 rpm and allowed the solution to be stirred gently for a period of 20 minutes. Meanwhile formation of flocs was observed and observations noted.

After 20 minutes of slow mixing stirrer was turned off and allowed the solution to stand for 30 minutes to enable settling of flocs.

200 ml of sample were taken from each beaker by means of 100 ml pipette and transferred to 200 ml plastic labelled bottle. Pipettes were cleaned for every beaker.

pH and EC was measured of each samples, using pH meter and EC metre as per standard method. The fluoride concentration was measured by SPADNS and ion selective electrode method as mentioned in 5.4.1.

The characteristics of model water for different run and coagulant dose, pH, EC, and fluoride concentration in raw and treated water is given in annex 11.

5.5.2 Contact test

Contact test were also carried out at IHE lab to observe removal of fluoride by different ion exchange and adsorbent species.

The model water and fluoride stock solution were prepared as described above in jar test. pH, EC and temp. measured.

After filling beakers with 1 L of model water having same fluoride concentration of 5 mg/l, 5 g of Cellulose, MnO_2, CuO, $Ca_3(PO_4)_2$, and $CaCO_3$ were added to five different beakers. The solution was stirred for 12 hours at 60 rpm to allow adsorption of fluoride.

After settling of solution in beaker 200 ml supernatant were taken from each beaker with 100 ml pipette and filtered through 45 micron filter paper with vacuum filtration.

After measuring pH and EC, determination of fluoride was carried out as stated in 5.4.1. Results of contact test is given in annex 12.

CHAPTER 6
RESULTS AND DISCUSSION

6.1 Performance evaluation of existing DFPs

The existing defluoridation plants in Mehsana district are evaluated to verify their performance under field conditions on following aspects.

6.1.1 Water supply scheme

Prior to implementation of DFPs, all villages are getting water from existing water supply schemes, implemented by GWSSB or District Panchayat. The villagers have been drinking this water for years together and cases of dental and skeleton fluorosis have been identified in these villages.

The concentration of fluoride in these villages is ranging from 2.62 to 7.0 mg/l. Water from existing sources was found unsafe for drinking purpose and certain villages were selected for installation of DFP, based on Nalgonda technique under Technology Mission.

Water is drawn from existing sources into ESR (elevated service reservoir) and supplied to villagers by gravity through standpost or house connection, without any treatment. These water sources contain excess fluoride. Details of sources, storage and raw water fluoride levels are given in annex 6.

The discharge from the source of water (tube well) at village Matpur and Thakrasana is very poor to meet the daily water requirements of the population to be served. At Matpur, due to less yield, the DFP can be operated for one cycle only, and to meet the water requirement treated water is mixed with raw water while delivering from plant. If power is available for more than 12 hours in a day, the plant can be operated for two cycles as per installed capacity. Immediately after installation of a DFP at Thakrasana village, failure of source was noticed and plant could not be put into operation till development of new source. Finalisation and drilling of new tube well has taken considerable time of nearly a year and it is almost a kilometre away from plant site, resulted in more difficult operation of the DFP for operators.

6.1.2 Design aspect of DFPs

Fill and draw scheme of defluoridation for supplying safe water to the villagers is incorporated. The number of reactors and capacity is decided on the basis of supplying treated water at the rate of 40 lpcd and number of cycle per day.

Each defluoridation scheme comprises of two or three reactors, a sump well, pumphouse, chemical store house and sludge drying beds. Elevated Service Reservoirs (ESR) are generally already existing at each village. Annex 3b indicates typical lay out plan of defluoridation scheme showing various components of a DFP.

Reactors

The reactors are cylindrical in shape and made of RCC or HDPE, except at village Thakrasana, which is of mild steel with fibre glass lining inside. Reactors comprises of dished bottom, inlet, outlet and sludge drain. The top slab has a manhole for inspection and chemical dosing, where as at village Thakrasana reactors are open at top. In such reactors water has every chance of getting contaminated with dust and other impurities.

All the pipe connections for outlet and sludge drain in HDPE reactors were found leaking. Consequently the mild steel supporting structures are corroded. The supporting structure at village Tavadia is worst affected by corrosion, and will still become weaker due to vibrations during operation. The mild steel reactors of the Thakrasana DFP are appeared to be corroded from out side due to weathering action, which can be prevented by anti corrosive paint. Reinforced cement concrete (RCC) reactors were found in sound condition.

All the reactors are equipped with mild steel agitator assembly and a reduction gear box confirming to design standards.

A suitable mild steel platform with sturdy railing across the sides, supported over horizontal girder is provided at a height of 20 cm above the top slab. The motor and gear box assembly is supported over this platform. Alum and lime solution tanks are to be placed over this platform.

The agitator assembly at new RCC plants were found without epoxy coating. This has increased possibility of getting corroded. At village Thakarasana grease was seen on the housing inside the reactor to support vertical agitating shaft, which always remains in water.

No complains reported by operators with agitator motor except at village Matpur. According to the operator, due to the broken coupling connecting motor with reduction gear box, since 1½ months, one reactor can not be operated. As such less quantity of water is treated and to meet with the daily demand of village population, treated water is mixed with raw water while delivering from plant to ESR.

All the reactors are provided with sturdy ladder with railings.

Sumpwell

It is circular in shape having same storage capacity as reactors installed. Treated water after each cycle from all reactor is withdrawn into sumpwell. It is equipped with suitable monoblock pump set for pumping treated water to ESR. Sumpwell at all DFPs was found to match the design considerations.

Elevated service reservoir (ESR)

The defluoridated water after being pumped into these ESRs is supplied by gravity to consumers through public standpost and house connections.

Sludge drying beds (SDB)

There are 2 to 6 sludge drying beds depending on the number of reactors installed at each plant. These are used for disposal of sludge accumulated at the bottom reactors after defluoridation operation. Two sludge drying beds are connected to each reactor and one bed is used at a time for each reactor. The other beds are to be connected to the reactor after the first ones are sufficiently filled with sludge and sludge delivery is discontinued. This sludge is allowed to dry in open atmosphere and supposed to be scrapped off by shovels for disposal by land filling.

So far no sludge drying bed was found scrapped off. The level of beds at village Amudh was found lower than ground level outside the plant compound. Due to improper functioning of drainage system, beds were seen over flowing, and as it can not be drained off. The stagnant water in side the bed had very bad quality and smell. The SDB at village Shahpur DFP has brick lining in the bottom which keeps it dry all the time by absorbing water, and sludge gets deposited over bricks. These can be replaced and old bricks can be used for construction work. It will minimise the problem of polluting groundwater by disposal of sludge in landfill areas

Pumphouse

This is a brick masonry structure with RCC slab to house the electrical controls of pumps and reactors. Usual size of pump house is 3mx3m and 3m height.

Chemical store house

The size of chemical store is decided to store 100 days' stock of alum, lime and bleaching powder or chlorinator. Except at the new DFPs (RCC reactor) almost all the DFPs are provided with chlorinator in chemical store house. All these chlorinators were found out of order during visits, and not used at all since installation, as learned during talks with plant operator, neither bleaching powder was used for disinfection.The stock of chemicals stored was not sufficient for 100 days at any of the DFPs.

6.1.3 Operation of existing DFPs

The reactors were filled with raw water by pumping from the borewell.Accordıng to concentration of fluoride and raw water alkalinity, varying doses of alum were applied to the raw water in the reactors. Three operators are employed at each DFP.

HDPE solution tanks are provided at each plants for preparing and dosing chemicals. Operators, only at Ganget and Sheshpur used these tanks to dose chemicals in solution form, the others were dosing directly in powder form. The weighing scale for measuring quantity of alum to be added was found broken and operators used to decide the quantity on volume basis, at Ranchhodpura and Mahekubpura villages. Alum solutions of 10% concentration and 1% lime slurry is to be prepared in these solution tanks which are placed on the platform above the reactor. The alum is supplied in brick form, which is to be crushed to powder form before adding to the raw water in reactor.

When the agitator assembly of each reactor is switched on, it moves paddles at 20 RPM. First alum solutions is to be added into reactor and mixed with raw water for 1 minute. After this lime slurries to be added and agitation to be continued for 20 minutes.

During agitation at 20 RPM, the contents in the raw water forms flocs of polymeric alumino hydroxide, and fluoride get absorbed on this flocs. The flocs in the reactor are allowed to settle for 3-4 hours. The clarity of settled supernatant can be checked by collecting samples through a tap fitted to the treated water pipe. This was not seen practised as such villagers at Badarpur village complained of sticky and milky water. Settling period of 4 hours duration is found essential for obtaining clear supernatant defluoridated water.

Supernatant is withdrawn into the sumpwell by gravity. It is than pumped into the ESR and supplied by gravity to the villagers. The supplies to the villagers at Mahekubpura, Khanpur, Badarpur and Karsanpura is made two times, once treated water for drinking purpose and once untreated water for general use. The timings of these different supplies are mentioned on notice board outside the DFP. This is done to reduce the operational cost by providing treated water sufficient for drinking and cooking purpose (20 lpcd). This method should be introduced to other villages also. At village Matpur, yield of tubewell is poor, and to meet the demand, treated water is mixed with raw water.

The settled flocs as sludge is withdrawn and spread over sludge drying beds. The seepage water from the beds are carried away through the drain pipe for disposal.This was not found working village Amudh.

Samples from DFPs were collected for raw as well as treated water and were analyzed for TDS, pH, alkalinity, chlorides, calcium, magnesium and fluorides at district laboratory of GWSSB at Mehsana. Results are shown in annex 7. Due to inefficient operation by unskilled/untrained operators and particularly improper dose of chemicals, fluoride level more than 1.5 mg/l is observed in treated water of Karsanpura, Ganget, Khanpur and Shahpur DFPs (annex 7). The treated water samples were also analyzed for residual aluminium at Physical Research Laboratory, Ahmedabad. The residual aluminium in the range of 1 to 5 mg/l is observed in treated water of Matpur and Badarpur plant.

After studying the chemical analysis reports obtained from District Laboratory Mehsana, the dose of alum and lime were prescribed (according to table 2.8) considering raw water alkalinity and fluoride to the plant operators. The result obtained are shown in annex 8, having fluoride level of less than 1.5 mg/l in all samples. This indicates lack of monitoring the water quality especially where fluoride concentration is more than 1.5 mg/l in treated water.

6.1.4 Quality control

The monitoring of raw as well as treated water is done monthly at all DFPs except at new DFPs, where samples are collected and sent to the District Laboratory, Mehsana every week for chemical analysis, by field office. Due to organisational procedure, the results of these analysis are sent to Scientific Officer, Regional Laboratory, Palanpur by district laboratory for authorised signature before sending it to field office. This takes couple of weeks, meanwhile application of chemical in same dose is continued, where fluoride level in treated water is higher than 1.5 mg/l. New proportion of alum dose is informed to the operators, and same procedure is followed for knowing the removal of fluoride with new dose, which generally involves only increased alum dosing. This can be seen in the chemical analysis results of DFPs given in annex 7f.

Samples containing raw water and treated water from a plant are always send together for chemical analysis. The laboratory staff denied to comment or warn the field offices regarding effluent fluoride level higher than permissible limits. During discussion, it was observed that they simply tried to escape form the responsibilities. They were willing to suggest suitable dose of alum and lime if specifically asked for by field offices.

6.1.5 Cost of operation

The cost of defluoridation operation is based on population, water demand, capital cost, personnel, chemicals and energy requirement. The abstract of cost analysis is given in annex 4 and 5. From the cost figures (graphically represented in annex 5b), it is observed that the cost of defluoridation per m^3 water is less for larger capacity plants.

6.2 Selection of fluoride removal technology

6.2.1 Available techniques

The fluoride removal processes described under literature review (ch.2), are listed below and few techniques are studied in detail to check its applicability in pilot area.

i Chemical precipitation

- Excessive lime softening
- Nalgonda technique
- Aluminium sulphate
- Andco process

ii Adsorption-ion exchange

- Calcium phosphate
- Activated alumina
- Synthetic strong base anion resins

iii Membrane processes

- Reverse osmosis
- Electro dialysis

An important objective of field studies was to verify the applicability of available techniques under field situation. The technology that suits the local field requirement are further evaluated on technical, practical, financial and environmental aspects, where as following removal processes not suitable for application in pilot area, are discussed briefly as under with reasons.

Lime process

This methods' efficiency depends on amount of magnesium present in raw water and fluoride removal efficiency is comparatively low. Lime process can not be applied in pilot area because very low magnesium level in groundwater will result in low removal of fluoride.

Aluminium sulphate addition

In this process requirement of chemical (Alum) is more compared to Nalgonda process, subsequently amount of sludge produced is more. The raw water sulphate, nitrate and TDS are quite high in pilot area (Annex 2), the sulphate concentration in treated water may exceed 400 mg/l (annex 7, as in case of DFPs in project area). Due to poor operational efficiency, as observed in DFPs of project area, there is chance of residual aluminium in treated water. Also the Mg^{2+} and Ca^{2+} ions interfere with the process, it can be applied to soft water. For these technique, groundwater in pilot area may require pretreatment.

Calcium phosphate addition

Phosphatic compounds may include several bone formulations. Both processes involving natural and synthetic are similar. The problem with synthetic bone is that it can not be made locally available and needs frequent regeneration and is more expensive too. Natural bone char has also limitations due to aesthetic and religious reasons.

Andco process

This method may prove effective and preferable due to low chemical consumption and reduced sludge production. As less information is available for these technique, its suitability for treating groundwater of pilot area, in quantity of 10-100 m^3 is not decided.

Synthetic strong base anion resins

Specially in comparison to other ion exchange media, synthetic resins are very expensive and non selective for fluoride. Operation and maintenance is too high as frequent regeneration of media is involved. Considering high technical skill and good process control requirements, these processes are not suitable for pilot area.

6.2.2 Comparison of suitable methods

Methods selected for detailed comparison are evaluated on the basis of technical, practical and environmental factors. These factors with their relative importance are listed in table 4 below.

Table 6.1 Comparison of selected techniques for applicability in pilot area

Factors	Relative importance for pilot area	Nalgonda	Bone char	Activated alum
Technical				
- Removal efficiency	yes	good	good	good
- Effluent F^- concentration (<1.5mg/l)	yes	yes	yes	yes
- Pre-treatment required	yes	no	no	±
- Split treatment required	no	no	no	no
- Final water quality (other than fluoride)	±	moderate	high	high
- Capacity upto 100 m^3/d	yes	yes	yes	yes
Practical				
- Treatment plant locally built	yes	yes	no	yes
- Equipments locally available	yes	yes	yes	yes
- Reliability	yes	moderate	moderate	moderate
- Labour input	no	moderate	less	less
- Operational skill required	yes	no	no	yes
- Institutional capacity (training for o&m)	yes	yes	±	±
- Existing plants	yes	yes	no	yes
Financial				
- Capital costs	yes	low	low	moderate
- O & M costs				
·chemical	yes	moderate	high	high
·energy	yes	low	low	low
·maintenance	yes	moderate	low	moderate
·personnel	yes	low	low	low
- Cost of waste disposal	yes	high	moderate	low
- Cost effectiveness	yes	good	good	good
Environmental				
- Chemical use	yes	high	moderate	moderate
- Waste produced				
·type	±	sludge	water	water
·quantity	±	moderate	low	low
Safety				
- Handling of chemicals	yes	no	yes	yes

From the result presented in table 6.1, it is obvious that all the three processes score almost equal on technical ground Activated alumina may not be that efficient with the raw water alkalinity higher than 200 mg/l in pilot area, but it is more favourable for Nalgonda process. Also performance of Nalgonda process depends on operational efficiency.

On the practical aspects requirements of skilled and trained operator is significant drawback for Activated Alumina system. GWSSB is having experience with Nalgonda technology, and with available training facility at GJTI, operators of DFP can be trained to attain maximum possible operational efficiency.

Cost of chemicals is high for activated alumina, considering financial aspect and also involves higher safety standards in handling chemicals. This holds true for bone char process too.

Over all conclusion can be derived that, for present situation the application of Nalgonda technology is practically, technically and financially more attractive.

Besides this it is also worthwhile to try Nalgonda process in combination with bone char, where fluoride level are very high. Bone char filters can be used to polish the water treated through Nalgonda process. Reduction in alum dose for Nalgonda process and higher loading rate of operation for bone char can be achieved, and number of regeneration can be reduced for filters.

6.3 Feasibility study for DFP in pilot area

The solution to fluorosis problem in pilot area comprises of two options viz. DFP & CWSS. The GWSSB has planned to install 11 DFP out of total 304 sanctioned in pilot area under Technology Mission (TM). Two CWSS covering 36 fluoride affected villages are also sanctioned by GWSSB in pilot area. The details of these DFPs and CWSS are listed in annex 3 & 4. Comparison of both these option is done considering various aspects as under.

Cost

As the planned implementation period for CWSS is of 3 years, capital costs are capitalised for consideration. Installation of DFP can be completed within 1 year or even less. For DFP of 10 to 70 m^3/d capacity, capital cost ranges between Rs.2.62 lacs & Rs.8.43 lacs, where as the same for CWSS is Rs.508.62 lacs & Rs.521.49 lacs, respectively for Hatharva Dobhada II (HD II) and Lalpur Davad (LD) CWSSs. The capital cost per capita for DFP of 10 m^3 capacity and 70 m^3 capacity is Rs.296.0 and Rs.1587.0 respectively. The same for CWSS is Rs.780.0 and Rs.920.0 for HD II and LD CWSS respectively. Similarly annual o & m cost per m^3 of water for DFP ranges between Rs.7.99 & Rs.30.49, and for CWSS HD II and LD are Rs.6.59 & Rs.7.67 respectively. Details are shown in annex 4 & 5 and this figures indicate that DFP is cheaper for larger capacities and higher populations. Graphically it is represented in annex 5b.

The charges to be paid towards services are same for both the options of Rs.14 per person per year. But figures in annex 4 represent only recovery of annual o & m charges only through these recovery system and nothing towards capital cost of CWSS. The cost recovery can be more effective in DFP, as it is concerned with one particular village. The recovery percentage can be raised by involving of community in o & m of the installed facility.

Liability of GWSSB

DFPs are to be implemented under TM programme. 75% of the fund is received from Government of India (GOI) and GWSSB has to contribute remaining 25% amount. This is also applicable for CWSS covering fluoride affected villages. CWSS usually covers more villages in addition to fluoride affected villages. This includes enroute, drought prone, and non functioning rural water supply schemes. Fund received from GOI for such CWSS is a part of total estimated cost, required for fluoride affected villages and not for all other villages included in the CWSS. O & M of both type of scheme rests with GWSSB.

Raw water quality

Water quality parameters of pilot area (annex 2), reveals groundwater quality is very poor, not only due to fluoride but also nitrates and TDS levels are higher than permissible limits as per IS:10500 (1991). Details are shown in annex 15. The chemical analysis results of water treated through Nalgonda technique shows increase in TDS and sulphates and no change in nitrates concentration. The villages having this type of water quality problem can not be put under DFP scheme. Sources for CWSS is either surface water or river bed infiltration wells, ensuring better raw water quality compared to groundwater.

Availability of local material, equipment, energy and expertise

Formerly DFPs were installed by NEERI or NIDC, now local contractors are also undertaking construction of DFP, confirming to TM specifications. GWSSB has a well established laboratory network, and experience with Nalgonda process, optimisation of chemical dose and training to operators are possible. All the CWSS implemented so far are designed by project wing of GWSSB. Engineering expertise is available for both options.

Energy requirement is more for CWSS compared to DFP. Although both systems depend on availability of power for pumping purposes, the CWSS requires more power than 12 hour/day and DFPs are designed considering 12 hour availability of power per day. To minimise number of sources and pump installations, special electrical feeder is erected for CWSS through Gujarat Electricity Board (GEB) to ensure 24 hour power supply. GWSSB has to bare the erection charges for such special feeder line which is expensive.

Impact of inflation

Time taken in perceiving, planning, formulating, designing and implementing a CWSS is always more than a DFP. For example, the Jalia Umedgadh CWSS covering 24 villages in pilot area was sanctioned in February '90 and commissioned in December '94. Time overrun and cost overrun is normal phenomena for CWSSs, which is not common for DFPs.New CWSS has a target for implementation of 3 years and for DFP of 1 year.

Safe yield

River bed infiltration well or intake from a dam is selected as a source of CWSS to ensure daily pumping of 3-5 MLD (3000-5000 m^3/d) through out the life of scheme. Any DFP has to be installed based on local source of water in vicinity of village, requires more emphasis on scientific source finding to ensure reliability of source during life of a DFP. The pilot area is drought prone and is affected every third year by drinking water scarcity. Depletion of ground water is 0.69 to 1.61 mt every year, so change in groundwater quality can not be ruled out. In safe yield consideration aspect CWSS scores high.

Beneficiary's acceptability

Design of new CWSSs to be implemented in pilot area are based on 60 lpcd supply rate, and the same for DFPs are 40 lpcd. GWSSB is trying to satisfy beneficiaries with treated water supply for drinking and cooking purpose only from DFPs to reduce o & m cost. During interviews in project area, consumers expressed hardship of storing water separately for drinking and other purposes. This may inclined them more towards a CWSS because the charges to be paid for services of GWSSB is same for both options.

Modular design

DFPs have more in built flexibility to take up and satisfy additional water demands. It can be achieved by increasing number of cycles per day or by installation of additional reactor (HDPE) which is readily available. In case of CWSS, it is designed for 20% additional water demand, but as water loses are not considered in design, and sometimes it is as high as 30% or more, meeting with additional demand is quite difficult. Changing of pipe lines, increasing pump capacity or laying parallel lines may not be economically attractive.

Load factor

Load factor consideration relates to the percent utilisation of installed capacity. In pilot area it is mainly depending on power availability, applicable to both options. Usually 24 hour power supply is made available for CWSS by paying extra to GEB for special feeder, this increases value of load factor for CWSS as compared to DFP.

Land requirement

The implementation of CWSS is often delayed due to acquisition of private land involving lengthy procedures, for getting possession. Land is to be acquired for the construction of head works and booster station sites. It also involves additional cost towards payment of land acquired. Within the village, piece of land is always available for construction of DFP, or it can also be incorporated at existing water works site.

Life of components

CWSSs are designed for 30 years life span where DFPs are for 20 years. DFPs are always more flexible for upgrading even after end of design period. HDPE reactors can be shifted to suitable population villages.

Design and implementation

Availability of spares and equipment is not problem for any of the options. GWSSB engineers (project wing), design CWSSs including surveying and formulations of project. These activities and approval of CWSS takes time. Again during procurement and implementation stage due to involvement of multifaced construction activities it requires considerable time. For DFP, GWSSB invites offer on contractor's own design, and as no procurement is to be done by GWSSB, implementation is fast.

Predicable and controllable water quality

Clear water quality is more constant through CWSS than DFP, as it is drawn from river bed infiltration wells constructed in the downstream of dam. The source of water for DFP is always groundwater, which changes with season and depth of aquifer. The water quality from DFP also depends on its operational efficiency as it involves treatment process, whole in CWSS only treatment involved is chlorination. Water is chlorinated by injecting chlorine into gravity mains through mechanical chlorinators.

Relative evaluation

During selection of options, as dealt with aspects mentioned above, deeper evaluation of them is made as here under. At this stage factors considered are listed below with their relative importance is considered for evaluation. These factors are listed below:

Factors

- Affordability
- Acceptability
- Implementation time
- Community participation
- Reliability
- Flexibility
- Health improvement
- Impact on environment
- Service level

The affordability is evaluated based on capital and recurring cost, as the tariffs to be paid for either options are same. But percentage of cost recovery will be higher for DFP. As far as acceptability is concerned, level of acceptability on community side has two possibilities, i) they have preference for what comes first and, ii) supply level of 60 and 40 lpcd through CWSS and DFP gives more preference to CWSS.

The options are to provide safe water, as at present, it contains excessive fluoride, and has direct impact on health of consumers. Earliest availability of safe water carries more importance, as such implementation time is most important and not compromisable as present water quality will cause undesirable effect on health is consumption is continued. Considering the relative importance of other factors following arguments are given for various aspects.

Regarding health improvement also both options aim at providing fluoride free safe water. As regards reliability CWSS is poor, since breakage in transmission main may affect the supply to the entire area. It is better with DFP. Being the piped supply providing water on standpost and house connection, service level for both the options are same and good.

Coverage of large number of fluoride affected villages through CWSS is not possible in short time. This can only be achieved by installing DFPs with HDPE reactors, which can easily be shifted when village is supplied safe water through CWSS. All other required structures like pump house, ESR, source of water with pumping machinery etc. already exists in all most all villages of pilot area. This type of flexibility with DFP will enable implementors to provide safe water immediately to worst affected villages.

Regarding impact on environment, for CWSS there is no environmental pollution, but in DFP chemicals are used for water treatment and disposal of fluoride rich sludge in landfill have negative impact on environment. The only treatment involve in a CWSS is chlorination.

Compared to DFP, CWSS is large in size and involves complicated o & m activities, it is difficult for the community to take over for o & m. The head works sites and booster stations feed number of villages at a time, involvement of community in o & m of mains and HWS is not feasible at present when community is not organised. In DFP there is much scope for involvement of community. DFPs are installed for individual villages, and organising community for a village is simpler than for large number of villages.

The relative grading is used for qualitative analysis in terms of positive sense of acceptance and presented in table as follows.

Table 6.2 Relative evaluation of CWSS and DFP

Criteria	Option 1 (CWSS)	Option 2 (DFP)
Affordability	Excellent	good
Acceptability	good	good
Implementation time	more	less
Community participation	average	good
Reliability	average	good
Flexibility	good	Excellent
Health improvement	good	good
Impact on environment	no	more
Service level	good	good

From this evaluation, it is concluded that option 2 (DFP) based on Nalgonda process is best suited alternative, specially when implementation time is given importance considering adverse health effect of fluoride if consumed for a long time. This is of vital importance as almost 6% of population is suffering from fluorosis at present in pilot area.

The other advantages, like utilising existing water source, involvement of community in o & m, shifting of DFP to other village will also be gained by selecting DFP as immediate solution for the villages where fluoride levels as higher than 3 mg/l, and waiting for coverage through CWSS may not be a wise decision. Moreover many village people have very clear preference for DFP, as they are well aware of fluorosis and not willing to suffer any more.

6.4 Involvement of community & Organisational responsibilities

GWSSB has planned to cover all fluoride affected villages and had already covered number of villages through DFP or CWSS, and now it is time to shift towards the critical issue of sustaining what is installed and will be installed. From the performance evaluation studies it is clear that o & m is becoming a challenge. GWSSB can not continue to carry over growing maintenance burden very much longer. The only lasting solution is to share the burden with user, who has to own and maintain the services.

Community involvement, however is still being envisaged as something that can be achieved by simply persuading the user to take charge, once implementor (GWSSB) has finished installing their target number of DFPs or CWSSs. O & M of a DFP is simple compared to that of a CWSS. Till today DFPs are GWSSB managed, and need is to make it user directed and user managed for better performance.

For both options, non involvement of community reflects failure of implementing agency to share decision making power with the user in planning and implementing stages. Members of Bhuvel Village Panchayat in pilot area expressed why should they come forward to shoulder o & m responsibilities, when they have no say in situation analysis, choice of technology and system of operation. They have clear preference for DFP and had also visited the Ranchhodpura defluoridation plant in project area. It is included under Lalpur Davad CWSS and also proposed to be covered under TM programme for installation of DFP.

The elders at village Sabalwad (pilot area) suggested an open well as a source of water supply for their village near a pond built by themselves to collect rain water for recharging of their field wells. They feel this well will be sufficient to meet their daily water requirements. The existing source is also an open well but contains excessive fluorides and yield from this well is not sufficient during peak summer days to met with the water demand of the village. GWSSB has planned to cover this village through now functioning Jalia-Umedgadh CWSS, and also sanctioned by TM for installation of DFP. Still villagers of Sabalwad and Bhuvel do not know, how GWSSB will be providing safe water to them i.e. through which option.

In this situation it is impossible to think of involving community in o & m suddenly after services are installed. Villagers need to be involved in defining problem (fluorosis), need for safe water and working out solutions. They will take over and manage only if they can direct the course of programme interventions. Women of Aroda village expressed that they would encourage family head or their husbands to pay charges for the water if services are designed considering their opinion too. Sarpanch at Aroda wondered why implementing agency has spend years together for survey and investigation and ultimately finalised to cover Aroda village through LD CWSS. Now all of sudden they have decided to install a DFP based on existing source (an open well), which is developed by GWSSB and has sufficient yield to meet the water requirement of village, under TM programme. They are not aware of the solution designed for them, like what Sarpanch of village Limbhoi expressed, that by linking to existing CWSS they can get safe water immediately instead of including in HD II CWSS and also proposing a DFP.

Fall out of this set of circumstances has been marginalisation of the role of community in process. People perceive Rural Water Supply (RWS) to be GWSSB's acknowledged responsibility and getting water supply as 'their right'. Till date planning, installation and o & m are carried out by GWSSB with little or no involvement of user, thus promoting a popular impression that implementor has unlimited capacity to provide and maintain water supply to all villages. It is also required to change the user from being a passive recipient of GWSSB planned benefits to an active co-partner of GWSSB in planning, installing and o & m of RWS.

Under given circumstances an alternative for going on for a particular option may be an optimal choice but the same may not help in another set of circumstances, as villagers of Bhuvel preferred a DFP and people of Limbhoi wants water from a CWSS.

6.5 Removal experiments

6.5.1 Coagulation tests

Fluoride removal experiments (coagulation) were carried out in IHE laboratory using aluminium and iron salts as coagulant to study removal mechanism in Nalgonda technique of defluoridation. Effect of coagulant aid was also studied in coagulation using polyelectrolyte. In contact test adsorption of fluoride on different absorbent were studied. Details of laboratory work is briefly described as under. Calibration curves and results are presented vide annex 11 to 13. Results with SPADNS and ISE are comparable where alum is used as coagulant and shows ISE results on much higher side than SPADNS for iron chloride as coagulant.

Run # 1

The initial alkalinity of model water was 355 mg/l and pH was 8.1. Due to less alkalinity, after coagulation with alum, reduction in pH was significant, which indicates necessity of higher raw water alkalinity and justifies addition of lime or sodium carbonate to ensure effective hydrolysis of aluminium salts.

The dose of alum administered was doubled than the recommended values as per table 2 for fluoride level of 1, 2 and 3 mg/l at certain alkalinity. The reduction in F^- after coagulation is significant and ranges between 0.19 to 0.44 mg/l, measured by ion selective electrode (ISE) method. Results are shown in annex 11a.

Run # 2

Nalgonda techniques removal of fluoride to permissible value of 1.5 mg/l with recommended dose of alum for a certain level of alkalinity. In this run same was established. For initial fluoride concentration of 2, 4 and 6 mg/l, and alkalinity of 435 mg/l, final fluoride concentration observed is 0.59, 0.68 and 0.76 mg/l. But for model water containing 6 mg/l fluoride and pH of 8.2, final pH value was dropped to 6.1, indicates need for higher raw water alkalinity. Measurement of fluoride is done with ISE and results are given in annex 11a.

Run # 3 & 4

For model water of pH 8.3, alkalinity 480 mg/l, and fluoride content of 2, 4, and 6 mg/l, iron chloride was used as coagulant in dose of 620, 940, and 1430 mg/l and polyelectrolyte as coagulant aid was added in 1.0, 1.50 & 2.30 ml proportion respectively. Formation and settling of flocs were observed only where final pH was higher than 5. Suspended flocs were seen for final pH value of 4.3 and no formation of flocs at pH 3.8.

Results as shown in annex 11b, indicates need for higher raw water alkalinity and higher dose of coagulant compared to coagulation with alum. Same experiment was repeated but performed without addition of coagulant aid, removal of fluoride ion is observed reduced by 50% and more lowering of pH.

Run # 5

All the model water parameters were kept same as run # 4, and 1M NaOH in was added in proportion of 4, 6.8 & 12 ml to the pre fluoridated water of 2, 4 and 6 mg/l respectively. Dose and type of coagulant are also not changed. Addition of NaOH has helped to maintain final pH of 6.9 and good flocculation and sedimentation was observed. Due to proper formation settling of flocs significant removal in fluoride is observed, when measured with SPADNS and shows negligible removal when measured with ISE. Results are shown in annex 11 c.

Run # 6

Model water containing 4 mg/l concentration of fluoride, pH 8.5 and alkalinity of 450 mg/l was coagulated with alum using starch as coagulant aid to check the possibility of reducing dose of alum for Nalgonda technique addition of starch dose not affect pH like polyelectrolyte. With 25% and 50% of recommended alum dose in addition with starch shows reduction fluoride from initial 4 mg/l to 0.93. Comparing with the removal of fluoride without starch in run # 2 where removal is from 4 to 0.63 mg/l, indicates removal efficiency decreases with addition of starch.

Starch can be used as coagulant aid to reduce dose of alum. It is easily available, except being biodegradable it may cause problems with sludge disposal and scaling inside reactor may affect the water quality due biodegradability of starch.

From all the coagulation experiments it is concluded that using iron chloride as coagulant is expensive compared to alum for removal of fluoride and requires more raw water alkalinity.

6.5.2 Contact tests

The contact tests were performed to study the effect of controllıng factors such as pH, contact time, ratıo of adsorbate (F^- ion) to absorbent on the rate of fluoride removal in batch operations. The absorbents used in contact test were $CaCO_3$, MnO_2, CuO, $Ca_3(PO_4)_2$ and cellulose. Model water containing 5 mg/l fluoride concentration, initial pH of 8, was stirred continuously at 60 RPM for 12 hours in jar test apparatus.

Test results measured with SPADNS shows significant reduction of fluoride from 5 mg/l to uniformly 1 6 to 1.7 mg/l for all absorbent. The same determination done with ISE shows removal of fluoride only where $Ca_3(PO_4)_2$ was used as absorbent. General observation shows test does not have much effect on pH. Results are shown in annex 12a & 12b.

6.5.3 Determination of fluoride

Regarding determination of fluoride values obtained with SPADNS are in good agreement with ISE for samples of treated water form DFP brought from India and tested at IHE (annex 8b). For the samples tested after coagulation experiments using alum at IHE laboratory, SPADNS gave lower values while ISE gave higher values. The results obtained with either method where iron chloride was used as coagulant are not comparable as SPADNS shows marked removal and ISE shows no removal of fluoride.

A summary of fluoride removal experiments is given in table 6.3.

Table 6.3 Summary of fluoride removal experiments

Run #	Process	Chemical used	Result
1 & 2	Coagulation	$Al_2(SO_4)_3$	Effective reduction in Fluoride content
3 & 4	Coagulation	$FeCl_3$	pH dropped below 5 for higher dose and no floc formation
5	Coagulation	$FeCl_3$ with pH correction	% Removal of F^- decreases even with increased dose of coagulant
6	Coagulation	$Al_2(SO_4)_3$ with starch	Starch improves removal efficiency
1 & 2	Contact test (Sorption tests)	$CaCO_3$, MnO_2, CuO, $Ca_3(PO_4)_2$ and cellulose	Removal of fluoride observed only with phosphatic compound

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

Based on analysis of data from laboratory work, field investigations and other findings, following conclusions are drawn.

7.1 Conclusions

General:

* For rural water supplies a fill and draw defluoridation plant (DFP) based on the Nalgonda process may work satisfactorily.

Raw water quality:

* Groundwater can not be used directly because of excessive content of nitrate, fluoride, sulphate and TDS, where as surface water quality is such that it can be used without treatment except disinfection, if drawn from the river bed infiltration wells on downstream of a dam.

DFP performance:

* Poor attention and sincerity in operation of DFPs reduce the efficiency of fluoride removal drastically, and also increases the risk of residual aluminium in treated water.

* No proper system for quality monitoring and process control is existing at all defluoridation plants.

* The Nalgonda process applied to groundwater does not improve any other quality parameter than fluoride, and treatment even results in an increased sulphate content of treated water.

Comparison of DFP and CWSS:

* Total cost of operation (Rs/m^3) for DFP of more than 60 m^3/day is same as CWSS of 3000 m^3/day and capital cost per capita for such DFP is half of that for CWSS.

* Cost of defluoridation per m^3 water demand is less for larger capacities.

* Clear water quality of studied CWSSs is better and more constant than DFPs because, a better raw water quality and disinfection is the only treatment.

Involvement of community:

* The complex nature of O & M of CWSSs limits the scope of community involvement. A DFP however can be maintained by villagers.

* Generally no involvement of community in any stage of project cycle was noticed.

* Awareness regarding fluorosis has developed a preference for DFPs among the beneficiaries. People of the majority of villages visited are willing to participate in O & M under particular conditions.

Organisational:

* Beneficiaries are not consulted by implementor before deciding the type of water supply system designed for them and this fact inhibits community participation for O & M.

* No manuals, rules and regulations for O & M exist, either for DFPs or CWSSs.

* Plant operators are electricians and are not aware of the process involved in defluoridation by coagulation. They are not trained for O & M of DFPs, even not by GWSSB.

* Reports from laboratories are not in full shape, comments and suggestions on water quality parameters which are not matching standards are lacking and information does not reach the plant operator in time.

Removal experiments:

* The dose of iron chloride, required as coagulant, is double than that of aluminium sulphate to realise the same removal of fluoride.

* Among the various adsorbents tested, only a phosphatic compound removed fluoride effectively.

* Regarding the determination of fluoride, values obtained with the SPADNS method are in good agreement with Ion Selective Electrode, when alum is used as coagulant. In case iron chloride was used the SPADNS method gave much lower values than ISE.

7.2 Recommendations:

General:

* The village water sources containing fluoride levels higher than 3 mg/l should be covered with DFPs instead of waiting for coverage through a CWSS.

* A defluoridation plant with movable HDPE reactors is most suitable choice for pilot area.

Performance:

* Optimum doses of alum, lime and bleaching powder should be suitably decided by laboratory staff at district level and recommended to field officers responsible for O & M of DFP, as a higher or lower dose adversely affects the treated water quality.

* Operators should be given full time appointment and paid proper salaries.

* Solutions of alum, lime and bleaching powder should be kept ready well in advance for next days operation. Solutions may be prepared in the evening to complete dissolution of chemicals.

* Both raw and treated water samples should be collected and sent for analysis every week. Results should be commented by head of the district laboratory and should be kept at plant site.

* Twice a month, the engineer in charge should visit and check the plant's performance.

* Operators must be trained at GJTI and on plant site for efficient and effective operation of a DFP.

Comparison of DFP and CWSS:

* Those villages having water requirement more than 60 m^3/d and raw water fluoride more than 3mg/l should be given priority.

* For groundwater containing excessive fluoride as well as nitrate, sulphate and chlorides, supply through a CWSS should be preferred instead of installing a DFP.

Involvement of community:

* Beneficiaries views must be known and considered prior to selecting a solution for their water supply.

* Not only the installation of DFP or CWSS for providing safe water, but involvement of community is needed to make the supply system successful and sustainable.

* Awareness and health education campaigns should be intensified to explain the importance of safe water.

* GWSSB and NGOs should be involved to organise and educate the communities to take active part in O & M of the scheme.

Organisational:

* Due to poor O & M efficiencies, often systems like DFP and CWSS fall into disuse and disrepair. This has strong demotivating effect on the community concerned. Need is to frame proper O & M regulations and norms.

* Follow up actions may be taken to study the benefits of defluoridation. Steps should be taken to evaluate the improvement in dental health at periodic intervals of consumers of defluoridated water.

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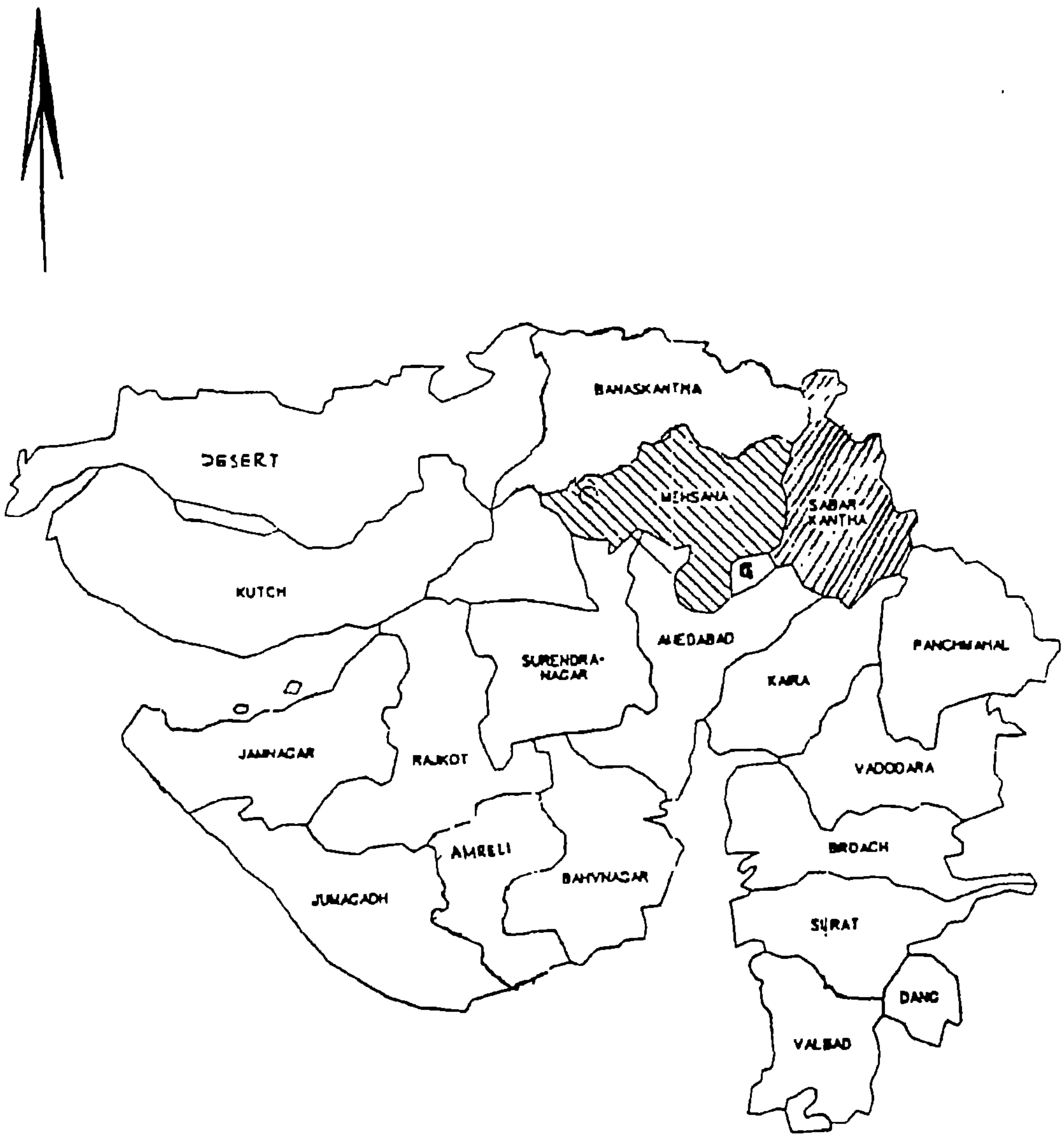
Map of Gujarat state showing Pilot area and Project area



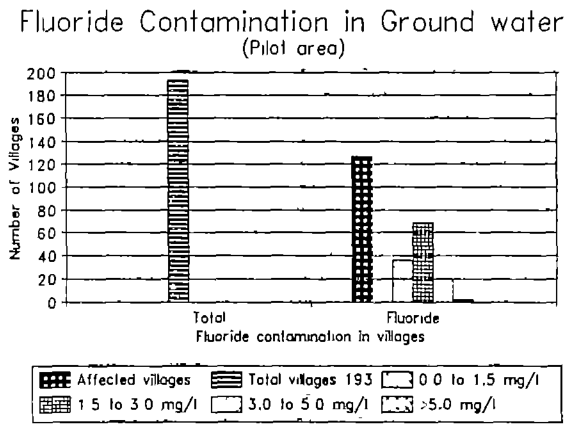
Pilot Area : Idar taluka, Sabarkantha District
Project Area : Mehsana District

Details of groundwater quality in pilot area (Idar taluka)

Fluoride Contamination in	Fluoride concentration in existing water sources in mg/l			
	0.0 - 1.5	1.5 - 3.0	3.0 - 5.0	>5.0
Villages	36	69	20	2
Hamlets	12	26	6	-

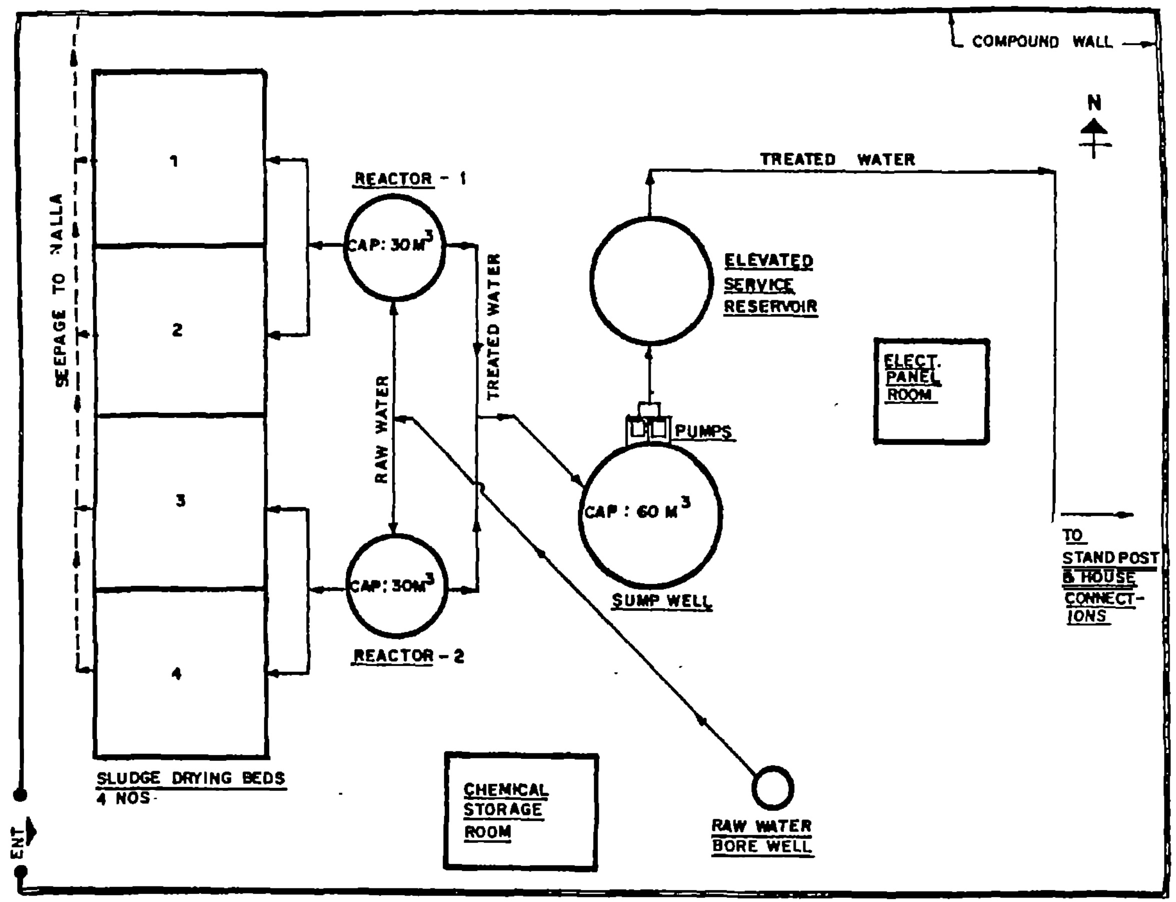
Nitrate Contamination in	Nitrate concentaration in existing water sources in mg/l				
	0 - 45	45 - 100	100 - 150	150 - 200	>200
Villages	57	28	25	6	11
Hamlets	18	14	8	1	3

Total Dissolved Solids in	Total dissoved solids in existing water sources in mg/l				
	500-1000	1000-1500	1500-2000	2000-3000	3000-4000
Villages	76	31	7	7	6
Hamlets	27	8	6	2	1



Installation of new Defluoridation plants in Idar taluka

Sr No	Name of village	Population 1991	1995	2009	F⁻ mg/l	Capacity of dfp m³/d	Cost Rs.in lacs	Details of source Type	Dia m	Depth m	Yield m³/h	Included in CWSS
1	Sabalwad	2359	2510	3251	3 70	70	8 43	Well	6	28	25	Jalia-Umedgadh
2	Vaghpur	359	382	495	4.35	10	2.62	HP		30	3	
3	Bhilvanta	400	426	551	4 70	10	2 62	Well	5.0	20	10	
4	Lalpur	1070	1138	1474	3 00	30	3 81	Well	2.7	20	20	Lalpur-Davad
5	Koyla	225	240	311	4 40	10	2.62	Well	3 7	15	10	
6	Sarangpur	155	165	213	4 20	10	2 62	Well	2.7	11	10	
7	Gajipur	1465	1559	2019	3.10	40	4 62	Well	3.0	17	10	Hatharva-Dobhada
8	Limbhoi	560	596	772	2 62	20	3 06	Well	5.0	23	10	Hatharva-Dobhada
9	Umedpura	1717	1827	2366	3 50	60	5.89	Well	6 0	31	15	
10	Manpur	492	523	679	3.20	20	3 06	Well	4 0	22	10	Jalia-Umedgadh
11	Mangadh	1206	1284	1662	4 00	30	3 81	Well	6 0	29	15	Lalpur-Davad



Schematic layout plan of fill and draw defluoridation plant

Annex 4a

Hatharva-Dobhada II Comprehensive Water Supply Scheme

Name of project:Hatharva-Dobhada Comprehensive Water Supply Scheme, Taluka: Idar, Dist: Sabarkantha

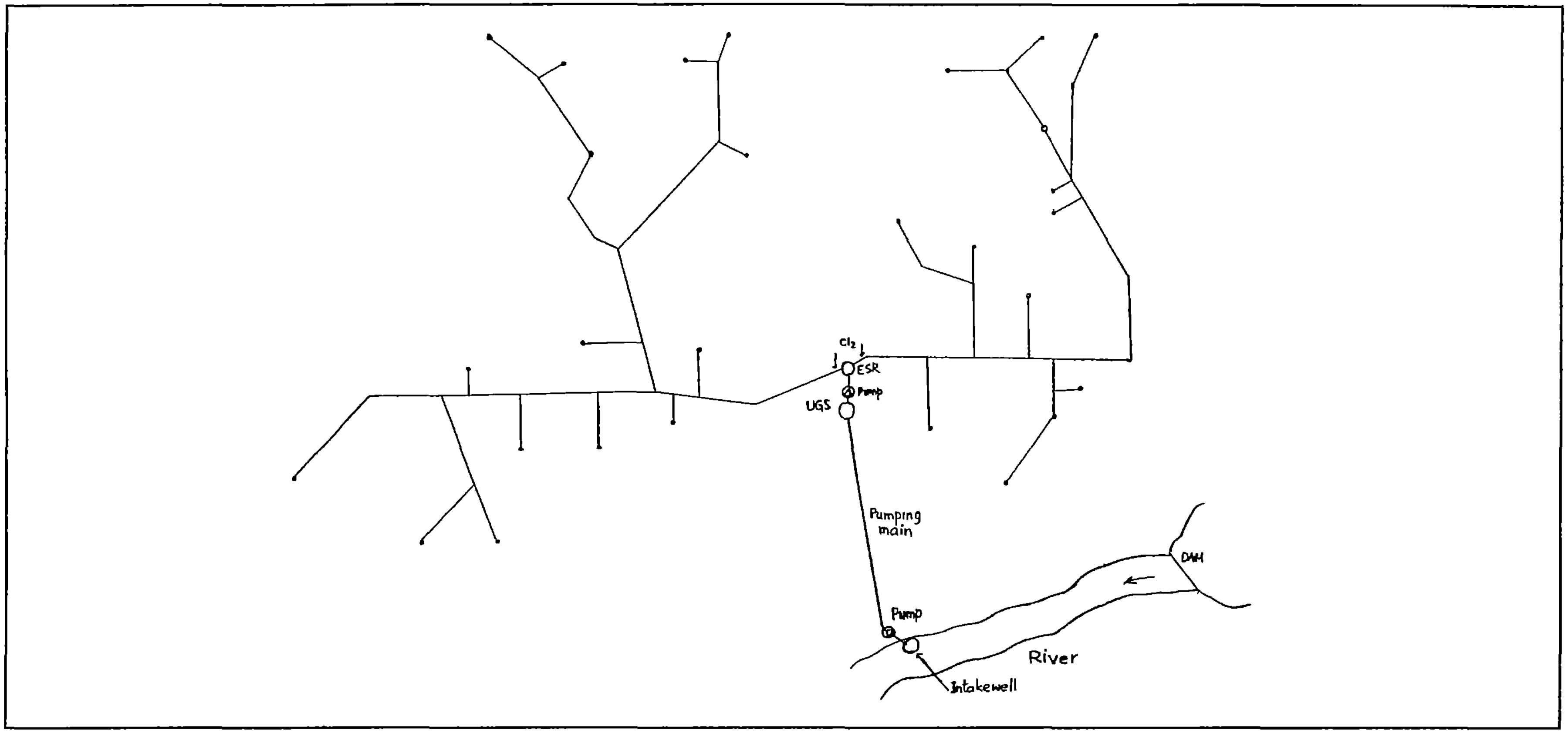
Covered Villages/Hamlets.29/13, Total-42

Population to be served		
1991 (Census)	:	46629
1995 (Present)	:	49613
2021 (Design)	:	70117
Cost of Project (Capital)	:	Rs.508.62 Lacs
Rate of water supply	:	60 lpcd
Water demand		
1995 (Present)	:	3135 m^3
2021 (Ultimate)	:	4430 m^3
Source of water	:	River bed infiltration Wells 4 Nos. of 6m dia. and 15m depth in down steam of Dharoi dam
Expected yield from a well	:	75,000 LPH
Hours of pumping	:	16 hours
Annual O & M (1995)	:	Rs. 14.2 lacs (Total)
Personnel	:	Rs. 6.42 lacs
Energy	:	Rs. 4.08 lacs
Chemicals	.	Rs. 0.91 lacs
Maintenance	:	Rs. 2.79 lacs
Annual Depriciation	:	Rs. 7.32 lacs
Annual Cost Recovery (1995)	:	Rs. 16.71 lacs
Rural population		
Rs 14 per capita for Standpost use	:	Rs. 1.11 lacs
Rs. 200 per house connection	:	Rs. 9.53 lacs
Urban center		
Rs. 1.60 per m^3	:	Rs. 6.07 lacs
Cost per person (Capital)	:	Rs. 920.00
Total cost of O & M	:	Rs. 7.67 per m^3

Annex 4b

Lalpur-Davad Comprehensive Water Supply Scheme

Name of project	:	Lalpur-Davad Comprehensive Water Supply Scheme,Taluka:Idar, Dist: Sabarkantha
Covered Villages/Hamlets	:	25/2, Total-27
Population to be served		
1991 (Census)	:	56220
1995 (Present)	:	59818
2021 (Design)	:	84241
Cost of Project (Capital)	:	Rs.521.49 Lacs
Rate of water supply	:	60 lpcd
Water demand		
1995 (Present)	:	3589 m^3
2021 (Ultimate)	:	5054 m^3
Source of water	:	River bed infiltration Wells 4 Nos. of 6m dia. and 18m depth in down steam of Dharoi dam.
Expected yield from a well	:	60,000 LPH
Hours of pumping	:	18 hours
Annual O & M (1995)	:	Rs. 11.57 lacs (Total)
Personnel	:	Rs. 5.23 lacs
Energy	:	Rs. 3.32 lacs
Chemicals	:	Rs. 0.75 lacs
Maintenance	:	Rs. 2.27 lacs
Annual Depriciation	:	Rs. 7.03 lacs
Annual Cost Recovery (1995)	:	Rs. 18.82 lacs
Rs. 14 per capita for Standpost use	:	Rs. 1.96 lacs
Rs. 200 per house connection	:	Rs. 16.86 lacs
Cost per person (Capital)	:	Rs. 780.00
Total cost of O & M	:	Rs. 6.59 per m^3



Schematic layout plan of Comprehensive water supply scheme.

UGS	-	Under Ground Sump
ESR	-	Elevated Service Reservoir
o	-	Village
______	-	Gravity main

Annex 5a

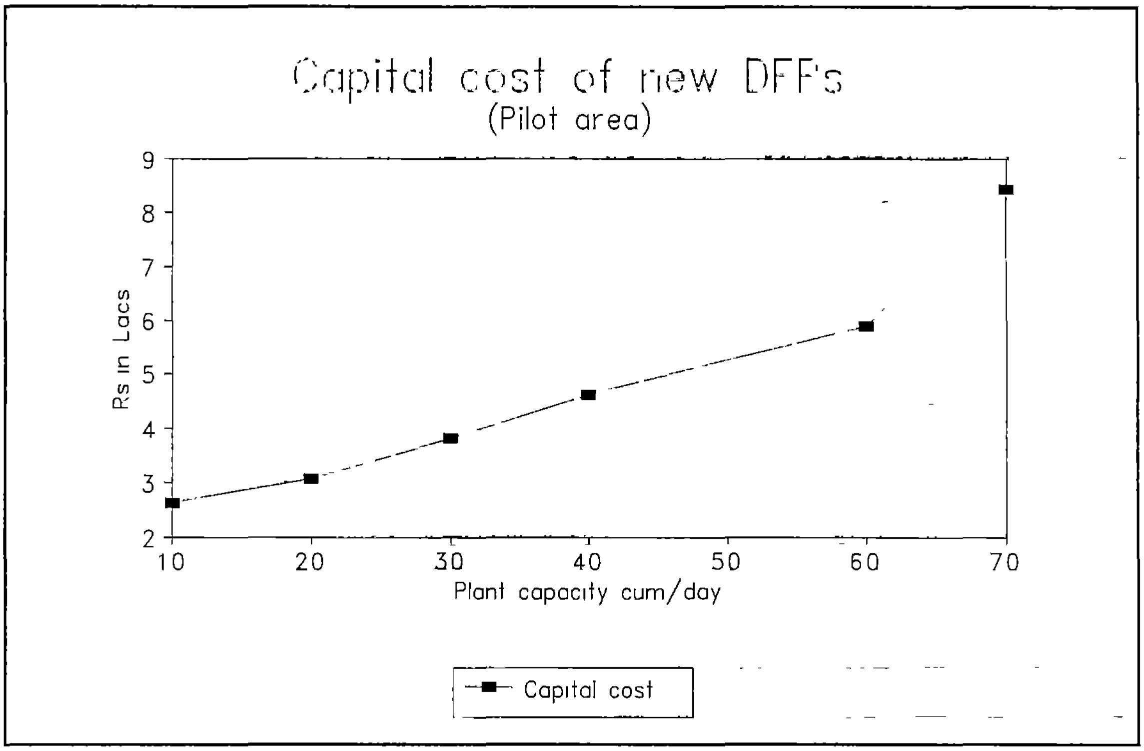
Cost analysis for new defluoridation plants in Idar taluka*

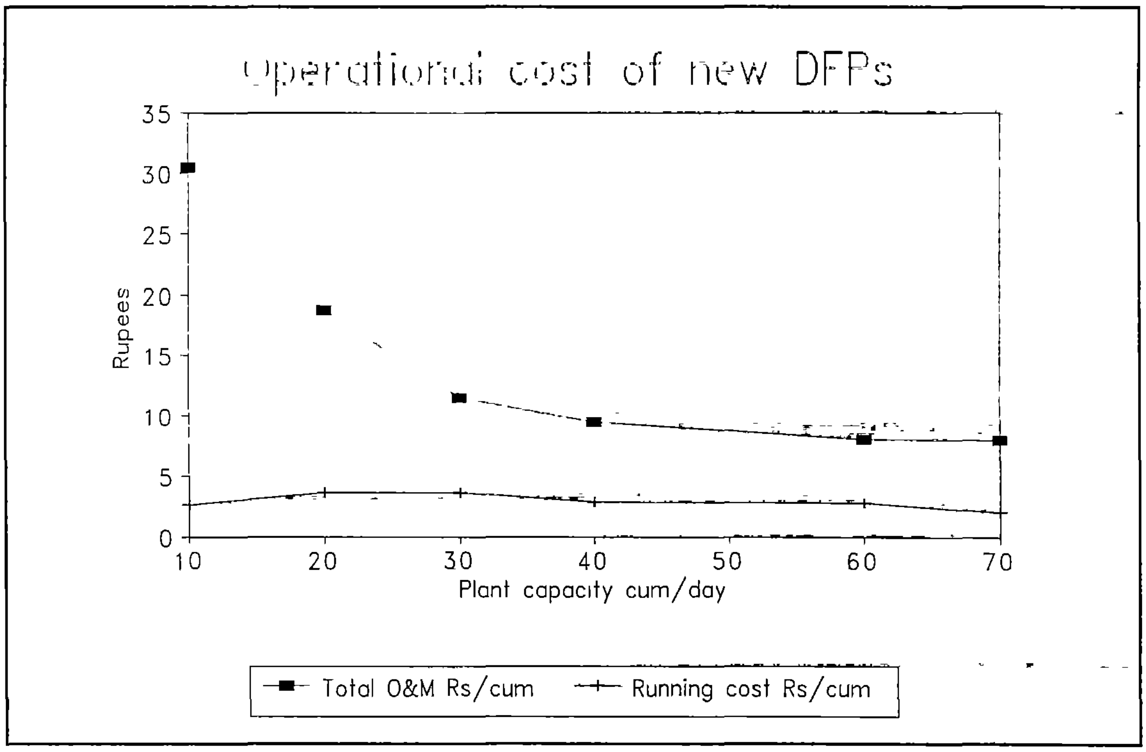
No	Name of village	Population 1995	Population 2009	Raw water F^-	Raw water Alkalinity	Plant capacity m^3/d	Cost in lacs Rs	Capital cost per capita Rs	Annual Expenditure: Depreciation +Interest +Maintenance Rs.	Annual Expenditure: Personnel Rs.	Annual Expenditure: Power Rs	Annual Expenditure: Chemical Rs	Total annual cost of operation Rs.	Total cost of operation Rs/m^3	Running cost of operation Rs/m^3
1	Sabalvad	2510	3251	3 70	232	70	8.43	336	185,460	43,200	33,683	44,055	306,398	7 99	2.02
2	Umedpur	1827	2366	3 50	236	60	5.89	322	129,580	43,200	62,489	29,310	264,579	8.05	2.79
3	Gajipur	1559	2019	3.10	320	40	4.62	296	101,640	43,200	41,659	21,973	208,472	9.51	2.90
4	Mangadh	1284	1662	4.00	440	30	3 81	296	83,820	43,200	33,082	26,626	186,728	11 36	3 63
5	Lalpur	1138	1474	3.00	352	30	3 81	335	83,820	43,200	42,884	18,286	188,190	11 45	3.72
6	Manpur	523	679	3 20	352	20	3 06	585	67,320	43,200	17,153	6,351	134,024	18.35	3 21
7	Limbhoi	596	772	2 62	360	20	3 06	513	67,320	43,200	17,153	9,545	137,218	18 79	3 65
8	Sarangpur	165	213	4 20	576	10	2 62	1,587	57,764	43,200	5,636	4,708	111,308	30 49	2 83
9	Koyla	240	300	4 40	316	10	2 62	1,091	57,764	43,200	5,636	3,923	110,523	30.28	2.61
10	Bhilvanta	426	551	4 70	264	10	2 62	615	57,764	43,200	11,272	7,847	120,083	16 45	2 61

* Based on 1995 population

Assumptions: Alum Rs.2.00/kg
Lime Rs.1.50/kg

Annex 5b





Capital and O & M cost of new DFPs to be installed in pilot area

Annex 6

Details of existing DFP in Mehsana District

Name of village	Ganget	Khanpur	Matpur	Malekpur	Khatasana	Amudh	Thakarasan	Karsanpura	shahpur	Ranchodpura	Badarpur	Shespur	Khodamli	Tavadia
Name of Taluka	Chanasma	Kheralu	Patan	Kheralu	Sidhpur	Sidhpur	Sidhpur	Kheralu	Kheralu	Sidhpur	Kheralu	Kheralu	Kheralu	Sidhpur
Population 1994	1900	700	2300	800	1500	2300	2100	1489*	2696*	3000	3200	350	1620	1500
Capacity of DFP m^3	40	10	40	15	30	40	60	30	58	60	20	10	30	20
Estimated Cost Rs lacs	7 66	3 75	7 66	3.76	5 83	7 66	15.00	6 05	12 12	7 48	3.10	3.47	6 05	3 45
Date of work order	6/12/89	6/12/89	6/12/89	6/12/89	6/12/89	6/12/89	6/12/89	18/5/94	18/5/94	-	-	-	18/5/94	-
Commissioning month	10/92	10/92	10/92	10/92	10/92	10/92	8/92	•	•	4/90	12/88	4/90	•	12/88
Source of water Type Dia Depth	Tube well 200 mm 250 mt	Open well - -	Tube well 200 mm 250 mt	Tube well 200 mm -	Tube well 200 mm 216 mt	Tube well 200 mm 300 mt	Tube well 200 mm 260 mt	Tube well 200 mm 60 mt	Tube well 200 mm 80 mt	Tubewell 200 mm 198 mt	Tube well 200 mm 120 mt	Open well	Open well 2 40 mt 13 40 mt	Tube well 150 mm 240 mt
Raw water F^- mg/l	2 62-3 80	6.45-7 00	2 68-3 60	2 88-3.00	3 40-4 15	3 00-3 40	5.60-6 20	6 45	6 00	3 75	3.75	5 15	6 45	4 75
Type of reactor	HDPE	HDPE	HDPE	HDPE	HDPE	HDPE	HDPE	RCC	RCC	RCC	RCC		RCC	HDPE
Capacity of Reactor m^3 No of Reactor Nos.	15 & 10 2 & 1	10	15 & 10 2 & 1	15 1	15 2	15 & 10 2 & 1	15 4	15 2	20 & 18 2 & 1	30 2	10 2	10 1	15 2	10 2
No. of cycles/day	2 Cycles	2 Cycles	2 Cycles	2 Cycles	2 Cycles	2 Cycles	2 Cycles	2 Cycles	2 Cycles	2 Cycles	2 Cycles	1 Cycle	2 Cycles	2 Cycle
Sump well capacity in m^3	40	10	40	15	15	40	60	30	60	60	20	10	30	20
Elevated service reservoir capacity in m^3	60	25	100 (GL)	25 (GL)	25	25	25	14	50 (GL) & 20 ESR	-	-	-	14	
Water demand m^3/d 1981 population Ultimate population	76 110	28 37 6	9 2 13 2	32 44.3	60 86 8	92 133 2	56 12 84 2	64.8 97.2	107 84 161.76	120 180	128 192	14 21	64 8 97 2	60 90
Annual o&m cost Rs lacs	1 45	1 01	1 43	1.14	1 04	1 42	1 83	•	•	2 08	1.65	1 03	•	1 81
cost of water Rs/m^3	4 95	9 98	4 34	10 38	4 76	4 31	7 69	•	•	4 75	11 28	20 24	•	8 26
Annual o&m Cost/capita Rs	71 93	144 73	62 39	147 65	80 06	61 12	108 20	•	•	69 40	51 47	295 55	•	120 70

• Under commissioning stage

Water quality results of DFP in Mehsana District

Name of village	Shahpurvad, Ta: Kheralu		Karsanpura, Taluka Kheralu		Khatasana, Taluka Sidhpur		Ranchhodpura, Taluka Sidhpur	
Source	Raw water	Treated water	Raw water	Treated water	Raw water	Treated water	raw water	Treated water
Date of sample collection	1/11/94		1/11/94		7/11/94		8/11/94	
Turbidity (NTU)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
pH	8.30	7 45	8 72	7.50	8.23	7 26	7 70	6.65
TDS	816	1058	932	984	722	820	1408	1642
Total Hardness (as $CaCO_3$)	228	342	42	84	104	130	220	280
Calcium (as Ca)	40	80	9	26	30	37	47	71
Magnesium (as Mg)	31	35	5	5	7	9	25	25
Chlorides (as Cl)	176	174	114	112	154	156	360	368
Sulphate (as SO_4)	60	317	90	232	53	253	110	**400**
Nitrates (as NO_3)	70 86	70.88	15 50	17 72	22.15	22.15	62 02	62 02
Fluorides (as F)	3 59	1 18	3 79	**2.72**	4 30	1.39	3 14	0.67
Alkalinity (as $CaCO_3$)	416	300	592	528	344	184	536	248

Water quality results of DFP in Mehsana District

Name of village	Ganget, Ta· Chanasma		Matpur, Taluka Patan		Sheshpur, Taluka: Kheralu		Badarpur, Taluka. Kheralu	
Source	Raw water	Treated water	Raw water	Treated water	Raw water	Treated water	raw water	Treated water
Date of sample collection	14/11/94		14/11/94		25/11/94		27/11/94	
Turbidity (NTU)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
pH	7.67	7 42	7.73	7.75	7 66	6 78	8 26	6 80
TDS	1130	1244	1224	1448	544	692	866	1056
Total Hardness (as $CaCO_3$)	250	266	194	286	226	282	58	120
Calcium (as Ca)	54	60	44	77	67	88	11	34
Magnesium (as Mg)	29	29	21	23	14	15	7	9
Chlorides (as Cl)	436	428	464	472	604	56	116	116
Sulphate (as SO_4)	76	202	47	288	49	310	27	**400**
Nitrates (as NO_3)	11.08	11 08	26 58	26 58	22 15	22.15	22.15	22 15
Fluorides (as F)	3.00	**1.62**	2.23	0 70	5 03	1 37	4.20	0.71
Alkalinity (as $CaCO_3$)	336	236	340	184	264	72	552	244

Water quality results of DFP in Mehsana District

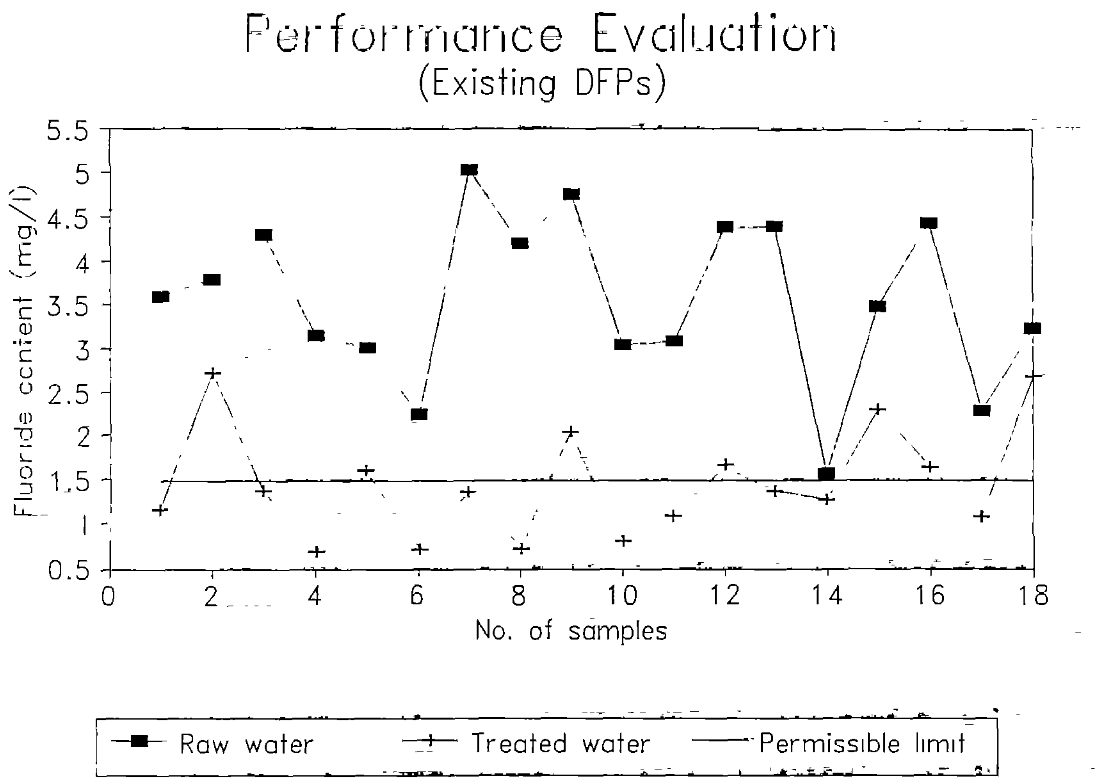
Name of village	Khanpur, Ta Kheralu		Ranchhodpura, Taluka Sidhpur		Tavadia, Taluka Sidhpur		Karsanpura, Taluka Kheralu	
Source	Raw water	Treated water	Raw water	Treated water	Raw water	Treated water	raw water	Treated water
Date of sample collection	27/11/94		28/11/94		28/11/94		28/11/94	
Turbidity (NTU)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
pH	8.02	7 35	8 08	6 94	7.86	7.05	8 57	7.59
TDS	1780	1870	1632	1600	1190	1360	956	1086
Total Hardness (as $CaCO_3$)	280	314	216	232	222	262	38	96
Calcium (as Ca)	43	68	46	50	50	61	7	26
Magnesium (as Mg)	42	35	26	27	24	28	5	8
Chlorides (as Cl)	464	464	372	368	348	404	148	112
Sulphate (as SO_4)	81	310	83	322	83	260	24	235
Nitrates (as NO_3)	**99.67**	**99.67**	66 45	70.88	22.15	22.15	13 29	13.29
Fluorides (as F)	4.75	**2.06**	3 04	0.80	3.07	1.10	4 37	**1.65**
Alkalinity (as $CaCO_3$)	676	504	536	252	348	192	616	432

Water quality results of DFP in Mehsana District

Name of village	Khatasana, Ta Sidhpur		Ganget, Taluka Chanasma		Shahpur, Taluka. Kheralu		Karsanpura, Taluka Kheralu	
Source	Raw water	Treated water	Raw water	Treated water	Raw water	Treated water	raw water	Treated water
Date of sample collection	29/11/94		1/12/94		2/12/94		12/12/94	
Turbidity (NTU)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
pH	8.25	6.94	7 26	6.98	8 36	7 58	8.50	7 00
TDS	676	808	1166	1200	912	992	972	1064
Total Hardness (as $CaCO_3$)	100	128	256	262	286	308	42	72
Calcium (as Ca)	24	34	58	60	58	64	9	20
Magnesium (as Mg)	10	11	28	28	36	37	5	5
Chlorides (as Cl)	148	152	404	404	176	176	120	112
Sulphate (as SO_4)	59	211	140	166	62	155	34	258
Nitrates (as NO_3)	19 94	19.94	13 29	17.72	53.16	53 16	13.29	17.72
Fluorides (as F)	4.41	1.37	1 58	1.28	3.49	**2.31**	4 43	**1.65**
Alkalinity (as $CaCO_3$)	320	164	276	252	472	380	652	444

Water quality results of DFP in Mehsana District

Name of village	Matpura, Ta Patan		Shahpur Taluka Kheralu	
Source	Raw water	Treated water	Raw water	Treated water
Date of sample collection	13/12/94		14/12/94	
Turbidity (NTU)	Nil	40	Nil	Nil
pH	8.50	8 10	7.95	7 62
TDS	1222	1556	960	956
Total Hardness (as $CaCO_3$)	198	364	312	302
Calcium (as Ca)	22	108	64	61
Magnesium (as Mg)	23	23	37	36
Chlorides (as Cl)	464	468	192	172
Sulphate (as SO_4)	59	376	62	146
Nitrates (as NO_3)	26.58	26.58	70 88	62 02
Fluorides (as F)	2 30	1.08	3.24	**2.70**
Alkalinity (as $CaCO_3$)	332	116	442	400



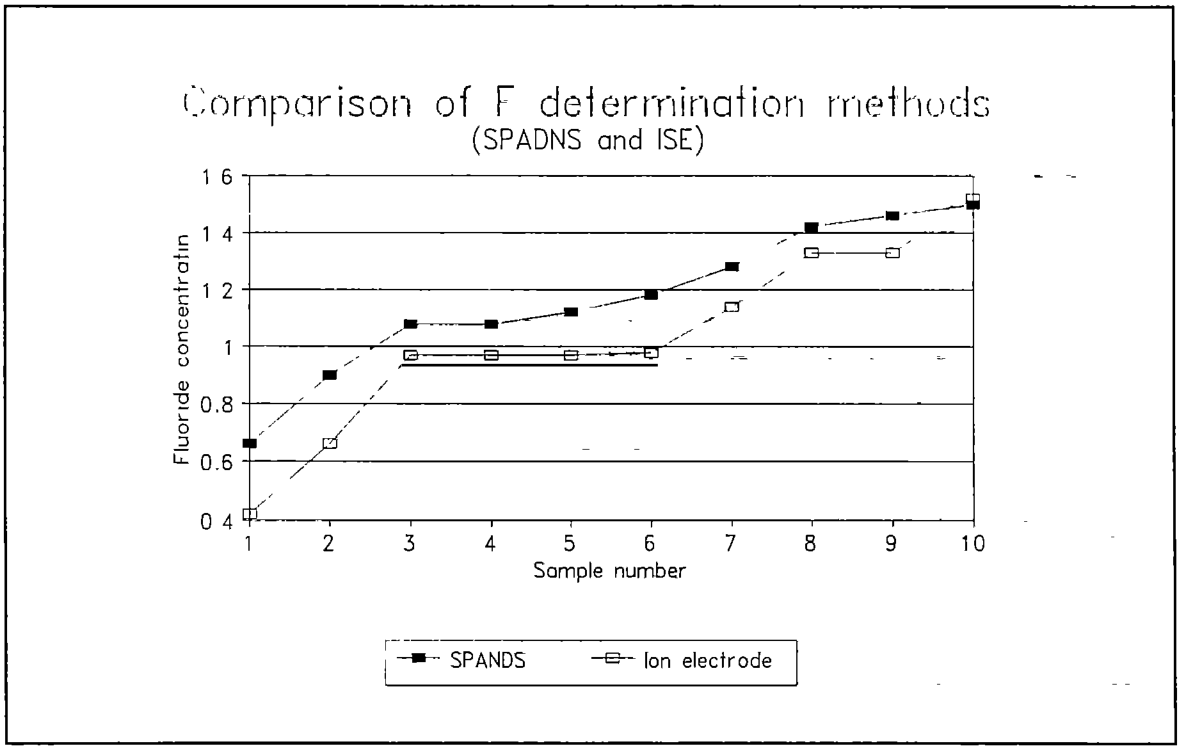
Results of water samples collected from existing defluoridation plants in project area. These DFPs are operated on the dose of chemical prescribed by installing agencies.

Fluoride removal results of DFP in Mehsana district

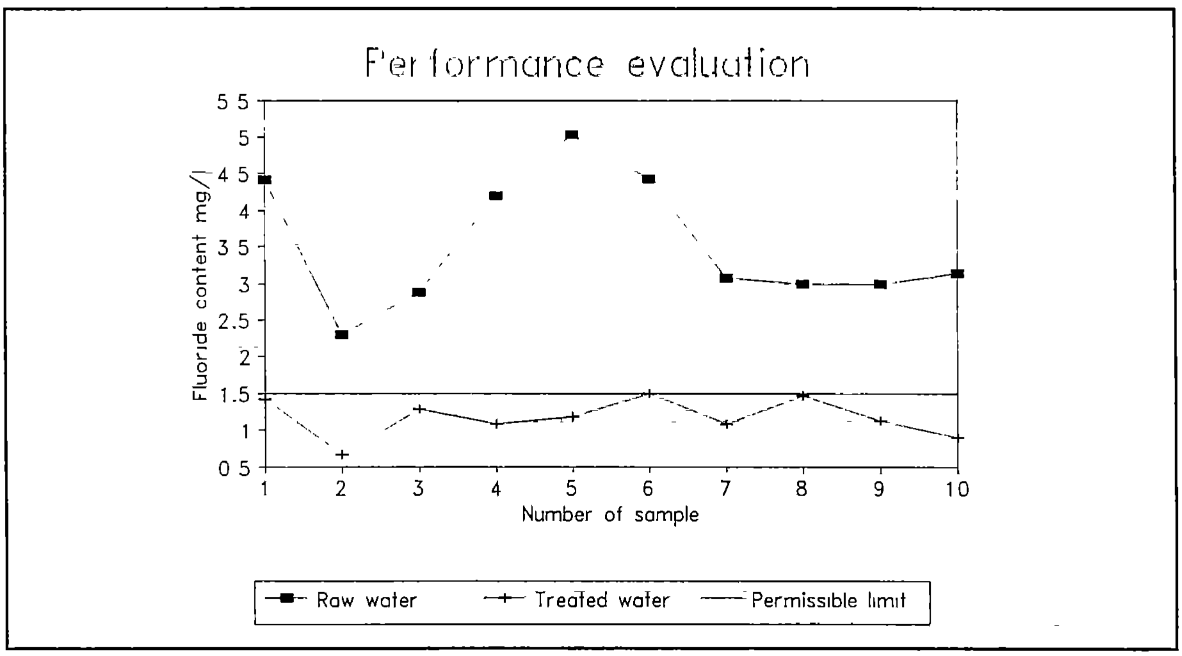
(According to dose prescribed by NEERI (Table 2.8))

Name of village where DFP is installed	Raw water parameter mg/l		Prescribed dose of Alum in g/l +(Lime 10% of alum)	Fluoride mg/l in treated water	
	Alkalinity	Fluoride		SPADNS*	ISE#
Khatasana	320	4.41	0.425	1.42	1.33
Matpur	346	2.30	0.375	0.66	0.42
Mahekubpura	450	2.88	0.470	1.28	1.14
Badarpur	552	4.20	0.650	1.08	0.97
Sheshpur	264	5.03	0.500	1.18	0.98
Karsanpura	652	4.43	0.650	1.50	1.52
Tavadia	348	3.07	0.375	1.08	0.97
Ganget	336	3.00	0.375	1.46	1.33
Amudh	332	3.00	0.375	1.12	0.97
Ranchhodpura	536	3.14	0.525	0.90	0.66

* Measured at GJTI Central laboratory with SPADNS reagent.
# Measured at IHE laboratory with ion selective electrode.



Comparision of F⁻ determination: Measurement of fluoride content in treated water was carried out by SPADNS method at GJTI laboratory in India, and later on at IHE laboratory using Ion Selective Electrode method.



Results obtained for fluoride content treated water in after applying chemical dose as recommended by NEERI for existing DFPs in project area.

Water quality parameter of villages included under Hatharva-Dobhada II Comprehensive Water Supply Scheme

No	Name of village	Source	Water quality parameters Iron	Fluoride	TDS	Nitrate	E Coli MPN/1000
1	Morad	HP[1]	0.28	0.15	**4485**	**730.98**	<3
2	Mathasur	HP & Well	0.28	0.45 **2.30**	**3380**	**403.14**	<3
3	Jetpur	HP	0.12	0.10	988	**117.45**	<3
4	Limbhoi	HP	0.09	1.00	566	70.86	<3
5	Vadali	TW[2]	0.01	1.15	1365	**101.89**	0
6	Kodreli	HP	0.04	**1.85**	694	35.44	<3
7	Vasana asai	Well	0.02	**1.85**	1105	**124.04**	460
8	Asai	Well	0.06	1.15	943	**143.98**	2400
9	Baradiakampa	HP	0.08	1.50	1164	**106.32**	
10	Raheda	Well	0.08	1.30	1105	66.45	460
11	Arsamda	HP	0 06	**2.10**	832	46.52	<3
12	Narayanpura	Well	0.04	**1.85**	520	2.22	
13	Himatpur	Well	0.12	**4.10**	**3380**	nil	2400
14	Dantroli	HP	0.02	1.50	266	2.22	
15	Jamrelakampa	Well	0.05	1.30	1820	77.53	
16	Limbhoi	HP	0.04	**4.45**	501	48.73	<3
17	Pahadiol	HP	0.09	1.50	910	86.39	<3
18	Jamrela	Well	0.07	**6.05**	876	64.24	2400
19	Mahor	Well	0.06	1.50	1144	19.94	2400
20	Surajpura	Well	0.03	1.50	793	19.94	460
21	Bavsar	Well	0.07	**2.45**	1144	22.15	2400

Continued

22	Ambavada	HP	0.02	**3.00**	260	44.30	<3
23	Dhira	HP	0.12	**1.75**	1183	84.17	<3
24	Movatpura	Well	0.08	1.15	846	**129.04**	
25	Kamalpur	Well	nil	1.20	408	44.30	
26	Raol	Well	0.08	0.50	936	79.74	
27	Pepalla	HP	0.02	0.90	552	31.01	
28	Kalyanpura	TW	0.02	1.30	456	17.72	
29	Badol	HP	0.08	**2.00**	318	39.67	
30	Badolkampa	Well	0.05	**2.00**	1164	90.82	
31	Verabar	Well	0.04	**2.45**	260	2.22	
32	Gajipur	Well	0.06	**3.00**	714	13.29	
33	Vasana	Well	nil	1.50	552	8.84	
34	Navavas	Well	nil	1.30	876	57.59	
35	Fudeda	Well	0.04	0.90	714	22.15	
36	Jalampur	Well	nil	0.90	630	**104.11**	
37	Rampur	Well	nil	0.90	756	28.8	
38	Golwada	Well	nil	0.25	408		
39	Suajpur	Well	nil	1.30	618	6.68	
40	Laxmanpura	Well	nil	1.30	636	18.73	
41	Bhandval	Well	0.12	**2.85**	**2405**	31.01	
42	Kamboya	HP	0.12	**1.75**	1183	84.17	

HP[1] = Hand Pump

TW[2] = Tube well

Bold Nos. value exceeds Indian water quality standard as per IS:10500 (1991)

Water quality of villages included under Lalpur Davad CWSS

Name of village	F^- mg/l
Prempur	4.75
Rangpur	3.06
Pethapur	3.50
Kanada	2.50
Pipodar	2.40
Sachodar	2.64
Lolasan	2.28
Manpur	2.84
Davad	2.90
Kishorgadh	3.45
Aroda	2.90
Lalpur	2.56
Jadar	2.80
Mangadh	4.80
Motivadol	2.22
Rudardi	2.90
Nanakotda	2.90
Bhuvel	5.20
Netramali	6.40
Chadasana	4.00

DEFLUORIDATION EXPERIMENTS

COAGULATION

Run # 1 19.09.94

Model water characteristics

pH	8.1
Conductivity	800 μs/cm
Alkalinity	355 mg/l

Beaker no.	1	2	3	4	5	6
F^- mg/l	1	1	2	2	3	3
Alum mg/l	310	310	470	470	715	715
Parameters after coagulation						
pH	6.5	6.9	6.2	6.2	6.1	4.8
EC μs/cm	650	1050	745	755	960	735
Potential mV F^- mg/l (ISE)*	366.6 0.35	378.4 0.19	372.4 0.27	375.5 0.23	372.3 0.27	362.7 0.44

* By Ion selective electrode method

Run # 2 20.09.94

Model water characteristics

pH	8.2
Conductivity	920 μs/cm
Alkalinity	435 mg/l

Beaker no.	1	2	3	4	5	6
F^- mg/l	2	2	4	4	6	6
Alum mg/l	310	310	470	470	715	715
Parameter after coagulation						
pH	6.9	6.9	6.6	6.6	6.1	6.1
EC μs/cm	960	960	980	980	1025	1025
Potential mV F^- mg/l (ISE)	357 0.59	356.6 0 57	353.8 0.65	354.1 0.63	351.3 0.76	351.4 0.76

Run # 3 21.09.94

Model water characteristics

pH 8.3
Conductivity 910 μs/cm
Alkalinity 480 mg/l

Beaker no.	1	2	3	4	5	6
F^- mg/l	2	2	4	4	6	6
$FeCl_3$ mg/l	620	620	940	940	1430	1430
Polyelectrolyte ml	1	1	1.5	1.5	2.3	2.3
Parameter after coagulation						
pH	5.1	5.1	4.3	4.3	3.8	3.8
EC μs/cm	1200	1200	1550	1550	2200	2200
Absorbance (SPADNS) F^- mg/l from graph	0.563 0.5	0.564 0.5	Suspended flocs		No floc formation	
Potntial mV F^- mg/l (Electrode)	346.8 1.01	350.7 0.74				

Run # 4 22.09.94

Model water characteristics
pH 8.3
Conductivity 920 μs/cm
Alkalinity 435 mg/l

Beaker no.	1	2	3	4	5	6
F^- mg/l	2	2	4	4	6	6
$FeCl_3$ mg/l	620	620	940	940	1430	1430
Parameter after coagulation						
pH	5.9	6.1	3.8	3.9	2.9	2.9
EC μs/cm	1085	1100	1250	1250	2250	2250
Absorbance(SPADNS) F^- mg/l from graph	0.447 1.05	0.451 1.05	Suspended flocs		No floc formation	
Potential mV F^- mg/l (ISE)	336.6 1.50	340 1.20				

Run # 5 22.09.94

Model water characteristics

pH	8.3
Conductivity	950 μs/cm
Alkalinity	450 mg/l

Beaker no.	1	2	3	4	5	6
F^- mg/l	2	2	4	4	6	6
$FeCl_3$ mg/l	620	620	940	940	1430	1430
NaOH (1M) ml	4	4	6.8	6.8	12	12
Parameter after coagulation						
pH	6.7	6.9	6.9	6.9	6.9	6.9
EC μs/cm	1175	1290	1610	1650	2110	2110
Absorbance (SPADNS) F^- mg/l from graph	0.363 1.46	0.351 1.5	0.266 1.66*	0.266 1.66*	0.249 1.7*	0.249 1.7*
Potentail mV F^- mg/l (ISE)	331 1.83	330 1.91	320.4 2.86	318.6 3.40	306.8 4.95	306 3 5.00

* Extrapolation

Run # 6 03.10.94

Model water characteristics

pH	8.5
Conductivity	900 μs/cm
Alkalinity	450 mg/l

Beaker no.	1	2	3	4	5	6
F^- mg/l	4	4	4	4	4	4
Alum mg/l	470	470	470	235	235	117
Starch mg/l	-	94	141	47	70.5	35
Parameter after coagulation						
pH	6.7	6.7	6.8	7.2	7.2	7.5
EC μs/cm	1010	1010	1010	970	960	930
Potential mV F^- mg/l (ISE)	347.9 0.90	349 0.93	348.9 0.93	331.5 1.9	335.9 1.57	322.2 2.67

CONTACT TEST

Run # 1 22.09.94

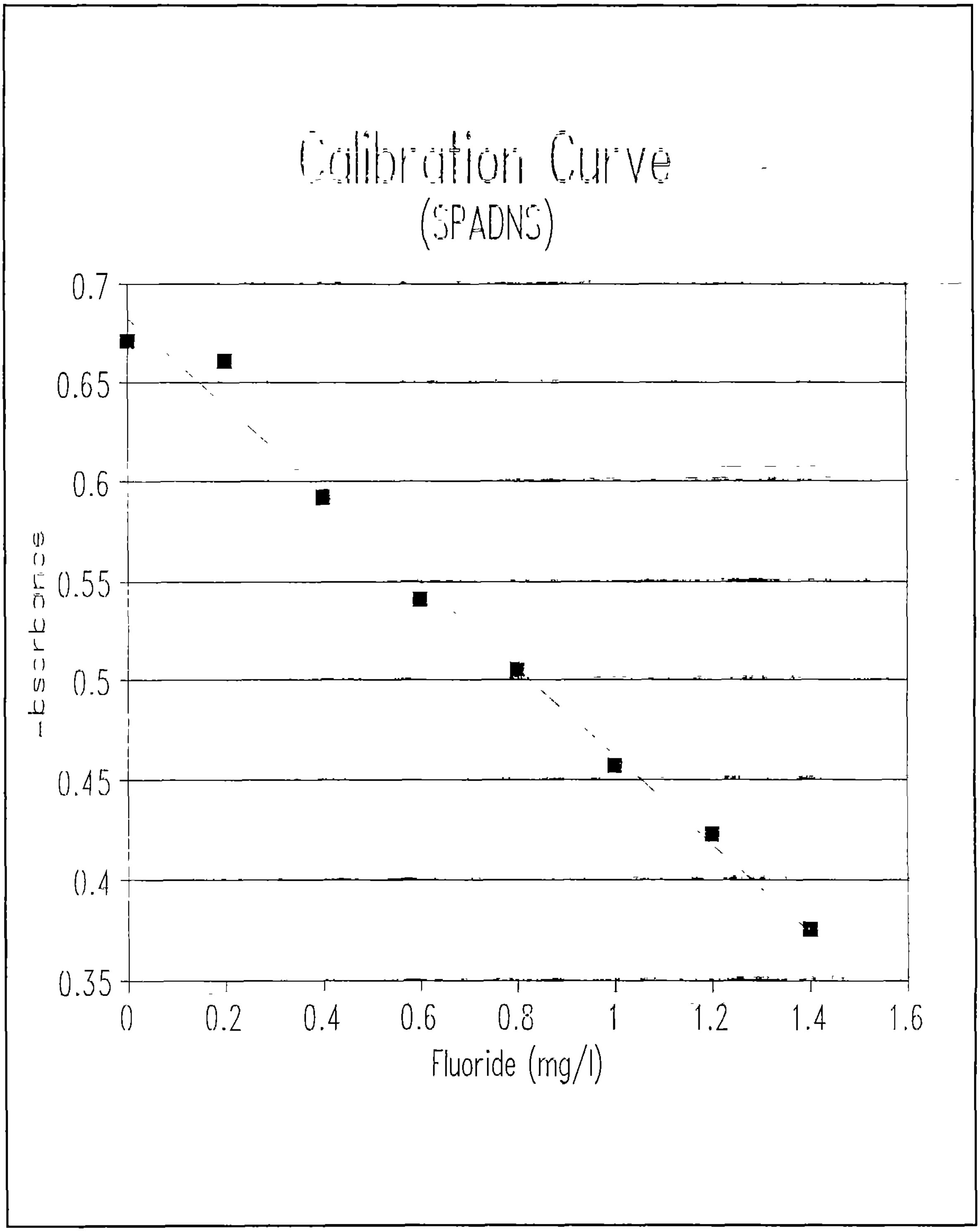
Model water	Demineralised water
Mixing speed	60 rpm
Contact time	12 hrs
pH	8.0
Conductivity	20 μs/cm

Sample no Volume	1 1 L	2 1 L	3 1 L
Chemical Quantity	$CaCO_3$ 5 g/l	MnO_2 5 g/l	Cellulose 5 g/l
F^- mg/l	5	5	5
Parameters measured after contact test			
EC μs/cm	70	45	35
pH	9.3	8.2	8.0
Absorbance (SPADNS) F^- mg/l (from graph)	0 252 1.68	0.264 1.64	0.258 1.65
Potential mV F^- mg/l (ISE)	308.4 4.93	308.4 4.93	307.9 4.95

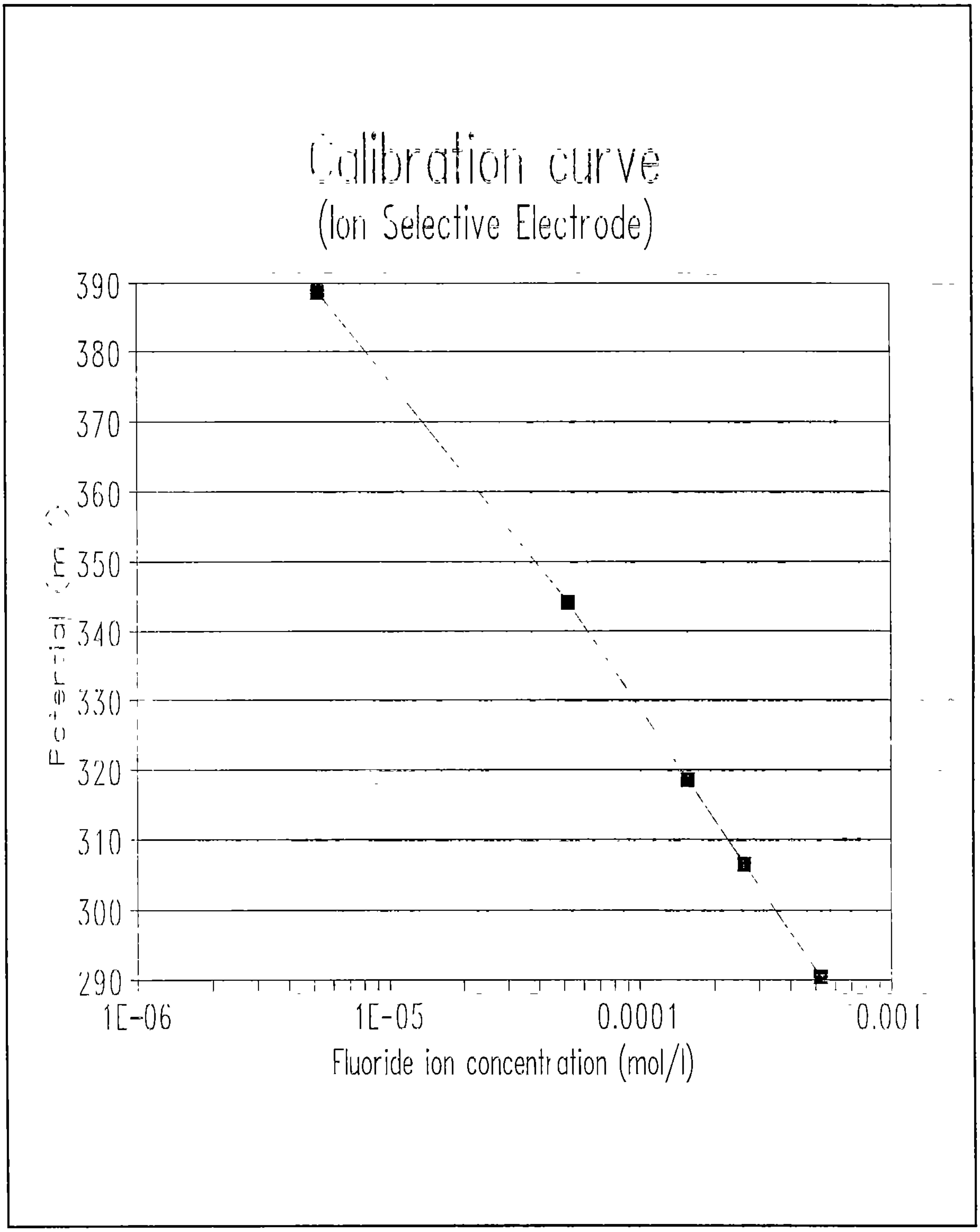
Run # 2 03.10.94

Model water	Demineralised water
Mixing speed	60 rpm
Contact time	12 hrs
pH	8
Conductivity	20 μs/cm

Sample no. Volume	1 1 L	2 1 L	3 1 L	4 1 L	5 1 L
Chemical Quantity	$CaCO_3$ 5 g/l	MnO_2 5 g/l	CuO 5 g/l	$Ca_3(PO_4)_2$ 5 g/l	Cellulose 5 g/l
F^- mg/l	5	5	5	5	5
Parameters measured after contact test					
EC μs/cm	72	40	30	35	48
pH	9.2	7.1	6.6	7.0	7.7
Potential mV F^- mg/l (ISE)	306.4 5	306.8 4.95	306.8 4.95	353.3 0.67	306.6 4.98
Absorbance (SPADNS) F^- mg/l (from graph)	0.255 1.66	0.256 1.66	0.253 1.69	- -	0.249 1.70



Calibration Curve for SPADNS reagent (Cat.NO. 25060-25)



Calibration curve for Ion Selective Electrode (ISE25F)

Annex 14a

Questionnaire for data collection

*** Plant operator**

Village: Date:

1. Name, age and qualification
2. Experience
3. Do you monitor influent water quality ?
   a. If yes, How often,
   b. and for which parameters ?
4. Do you check treated water quality ?
   a. If yes, which parameters are measured,
   b. and at what interval ?
5. Where water samples are analyzed ? (GWS&SB lab/with field kit/other)
6. How you monitor dose of chemicals ?
7. Have you undergone any training regarding operation of DFP ?
8. What is the seasonal variation in influent fluoride content with fluctuation in water table?
9. Which log books are maintained ?
10. Who is responsible for your salary ? (GWS&SB/Community)
11 Is supply of chemical efficient ? (Yes/No)
12. What are the main problems encountered with o & m ?
13. What are the major & minor repairs reported so far ?
14. How often ?
15. How complaints attended ?
16. What is the sludge quantity per month ?
17. How sludge is disposed ?
18. How often plant is visited by incharge engineer ? (Weekly/Monthly/Other)
19. Do you think plant can be operated by community if enough training is given ?
20. Is electricity available regularly ? (Yes/No)
    and for how many hours a day ?

*** Field staff (Sub division office)**

1. What is the criteria for selection of village for installation of DFP or linking with CWSS?
2. Source of water
   a. No. and size of source
   b. Max. and min. fluoride content
3. No. of DFPs installed.
4. Age of DFPs installed.
5. By whom plant is designed ? (GWS&SB/NEERI/NIDC)
6. Which components of plant is designed by external agency,
7. and by GWS&SB ?
8. What is the design period ?
9. What is the capacity of plant ?
10. How plant is functioning ? (Continuous/Intermittent)
11 What is the investment cost for plant ?
12 What is the source of fund ? (GOI/GOG/Other)
13. What is the operational cost ?
14. Time required for DFP's
    a. planning and design
    b. sanction
    c. construction
    d. commissioning and test run
15. What are the chemicals used ?
16. Quantity of chemicals required per annum ?
17. What is the storage capacity and facility ?
18. What is the cost of chemicals per annum ?
19. Operation of plant is done by ? (GWS&SB/Community)
20. Whether operator had any pre job training ? (Yes/No)
21. If yes, by whom and where and for how many days ?
22. Is plant incharge(engineer) trained ? (Yes/No)
23. Who is paying the operator ? (GWS&SB/Community)
24. What is the min. qualification required for the post of operator ?
25. Plant operator is selected from ? (Within village/Other area)
26. What types of performance problems are encountered ?
27. Events of breakdown since operation of plant ?

28. What are the operational problems in your view ?
29. What measures are taken to overcome ?
30. Does expert consultation is available in case of emergency ?
31. Does DFPs are visited by experts for performance evaluation?
32. Date of last visit and remarks made by the expert ?
33. Details of follow up actions ?
34. Are you observing treated water quality through out the year ?
35. If yes, how often and where samples are analyzed ?
36. Can operator analyze the sample at plant site with field kit ?
37. How plant is performing in your view ?
38. Do you think community can operate the plant ?
39. Whether any DFP is handed over to community for o & m ?
40. What are the reasons ?
41. Would recommend the DFP for other fluoride affected areas ?
42. Reasons for yes or no.
43. What do you prefer CWSS/DFP ?
44. Are the villagers aware of fluorosis ?
45. What role this office has played to develop awareness ?
46. Does this office has attempted ever to bring awareness regarding water quality among the villagers ? (Yes/No)
47. Is the quantity of water treated and supplied meant for drinking purpose only or i t includes all other water use ?

Annex 14c

*** Village level**

Name of the village : Respondent : Date :

1. General information about village
   a. Population
   b. Main occupation
   c. Average income level
   d. Health institutions
   e. NGOs active in the village
2. What educational institutions are existing in the village ?
   primary school/ upper primary school/ high school.
3. Does the village is having transport facilities to and from town ?
4 Are there major social and cultural differences with in communities ?
   Religious groups/ caste/ political parties
5. What are the main sources of income ?
   Agriculture/ dairy/ agriculture labour/ service/ trade.
6. How is the distribution of income in the year ?
   weekly/ monthly/ seasonal/ annually.
7. Do you attend primary health centre ?
8. Does primary health centre inform you about water quality ?
9. Do you know why water treatment plant is built in your village ?
10. Have you heard of awareness camp ?
11. What source of water was used before installation of DFP ?
12. Since when DFP is operating ?
13. Does for all purpose treated water is used or only for drinking purpose ?
14. Is DFP handed over to Panchayat for o & m ?
15. Reasons for yes or no.
16. Do village people pay for water ?
   a. if yes, How much ?
   b. if no, reasons for not paying ?
17. Is skilled labour available within the community for taking up certain minor repair works such as arresting leaks, maintenance of taps, cleaning/operation of reservoirs, chlorination of reservoirs, pump operations, operating of valves,etc.
15. Is the community willing to take part in the operation and maintenance ?
16. If not why ?

17. Would the community be willing/able to pay an operator ?
18. If yes, what type of problems are you expecting during operation ?
19. If a person from your village is trained to operate the plant, can community pay his salary ?
20. How often the plant is visited by officers ?
21 How do you inform to the GWSSB of major breakdowns in the system ? (communication system - post cards, messengers, telephone, etc.)
22. What are the existing institutions/organizations/committees with in the village ?
23. Is there any existing organization/ committee in your village which can operate the DFP ?
24. In your opinion who has to operate and maintain the DFP ?
(GWSSB/ Community/ Private contractor/ GWSSB & Community)
25. Why is it so ?
26. What are the arguments for and against the same ?
27. What type of problems do you expect, if the scheme is maintained by community ? (non cooperation from villages, political problems, religious problems, lack of knowhow, financial constraints etc)
28. What type of services do you expect from the GWSSB in turn of your participation?
    a. Better service ?
    b. Subsidy in tariff ?
    c. Supply of chemicals ?
    d Technical guidance ?

*** Committees**

Name of the committee : Respondent : Date :

Village :

1. Type of committee existing within the village ?
   water committee/ health committee/ gram panchayat
2. How was it formed ?
   a. Elected by the community ?
   b. Selected by the community ?
   c. Ruling families or hereditary chiefs as head of the committee ?
3. When was it formed ?
4. How is the chair person of the committee elected ?
   a. Elected ?
   b. Nominated ?
5. Are the chairman and other members of the committee attending the committee meetings regularly ?
6. What are the goals of the committee ?
7. What activities are taken up by the committee ?
8. How often does the committee meet ?
9. How many times the committee met in last six months ?
10. Are influential persons like village chief, priest, development committee, etc. members of the committee ?

11. Who is taking the decisions in the meeting ? (whether community members or chairman)
12. Is the committee imposing the decisions taken by them or taking the views of the community members into consideration ?
13. Does the committee able to implement the decisions taken ?
14. How are the different committees coordinating with each other ?
15. Does the committee have experience in taking up certain activities like organization of community/labour, construction of water supply systems, promoting health campaigns, maintenance of water supply systems, etc., If yes,
16. What are the previous experiences of committee with respect to community participation works ?
17. Is the community successful in executing the works with community participation?

18. Is the committee in a position to use the locally available resources ?
19. Can the committee collect funds from the community for taking up the new works
20. Is the committee keeping records ?
21. Does the committee decide how much tariff from whom has to be collected
22. Does the committee collect any other taxes, funds etc. ?
23. Does the committee account for the collected fund ?
24. Who is responsible for the collected fund to be utilised properly ?
25. Is the whole community participating in the committee meetings ?
26. If not, which section of the community is not attending ?
27. What are the effects of these on the community development ?
28. How it hinders the progress of the community activities ?
29. What is the opinion about the community management of the schemes ?
30. What is the opinion about the cost recovery of operation and maintenance cost from the community ?
31. What suggestions would you like to propose for more effective o & m of the DFP.

Water quality standards in India as per IS:10500 (1991)*

Water quality parameter	Desirable limit	Permissible limit
1. Colour (Hazen units)	5	25
2. Odour	UO	UO
3. Turbidity (NTU) Max	5	10
4. pH	6.5 to 8.5	-
5. Dissolved solids mg/l	500	2000
6. Total hardness (as $CaCO_3$) mg/l	300	600
7. Calcium (as Ca) mg/l	75	200
8. Magnesium (as Mg) mg/l	30	100
9. Chloride (as Cl) mg/l	250	1000
10. Sulphate (as SO_4) mg/l	200	400
11. Nitrate (as NO_3) mg/l	45	100
12. Fluoride (as F) mg/l	1.0	1.50
13. Alkalinity (as $CaCO_3$) mg/l	200	600

* Issued by Bureau of Indian Standards (BIS)

Determination of fluoride ion in water

Among the methods suggested for determining fluoride ion (F^-) in water, the electrode and colorimetric methods are the most satisfactory. Because both methods are subject to errors due to interfering ions (Table 1), it may be necessary to distil the sample before making the determination. When interfering ions are not present in excess of the tolerances of the method, the fluoride determination may be made directly without distillation.

Interference:

Table 1 Concentration of some substances causing 0.1 mg/l error at 1.0 mg F/l in fluoride methods[1]

Substance	Electrode method		SPADNS method	
	Concentration mg/l	Type of Error*	Concentration mg/l	Type of Error*
Alkalinity ($CaCO_3$)	7 000	+	5 000	-
Aluminium (Al^{3+})	3.0	-	0.1#	-
Chloride (Cl^-)	20 000		7 000	+
Chlorine	5 000			Remove completely with arsenite
Colour and turbidity				Remove or compensate for
Iron	200	-	10	-
Hexametaphosphate ($[NaPO_3]_6$)	50 000		1.0	+
Phosphate (PO_4^{3-})	50 000		16	+
Sulfate (SO_4^{2-})	50 000	-	200	-

* + denotes positive error
- denotes negative error
Blank denotes no measurable error

\# On immediate reading. Tolerance increases with time: after 2 h, 3.0; after 4 h, 30.

Precision and Accuracy[2]:

SPADNS Method

On a sample containing 0.83 mg/l F with no interferences, 53 analysts using the Bellack distillation and the SPADNS reagent obtained a mean of 0.81 mg/l F with a standard deviation of ± 0.089 mg/l.

On a sample containing 0.57 mg/l F (with 200 mg/l SO_4 and 10 mg/l Al as interferences) 53 analysts using Bellack distillation obtained a mean of 0.60 mg/l F with a standard deviation of ± 0.103 mg/l.

On a sample containing 0.68 mg/l F (with 200 mg/l SO_4, 2 mg/l Al and 2.5 mg/l $[Na(PO_3)_6]$ as interferences), 53 analysts using the Bellack distillation obtained a mean of 0.72 mg/l F with a standard deviation of ± 0.092 mg/l.

Electrode Method

A synthetic sample prepared by the Analytical Reference Service, PHS, containing 0.85 mg/l fluoride and no interference was analyzed by 111 analysts; a mean of 0.84 mg/l with a standard deviation of ± 0.03 was obtained.

On the same study, a synthetic sample containing 0.75 mg/l fluoride, 2.5 mg/l polyphosphate and 300 mg/l alkalinity, was analyzed by the same 111 analysts, a mean of 0.75 mg/l fluoride with a standard deviation of ± 0.036 was obtained.

Test methods	Level mg F/l	Obtained mean	$\mu - \bar{u}$	Relative error %	Standard deviation %
SPADNS	0.83	0.81	-0.02	2.4	11.0
SPADNS	0.68	0.72	0.04	5.9	2.8
SPADNS	0.57	0.60	0.03	5.3	17.2
Electrode	0.85	0.83	-0.02	0.7	3.6
Electrode	0.75	0.75	0.0	0.2	4.8

(Source: Standard Methods)

Determination of fluoride in 88 samples of defluoridated water were carried out using both electrode and SPADNS method at NEERI, and values obtained with SPADNS were higher than the values obtained with electrode. The techniques used to defluoridate water include Defluoron-2, Magnesia, and Nalgonda[3].

References

1 APHA, AWWA and WPCF (1989). Standard methods for examination of water and waste water, APHA Publishing, Washington, New York.

2 EPA (1983). Methods for chemical analysis of water and wastes, United States Environmental Protection Agency, Cincinnati, OH.

3 Bulusu, K.R., Sundaresan, B.B., Pathak, B.N., Nawlakhe, W.G., Kulkarni, D.N. and Theragaonkar, V.P. (1979). Fluorides in water, Defluoridation methods and their limitations', Journal of Institution of Engineers (India), Env. Engg. Div. Vol. 60, pp 1-25.