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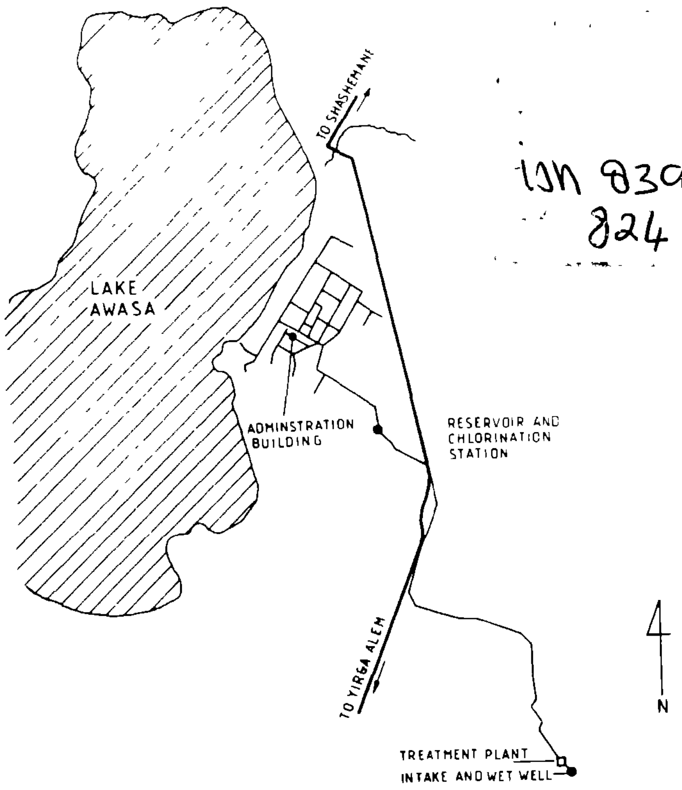

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DISINFECTION PRACTICES IN URBAN WATER SUPPLY IN ETHIOPIA

Page

TABLE OF CONTENTS

ABSTRACT

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ABSTRACT

Water related diseases are the major causes for high death rates in developing countries. These diseases can be minimized or reduced by disinfection of water. The disinfectants ability to penetrate through the cell membrane of the organisms result in destruction of the pathogenic organisms. Thus, disinfection is used to inactivate or destroy disease producing organisms of intestinal origin and has positive impact on improving health.

The objectives of the study were to evaluate the disinfection practices and to identify the common problems related to disinfection, and to propose their possible solutions in Ethiopia. Seven urban water supply systems were studied in Ethiopia. Chlorination is the only method of disinfection used in water supply of these towns.

The study was based on a literature review and on a field research. A membrane filter technique was used in analysing the bacteriological water quality in the field and N , N - diethyl-p-paraphenylene diamine (DPD) method was used to determine the concentration of residual chlorine. The other water quality parameters (pH, turbidity, conductivity and temperature) were measured on each site. A thorough study of the treatment plants and discussion with the operators were also made.

In the treated water entering the distribution system, presence of coliform organisms per 100 ml of water samples tested was not detected. The residual chlorine was 0.3 -2.2 mg/l. However, quality deterioration was observed in most of the network systems. Thus, no chlorine residual was observed and presence of coliforms, total and faecal, per 100 ml of test sample was detected. Contamination through cross-connections, back syphonage and lack of maintaining the required chlorine dose were the causes of deterioration. Further, lack of preventive maintenance and logistic support are the most severe problems in all the disinfection systems.

Maintaining of residual chlorine of 0.1 - 0.2 mg/l at the furthest end of the network should be considered satisfactory. Quality control, monitoring and surveillance should not be the responsibility of one organization, hence these tasks have to be shared by the Ministry of Health and WSSA. Due to the unreliability of gas chlorine supply and equipment a back-up system of calcium hypochlorite ($Ca(OCl)_2$) is recommended.

1 INTRODUCTION

Many of the water-borne diseases like cholera, dysentery and typhoid are transmitted by use of polluted water for drinking and food preparation purposes. Bacteria, viruses, protozoa and cysts are among the various types of disease causing organisms (pathogens) found in polluted water. These disease causing organisms originate from the intestine of warm blooded animals. These are the organisms in water which have to be destroyed by disinfection.

The relation between health and water quality has been established for centuries. Already in 400 B.C. Hypocrates emphasized the importance of boiling and straining water. However, not until the 1800's significant progress was made in improving the quality of water. This was largely accomplished by adoption of filtration and chlorination (Stratman 1988).

The wide use of slow and rapid sand filters improves the microbiological quality. Bacteria and other organisms have to be removed by use of disinfection. Thus the hygienical safety of the water supply depends on disinfection, which can be achieved by physical or chemical means. Disinfection is used at the final stage of water treatment. In practice, chlorine has been the most widely used chemical disinfectant.

The principal reasons for disinfecting drinking water are: to ensure the destruction of pathogens, to maintain a protective barrier against pathogens entering the distribution system and to suppress bacterial regrowth in the pipe (WHO 1984 b). In practice, all town water supplies require disinfection.

It has been shown that adequate chlorine produces zero coliforms/100 ml of test sample. However, loss of residual chlorine in the water supply systems is a great concern. Particularly, presence of faecal coliform in the system of Shashemane water supply indicates faecal pollution. The consumer health is endangered from contamination. Remedial measures such as repairing the leaks and superchlorinating the system has to be considered.

In recent years efforts have been made to supply safe and adequate water to the whole urban population in Ethiopia. However, the level of development of disinfection systems is very low. More efforts have to be made to develop simple chlorination systems and to provide all towns with disinfection.

2 MODE AND METHODS OF DISINFECTION

2.1 Mode of disinfection

The presence of faecal micro-organisms in drinking water sources is a constant danger of water-borne diseases carried through the water distribution system to the consumers. These disease causative agents could be identified as viral, bacterial, protozoal and helminthic (Pretorius 1983). The common diseases caused by ingestion of contaminated water includes gastro-enteritis, bacillary dysentery, typhoid, cholera, virus hepatitis and amoebiasis (Rakotavahiny and Arrestat 1982). Table 1 shows the common water-borne diseases and their health effect. These diseases could be prevented through safe water supply, proper disposal of sewage, and improved standard of living.

Table 1. Water-borne diseases due to microbes (Thompson 1987).

Water-borne disease	Organism	Health effect
Gastro-enteritis	various pathogens	acute diarrhea and vomiting
Typhoid	Salmonella typhosa (bacteria)	inflamed intestine, enlarged spleen, high temperatures - fatal
Bacillary dysentery	Shigella (bacteria)	diarrhea, rarely fatal
Cholera	Vibrio comma (bacteria)	vomiting, severe diarrhea rapid dehydration, mineral loss - high mortality
Infectious hepatitis	virus	yellow skin, enlarged liver, abdominal pain - low mortality - lasts up to four months
Amebic dysentery	Entameoba histolytica (protozoa)	mild diarrhea, chronic dysentery
Giardiasis	Giardia lamblia (protozoa)	diarrhea, cramps,nausea and general weaknesses - lasts 1 - 30 weeks not fatal

The different treatment processes practised in water purification, particularly disinfection, play a great role in removing and destroying the disease causing organisms. The inactivation mechanism of viruses by chlorine and other disinfectants has never been well understood. It is thought that the oxidant penetrates the cell membrane and attacks the nucleic acid (White 1986). Basically, a virus is composed of genetic material encased in protein cell or capsule. The genetic material is either deoxibonucleic acid (DNA) or ribonucleic acid (RNA). The capsule protects the virus from unfavourable environmental conditions and promotes development of virus (ASCE 1983).

The penetration of oxidants through the cell membrane will impair the action of the enzymes; as a result the organism dies. It is generally agreed that the relative efficiency of various disinfectants depends on disinfectant concentration and contact time (Oliveri 1986). Figure 1 shows the essential elements of a bacterial cell.

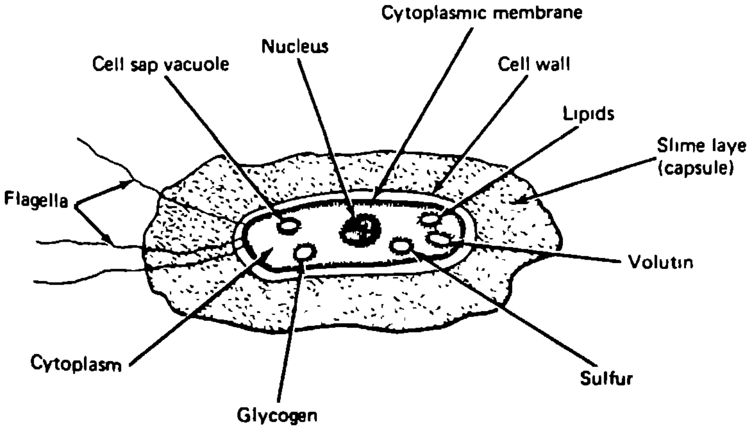


Figure 1. Schematic diagram of a bacterium (White 1972).

In general, the chemical disinfectants used in water treatment being powerful oxidising agents, destroy the semi-permeability and enzymic activity of cell membrane, impair protein synthesis and react with nucleic acid (Packham 1988). Similarly, the ultraviolet radiation results in activation of micro-organisms DNA at 254 nm (Anghern 1984, Scott 1987).

Small dose of free chlorine is capable of inactivating 90 - 99 % of Escherichia coli (E. coli) and other enteric bacteria, faecal coliforms and faecal streptococci, and 50 % or more of different types of viruses and 100 % of cercaria of bilharzia (Mann 1983).

2.2 Different methods of disinfection

Disinfection of potable water can be accomplished by physical or chemical means. The chemical method has been extensively used for over a century. The various disinfectants tried in full or in laboratory scale include chlorine in its various forms, ozone, bromine, iodine, chlorindioxide, ultraviolet radiation, silver, chloramines and potassium permanganate (Hutchinson and Ridgway 1977).

The criteria for appraising the suitability of various disinfectants for water supply as summarized by Fair et al (1971, cited by AWWA 1971) are:

i) Disinfectants ability to destroy the organisms within the contact time available and the range of water temperatures encountered.

ii) Ready and dependable availability of the disinfectants at reasonable cost and in a form conveniently, safely and accurately applied.

iii) Disinfectants ability to accomplish the desired objectives without rendering the water toxic or objectionable aesthetically or otherwise.

iv) Disinfectants ability to persist in residual concentrations as a safeguard against recontamination.

v) Adaptability of practical, duplicable, quick and accurate assay techniques for determining the disinfection concentration for operating control of the treatment process, and as a measure of disinfecting efficiency.

Currently, there is no single disinfectant which satisfies all the above mentioned criteria. Even, chlorine once considered to be free of any adverse health effect has shown its limitation. Without forgetting the final objective of producing hygienically safe water, each factor has to be weighted carefully and proper selection of disinfectant has to be done.

In general, disinfection of water and consequently the kind of treatment process employed in water treatment is influenced by the following factors (Hofkes 1987):

i) nature and number of organisms to be destroyed
ii) type and concentration of the disinfectant used
iii) temperature of the water to be disinfected
iv) contact time
v) nature of water to be disinfected
vi) pH of the water
vii) mixing.

2.2.1 Chlorination

The addition of chlorine and chlorine compounds in water is called chlorination. Chlorine is commercially available in three forms: liquid, powder and liquefied compressed gas (Zeh 1986). Among the available disinfectants chlorine in its various forms is widely used to disinfect drinking water. This is attributed to cheap cost, ease to apply and readily adaptability to different circumstances.

The main advantages of chlorination are the residual chlorine in the distribution network and storage which provides protection against recontamination and microbial aftergrowth.

When chlorine is added to pure water, i.e. free from ammonia and organic matter, it produces hypochlorous acid ($HOCl$) and hypochlorite ion (OCl^-), which are the actual disinfecting agents (Nathanson 1986). The reaction depends on pH and temperature of the water. The disinfecting capacity is retained in $HOCl$, and it is regarded to be greater than OCl^-. It has been shown that $HOCl$ kills 80 - 100 times more E.coli than OCl^- (Snoeyink and Jenkins 1980).

Chlorination of faecally polluted source can produce virus free water when the concentration of free residual chlorine is at least 0.5 mg/l, for a contact period of 30 minutes, at pH below 8 and turbidity equal or below 1 NTU (WHO 1985). When practising chlorine, the disappearance of residual from the system is an indication for the entry of pollutants or malfunctioning of the system.

Besides fulfilling its role as a bactericide, chlorine also acts as an oxidant in solving pollution problems which arise due to the presence of ammonia, cyanides, nitrates and in general all substances which remove natural oxygen from water to be oxidised (Rosa & Fabris 1988). This ability is one of the drawbacks of water chlorination. Its reaction with the naturally occurring substances in the water results in formation of trihalomethane (THM) which is regarded as a potential cancer risk (WHO 1984 a), and chloro-organic compounds some of which can cause unpleasant taste and odour (Packham 1988). Also the presence of impurities, ammonia and particularly the organic nitrogen compounds weaken the effect of chlorine as they bind to free chlorine to form organic chloramines which are poor disinfectants (Hiisvirta 1988).

The prime objective of any water treatment being health protection, distribution of pathogens is of a major importance. Chlorine applied in its various forms fulfils this objective by destroying the enzymes essential for the existence of the micro-organisms. Also, the spread of water-borne diseases as a consequence of incomplete disinfection is substantial. This is particularly true in developing countries, where water-borne diseases cause thousands of deaths every day. The World Health Organization (WHO) supports the use of chlorine for water disinfection in developing countries (WHO 1984 a).

2.2.2 Ozonation

Ozonation is the method of diffusing ozone, an allotropic form of oxygen (AWWA 1971), into the water for the purpose of disinfection. The name ozone is derived from a Greek word 'ozein' which means 'to smell' and it got its name from its characteristics pungent odour (Kinmann 1972). The earliest use of ozone as disinfectant has occurred in France, in 1886 (Palin 1980). The first operational major installation in public water supply was in Nice, France in 1906 (Kinmann 1972). Ozone is fairly common disinfectant particularly in France and Switzerland (Smethurst 1988).

The inherent instability of ozone to decompose back to oxygen necessitates its production on-site for immediate use. It is produced by passing an electric discharge of high voltage alternating current through the dry air. In the generation process a voltage of 4 - 20 kV is applied to dielectric plates about 6 mm part or to concentric tubes through which clean, dry oxygen rich gas is blown (Twort et al 1987). Figure 2 illustrates the basic configuration for generation of ozone.

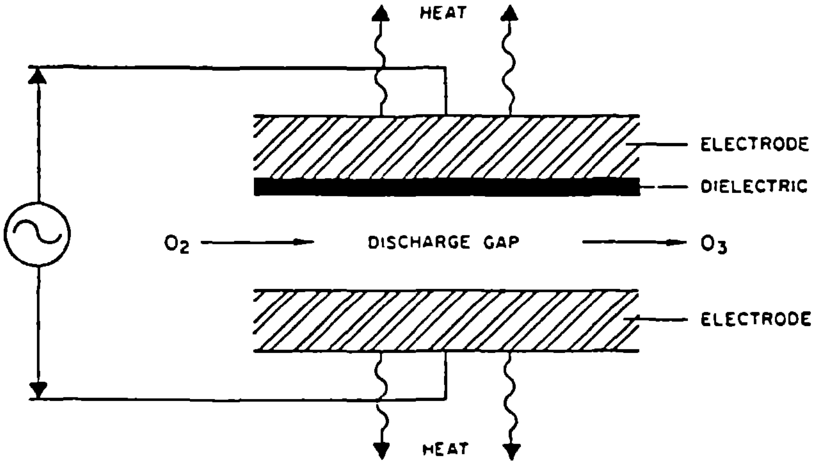


Figure 2. Basic ozonator configuration (Rosen 1972).

The amount produced may be up to 30 mg/m^3 of the blown air (Palin 1980). The generation process and the need of skilled manpower for operation and maintenance leads to higher cost. These disadvantages hinder its adoption in developing countries.

Ozone is also used for taste and odour control, colour removal (Evans 1972) and oxidation of iron and manganese and organic removal (Palin 1980). This mechanism, disinfection and oxidation, with ozone is related to the following reaction:

$$O_3 \text{ ---> } O_2 + \text{'O'} \qquad (1)$$

where the nascent oxygen produces a high energy oxidation through a free radical mechanism (Kinmann 1972). When using ozone as a disinfectant the recommended dosage is 0.2 - 1.5 mg/l (Palin 1980). If a residual of 0.2 - 0.4 mg/l is maintained for 4 minutes, ozone has shown to be an effective viral disinfectant (WHO 1984 a). Even though it is a very potent viricidal agent it lacks provision of lasting residual disinfecting power due to its decomposition back to oxygen. Thus, addition of chlorine, chloramine or chlorine dioxide to obtain residual in the network is unavoidable.

The use of ozone as disinfectant has the following advantages (WHO 1984 a):

- It is a highly effective disinfectant in destroying pathogenic bacteria and viruses.
- It is more effective in disinfecting water containing ammonia than chlorine.

Ozone's ability to decompose organic matter may cause problems in the network, due to increasing volume of bioassimilable compounds, unless the degradation products are removed or an additional disinfectant with a long term effect is used (Hiisvirta 1988). Its high cost and the inability to maintain residual might be the main reason why it has not been widely used for water disinfection. Table 2 summarizes the advantages and disadvantages of using ozone as disinfectant.

Table 2. Advantage and disadvantage of ozone for water disinfection (Kinmann 1972).

Advantages	Disadvantages
Wide spectrum disinfectant	High capital cost for equipment
Avoids taste and odour problems	Must be generated at site
Removes colour	High reactivity results in low selectivity
Adds oxygen to water	Low solubility under normal conditions
Disinfection is rapid	Operation and maintenance may be a headache
Has high oxidation potential	Residual O_3 cannot be maintained in H_2O for long periods
Lowers BOD and COD values	More expensive than chlorine
Low concentrations are adequate	
Does not form noxious compounds in treated water	
Avoids problems associated with transportation of potentially harmful chemicals	

2.2.3 Chlorine dioxide

Chlorine dioxide (ClO_2) has been tried experimentally for disinfection of water in 1900, but practical application proved to be difficult, because of instability of the gaseous material necessitating on-site generation (AWWA 1971). Its first application as a water treatment chemical, for control of phenolic tastes and odours, was in 1944 at a plant in Niagara Falls, USA (Palin 1980).

The gas has an intense greenish yellow colour with a distinctive odour similar to chlorine, but more irritating and toxic (White 1986). The interest for ClO_2 as an alternative to chlorine has received considerable attention in water treatment over the last 20 years (Anon 1987). Due to its explosive nature, it must be generated on-site for immediate use (Aieta and Roberts 1986). It is always applied in aqueous solution after its generation (Anon 1987).

Generation of ClO_2 is achieved from the reaction of aqueous sodium chlorite with chlorine (either as a gas or in solution) or hydrochloric acid (Anon 1987). ClO_2 being a very strong oxidant (Richard 1987) is used in water treatment for organic oxidation, taste and odour control, colour removal, disinfection, and oxidation of iron and manganese. Unlike chlorine it does not react with ammonia and with most organic substances (White 1972). Also it is shown to be superior to chlorine in water containing phenol compounds (Richard 1987). However, the residues of ClO_2 (chlorite and chlorate) seem to be of greatest toxicological interest.

For this reason the U.S. Environmental Protection Agency (EPA) has recommended that the residues of these products should not exceed 1 mg/l in treated drinking water (Contruvo and Vogt 1986).

In drinking water disinfection with ClO_2 destroys or inactivates bacteria and viruses over a wide pH range, does not produce THMs and provides a measurable residual (Aieta et al 1984). Main disadvantage of ClO_2 is its instability and requirement of skilled labour for operation and maintenance. Due to these constraints it is not suitable for the developing countries. Table 3 summarizes advantages and disadvantages of ClO_2 as a drinking water disinfectant.

Table 3. Advantages and disadvantages of chlorine dioxide as a disinfectant (AWWA Committee Report 1982 and Grombach 1983 cited by Vigneswaran et al 1987).

Advantages	Disadvantages
Has a very high oxidizing power and thus a low reaction time (only a few minutes).	Chemical and equipment costs are substantially high compared to chlorine.
Never causes bad taste and odour by combining with substances in water.	The by-products chlorate and chlorite may be toxic.
Forms residuals persistant throughout the distribution system.	Contact between chlorine dioxide and organic substances such as wood may lead to self-ignition.
More effective bacteriacide and viricide at pH 8.5-9.0 rather than pH 7.0 and water is frequently disinfected at pH 8.5-9.0.	The manufacturing equipment are complicated and are subject to corrosion.
Promotes better coagulation and flocculation, especially when coloured compounds are present in raw water.	Application is still limited.
	Reaction product poses anti thyroid activity and by-product ClO_2 may cause hemolytic anemia.
	Odours have been noticed at the tap when using chlorine dioxide.

2.2.4 Ultraviolet radiation

The existence of short wave rays was first proved experimentally by J.W. Ritter in 1801 (Anghern 1984) and the first bactericidal effect of radiant energy from sunlight was reported in 1877 (Masschelein 1983).

The first disinfection of potable water using ultraviolet (UV) was in 1910 in Marseille, France. The unit was not a success due to the unreliable quartz lamp and complicated and expensive design, operation and maintenance. The first successful plant operated in Switzerland in 1955 after improvements made on the UV lamp (Anghern 1984).

The UV rays are part of the electromagnetic spectrum (Figure 3) in the wave length of 10 - 400 nm, i.e. between X-rays and visible light (Anghern 1984). The UV radiation which reaches to the earth's surface is confined to wave lengths higher than 290 nm to near infrared range. This means that the most energitic wave lengths are absent from the sunlight reaching the earth, fortunately absorbed by the ozone layers (Masschelein 1983).

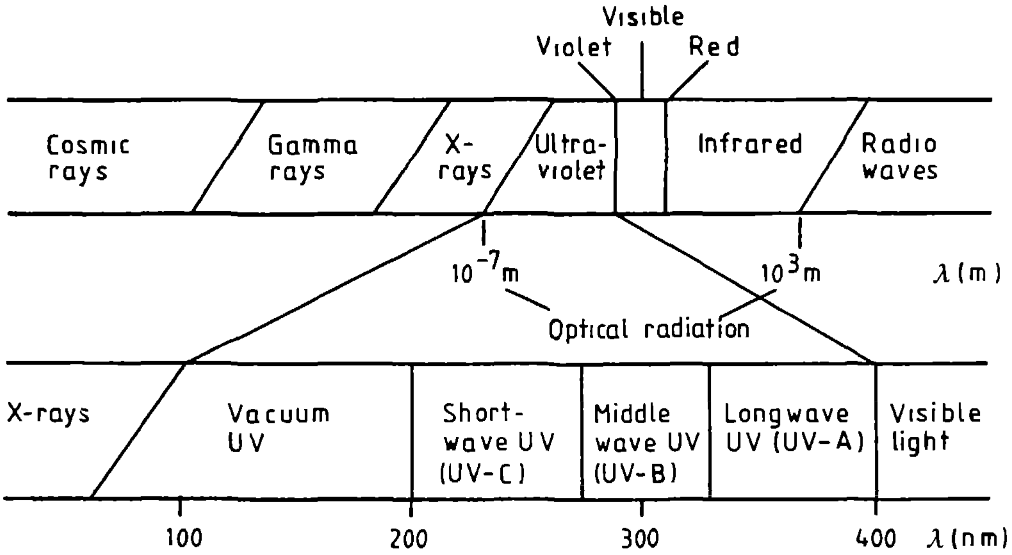


Figure 3. Electromagnetic spectrum with expanded scale of ultraviolet radiation (Anghern 1984).

The UV radiation may be subdivided into three types (Scott 1987):

- UV-A or longwave (400 - 330 nm)
- UV-B or medium wave (330 - 270 nm)
- UV-C or short wave (270 - 200 nm).

The lethal effect of UV varies with wave lengths, having highest bactericidal efficiency between 250 - 260 nm with a maximum at 255 nm (Masschelein 1983).

The most common source of UV-C radiation is the uncoated mercury low pressure lamp. This type of lamp is mostly used in existing UV plants for disinfection purposes. There are two types of tube lamps available commercially: the hot cathode and cold cathode lamps. The cold cathode lamps are preferable due to higher optical efficiency and longer life (Scott 1987).

To achieve the maximum efficiency the lamps must be kept clean (Zeh 1986) so that the organisms are exposed to the full intensity of the UV light. The germicidal effect of the light is as the result of its action on the nuclic acid of the bacteria, and depends on the light intensity and time of exposure (Tobin et al 1983).

UV light radiation is a non-chemical method of disinfection of water. Disinfection is accomplished when the water is exposed to the UV light source. For effective disinfection the water must be without turbidity or colour and free from organic colloids that might form deposits on the tubes or obstruct the passage of light. Also the depth of the water must be shallow. If these conditions are satisfied, UV is an effective disinfection method (Richard 1987).

Because the UV radiation leaves no residual, the disinfection has to be complimented either with chlorine or chlorine dioxide. The shortcomings coupled with the hardware problems make UV unfeasible in developing countries. Table 4 summarizes some of the advantages and disadvantages of UV disinfection of potable water.

Table 4. Advantages and disadvantages of UV for disinfection of potable water (AWWA 1971).

Advantages	Disadvantages
Foreign matter is not introduced into water and physical or chemical character is not significantly affected.	Spores, cysts, and viruses are less susceptible than vegetative bacteria.
Constituents of the water in solution, such as ammonia, exert no effect on disinfecting capacity.	Thorough water preconditioning is required because UV is absorbed by many constituents normal even to pretreated waters.
Tastes or odours are not produced (but UV has no effect on removal of odour or colour).	Residual disinfecting capacity apparently is not provided.
Short contact time is effective.	Extensive amounts of electric energy and expensive equipment are required.
Overdosing produces no detrimental effects.	Frequent and expensive apparatus maintenance is necessary to ensure stable energy application and essentially uniform density throughout effective radiation area. Treatment efficiency is not readily determinable (lack of rapid field test).

2.2.5 Comparison of different disinfectants

At present, there is no single disinfectant which can satisfy all the requirements of a 'perfect' disinfectant in terms of disinfection efficiency and formation of undesirable by-products (Hiisvirta 1988). When comparing different disinfectants, their ability to remain as residual during storage and distribution of potable water has to be considered. Ozone and UV lack the ability to leave a residual.

It seems that there is no competive alternative to chlorine as disinfectant. Rosa and Fabris (1988) have suggested that ClO_2 is perhaps the only disinfectant alternative to chlorine, although its use is limited in water with high ammonia content. The toxicological effect of residues resulting from ClO_2 disinfection should not be underestimated.

Wilson and Hsu (1988) said that ClO_2 is not an alternative to chlorine. They have stated that ozone and UV are the most common chlorine alternatives, but they have inherent shortcoming in not providing residues. Monitoring of the treated water will be difficult unless they are complimented by chlorine or ClO_2 before the water enters the distribution network.

While comparing the disinfectants the adverse health effect on the long term use should also be taken into consideration. As ozone and UV lack the property to provide disinfectant residual their anticipated health risk will be minimal, whereas all the chemical disinfectants have shown to produce adverse health effects. The limited toxicological information available makes the choice very difficult. Chlorine is the only chemical disinfectant thoroughly investigated and studied. Because chlorine is the cheapest, easiest to transport, to store for future use and effective in destroying pathogenic organisms its use particularly in the developing countries is recommended.

3 WATER CHLORINATION AND ITS DEVELOPMENT

3.1 Development of water chlorination

Chlorine, which is never found in uncombined state in nature, is a chemical element of the halogen family, group VII in the periodic table. About 0.15 % of the earth's crust is estimated to be in the form of soluble chlorides (Encyclopaedia Britannica 1957). Molecular chlorine, at ordinary room temperature and pressure, is a greenish yellow gas. The gaseous form is very toxic but, when dissolved in clean water it becomes harmless (Nathanson 1986).

Swedish chemist K.W. Scheele discovered the gaseous chlorine in 1774 as a product of reactions between hydrochloric acid and manganese dioxide (White 1972). The gas was first liquefied in 1805 by T. Northmore and was identified as an element by H. Davy in 1810. H. Davy gave its present name chlorine from the Greek word '<u>cloros</u>' (which means green), because of its characteristic colour (AWWA 1971).

Chlorine (hypochlorite form) was first introduced in water supplies in 1850's. The common belief was that odour spread diseases and the control of the odour would stop the spreading. Its capacity to destroy micro-organisms was not well understood until 1890's. The first continuous treatment of water chlorination was adopted in Middlekere, Belgium, 1902 (Palin 1980). After that chlorination became a predominant method for disinfection of potable water.

Initially, chlorine disinfection was based on adding plenty of chlorine to ensure safety irrespective of the water quality or the reaction of added chlorine. Consequently, the practice was uneconomical and left detectable taste in the treated water. Later the orthotolidine test for determination of the residual chlorine made the control of chlorination possible. The discover of the breakpoint chlorination in 1939 by Faber and Griffin provided selective operation and control of operation. This discovery marked the beginning of the free residual chlorination process. Subsequently, various tests for free and combined chlorine were introduced (Morris 1966).

The development and the experience on water chlorination during the past 90 years have made the current knowledge of chlorination vast and refined. Chlorine was considered to be free from adverse health effects. However, the findings of THMs by Roorke in 1974 has demonstrated chlorination of water to possess cancer risk (Umphres et al 1981). Currently research is mainly oriented on the improvement of chlorination practices and finding new alternative disinfectants.

Some countries have established THMs standards in drinking water. At present most countries and certainly all developing countries may take the view that the presence of THMs is of negligible public health importance (Cairncross and Feachem 1983). WHO supports the use of chlorine in developing countries.

3.2 Chlorine and its compounds

3.2.1 Chlorine gas

Chlorine gas is generally used for disinfection in large water treatment plants. Commercially it is produced from electrolysis of sodium chloride (Palin 1980). It is supplied as a liquid gas under pressure in steel containers or cylinders. The capacity of the cylinders range 45 - 100 kg and tank trucks 15 000 - 50 000 kg (Steel and McGhee 1988). The chlorine content is 100 %. The size of containers commonly used in Ethiopia are 65 kg cylinders containing 45 kg of chlorine.

The chlorine gas is dispensed by gas chlorinator, which controls and meters the gas applied into the water to be disinfected. There are two types of gas chlorinators: pressure feed type and vacuum type (Zeh 1980). In both cases the gas regulator is fixed to the chlorine gas cylinder. The pressure feed type, meters and controls the feeding rate to a gaseous chlorine diffuser located at the point of application. The vacuum type (Figure 4) dispenses the gaseous chlorine at the point of chlorination. When the water flows through the aspirator located at the point of chlorination vacuum is created. This vacuum is conveyed to the cylinder mounted regulator. Then the gas leaves the cylinder valve and enters the regulator where it is metered and the flow rate is controlled (Zeh 1986). The vacuum type is the one which is used in Ethiopia.

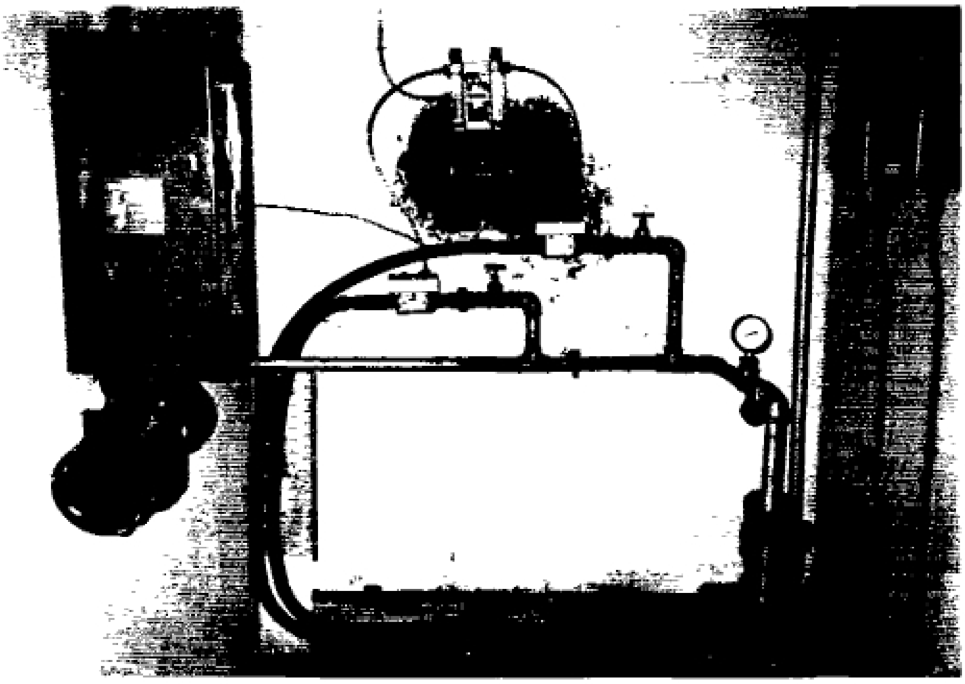


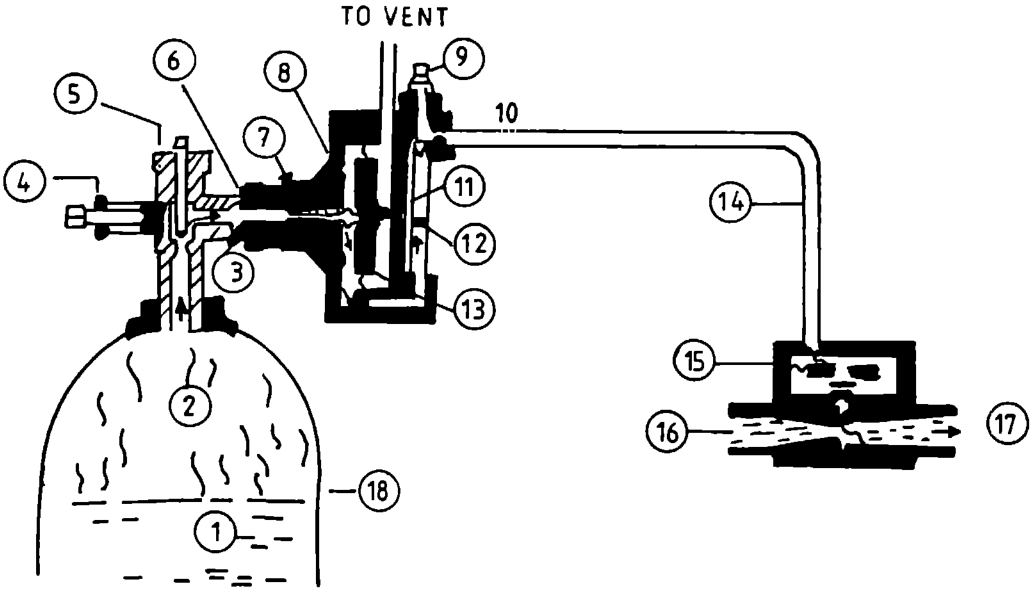
Figure 4. Vacuum type solution feed gas chlorinator in Awassa Treatment Plant, Ethiopia.

The main features of chlorine gas installation (Figure 5) are (White 1982):

i) Chlorine supply system, where the liquid is stored under pressure.

ii) Metering and control system. This task is accomplished by chlorinators while the chlorine flows from the supply through them.

iii) Injection system. The power developed by the injector allows chlorine to flow through the chlorinator and finally into the injector. This system is the heart of chlorination, because its function is vital for successful operation.



LEGEND

1	chlorine liquid
2	chlorine gas
3	inlet filter
4	yoke clamp
5	chlorine cylinder valve
6	lead gasket
7	inlet safety
8	vacuum seal 'O' ring
9	rate valve
10	outlet connection
11	vent valve
12	rate indicator
13	regulating diaphragm assembly
14	vacuum line
15	ejector and check valve assembly
16	water supply
17	chlorine solution
18	chlorine cylinder

Figure 5. Chlorination apparatus (Steel and McGhee 1988).

3.2.2 Calcium hypochlorite

The powdered form of chlorine is known as calcium hypochlorite, $Ca(OCl)_2$, and it is used as loose powder or compressed tablet forms (Zeh 1986). It is commercially available as bleaching powder containing about 30 % available chlorine and calcium hypochlorite granules with about 75 % available chlorine (Mann 1983). When mixed with water it produces suspension which needs precipitation, which is one of the disadvantages of using $Ca(OCl)_2$.

Bleaching powder (chloride of lime)

This form of chlorine was the first disinfectant used in potable water chlorination. Bleaching powder is prepared from the reaction of slaked lime and chlorine (Equations 2 and 3). The resulting powder contains 70 % the bleaching powder, calcium oxychloride. Upon the hydrolysis of this powder, calcium hypochlorite and calcium chloride ($CaCl_2$) are formed (White 1972).

$$Cl_2 + Ca(OH)_2 \longrightarrow Ca(OCl)_2 + H_2O \qquad (2)$$

$$2\ Ca(OCl)_2 \longrightarrow Ca(OCl)_2 + CaCl_2 \qquad (3)$$

Although it deteriorates while storing and looses available chlorine content, it is perhaps the cheapest form of chlorine available for chlorination in small water supplies.

Calcium hypochlorite granules

This is similar material to the bleaching powder except the available chlorine content which is 65 - 70 % by weight. This form of chlorine is the one which is often used for oxidation and disinfection purposes in the urban water supply plants in Ethiopia. It is also used as a back-up for gas chlorination. The standard strength solution is mostly pumped into the water by dosing pumps (Figure 6) or fed by gravity using drip feeders (Figure 7). The chemical is supplied in 50 kg drums of plastic lined containers containing 45 kg of $Ca(OCl)_2$.

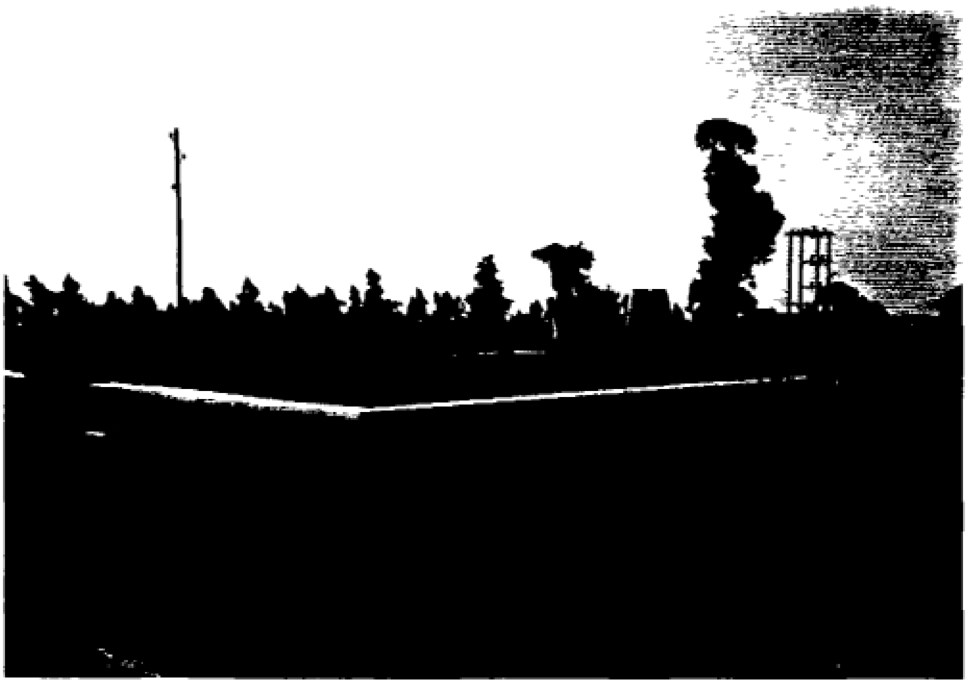


Figure 6. Gravity feeding devices arrangements for lime, alum and calciumhypochlorite $Ca(OCl)_2$ solutions at the balancing chamber of Shashemene Water Treatment Plant, Ethiopia.

Figure 7. Design pump device arrangement at Arba Minch Water Supply for $Ca(OCl)_2$ solution, Ethiopia.

The storage period of $Ca(OCl)_2$ is relatively longer than that of the bleaching powder, if it is stored in sealed plastic or glass containers (Williams 1983). For making the standard strength solution of $Ca(OCl)_2$ it is preferable to use water containing hardness ($CaCO_3$) less than 75 - 100 mg/l. Use of hard water results in precipitation of its hardness (Cox 1973).

3.2.3 Sodium hypochlorite

Sodium hypochlorite (NaOCl) solution is the liquid form of chlorine which can be fed to water through solution feeding devices. The solution is prepared from the reaction of caustic soda (NaOH) and chlorine (Cox 1973), and it is the most widely used of the hypochlorites. Its stability is highly affected by temperature, pH, light and presence of heavy metals (White 1986). Freshly prepared solution has available chlorine of about 15 %, but it slowly decomposes on storage (Williams 1983). It is commercially available as a solution in various strengths containing 1 - 15 % of available chlorine (Mann 1983).

The non-clogging nature of NaOCl is an advantage over $Ca(OCl)_2$ solution. Due to its instability in exposure to atmosphere it has to be supplied in small containers for short time use. Consequently, freight and package is expensive. Hence its use in developing countries is not recommended (Twort et al 1987).

3.3 Chemistry of potable water chlorination

3.3.1 Chlorine in water

Chlorine is either directly dissolved in water by chlorinators or fed to the water in solution form. When chlorine is added into water free from organic matter and ammonia, HOCl is produced as an end product (Equation 4). The hydrochloric acid (HCl) is neutralized by the alkalinity of the water, further the HOCl partly dissociates to hydrogen and OCL^- (Equation 5) (Cox 1973).

$$Cl_2 + H_2O \Longleftrightarrow HOCl + HCl \qquad (4)$$

$$HOCl \Longleftrightarrow H^+ + OCl^- \qquad (5)$$

Chlorine existing in the form of HOCl and OCl^- in the water is defined as free available chlorine (Hach 1981). The concentration of HOCl and OCl^- depends mainly on pH and temperature of the water. When pH is less than 7.5 HOCl predominates and above pH 7.5 OCl^- is predominant. Figure 8 illustrates this phenomenon.

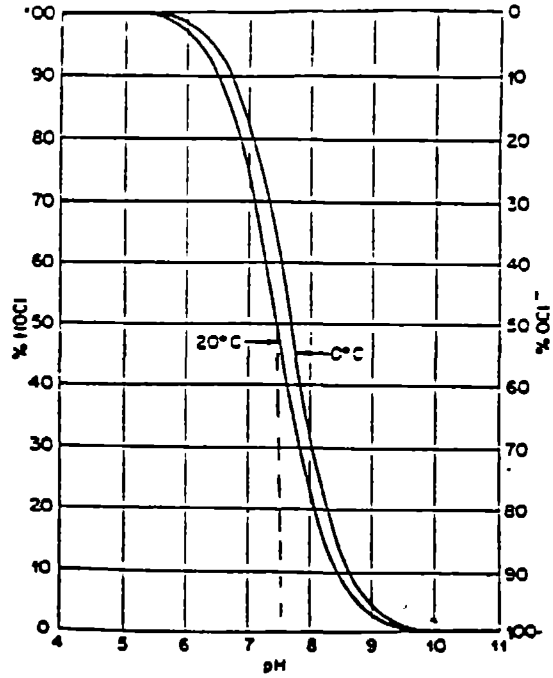


Figure 8. Distribution of HOCl and OCl^- in water (AWWA 1971).

Between pH 6 - 8.5 there is a sharp change from undissociated HOCl to almost complete dissociation. But at about pH 7.5 and 20 °C, approximately equal concentration of HOCl and OCl^- exists. The pH of water supply is normally between 6.5 - 8.5 (Sayre 1988) where chlorine exists both as HOCl and OCl^-.

The reaction of the hypochlorites with water has the same end product like in Equations 4 and 5. For example, when $Ca(OCl)_2$ is dissolved in water (Equations 6 and 7) the reaction will be (Steel and McGhee 1988).

$$Ca(OCl)_2 + H_2O \Longleftrightarrow Ca^{2+} + 2\ OCl^- + H_2O \qquad (6)$$

$$H^+ + OCl^- \Longleftrightarrow HOCl \qquad (7)$$

In general, die-off of the bacteria is achieved when the free available chlorine reacts with the enzyme essential to the metabolic process of bacterial cell. This results in disruption of the essential metabolic function consequently killing the bacteria cell (Fair et al 1971, Wolfe et al 1984).

3.3.2 Chlorine reaction with inorganic compounds

The common inorganic compounds found in potable water sources are Mn^{2+}, Fe^{2+}, NO_3^- and S^-. The reaction of these compounds with chlorine follows the same pattern as Equations 8 and 9, except for Mn^{2+} which oxidized at pH greater than 8.5. In the process, these reducing in organic compounds oxidized consuming the added chlorine (Snoeyink and Jenkins 1980).

$$Cl_2 + 2Fe^{2+} \Longleftrightarrow 2\ Fe^{3+} + 2Cl^- \qquad (8)$$

$$HOCl + H^+ + 2Fe^{2+} \Longleftrightarrow 2Fe^{3+} + Cl^- + H_2O \qquad (9)$$

Figure 9 illustrates the phenomenon which might occur in the presence of a ferrous iron solution in pure water when Cl_2 is added.

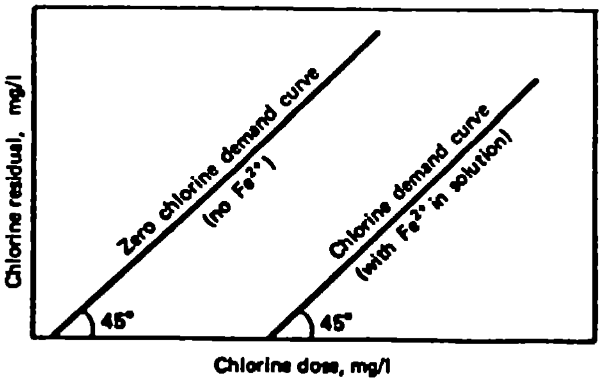


Figure 9. Chlorine dose residual curve for Fe^{2+} oxidation (Snoeyink and Jenkins 1980).

3.3.3 Chlorine reaction with ammonia

Most natural waters contain organic or inorganic nitrogen. The compounds of inorganic nitrogen in water are ammonia, nitrites and nitrates. The reaction of chlorine with any compound containing nitrogen atom with one or more hydrogen atoms attached will form a compound broadly classified as an N-chloro compound (chloramine) (White 1986).

When chlorine is added to water containing natural or added ammonia, the ammonia reacts with HOCl and forms various chloramines which, like HOCl, retain the oxidizing power of chlorine (AWWA 1971). This chlorine existing in water as form of chloramines is defined as combined available chlorine (Hach 1981).

The chemical reactions that occur during the formation of chloramines are (Barnes and Wilson 1983) :

NH_3 + HOCl ---> H_2O + NH_2Cl (monochloramine) (10)

NH_2Cl_2 + HOCl ---> H_2O + $NHCl_2$ (dichloramine) (11)

$NHCl_2$ + HOCl ---> H_2O + NCl_3 (nitrogen trichloride) (12)

The above reactions depend on the concentration of the reactants, pH and contact time (Hutchinson and Ridgway 1977). In general, when the pH of the solution decreases and the chlorine - to - nitrogen weight ratio (Cl_2:N) increases, the ammonia molecule becomes more chlorinated: NH_3 --> NH_2Cl --> $NHCl_2$ --> NCl_3 (Wolfe et al 1984).
This combined available chlorine together with the free available chlorine in water is defined as total available chlorine (Hach 1981). Figure 10 illustrates the formation of chlorine residuals in presence of ammonia.

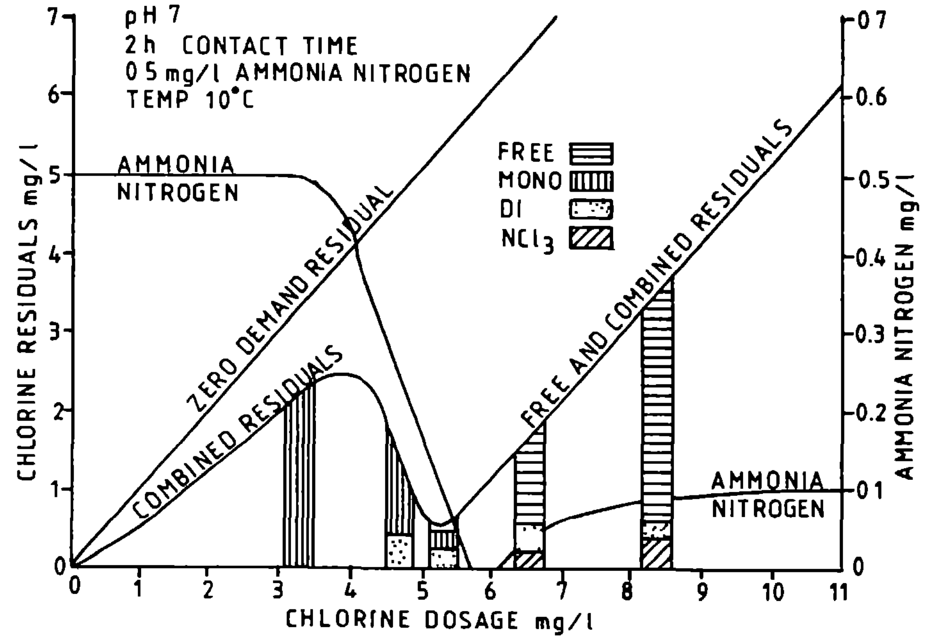


Figure 10. Relationship between ammonia and organic nitrogen and chlorine (White 1968).

Thus, at pH 7 all the ammonia is converted to NH_2Cl when Cl_2:N is 5:1 or less. As the Cl-N ratio exceeds 5:1 and reaches 10:1, i.e. approximate ratio of break point (dip on residual chlorine curve of Figure 10) $NHCl_2$ will be formed. Finally, as the Cl-N ratio exceeds to 15:1 or more NCl_2 will be formed (White 1972).

The monochloramine retains the disinfecting capacity of chlorine. The formation of $NHCl_2$ and NCl_3 is undesirable, because these compounds are thought to impart a disagreeable chlorinous taste at concentrations above 0.8 mg/l and 0.02 mg/l respectively (Wolfe et al 1984).

Krasner et al (1989) have shown that when chloramines are used as disinfectant taste and odour have changed. The developed taste and odour was an indirect consequence of chloramination and was not caused by the presence of the odorous chloramine species, $NHCl_2$ or NCl_3. Many systems operate with apparent success using marginal chlorination in which the chlorine residual formed is predominantly monochloramine (Hutchinson and Ridgway 1977).

In the absence of natural occurring ammonia in the water inorganic ammonia is added to the chlorinated water to generate the inorganic monochloramine. This treatment is called chloramination or the ammonia - chlorine process (Wolfe et al 1984).

The formation of THMs due to the reaction of chlorine with organic compounds present in water has prompted to look for an alternative disinfectant. Chloramine is one of the disinfectants considered as an alternative to chlorine. Especially in USA its use is wider than other possible alternatives of chlorine (Vigneswaran et al 1987). Even though the disinfecting capability of chloramines at longer contact time is comparable to that of chlorine, chloramines are not as good oxidants as free chlorine (Krasner et al 1989).

Nitrification development on chloraminated drinking water is increasing concern. The nitrification occurred in the two covered reservoirs of the water district of South California was attributed to change from chlorine to chloramines. As a result of the nitrification the two reservoirs were breakpoint chlorinated and removed from service for several days (Wolfe et al 1988). Chloramine is not as effective as chlorine in deactivating bacteria and viruses (Vigneswaran et al 1987). Also its potential health risk is still questionable pertaining to little available information (Wolfe et al 1984).

3.3.4 Chlorine reaction with organic compounds

Most surface waters used for drinking water source contain organic substances as a result of aquatic life activity and discharge of domestic, agricultural and industrial wastes. Based on source of origin (generation) Randtke (1988) has grouped the organic contaminants to three classes:

1) Natural organic matter, including humic substances, microbial oxidates, and other organic materials dissolved into the water from sources such as plant tissue and animal wastes.

2) Synthetic organic chemicals, including pesticides, volatile organic chemicals, and other synthetic chemicals produced commercially or generated as waste products.

3) Chemical by-products and additives that enter (or are formed in) the water during treatment or in the distribution system.

Of the various types of pollutants the natural organic matter is present almost in all water supply sources. Most organic pollutants are removed by other treatment processes, coagulation and filtration, prior to disinfection. Their removal is essential to reduce the chlorine demand and to avoid the disinfection by-products identified as possessing adverse health effects.

Currently the number of organic compounds identified in water is over a thousand. Most of these occur in very small concentration. Health effects of most of these compounds are not yet known. However, some organic compounds, or groups of compounds, are known to be either toxic, or carcinogenic or to produce odours or tastes, sometimes after reacting with chlorine used for disinfection (Cairncross and Feachem 1983).

Organic nitrogen compounds are abundant and essential component of nature. Several studies have attempted to subdivide the organic nitrogen fraction into amino and non-amino nitrogen compounds. The major amino nitrogen present in natural water is tied up in proteins and polypeptides rather than as free amino acids. The presence of high concentration of proteins and amino acid in natural water seems to be related to algal activity and both human and animal waste (Scully et al 1986).

All proteins contain nitrogen, carbon, oxygen, and hydrogen, and some also sulfur. Of these elements nitrogen, carbon and sulfur exert a chlorine demand (White 1986). Chlorine reacts with many organic nitrogen compounds. The organic amines which have the group $-NH_2$, $-NH-$, or $-N=$ as part of their molecule are very common. In reaction with these compounds chlorine is substituted for a hydrogen atom. The elementary reaction with methylamine (Equation 13) is typical (Snoeyink and Jenkins 1980):

$$HOCl + CH_3NH_2 \text{ ---> } CH_3NHCl + H_2O \qquad (13)$$

Presence of organic nitrogen in concentration as low as 0.3 mg/l will interfere chlorination process. The significant difference between the two forms of nitrogen is the reaction time. Ammonia compounds react with chlorine within 20 - 30 minutes while the reaction of organic nitrogen with chlorine might take days before completion. The chemistry of chlorination of organic nitrogen compounds is extremely complex, because of the hydrolysis products which might be encountered. Fortunately most proteins are colloids that are partially removed in normal water treatment processes (White 1972).

3.4 Methods of chlorination

3.4.1 Plain or simple chlorination

In some water supplies the only treatment performed is chlorination, which is called plain or simple chlorination. Groundwater sources, unlike surface sources which are turbid, are often found to be clean. Due to indiscriminate disposal of wastes to the soil these sources get contaminated. Sometimes drinking water which is found to be bacteriologically safe at the source gets contaminated in the distribution network. To avoid further contamination of water and to retain a measurable residuals in the network as a safeguard all distributed sources should be disinfected. This method of chlorination is the only type of treatment often provided for groundwater and sources in Ethiopia.

3.4.2 Pre-chlorination

Chlorinating the raw water before any other type of treatment is called pre-chlorination. This method has been mainly practised to achieve improvement on coagulation, reduction of taste and odour caused by organic sludge in the sedimentation tank by oxidation, and improve filter operation by reducing bacterial and algal load by control of mud ball formation (AWWA 1971). Dosage required for this purpose may be 5 mg/l to meet the chlorine demand of the water, and leave 0.2 - 0.5 mg/l free residual chlorine (Cox 1973). This method of chlorination is common in the conventional treatment plants in Ethiopia. Due to the possible formation of THMs with reaction of chlorine to organic pollutants the use of pre-chlorination would have to be eliminated or restricted (Twort et al 1987).

3.4.3 Post-chlorination

Post-chlorination is defined as the addition of chlorine to water subsequent to other treatment processes. The chlorine may be added to the filter effluent pipe or to the clear water tank so that the contact time may be as long as possible. The contact time should be at least 30 minutes resulting a free chlorine residual of 0.2 - 0.5 mg/l in the entire network (WHO 1984 a). Dosage of the chlorine depends on the quality of water to be disinfected and the amount of residual required in the distribution system. Occasionally the chlorination at the plant is augmented by addition of chlorine at one or more points in the distribution system. The purpose of this practice is to hold the disinfection effect throughout the system so that growth of organic matter in the mains and contamination resulting from cross connection can be prevented (Steel and McGhee 1988).

3.4.4 Breakpoint (or free residual) chlorination

When chlorine is added to water it oxidizes the reducing compounds and reacts with organic and inorganic nitrogen compounds, particularly with ammonia to form the chloramines. The formation of chloramines continues until the ratio of chlorine to ammonia compounds reaches about 5:1. Further increase of chlorine causes reduction in chloramines, because of their oxidation by the excess chlorine. This reaction results in the formation of free chlorine. The point at which all available ammonia is oxidized and low level or residual chlorine is, is called the breakpoint of the water (Wolfe et al 1984). After the breakpoint addition of more chlorine results in the formation of free chlorine, i.e. the amount of chlorine added will be equal to the free available chlorine.

Where there is no ammonia present in the water there will be no breakpoint as the added chlorine will result in increase of free available chlorine. The principal advantage of breakpoint chlorination is that it ensures the production of free chlorine which is more effective disinfectant than chloramine (Twort et al 1987).

3.4.5 Superchlorination followed by de-chlorination

The method involves addition of excess chlorine to keep high concentration of chlorine residual for some time in the plant. It is advantageous to fight against intermittent pollution. Sometimes, natural calamities, like cyclone, flood, earthquake etc., may occur resulting in complete disruption of water supplies and pollution of the system. In such cases and cleaning out newly laid pipes, reservoirs or restoring back the water supply system into operation high dosage of chlorination is essential (Hofkes 1987).

The dechlorination, i.e. reduction of chlorine concentration can be achieved by addition of sulphur dioxide or sodium thiosulphate or bypassing the water through granular activated carbon filter (Barnes and Wilson 1983). Of the different methods of dechlorination, sulphur dioxide is the most popular as the chlorination device and can also be used to handle the gas (White 1986). However, in absence of the above mentioned chemicals or devices dechlorination can be achieved by flushing the water through un open hydrant until the required chlorine residual is attained. The disadvantage of flushing through open hydrant is loss of treated water. However, since the operation is not a frequent phenomenon the amount of water flushed would not be significant compared to the advantages attained.

3.5 Factors influencing disinfection efficiency of chlorine

There are several factors, which have to be taken into account for effective disinfection with chlorine:

i) Nature of water to be disinfected

If the water to be disinfected has high turbidity and plenty of organic matter including ammonia, the disinfection process is hampered (Hofkes 1987). The presence of turbidity hinders the chlorine to reach to the organisms because of physical barrier, and chemical reaction with turbidity particles (Gorchev 1988).

Turbidity in water is caused by the presence of suspended matters, such as clay, silt, colloidal organic particles, plankton and other microscopic organisms. The presence of turbidity has a significant effect on the microbiological quality of drinking water, because high level of turbidity can protect micro-organisms from the effect of disinfection. Turbidity also stimulates the growth of bacteria in the water and itself exerts a significant chlorine demand, hence it is vitally important in producing safe drinking water. If chlorine is used as disinfectant, the turbidity should be kept low, preferably below 1 NTU (WHO 1984 b).

ii) Temperature of the water to be disinfected

As water chlorination is a chemical reaction it is affected by the prevailing temperature. It is often necessary to increase the chlorine dose when the temperatures are low or in warmer condition where most of the disinfectant is lost to the environment due to side reaction (Hutchinson and Ridgway 1977). In general, when the temperature increases the more rapid will be the disinfection process (Hofkes 1987).

iii) Contact time

Contact time is the time available for the interaction between chlorine and constituents of the water. To allow enough time for destruction or oxidation of the water constituents, the contact time should be longer. The longer it is the higher will be the effect of disinfection. The minimum contact time recommended before the water reaches the consumer tap is 30 minutes.

iv) Type and concentration of organisms to be destroyed

There are several micro-organisms which are identified to exist in water, particularly in surface water sources. Some of these micro-organisms are capable of causing water related diseases through ingestion of the water. Higher concentration of the micro-organisms may cause agglomeration making the chlorine penetration difficult. To destroy or to inactivate these micro-organisms the dose of chlorine has to be increased. This will result in high chlorine consumption for that particular water.

v) Concentration of chlorine

The die-off of organisms, other factors being constant, is proportional to the concentration of disinfectant and the reaction time (AWWA 1971). The amount of chlorine to be added for clear water tends to be lower while for those sources which are suspected to pollution the amount is higher. Chlorine has been found to produce virus free water when the concentration of the free chlorine residual is at least 0.5 mg/l. The higher the concentration is the higher will be its germicidal effectiveness. Undesirable high concentration of residual chlorine in the water might result in consumers complaint.

vi) pH of water

Raw water pH has significant influence in the chlorine demand, because the form in which the residual chlorine occurs is governed by the pH. As the pH increases the HOCl becomes more dissociated to OCl^-. Further the solution looses its strength as HOCl is the principal disinfectant. Hence it can be concluded that, other factors being constant, the higher the pH the lower will be its disinfecting capacity. If the pH increases above 8 or decreases below 6.5 during other treatment processes, pH correction has to be made to utilize effectively the added chlorine.

vii) Mixing

The main objective of mixing is to disperse the chemical added to water so that it comes into close contact with the impurities in the water (Vigneswaran et al 1987). To insure thorough mixing a sufficient contact time has to be provided. In larger water supplies, after the solution is discharged, mixing of chlorine can be achieved in the mains (Figure 11) whereas in small supplies, where water is directly pumped to the system, attaining a thorough mixing in the pipe might be difficult due to short contact time (White 1982). Hence, proper provision has to be made in the tank or reservoir before pumping to the system.

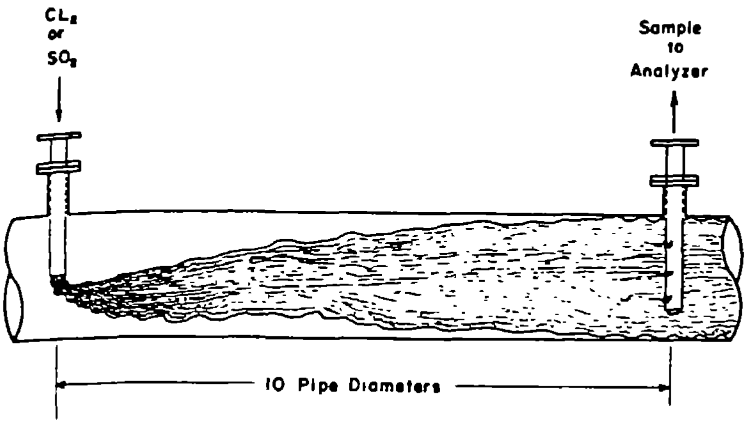


Figure 11. Pipeline as a mixing device (White 1972).

Figure 12 illustrates the apparatus for discharging chlorine solution (in this case $Ca(OCl)_2$) into pipe flowing full.

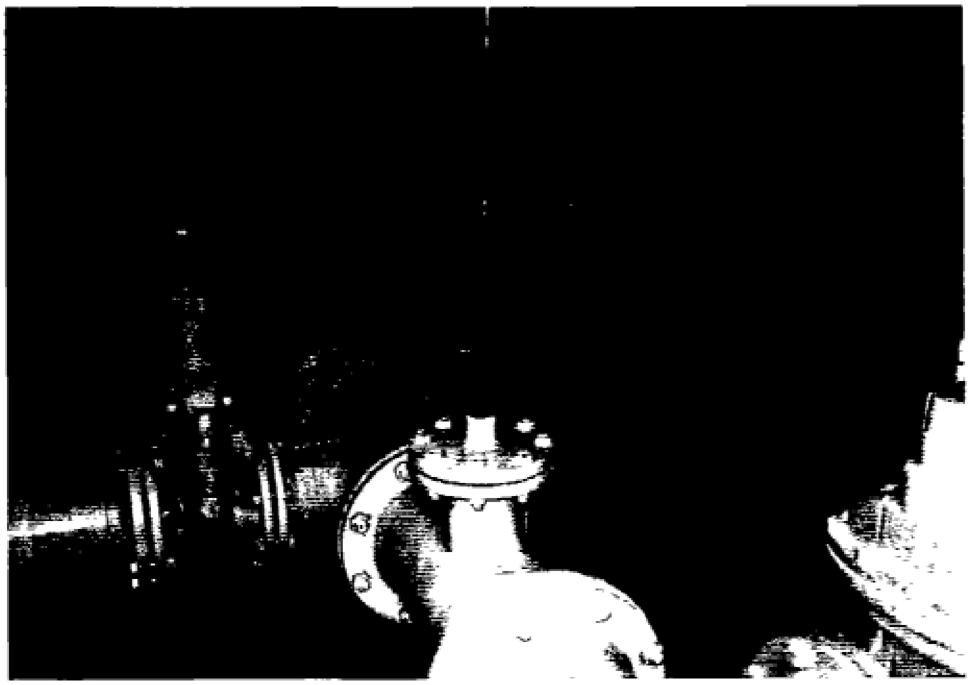


Figure 12. Chlorine solution diffuser in Goba Water Supply, Ethiopia.

3.6 Bacteriological quality control of drinking water

3.6.1 Bacteriological quality control

It is impracticable to monitor drinking water for every possible microbial pathogens that might occur with contamination (WHO 1984 b). Fortunately, less harmful, easily isolated bacteria called indicator organisms (coliforms) travel with the disease causing microbes. They live in the intestine of man and other animals and are almost always present even in healthy persons (Hach 1981). Among the coliforms E. coli is found in higher density and with greater frequency than other coliforms. Thus, presence of E. coli in water is an indicative of faecal contamination (Dufour 1976).

Control of bacteriological quality of water can be achieved by monitoring the indicator bacteria such as total coliform and faecal coliform organisms (WHO 1984 a). The absence of total coliform normally indicates that the water has been sufficiently treated/disinfected to destroy the various pathogens (WHO 1985). It is also a valuable measure for checking the quality of finished water in distribution system as an indicator of microbial regrowth and sediment build up in slow flow sections and dead ends (APHA-AWWA-WPCF 1985).

The coliform group comprises all aerobic and facultative anaerobic gram negative, non spore forming, rod shaped bacteria, that ferment lactose with gas formation within 48 hours at either 35 ^{o}C or 37 ^{o}C or that produce a dark colony with a metallic sheen on an Endo-type medium containing lactose within 24 hours at 35 ^{o}C. Those which have same properties at a temperature of 44 ^{o}C or 44 - 45 ^{o}C are described as faecal coliforms. The standard test for the coliform group may be carried out either by the multiple tube fermentation technique (presumptive test, confirmed test or completed test) or by membrane filter technique (APHA-AWWA-WPCF 1985, WHO 1984 b):

a) Multiple tube fermentation technique

In this method a series of fermentation tubes, containing a suitable culture media are inoculated with test portion of the water sample (WHO 1985). The inoculated water samples are incubated for detection of gas formation in the inverted vial called 'Durham tube'. The absence of gas formation constitutes as a negative test, and presence of gas formation at the end of the test is positive for total coliforms or faecal coliforms depending on the incubation temperature and time of incubation. The result is reported as statistical estimate called the most probable number (MPN) per volume of the inoculated sample.

The advantage of this method is that it is applicable for all water samples. According to WHO (1985) it can be used for clean, coloured or turbid water containing sewage sludge or mud and soil particles, provided that the bacteria are homogeneously distributed in the prepared test samples. The longer time required for the final result can be stated as a disadvantage. The volume of water sample used for treated water is normally 10 ml.

b) Membrane filter technique

In this method a measured volume of water sample, normally 100 ml, is filtered through a membrane with a pore diameter of 0.45 μm (Stratman 1988). The filter membrane is capable of retaining coliforms and other bacteria found in water. The filter membrane is then placed on a petri-dish containing absorbent pad soaked in the culture media. Then it is incubated for 22 - 24 hours turning the petri-dish upside down. Any bacteria which is able to grow will multiply to form visible colonies on the membrane filter surface (Hutton 1986 a). At the end of the incubation period based on the prevailing temperature presence of total coliforms or faecal coliforms can be ascertained.

The result obtained by this method might not be similar to that of multiple tube method, although it is comparable in practice (WHO 1984 b). The main disadvantage of this method is its unsuitability to high turbid water and for water containing non-coliform bacteria. Otherwise, it is useful and very effective method for enumeration of coliform organisms within short time compared to the multiple tube fermentation technique.

3.6.2 Test for residual chlorine

Presence of adequate free residual chlorine in the water can be directly correlated to the bacteriological quality of the water. Thus, absence of free residual chlorine in chlorinated water supplies is an indication of contamination and unacceptable bacteriological quality of the water. If an adequate free residual chlorine is present in the water supply system it will be bacteriologically safe for domestic consumption (Hutton 1986 a, Mark 1987). The longer time requirement for obtaining the bacteriological quality result necessitates the need to test for the presence of an adequate residual chlorine for immediate measure.

To fulfil the primary purpose of chlorination and to minimize any adverse effects it is essential that proper testing procedures be used with a foreknowledge of the limitations of the analytical determination (APHA. AWWA. WPCF 1985). With this understanding it is essential to measure the concentration of chlorine frequently and to record the results. There are different methods and equipment developed to control the amount of chlorine to be added and monitor the amount of residual chlorine produced.

When the demand variation fluctuates between wide limits a continuous indication and record of residual chlorine is desirable. This can be achieved by automatic residual indicators and recorders, whereas the presence of the residual in the supply system is always determined by taking the water sample. This can be achieved by two methods i.e. laboratory method and field method.

Practice of free residual chlorine attainment helps for confirmation of treatment efficiency and monitoring the water quality. The conventional methods of determining residual chlorine are based on the oxidizing power of chlorine in reaction with the reducing agents. While determining the free residual chlorine it has to be done immediately after the sample collection:

a) Laboratory method

i) Iodometeric (starch - iodide)

This method is useful for determination of high concentration (1 mg/l) of total chlorine (Gordon et al 1988). The principle involved in this method is liberation of free iodine from potassium iodine (KI) solution while titrating against a standard solution of sodium thiosulfate ($Na_2S_2O_3$) with starch as the indicator (APHA-AWWA-WPCF 1985, Hatch and Yang 1983). The method even though not necessarily used routinely most laboratories use it as a reference (Gordon et al 1988).

ii) Amperometric titration

The method is a standard of comparison for the determination of free or combined chlorine. It can be used to determine total residual chlorine and to differentiate between free and combined available chlorine. However its operation requires high experienced analyst. The method remains to be the standard method of measurement in the laboratory. The advantage of this method is that it is little affected by common oxidizing agents, temperature variation, turbidity and colour (APHA-AWWA-WPCF 1985, Gordon et al 1988).

b) Field methods

i) N-N-diethyl-p-phenylenediamine (DPD)

This method has been the most widely used for measuring residual chlorine. The free chlorine can be measured using DPD tablets or solution and a comparator (Lovibond, Hach or similar). The reaction of DPD to free chlorine produces pink colour and the intensity of the colour is proportional to free residual chlorine (Mark 1987). According to WHO (1985) the method can be conveniently used in the field by use of commercially available visual comparators. There are

two types of comparators: the disc type containing a wheel of small coloured glasses and the slide type containing liquid standard in glass tubes. In both cases the box used is similar. The reagents can be conveniently used without buffering in pH 6.5 - 8.5 (WHO 1985). Any water treatment plant which uses chlorine as a disinfectant should not be without DPD and the testing equipment.

ii) Orthotolidine (OT)

This method had been used for many years for test of residual chlorine. However, OT being recognized as chemical substance capable of causing cancer has been deleted from standard methods for examination of water and wastewater (APHA-AWWA-WPCF 1985).

Due to this reason preference is given to DPD method. If OT is still used special care should be taken to ensure that it is never taken by mouth pipette, and also inhalation or exposure to the skin must be avoided (WHO 1985). The equipment used and the procedure to carry out the test is similar to DPD method.

3.7 Problems linked to chlorination

3.7.1 Water quality problems

i) Trihalomethane formations

Several researchers have shown disinfection of drinking water with chlorine containing organic substances to produce chlorinated compounds. Of these chloro-organic compounds which have attracted considerable attraction recently is the halogenated compounds. Fulvic and humic substances which are found in most surface waters are considered to be the principal precursors of THMs (Symon et al 1981). The group of organic compounds formed in reaction with chlorine include: chloroform or trichloromethane ($CHCl_3$), bromodichloromethane ($CHCl_2Br$), diromochloromethane ($CHClBr_2$), bromoform or tribromomethane ($CHBr_3$), 1, 2-dichloroethane and carbon tetrachloride. The first four compounds are collectively termed as trihalomethanes (Wolfe et al 1984).

These THMs compounds have a basic chemical structure of methane in which three hydrogen atoms are replaced by a halogen atom, typically chlorine or bromine (Umphres et al 1981). Their general form is CHX_3 where X can be Cl, Br or I. Chloroforms are particularly suspected of carcinogens (Snoeyink and Jenkins 1980).

To minimize the formation of THMs in water supplies and to control their formations some water utilities, particularly in USA, have established a maximum contaminant level of 0.10 mg/l for total THMs (McGuire and Meadow 1988), which is the arithmetic sum of the concentration of $CHCl_3$, $CHCl_2Br$, $CHClBr_2$ and $CHBr_3$.

For controlling production of THMs many alternatives have been considered (Umphres et al 1981):

- removal of THM precursor prior to chlorination
- reducing chlorine dosage and point of application
- use of alternative disinfectant
- removal of THMs after they are formed.

After introduction of chlorine in disinfecting drinking water supply, the more widely discussed adverse effect recently might be the formation of THMs. In some cases the importance might have been overestimated. As Hiisvirta (1988) pointed out a carcinogenic bioassay reported in 1985, in which laboratory animals were exposed to chloroform in drinking water, gave much lower tumour incidence rate than a study from 1976.

Even though it is shown that THMs can be carcinogenic in laboratory animals, in high and sustained dose there is no conclusive evidence in risks to human through drinking water with low level of exposures, and the many other sources of cancer have to be kept in mind (Cairncross and Feachem 1983, Twort et al 1987). Most countries, certainly all developing countries, may give presence of THMs negligible public health importance.

ii) Odour and taste problem

If an excessive dosage of chlorine is used for disinfection it imparts an objectionable taste to the water. And as a result of industrial discharges or pollution from tarmac roads, phenol compound can be present in surface water sources. The reaction between chlorine and the phenol compounds result in formation of chlorophenols which are very odorous compounds (Snoeyink and Jenkins 1980). Also, the formation of nitrogen trichloride in presence of natural or added ammonia imparts unpleasant taste in the water. With the amount of chlorine usually used for disinfection purpose its odour or taste production is small and negligible. Thus if the amount of chlorine to be added is too little it will not be effective, and if it is too much it results in odour and taste problems. Hence careful controlling procedure has to be followed to achieve the objective of potable water chlorination.

3.7.2 Operational problems

i) Chlorine leak

Chlorine is a toxic chemical. When sufficiently concentrated it causes suffocation, constriction in the chest, tightness in the throat after severe exposure (Encyclopaedia Britannica 1957). With this light chlorine leak should have to be averted and the necessary precaution measures have to be taken. Particular attention and care has to be taken while transporting the chemical and when using gas chlorination.

When using gas chlorine, for water disinfection, the most likely place for leak to occur seems to be the outlet valve of the gas cylinder or at the chlorinator. Hence it is a common practice to install the gas cylinder on a weighing machine so that the amount of chlorine being used can be counterchecked against the actual amount indicated by the chlorinator (Smethurst 1988). To avoid possible danger resulting from the chlorine leak, chlorine cylinders should always be installed in a separate room from the chlorinating device having access from the open door. Doors should open outwards. And also as a precaution measure leak detectors with an alarm equipment can be installed (Twort et al 1987).

The chlorine gas being heavier than air, whenever leak occurs, settles at the floor level, hence ventilation opening has to be arranged at the floor level. Storing or using of chlorine inside a building with a basement has to be avoided (Cairncross and Feachem 1983). Chlorine is corrosive in presence of moisture and for this reason most parts of chlorination apparatus and chlorine solution delivery lines have to be noncorroding materials.

ii) Stiff container and valve

When chlorine is used in powdered form, hypochlorites solution, production of lime as a sediment and as suspension in the solution water is inevitable. This product tends to clog up feeding devices and valves, creating difficulties in keeping the system in working condition. Therefore, flushing arrangement with clean water for the solution feeding lines has to be foreseen in the design of hypochlorite solution systems. Also piping arrangement for discharge of the sediment from the solution container has to be made when dosing pumps are used.

iii) Storing and handling

The reaction of chlorine with many substances can be violent, particularly at high temperature. Therefore all forms of chlorine should be stored in a well ventilated area away from organic products i.e. not to be stored in workshops or pumphouses (Williams 1983).

When the amount of chlorine powder form to be handled is in large quantities, dust nuisance will be unavoidable. To avoid the inhalation by those handling it, mask provision has to be used. The deterioration of hypochlorite chemicals due to exposure to light, air and moisture makes necessary their storage in a dark, cool and dry place in closed, corrosion resistant containers (Hofkes 1987).

4 EXISTING SITUATION OF WATER SUPPLY AND QUALITY CONTROL IN ETHIOPIA

4.1 Operating of water supplies

The water supply system of the country is divided into urban and rural. 90 % of the estimated 50 million population live in rural areas. The coverage of the population with drinking water supply is about 15 % of the total population and 80 % of the urban population (Ethiopia 1988).

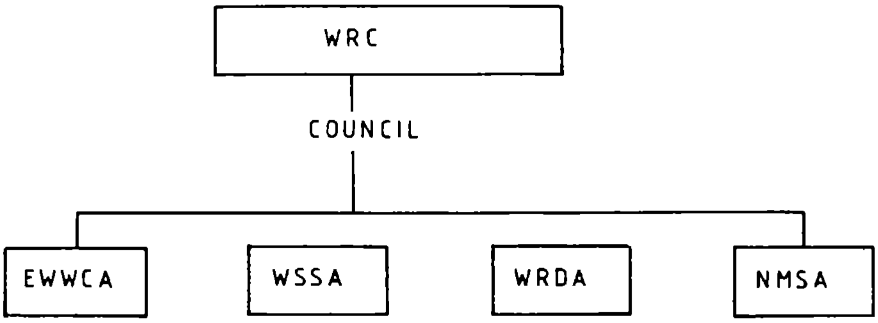
According to the Central Statistic Office rural is defined as a community with inhabitants less than 2 000 (EWRA 1978). However, from the point of drinking water supply this delineation seems to be low. In some cases an area with 5 000 inhabitants is considered to be rural.

The development and operation of the water supply of Addis Ababa city is fully undertaken by its own Water Supply and Sewerage Authority. The second largest city of Ethiopia, Asmara, is not yet brought within Water Supply and Sewerage Authority's (WSSA) full control. Asmara city runs its water supply with technical assistance from WSSA. Similarly, small municipalities (city councils) run their own water supplies with technical assistance from WSSA. In the future these small water supplies will be transferred to full control of WSSA.

WSSA is responsible for running the water supplies of the whole country, excluding Addis Ababa. The organization which was established in 1981 has the main responsibility for provision operation and maintenance of water supply and waste disposal services (WSSA 1984).

The other governmental organization which shares the responsibility particularly in rural areas in design, construction and sometimes running the schemes is the Ethiopian Water Works Construction Authority (EWWCA). EWWCA, which was established in 1980, is responsible for constructing all water works.

The Water Resource Commission (WRA), established in 1981, serves as the umbrella organization for WSSA, EWWCA, Water Resource Development Authority (WRDA) and the National Meteorological Service Agency (NMSA). WRA is responsible for all policy formulation, administration regulation, protection and allocation of the nations inland waters. Figure 13 shows the present organizational set-up of WRC.



Members of the council:
Commissioner of the Commission, Chairman
Permanent Secretary of the Ministry of Mines and Energy Resources
Permanent Secretary of the State Farms Development
Permanent Secretary of the Ministry of Agriculture
Permanent Secretary of the Ministry of Health
Permanent Secretary of the Ministry of Industry
Permanent Secretary of the Ministry of Urban Development and Housing

Figure 13. Present organization of Water Resource Commission, Ethiopia (PAS 1982).

In most rural water supplies the beneficiaries', the community, involvement in construction and running the schemes has a significant role for success of the existing rural water supply systems.

Other governmental and non-governmental organizations have great role, in particular, in the implementation of the rural water supply schemes. Their involvement include financial and material assistance and sometimes involvement in implementation programmes. The actual running of these rural water supplies have been the responsibility of the community, WSSA and EWWCA.

The development and operation of the urban water supplies is the sole responsibility of WSSA. Currently WSSA has got seven regional offices established in 1984: Addis Ababa (central), Awassa (southern), Jimma (western), Dire Dawa (eastern), Combolcha (north-eastern), Bahr Dar (north-western) and Asmara (northern). The organizational set-up of WSSA is illustrated in Figure 14.

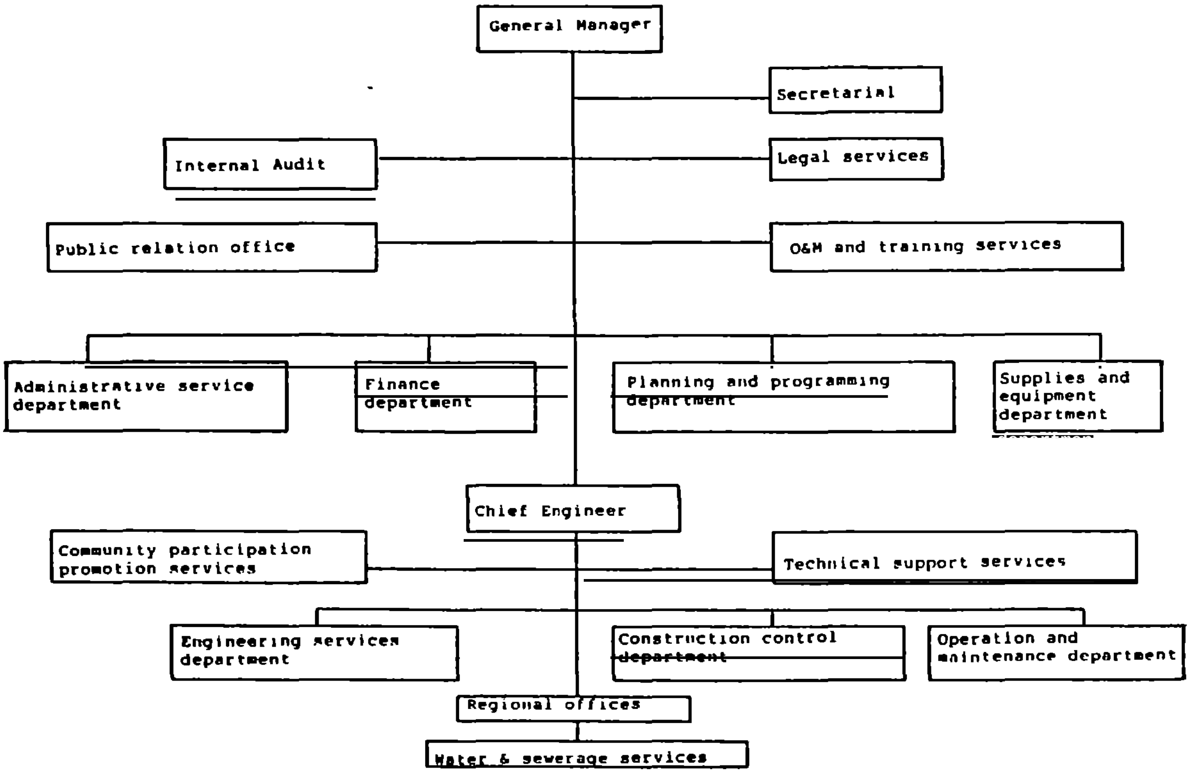


Figure 14. Existing orgnizational chart of Water Supply and Sewerage Authority (NWRC 1984, cited by Issayas 1988).

The regional offices with the back-up support from the head office assist the urban and rural water systems: in procurement of materials, in preventive maintenance work, in major repairs, in provision of trained manpower and in water quality and monitoring. The daily routine operation of the systems is the responsibility of the urban water service offices located within the town. Ninety four (94) urban systems (WSSA 1988) and about 5 000 rural water supply systems (Ethiopia 1988) were included in 1988 within the scope of WSSA's active responsibility.

4.2 Disinfection on general level

Most of the water supply sources utilized in rural areas are springs, shallow wells (hand dug wells) and deep wells. Traditionally the surface sources are extensively used for domestic purposes without any treatment. That might be one of the reasons for high mortality (14 %) and morbility rates (24 %) (Ethiopia 1988).

Protected and developed springs and deep wells are often found to be bacteriologically in good condition, but the shallow wells show deterioration of quality as a result of contamination. This has been verified during the bacteriological test carried in the Southern Region of Ethiopia 1984 - 1988 by Hanna (1985). The main reasons for the quality deterioration are poor drainage, inferior workmanship and site location of the wells.

Due to constraints, those who are involved in rural water supplies, are more often concerned in provision of the required amount of drinking water than the water quality. Normally no treatment is practised for the rural water supplies. Hence, effort should always be made to locate sources that need no treatment. To maintain the quality of the water after production, sources have to be well protected. Monitoring of the bacteriological quality of the water has to be carried out in regular basis.

The water supply systems found in urban centres of Ethiopia use various water sources: deep wells, rivers or streams, springs and impounded reservoirs. All supplies obtained from surface sources are provided with various treatment processes: often sedimentation basin followed by sand filters or pre-chlorination with vertical up-flow clarifier followed by gravity sand filters. In all surface sources chlorination, either gas chlorine or calcium hypochlorite, is practised in the final treatment process. For supplies using deep wells the only treatment practised is chlorination. However the number of well supplies chlorinated are very few. Currently the number of urban water supplies with treatment plants is 24, excluding Addis Ababa and Asmara. All, except five, water supplies use surface sources and the conventional treatment process.

In developing countries where continuous supply of gas chlorine is difficult some form of back-up using calcium hypochlorite should generally be provided (Gill 1988). This is particularly true in Ethiopia: only in one study plant the gas chlorination was working. The reason was, in all cases, shortage of spare parts. The remaining water supplies get their water either from deep wells or protected springs without treatment.

4.3 Organizational aspect with respect of water quality control

Water quality studies and control in Ethiopia, except Addis Ababa, are under the WRC and the Ministry of Health. Within WRC there are laboratories under WRDA and WSSA. Currently WRDA does not have any active involvement in water quality control. WSSA is the only organization under WRC with active role in water quality control. At present there are three regional laboratories at Awassa, Jimma, Bahr Dar and a central laboratory at its head office under the Operation and Maintenance Department. Figure 15 shows the organizational set-up for water quality control within WSSA.

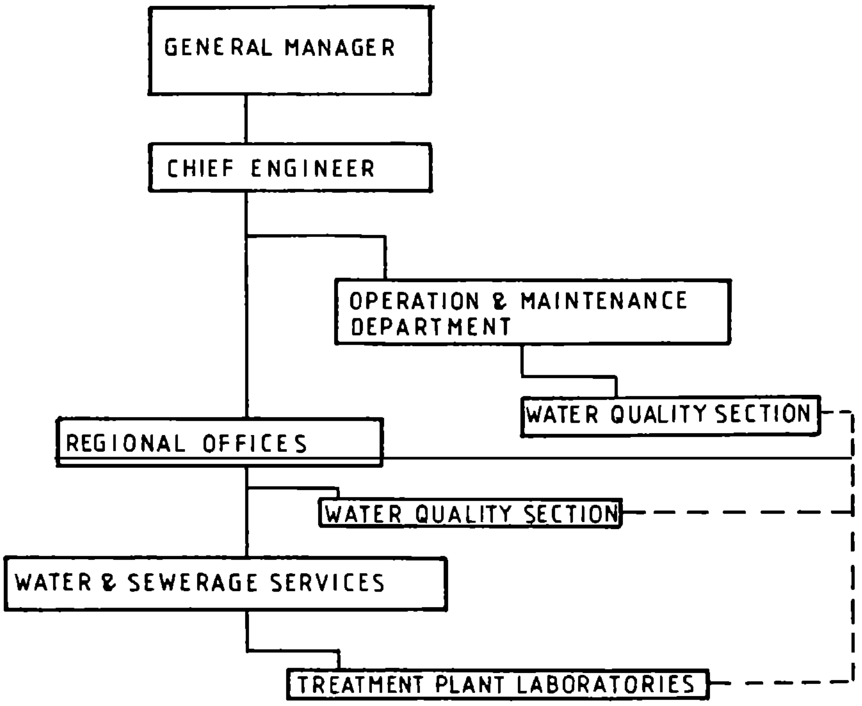


Figure 15. Organizational set-up of water quality control within WSSA.

The Ministry of Health has a central laboratory at the Industrial Chemistry Division. This laboratory (other than doing water quality analysis requested by sample senders) does not involve in studies on water quality control. The Ministry under the Environmental Health Department has the Water and Wastewater Control Division. One of the responsibilities of this division is water quality control. To enforce the objectives of the section sanitarians who have done two years training in sanitary science are stationed at the Regional Health Departments and Awraja (district) Health Centers, nationwide (Ethiopia 1988). Their involvement in water quality control has been passive. Lehmusluoto (1979) has stated that the reasons for the low use of the laboratories are: lack of water quality monitoring and surveillance plans and programmes, inadequate field operations and partly inadequate laboratory facilities and support.

4.4 Monitoring and quality control of drinking water

The Ministry of Health and Water Resource Commission is responsible for monitoring the quality of drinking water. Bacteriological, virological and other communicable diseases transmitted by water are subjected to the Ministry of Health (Lehmusluoto 1979) whereas monitoring all other aspects of the water quality are the responsibility of WRC. Most water quality analyses are carried out by WSSA's Regional Laboratories, head office laboratory and the Treatment Plants Laboratories.

WSSA carries the surveillance of water quality in addition to provision, operation and maintenance of water supplies. The co-operation between the other laboratories has a significant impact on monitoring the quality of the country's drinking water supplies.

Since 1988 operators, with two years of training in water supply and sanitation in Arba Minch Water Technology Institute, are assigned in water treatment plants. Due to lack of chemicals and equipment in some of the plants the operators cannot perform water quality analysis. Consequently chemical dosage is carried out by guess. In those plants with chemicals and equipment water quality tests like pH, turbidity, colour, residual chlorine are carried out by the operators. The test results are not recorded for future reference.

For the other urban water systems and rural areas the water quality tests are carried out by the regional laboratories and the Head Office Laboratory of WSSA. The main sources for chemical and equipment for these laboratories have been the donor agencies.

5 EVALUATION OF SELECTED URBAN WATER SUPPLIES

5.1 Rationale for the study area selection

The study was carried out in the southern part of the country 19.9 - 20.11.1989. The towns were Debre Zeit, Mojo, Shashemane, Awassa, Yirga Alem, Arba Minch, Hosana, Goba and Ginir. Bacteriological and physical tests were carried out of the water samples collected from the seven towns except Goba and Ginir.

The rationale for selecting these towns has been:

- They represent different time of construction and operation span: Shashemane, Hosana and Ginir have been in operation since 1977; Awassa and Yirga Alem since 1983; and, Debre Zeit, Mojo, Arba Minch and Goba since 1988.
- All these systems utilize the different water sources using the various treatment processes and particularly disinfection.
- The construction of all the systems had been financed by 10 % from the Government and 90 % from external loan. Consultants and contractors had been involved in the implementation of the systems.
- All plants have operation building with laboratory and equipment for basic water quality analyses.
- The location of the towns (Figure 16) is on the same route or in close distance range.

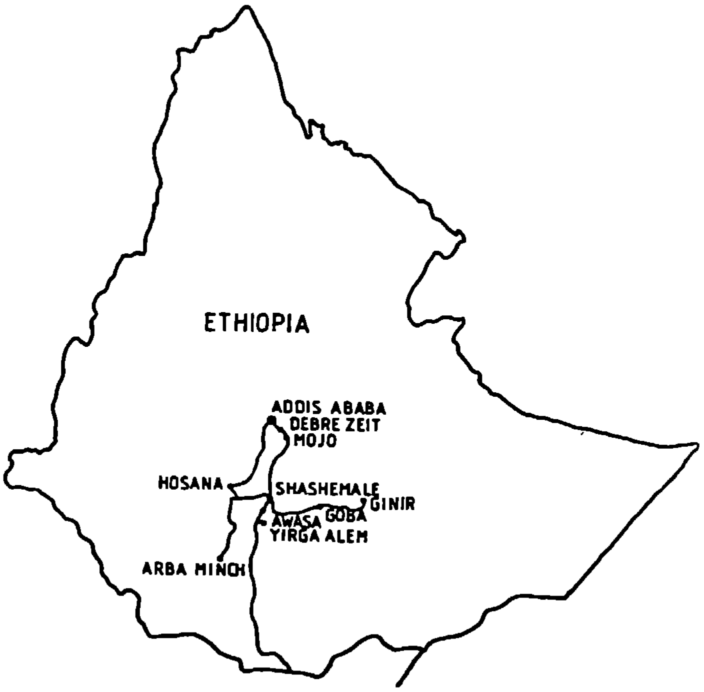


Figure 16. Location of the study area.

5.2 Methodology used for evaluation

Representative samples from various locations in the distribution system and the treatment plants were taken according to the methods recommended by WHO (1985). These samples were taken at the end of each treatment process and throughout the distribution network. Presence of coliforms, residual chlorine, temperature, conductivity (EC), total dissolved solids (TDS), pH and turbidity were tested.

The membrane filter technique was used for coliform enumeration. 100 ml of sample was filtered through the filter membrane and incubated at 35 °C for total coliform. For the same source 100 ml of sample was filtered through the filter membrane and incubated at 44.5 °C for faecal coliform. Incubation temperature was maintained by two portable field incubators connected to the car battery. The culture media used were: ampoulled M-Endo type for total coliform determination and M - Fc Agar for the faecal coliform determination. The petri dishes, the membrane filters and the absorbent pads were pre-sterilized at the factory. Before filtering samples from different sources the funnel assemble, the stainless steel graduated cup and the forcep were sterilized by the use of formaldehyde gas. This bactericidal gas is produced from the incomplete combustion of the methyl alcohol. Figure 17 shows the apparatus and the culture medium used during the coliform test.

Figure 17. Portable water laboratory (Millipore 1965).

The most difficult problem with field bacteriological test is the power source used to the incubators. Frequent failure of the power (i.e. car battery) has lagged the progress of the work. Enumeration was made by direct counting without the help of microscope. When there are too many coliforms the result will be erroneous. Because the distributed water should not contain any coliforms, their exact number is not necessarily needed; even a single coliform can cause remedial action. While taking samples one should be very careful, because the increment of coliform population might occur due to dust and any other impurity. Hence the results obtained in some cases might show higher coliform count than the actual.

Turbidity was measured for the raw water and after each unit process. Few samples were analysed also from the network when the system is suspected of pollution. Direct Reading Spectrometer Hach DR/200 was utilized to measure the turbidity. The test was conducted at WSSA's Southern Regional Office Laboratory, Awassa. The reason for not analysing all samples for turbidity was the inconvenience of the test and requirement of many sampling bottles.

Hach DPD Reagent Powder pillows and Visual Comparator with rotating disc 0 - 3.5 mg/l were used to determine the residual chlorine. For the disinfected water supply systems free and total residual chlorine were measured for the same samples.

Hach portable conductivity/TDS meter was utilized to measure temperature, conductivity and total dissolved solids.

The other parameter tested was pH. For its measurement the pH paper and the pH meter were utilized. The pH paper was not reliable as the matching of colour depends on personal judgement and the degree of accuracy being wide. The meter used was not reliable because of loose connection. Hence the validity of the result is questionable.

The observation made through the visit of the systems, the information obtained through discussion with the concerned personnel at different levels and personal experience as an employee in WSSA have been utilized while evaluating the disinfection practices.

5.3 Description of treatment plants and disinfection practices

1 Debre Zeit

Debre Zeit is a town with an estimated population of 60 000, located about 40 km south-east of Addis Ababa on the international highway to Nairobi, Kenya. The railway line from Addis Ababa to Djibouti, passes through the town. The town is provided with piped water supply system since 1958 from deep well sources. To meet the demand of the growing population additional borehole was added in 1971 (UWSA 1980). New water supply system was developed and has been in operation since 1988. Both water supply systems serve the population independently.

The bacteriological, chemical and physical quality of the well water satisfies the recommended guideline values of WHO (1984 a). The result of the chemical analysis of the wells water is shown in Table 5.

Table 5. Debre Zeit wells water chemical and physical analyses, modified by author (UWSA 1980, WHO 1984 a).

Constituent or characteristic		Unit	Well no 1	Well no 2	Well no 3	Well no 4	Well no 5	Well no 6	WHO guideline values
Appearance			CL	CL	CL	CL	CL	CL	
Colour		TCU	CL	CL	CL	CL	CL	CL	15
Odour			OL	OL	OL	OL	OL	OL	
Taste			TL	TL	TL	TL	TL	TL	
Turbidity		NTU	0	0	0	0	0	0	5
Settleable solids			A	A	P	P	P	A	
Floating solids		mg/l	A	A	P	A	A	A	
Suspended solids		mg/l	A	A	P	A	P	P	
Dissolved solids (total)		mg/l	397	360	376	377	342	356	1 000
Total hardness as $CaCO_3$		mg/l	183	201	191	202	205	220	500
Carbonate alkalinity as $CaCO_3$		mg/l	15	15	0	0	0	0	
Bicarbonate alkalinity as $CaCo_3$		mg/l	210	240	250	255	275	280	
Ammonia	NH_4	mg/l	0	0	0	0	0	0	
Sodium	Na	mg/l	33	32	31	31	33	29	200
Potassium	K	mg/l	9	9	8	6	10	9	
Calcium	Ca	mg/l	48	52	51	182	55	57	100-300
Magnesium	Mg	mg/l	15	17	16	18	17	19	
Iron	Fe	mg/l	0.03	0.03	0	0	0	0	0.3
Manganese	Mn	mg/l	0	0.2	0	0	0	0	0.1
Chloride	Cl	mg/l	18	11	14	16	11	11	250
Nitrite	NO_2	mg/l	0.05	0.03	0.05	0.03	0.03	0.02	
Nitrate	NO_3	mg/l	1.9	2.0	2.8	2.7	2.6	1.2	10
Fluoride	F	mg/l	0.5	0.6	0.4	0.4	0.5	0.4	1.5
Bicarbonate	HCO_3	mg/l	256	292	305	311	336	342	
Carbonate	CO_3	mg/l	18	18	0	0	0	0	
Silicon	SiO_2	mg/l	69	61	68	71	70	66	
Sulfate	SO_4	mg/l	0	0	0	0	0	0	400
Phosphate	PO_4	mg/l	0.10	0.12	0.10	0	0.10	0.10	
pH			8.3	8.4	7.6	7.8	8.0	8.0	6.5-8.5
Dissolved (free) Ammonia		mg/l	0	0	0	0	0	0	

CL = colourless
OL = odourless
TL = tasteless
P = present
A = absent

The new system gets its water from six boreholes located north of the town in the same vicinity. The only type of treatment required and used is chlorination with $Ca(OCl)_2$. It is effected at the injection chamber near the operation building (Figure 18) by solution dosing pumps.

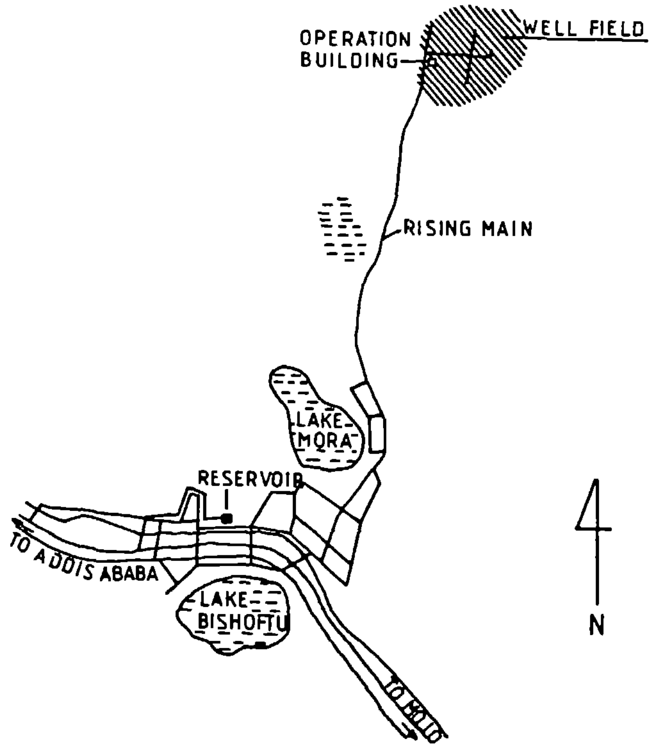


Figure 18. Layout of Debre Zeit town distribution network (UWSA 1980).

Mixing of chlorine to the raw water is achieved in the rising main. The water is directly pumped to the network and the reservoir. The reservoir can serve as a chlorination point in case of pump failures.

To prepare the chlorine solution two 850 l capacity plastic containers equipped with mechanical stirrers and two solution dosing pumps are provided. The dosing pumps serve alternatively. The operation building in addition to housing the chlorine dosing room has chlorine store, operation and laboratory rooms. The chlorination room and the chlorine store room do not have ventilation at the floor level of the wall.

Even though, the scheme is new it had run without chlorination for two months due to failure of dosing pumps. The main reason for the pump failure had been oil leakage and discharge pipe line breakage. During the study visit the network system was without residual chlorine except the nearest public tap (Table 6) to the chlorination point. This might be due to the small amount of dosage used, the large size of the network and lack of residual monitoring programme. This problem can be solved by increasing the

chlorine dose at the operation building and by adopting re-chlorination at the reservoir. Residual chlorine has to be checked by the water supply's office. The reason for coliform count in the network might also be during sampling. Otherwise the water was free from coliform.

Table 6. Debre Zeit water supply: bacteriological and physical analyses.

Date of sampling 7 10.1989

Source of water sample	Residual chlorine		Coliform count		Conductivity	Total dissolved solids	Temperature	Turbidity	pH	Time of sampling
	total mg/l	free mg/l	total no/100 ml	faecal no/100 ml	µs/cm	mg/l	°C	NTU		
Raw water mixed from six wells			0	0	480	250	23	1	8 0	12 00 pm
Reservoir inlet	0.1	0	0	0	500	280	25	1	8 0	1.45 pm
Distribution network (centre of the town)	0 01	0	7	0	530	270	26			3 15 pm
Distribution network (near the chlorination point)	1.0	0.8	0	0	540	270	26			3 40 pm
Distribution network (dead end in the north-west)	0	0	9	0	500	260	23			4 00 pm
Distribution network (dead end in the south-west)	0	0	0	0	540	270	23			5.30 pm

Although the source is free of bacteriological pollution, any activities which might result in pollution of the aquifer have to be prohibited. To prevent contamination of the water in the network sufficient dosage of chlorine to get 0.1 - 0.2 mg/l of residual in the system has to be practised with minimum interruption. In case of prolonged time of interruption of chlorine flushing of the line, bacteriological water quality has to be monitored, either on the site or in the laboratory. Lack of sampling point near the chlorination makes monitoring difficult.

The raw water used for making the chlorine solution has hardness above 100 mg/l, which results in precipitation of the insoluble calcium ions on the dosing equipment. The chlorine solution should be made of soft water like rainwater.

Running of the system, like any other town water supply in the country, is the responsibility of Debre Zeit Town Water Supply and Sewerage Service Office.

2 Mojo

Mojo town is located about 75 km south of Addis Ababa on the international highway to Nairobi. An estimated population of the town, 2 000, has been supplied with piped water system since 1960. At present the town gets its water from three deep wells commissioned in 1988. The water supply system is similar in all aspects, except the size of the network and the number of productive wells, to that of Debre Zeit town (Figure 19).

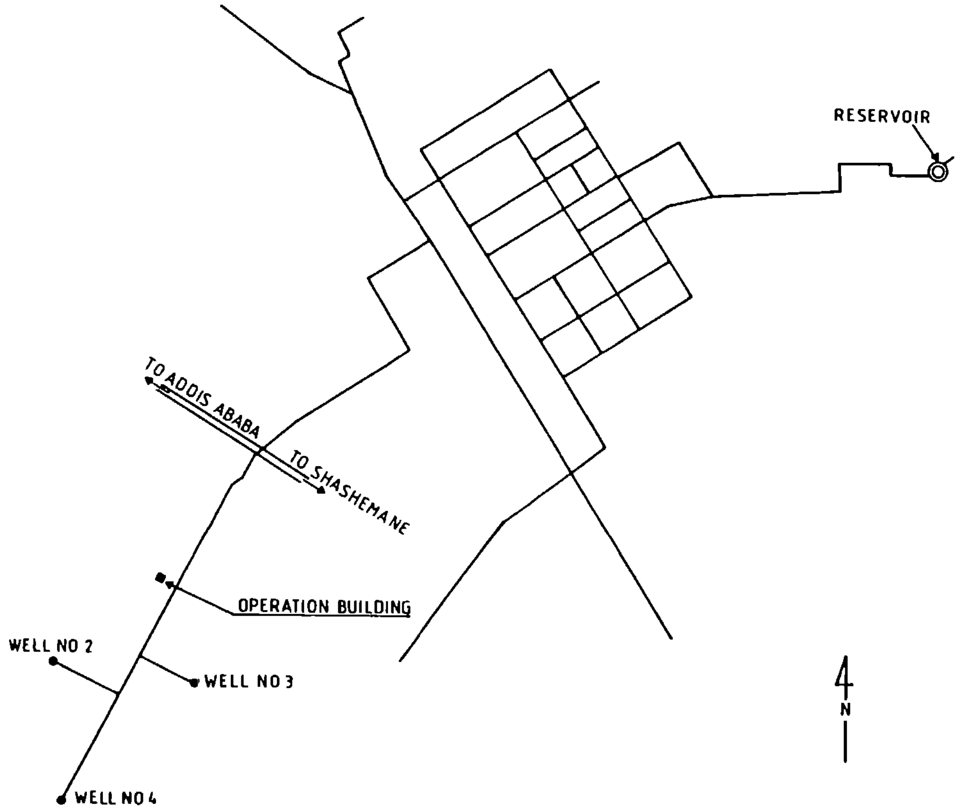


Figure 19. Schematic layout of Mojo water supply system.

The bacteriological, chemical and physical water quality of the wells satisfies the recommended guideline values of WHO (1984 a). The chemical analysis result of the wells water is shown in Table 7. The only type of treatment required and used is chlorination. It is effected at the operation building by solution dosing pumps. Mixing of chlorine to raw water is achieved in the rising main.

Table 7. Mojo wells water chemical and physical analyses.

Date of sampling 9.10.1989

Source of water sample	Coliform count		Conductivity	Total dissolved solids	Temperature	Turbidity	pH	Time of sampling
	total no/100 ml	faecal no/100 ml	µs/cm	mg/l	°C	NTU		
Raw water (at the operation building)	1	0	570	290	24	1	7 5	9.45 pm
Distribution network (centre of the town)	9	2	590	300	23			10.40 am
Reservoir outlet	7	0	580	300	25	0		11.15 am
Distribution network (dead end in the north)	95	0	560	290	23			11 50 am

During the study visit the chlorination was not working. Lack of lubricant oil for the dosing pumps has been the cause for interruption of chlorination. However the reservoir could have been used as chlorination point as a temporary solution. The bacteriological study revealed presence of total coliform in all samples tested (Table 8). The temporary solution seems to superchlorinate the network by gravity feed chlorine solution from the reservoir located at the other side of the wells at higher elevation.

Table 8. Mojo water supply: bacteriological and physical analyses (WSSA 1986, modified by author, WHO 1984 a).

Constituent or Characteristic		Unit	Well no 1	Well no 2	Well no 3	Well no 4	WHO guideline values
Colour		TCU	CL	CL	CL	CL	15
Odour			OL	OL	OL	OL	
Taste			TL	TL	TL	TL	
Turbidity		NTU	0	0			5
Conductivity		μs/cm	40	500	500	500	
Settleable solids			P	P	P	P	
Floating solids			A	A	A	A	
pH			8.0	8.5	7.6	8.6	6.5 - 8.5
Carbonate alkalinity as $CaCO_3$		mg/l	0	40			
Bicarbonate alkalinity as $CaCO_3$		mg/l	340	300			
Total hardness as $CaCO_3$		mg/l	212	172			500
Total silica as SiO_2		mg/l	90	95			
Ammonia	NH_4	mg/l	0.26	0	0.10	0.05	
Sodium	Na	mg/l	70	97	61	88	200
Potassium	K	mg/l	14	15	14	12	
Calcium	Ca	mg/l	50	50	48	45	100 - 300
Magnesium	Mg	mg/l	21	12	10	12	
Iron (total)	Fe	mg/l	0.1	0	0	0.1	0.3
Manganese	Mn	mg/l	0	0	0	0	0.1
Aluminium	Al	mg/l	0	0			0.2
Chloride	Cl	mg/l	16	14	14	14	250
Nitrite	NO_2	mg/l	0.01	0.01	0.01	0.26	
Nitrate	NO_3	mg/l	0.4	0	0.6	0.3	10
Fluoride	F	mg/l	1.4	1.1	1.3	1.4	1.5
Bicarbonate	HCO_3	mg/l	415	366	360	354	
Carbonate	CO_3	mg/l	0	48	0	36	
Sulfate	SO_4	mg/l	0	0	0	0	400
Phosphate	PO_4	mg/l	0	0	0.02	0	

CL = colourless
OL = odourless
TL = tasteless
P = present
A = absent

The water has not been chlorinated for three months. This problem at the early stage of the operation period can be attributed to lack of maintenance and the type of materials and accessories supplied. To avoid this kind of problems priority has to be given by the organization, WSSA.

When the source is deep well and the network is relatively small marginal chlorination is enough to protect the water from contamination. From the record of the test results, obtained from Mojo Water Supply and Sewerage Service Office, from September 1988 - February 1989 the average residual chlorine in the network was 0.3 mg/l and pH 7.4. This practice of monitoring and recording has to be continued when chlorination is resumed.

3 Shashemane

The existing system of Shashemane town, which was commissioned around 1977, serves an estimated population of 40 000. The town is located 250 km south of Addis Ababa on the international highway to Nairobi. The design population of the town was around 25 000, at present it is serving beyond its capacity. Due to this there is severe water shortage. To solve this problem WSSA is planning to implement the second phase.

The existing system comprises an intake structure within Wosha river, raw water pumping house with high pressure centrifugal pumps, balancing chamber of 30 m^3, clarifier 75 m^3, automatic gravity filter with 70 m^3/h output, 350 m^3 reservoir, distribution network and administration building. The treatment plant and the operation building are within the same compound. The flow diagram of the system is illustrated in Figure 20.

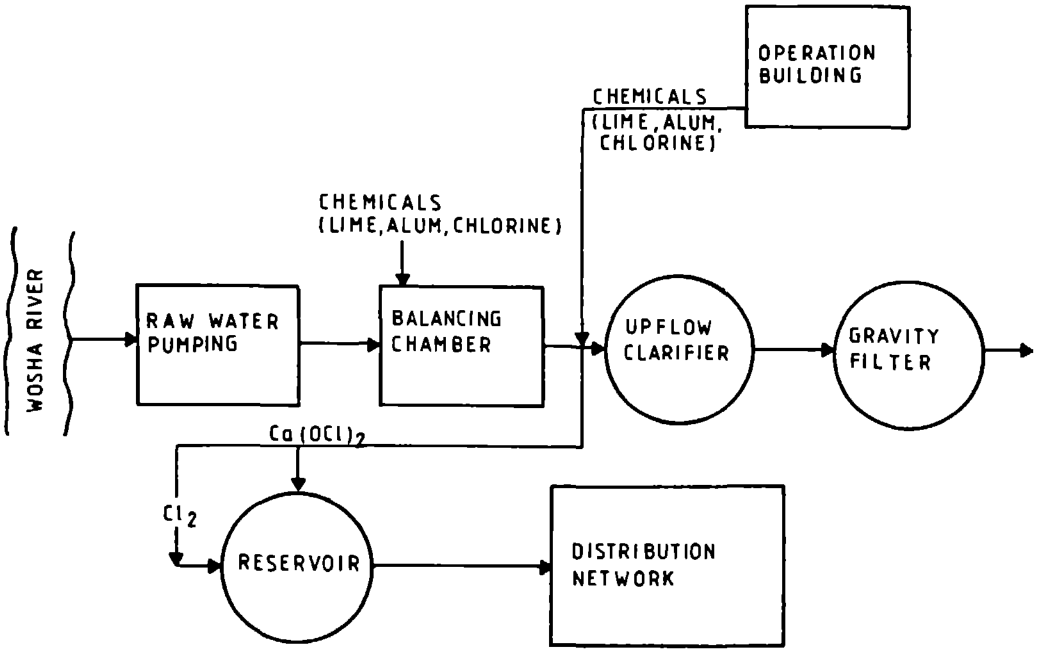


Figure 20. Process flow diagram of Shashemane water supply.

The operation building consists of operation and laboratory room, chlorine bottle room, chemical dosing room, chemical store and washroom with toilet. In the laboratory equipment for residual chlorine, pH and colour tests are available. However, there are not enough chemicals.

The different chemicals used in the plant are aluminium sulfate, hydrated lime and chlorine. At the completion of the plant the chemicals were fed directly from the operation building. For the purpose, two 500 l containers for aluminium sulfate solution and one 500 l container for lime solution equipped with stirrers and dosing pumps were used. These chemicals were injected at the inlet pipe to the clarifier. Also gas chlorine was used for pre- and post-chlorination at the clarifier and the reservoir inlet pipes respectively.

Because of the failure of the mechanical equipment, lack of replacement and maintenance, all the chemicals are gravity fed from bucket containers holding the pre-prepared solutions at the balancing chamber. Similar arrangement is done for post-chlorination at the reservoir. As the buckets used are small, strong solutions are often prepared. As a consequence the discharge hoses are frequently clogged. This can be solved, by constructing a wooden platform at the balancing chamber and by using bigger containers. Currently the solutions fed at the balancing chamber are prepared directly from the raw water. This practice results in loss of chemicals in reaction with the raw water impurities used for solution preparation. This could have been easily solved by laying pipes from the operation building to water service line, which is not more than 50 m distance.

At the original design, the gravity feeding system of chemical solutions as an alternative or as a backup was not foreseen, hence no provision was made.

Due to this chemicals are placed at the edge of the balancing chamber, which is only 20 cm thick (Figure 21). This insecure position might result in toppling of the containers by the wind action. Due to the unstable nature of chlorine, the discharge hose being short will result in loss of chlorine content to the atmosphere before mixing with the raw water.

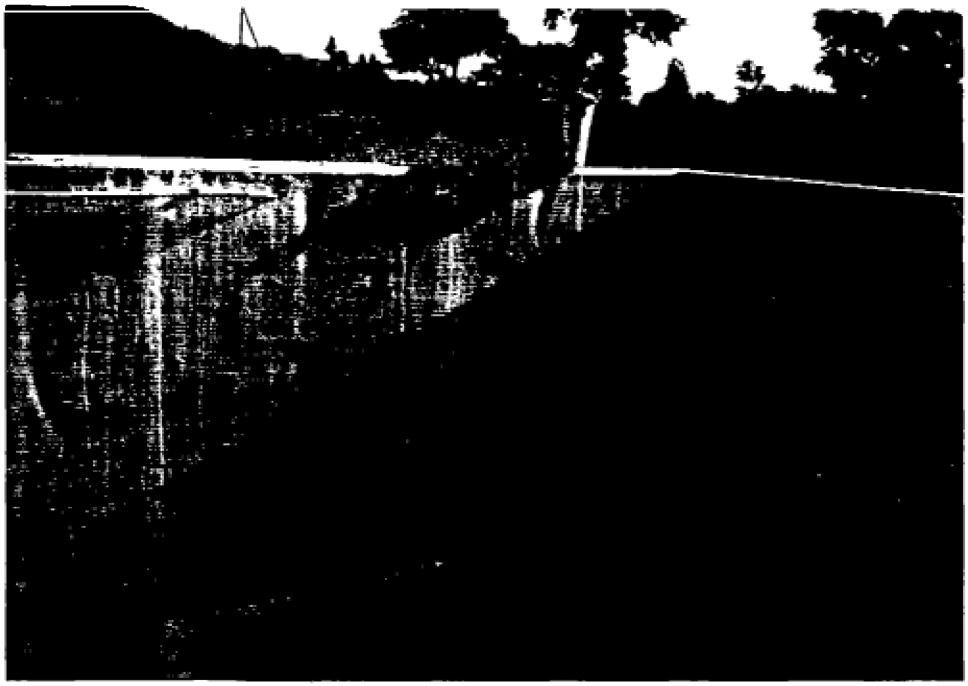


Figure 21. Calciumhypochlorite $Ca(OCl)_2$ solution dosing arrangement at Shashemane water supply, Ethiopia.

For follow-up and monitoring the treatment plant, particularly the chemical dosing, and quality of the finished water, water technician from Arba Minch Water Technology Institute has been assigned since 1988. Lack of chemicals and some of the basic laboratory equipment (like flocculator, test tube etc.) has been an obstacle to perform the test. Due to this main shortcoming chemicals are applied by guess. Often the amount of chlorine used does not correlate to the water produced.

During the study visit no residual chlorine was observed in the network, except the nearest point of chlorination. All water samples taken from the network showed high count of total and faecal coliforms (Table 9). But when the water left the plant it was free from coliforms. Also, the turbidity of the water in the network increased from 10 NTU to 27 NTU.

Table 9. Shashemane water supply: bacteriological and physical analyses.

Date of sampling 3.10.1989

Source of water sample	Residual chlorine total	free	Coliform count total	faecal	Conductivity	Total dissolved solids	Temperature	Turbidity	pH	Time of sampling
	mg/l	mg/l	no/100 ml	no/100 ml	µs/cm	mg/l	°C	NTU		
Raw water (inlet of the balancing chamber)			TNTC*	TNTC	127	63	20	31	6.9	10.45 am
Clarified water (clarifier outlet)	0.70	0.60	0	0	97	49	20	16	6.8	11.30 am
Filtered water (filter outlet)	0.10	0.20	0	0	120	60	20	10	6.8	12.00 pm
Distribution network (near the reservoir)	0.25	0.10	1	0	95	47	23			1.00 pm
Distribution network (centre of the town)	0	0	TNTC	TNTC	102	51	20	26		3.40 pm
Distribution network (dead end in the north-west)	0.08	0	TNTC	40	97	48	21	27		2.10 pm
Distribution network (dead end in the south-west)	0.07	0	TNTC	TNTC	97	48	21			2.45 pm

*TNTC = too numeorus to count

The main reason for the contamination of the network might be the negative pressure which develops due to the intermittent water supply or intrusion of pollutants through the connections. Thus, the consumer health is in danger of contamination from drinking water supply. Immediate measures such as superchlorination followed by flushing of the network and increased dosage of chlorine at the plant has to be practised.

The high turbidity (10 NTU) of the water after the filtration process will hamper the chlorination process. It will result in high consumption of chlorine protecting the micro-organisms against the action of chlorine. The low efficiency of the filter has been due to the small layer of the filter medium. Its solution lies on improvement of the filter medium. The turbidity of the water for effective chlorination has to be less than 1 NTU (WHO 1985).

4 Awasa

The town of Awasa is located 275 km south of Addis Ababa on the highway to Nairobi. This town is the seat for the south Regional Office of WSSA. The existing water supply system uses Cado River as its source. The system was commissioned around 1983 and serves an estimated population of 45 000.

The scheme (Figure 22) comprises intake structure at Cado River, two clarifiers gravity fed from the wet well, two gravity filter duovalve type, two reservoirs of each 500 m^3, operation building and administration office within the town. The system is fully gravitational.

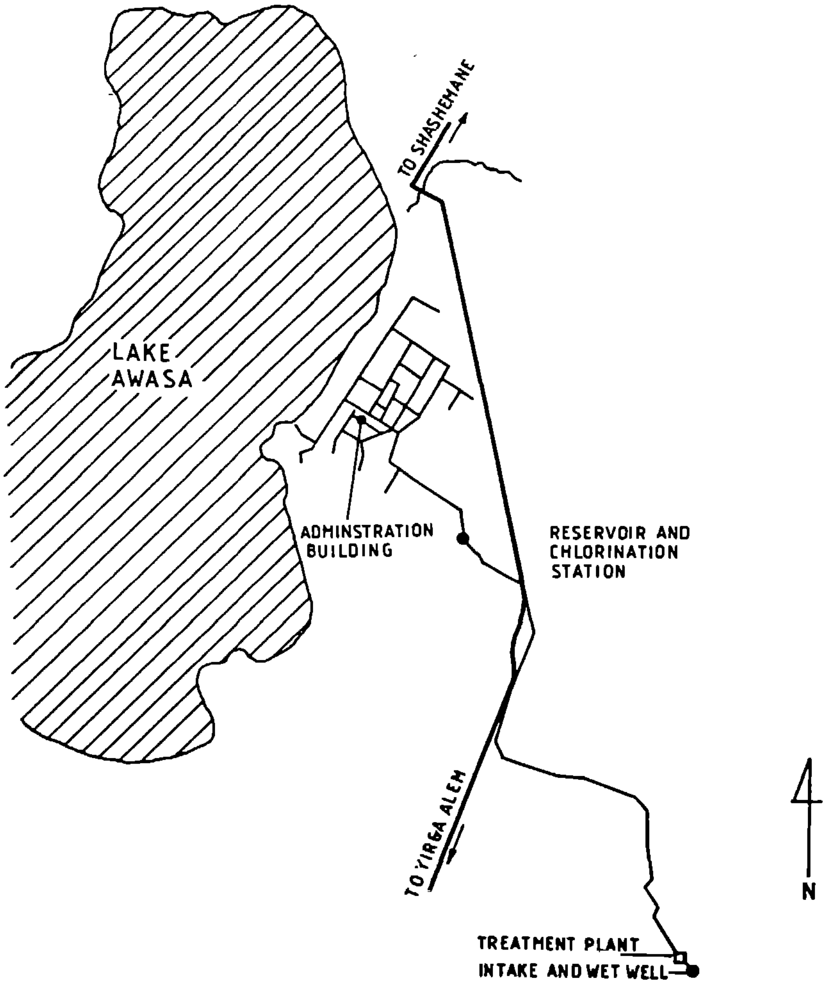


Figure 22. Schematic layout of Awasa water supply system (WSSA 1985 a).

The operation building and the treatment plant are located 17 km south of the town within the same compound, near the intake structure. The operation building consists of laboratory and operation room, chlorination room, chlorine bottle room, chemical dosing room, chemical storage room and shower room with toilet. Figure 23 illustrates the process flow diagram.

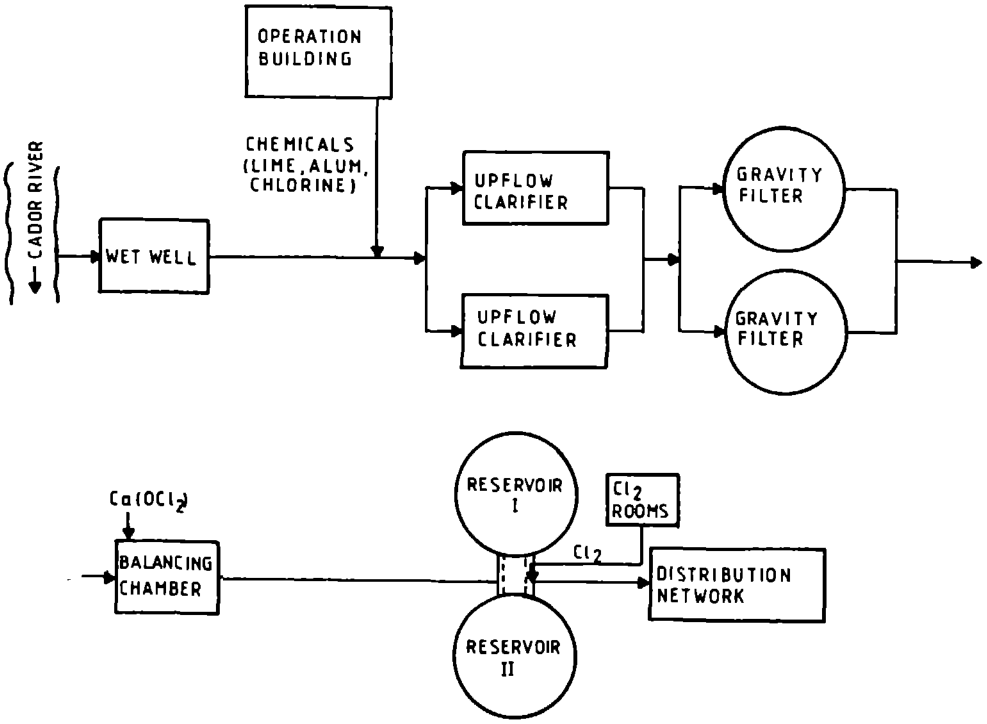


Figure 23. Process flow diagram of Awasa water supply system.

The chemicals used in the plant are lime, aluminium sulfate and chlorine. The chemical solutions are injected to the inlet pipe of the clarifiers. During the visit the only chemical injected was aluminium sulfate solution. Lime was not available and pre-chlorination was abandoned due to failure of the chlorinator.

The water distributed is disinfected at two points. The first disinfection point being the balancing chamber and the rechlorination point at the reservoir located about 16 km from the treatment plant. During the study visit, gravity fed $Ca(OCl)_2$ solution was effected from bucket container at the balancing chamber. At the reservoir gas chlorine was used.

The plant laboratory is complete with the laboratory equipment to perform the basic water quality tests and monitoring the treatment process. It has got a flocculator with accessories, residual chlorine tester, pH and colour tester. To control the purification process and to monitor the quality of the water, a water technician from Arba Minch Water Technology College has been assigned to the plant since 1988. However no record of test performed was available.

The test carried out during the study indicated that the pH of the treated water was unacceptably low, while the raw water pH was 7. This was due to the alum solution added. Low pH can be rectified by addition of lime after the alum solution, preferably at the inlet of the clarifier.

The filtered water which was chlorinated at the balancing chamber showed presence of total and faecal coliform. As there are consumers before the rechlorination point dosage of chlorine needs to be increased at the balancing chamber. The bacteriological quality of the water was found to be good after the rechlorination point (Table 10). At the dead ends of the network residual chlorine was not obtained. Flushing of the network has to be done and the chlorine dosage at the rechlorination point should be maintained till 0.1 - 0.2 mg/l of residual is obtained at the dead ends.

Table 10. Awasa water supply: bacteriological and physical analyses.

Date of sampling 30.9 1989

Source of water sample	Residual chlorine total	Residual chlorine free	Coliform count total	Coliform count faecal	Conductivity	Total dissolved solids	Temperature	Turbidity	pH	Time of sampling
	mg/l	mg/l	no/100 ml	no/100 ml	µs/cm	mg/l	°C	NTU		
Raw water intake			TNTC*	TNTC	46	23	17	54	7.2	10.30 am
Clarified water (clarifier outlet)			60	6	77	38	17	10	5.3	5.00 am
Filtered and chlorinated water (balancing chamber outlet)	0.01	0	50	5	79	39	17	4	5.0	5.45 am
Reservoir outlet	1.00	0.90	0	0	86	43	18		2.0	2.15 pm
Distribution network (dead end in the north)	0.01	0	0	0	84	42	21			3.30 pm
Distribution network (centre of the town)	0.30	0.15	0	0	80	40	20			4.00 pm
Distribution network (dead end in the south)	0	0	0	0	91	45	20			4.25 pm

*TNTC = too numeorus to count

5 Yirga Alem

The town of Yirga Alem is located about 315 km south of Addis Ababa. The existing water supply was commissioned around 1983. It comprises intake structure at Gedeo river, raw water pumping station with centrifugal pumps, sedimentation basin, three slow sand filters, 300 m^3 reservoir, operation building, administration building and distribution network (Figure 24). The operation building and the treatment plant are located within the same compound, whereas the administration building is situated at the centre of the town.

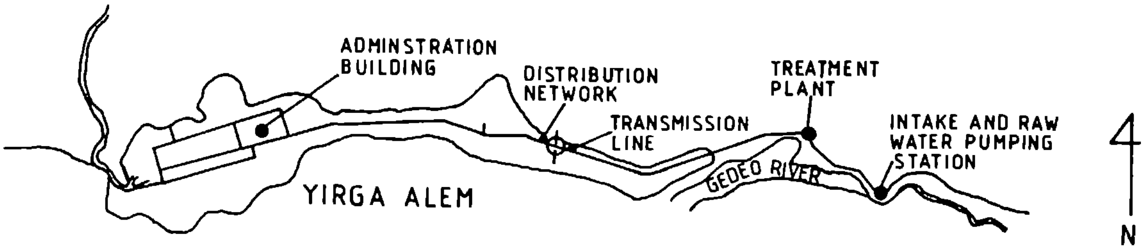


Figure 24. Schematic layout of Yirga Alem water supply system (WSSA 1985 b).

The operation building comprises laboratory and operation room, chlorination room, chlorine bottle room, chemical dosing room, chemical store room, toilet and shower rooms. The available laboratory equipment are flocculator complete with accessories, residual chlorine, colour and pH testers.

Yirga Alem town water supply system flow process is illustrated in Figure 25.

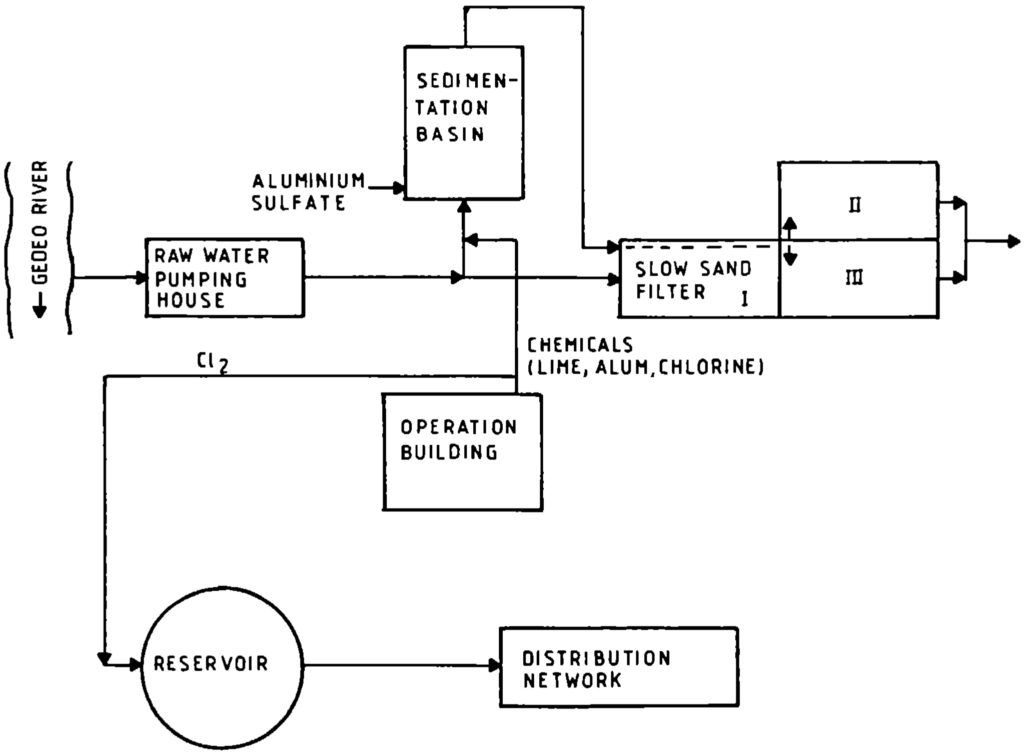


Figure 25. Process flow diagram of Yirga Alem water treatment plant.

The chemicals used at the plant are lime, aluminium sulfate and chlorine. Chlorine and lime solutions are injected at the inlet pipe and alum solution is added from bucket container at the inlet chamber of the basin. In Yirga Alem treatment plant the sedimentation basin acts as a horizontal flow clarifier. Gas chlorine was used for both pre- and post-chlorination. The reservoir is the contact point for post-chlorination.

The water supply system relies on the improvement of the bacteriological quality of water on chlorination. The slow sand filter is used for purification purpose only, i.e. turbidity removal was found to be 100 %. It does not improve the bacteriological quality of the water (Table 11). This might be due to the presence of chlorine in the clarified water which results in destroying the micro-organisms in the slow sand filters. By abandoning the pre-chlorination point, the slow sand filters can be utilized for bacteriological improvement and by-products of chlorination can be reduced. The reduction in the amount of chlorine used at the plant could be considerable. To control the treatment process and to monitor the water quality a water technician from Arba Minch Water Technology College has been assigned to the plant since 1988. No records of water tests performed were available to support the activity.

Table 11. Yirga Alem water supply: bacteriological and physical analyses.

Date of sampling 2.10.1989

Source of water sample	Residual chlorine		Coliform count		Conductivity	Total dissolved solids	Temperature	Turbidity	pH	Time of sampling
	total mg/l	free mg/l	total no/100 ml	faecal no/100 ml	µs/cm	mg/l	°C	NTU		
Raw water			TNTC*	TNTC	54	27	19	43	7.1	11.30 am
Clarified water (slow sand inlet filter)	0.15	0.05	8	0	75	37	19	5	6.5	12.00 am
Filtered water (slow sand filter outlet)	0	0	40	0	83	41	19	0	6.7	12.30 pm
Reservoir outlet	2.60	2.20	0	0	93	47	19		6.6	1.00 pm
Distribution network (centre of the town)	0.40	0.35	0	0	88	44	21		6.7	1.50 pm
Distribution network (dead end in the west)	0.20	0.15	0	0	80	40	21			3.05 pm

*TNTC = too numerous to count

During the study visit all the chemical dosing equipment except the aluminium sulfate solution dosing pump, were in working condition. The bacteriological quality of the distributed water was satisfactory.

6 Arba Minch

Arba Minch town is located about 510 km south-west of Addis Ababa with about 30 000 inhabitants. The source of water supply for the town for the last 25 - 30 years has been Arba Minch springs (Forty Springs). The existing system which started the operation in 1988, uses this source. The system consists of spring intake structure, pumping house with centrifugal pumps, operation building, two reservoirs of 500 m^3 and 300 m^3, administration office and distribution network. Figure 26 illustrates the schematic layout of this system.

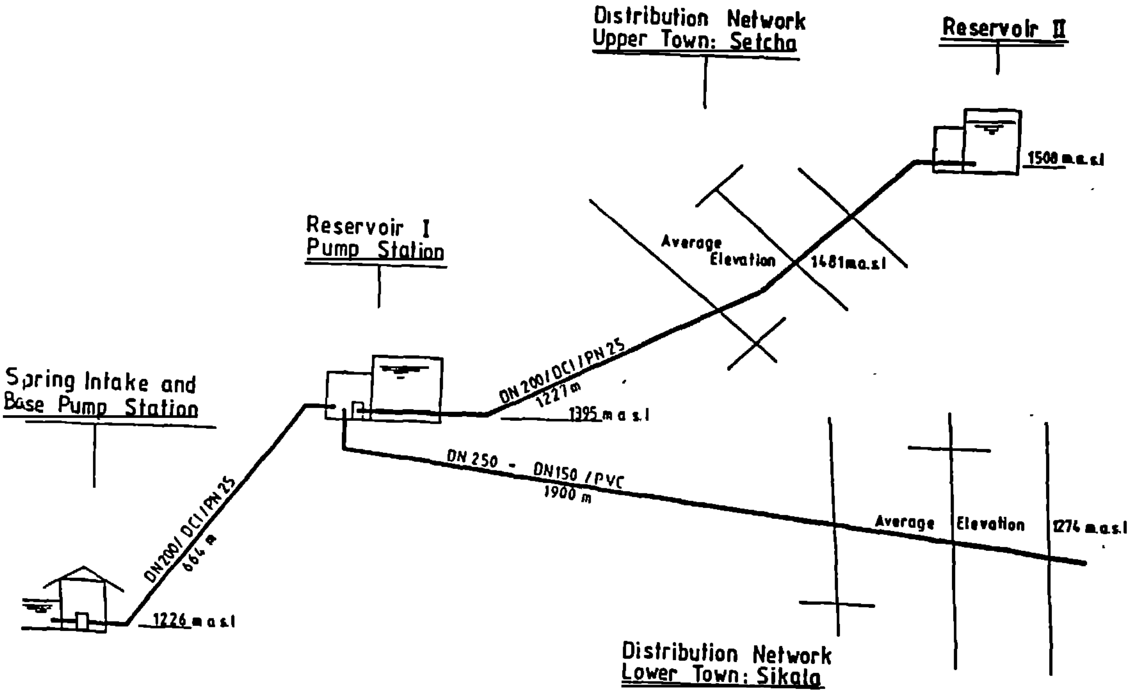


Figure 26. Schematic layout of Arba Minch water supply system (WSSA 1988 a)

The only type of treatment needed for Arba Minch spring is disinfection. This is achieved by chlorination with $Ca(OCl)_2$ solution. It is mainly adopted for prevention of contamination during storage and distribution. Otherwise the spring water is bacteriologically satisfactory for drinking purposes (WSSA 1988 a). Table 12 shows the water analysis results.

Table 12. Summary result of Arba Minch spring water analysis (WSSA 1983, modified by the author and WHO 1984 a)

Constituent or characteristics		Unit	Level at worst condition	WHO guideline values
Temperature		^oC	22.0-22.5	
Appearance			clear	
Colour		TCU	CL	15
Odour			OL	
Taste			TL	
Turbidity		NTU	0	5
Settleable matters			P	
Conductivity		μs/cm	230	
pH			7-7.8	6.5-8.5
Floating solids		mg/l	0	
Suspended solids		mg/l	543	
Dissolved solids		mg/l	310	
Total solids		mg/l	724	1 000
Total hardness as $CaCo_3$		mgl	150	500
Carbonate alkalinity as $CaCO_3$		mg/l	0	
Bicarbonate alkalinity as as $CaCO_3$		mg/l	180	
Total alkalinity		mg/l	170	
Carbondioxide (combined)		mg/l	210	
Dissolved (free) carbondioxide as CO_2		mg/l	9	
Dissolved (free) ammonia		mg/l	1.6	
Ammonia	NH_4	mg/l	1.6	
Sodium	Na	mg/l	64	200
Potassium	K	mg/l	2	
Calcium	Ca	mg/l	31	100-300
Magnesium	Mg	mg/l	13	
Iron	Fe	mg/l	0.15	0.3
Manganese	Mn	mg/l	1.20	0.1
Chlorides	Cl	mg/l	50	250
Nitrites	NO_2	mg/l	0.13	
Nitrates	NO_3	mg/l	6.7	10
Fluorides	F	mg/l	2.2	1.5
Bicarbonate	HCO_3	mg/l	220	
Carbonate	CO_3	mg/l	0	
Silicon	SiO_2	mg/l	60	
Sulfate	SO_4	mg/l	73	400
Phosphate	PO_4	mg/l	0.2	
Meta/poly Phosphates	PO_4	mg/l	2	
Calcium carbonate	$CaCO_3$	mg/l	71	
Sodium chlorid	NaCl	mg/l	83	

CL = colourless
OL = odourless
TL = tasteless
P = present

The operation building consists of the chlorination room, chlorine store, laboratory room, toilet and shower rooms. The chlorination room and chlorine store do not have ventilation at the floor level. The laboratory equipment available are flocculator with the accessories, portable spectrometer, chlorine residual and pH tester. The laboratory instruments are not utilized yet. This might be due to lack of water technician and irrelevance of some of the equipment to the existing system.

To prepare chlorine solutions two 100 ml plastic containers are provided. Due to the small size of the containers the prepared solution has a high strength (2 %). Even though flushing arrangement for the discharge hoses is provided, due to negligence often the time is clogged. It had also been experienced burst of chlorine solution discharge hoses due to the high pumping pressure (about 170 kPa) head of water. This can be avoided by provision of the chlorination point at the Reservoir I. The test result (Table 13) revealed the bacteriological quality of the water and residual chlorine in the system to be satisfactory.

Table 13. Arba Minch water supply: bacteriological and physical analyses.

Date of sampling 19 - 20.10.1989

Source of water sample	Residual chlorine		Coliform count		Conductivity	Total dissolved solids	Temperature	Turbidity	pH	Time of sampling
	total mg/l	free mg/l	total no/100 ml	faecal no/100 ml	µs/cm	mg/l	°C	NTU		
Raw water (unchlorinated)			0	0	320	153	23	1	7.1	12.25 pm
Transmission line (chlorinated water)	0.60	0.50	0	0	320	152	23			12.40 pm
Reservoir I outlet	0.30	0.30	0	0	320	155	23			2.25 pm
Distribution network (lower town)	0.30	0.25	0	0	320	156	23			3.00 pm
Distribution network (upper town)	0.25	0.25	1	0	314	158	25			4.00 pm
Reservoir II outlet	0.15	0.15	0	0	315	157	23			5.00 pm
Distribution network (lower town)	0.20	0.15	0	0	316	157	27			11.50 am
Distribution network (lower town dead end)	0.10	0.05	0	0	316	159	28			1.40 pm

7 Hosana

Hosana town is located 250 km south-west of Addis Ababa. The town water supply currently uses an impounded reservoir constructed and commissioned around 1977. The system comprises an impounded reservoir, upflow clarifier, rapid gravity filters, two reservoirs, clean water pumping house with centrifugal pumps, operation building, administration building and distribution network. All buildings and the treatment plant are located within the same compound. Figure 27 illustrates the process flow diagram of the water supply system.

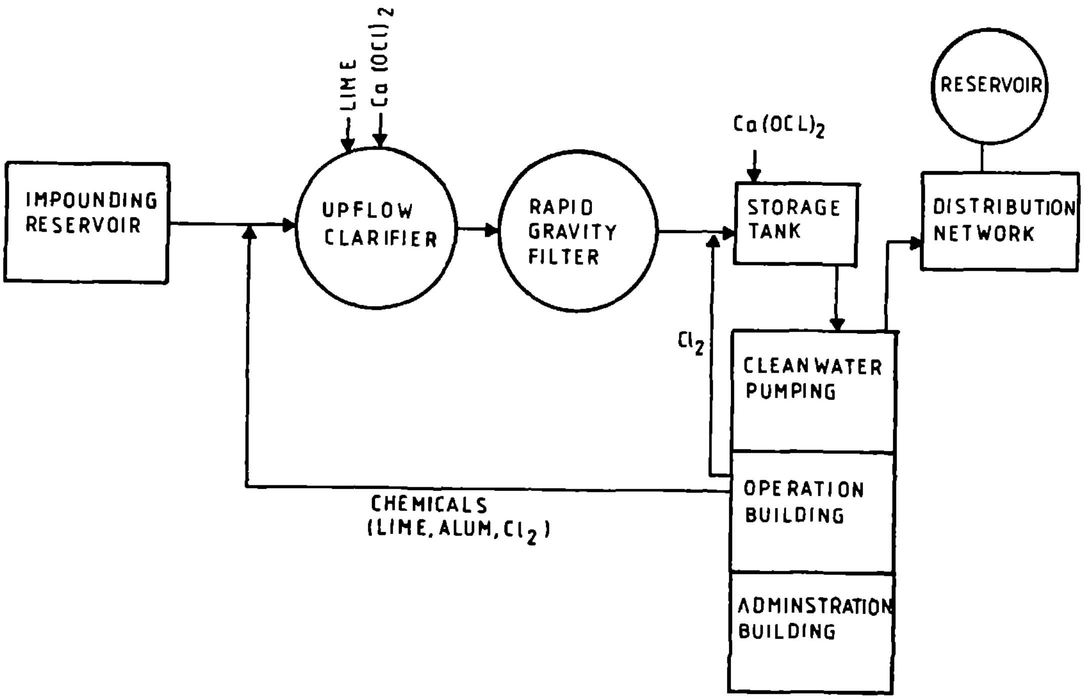


Figure 27. Process flow diagram of Hosana water supply system.

To control the water purification process and particularly the chemical dosing and water quality monitoring a water technician from Arba Minch Water Technology College has been posted since 1988. pH and residual chlorine test have been carried out on the site. Some of the basic laboratory equipment and chemicals are not available.

During the study visit the water in the distribution network was found to be free from coliforms. Increment of turbidity from 2 NTU to 17 NTU has been observed. The type of residual chlorine obtained in the network was only total chlorine (average 0.2 mg/l). Table 14 shows the bacteriological and physical test results obtained during the study period.

Table 14. Hosana water supply: bacteriological and physical analyses.

Date of sampling 23.10 1989

Source of water sample	Residual chlorine		Coliform count		Conductivity	Total dissolved solids	Temperature	Turbidity	pH
	total mg/l	free mg/l	total no/100 ml	faecal no/100 ml	µs/cm	mg/l	°C	NTU	
Raw water reservoir			TNTC*	50	86	43	22		7.0
Clarified water (outlet)	0.90	0.25	0	0	220	120	17	11	6.8
Filtered water (outlet)	0.50	0.05	0	0	193	96	18	7	6.8
Reservoir (outlet)	0.90	0.30	0	0	199	100	18	7	6.8
Distribution network (dead end in the north)	0.15	0.09	0	0	170	86	19		
Distribution network (southern part)	0.10	0	0	0	171	86	19		
Distribution network (centre of the town)	0.15	0	0	0	175	88	22		

*TNTC = too numeorus to count

The Hosana town water treatment plant has similar features to that of Shashemane town, except the location of the pumps and the source of water supply.

The impounding reservoir relies on the seasonal rain. Since its completion it has not been empty. Because the area is not fully fenced, it is accessible to domestic and wild animals. This results in pollution of the impounded water making the task of purification difficult and expensive. The only solution is to protect the source by proper fencing and to prohibit activities which might result in pollution of the impounded water.

The floating intake structure once used to take the settled water from impounding reservoir is no more functioning as it has been conceived, due to the separation of the float and the connection pipe. At present the raw water is drawn from lower level of the reservoir. This results in an increased load on the clarifier and on the filter, and subsequently in high consumption of the expensive chemicals.

The chemicals used in the plant are lime, aluminium sulfate and calcium hypochlorite. Previously there was gas chlorination arrangement for pre- and post-chlorination. Due to the failure of the chlorinator and the other related devices gas chlorination has been abandoned. Since then $Ca(OCl)_2$ solution is used. This solution is gravity fed from plastic containers at the clarifier inlet and the clean water tank. Lime solution is also similarly added at the clarifier inlet from a bucket container. The only dosing pump found to be working was alum solution dosing pump. But the discharge hose which was exposed on the ground suffers from leakages due to lack of protection and age.

6 CONCLUSIONS AND RECOMMENDATIONS

Based on the findings from the study the following points are made:

1. In practice full conventional treatment is not required for all water supplies. Particularly groundwater sources are free of pathogenic organisms and require minimum treatment. To control further contamination in the network disinfection has to be practised till the minimum residual 0.1 - 0.2 mg/l is found at the furthest end.

2. Compared to the available alternative disinfectants there is strong economic and technical advantage of using chlorine as a disinfectant. Most of the other alternative disinfectants are expensive and their health effect is not as well understood as chlorine.

3. The purpose of disinfection is to prevent spreading of disease. This can be achieved only if the operators maintain the required dose and proper functioning of the dosing equipment.

4. In all cases when the treated water leaves the plant there was a measurable amount of chlorine. However the residual in the network was less and often no residual was observed. The most common and widespread danger associated with the drinking water systems of the towns is contamination either as a result of leakage through connections or back syphonage as revealed during the study. Remedial measures such as:

   - Flushing through hydrants has to be practised as a routine maintenance.

   - Dosage of chlorine at the plant has to be increased to maintain residual 0.1 - 0.2 mg/l at the furthest point in the network. The residual chlorine should be measured daily at selected and representative points and the result has to be recorded.

   - Superchlorinating and flushing has to be practised.

5. Hypochlorite has been used in the cases when chlorine gas was not available and of failure of the equipment i.e. in Shashemane, Hosana and Awassa. To utilize gravity dosing which is reliable, easy to operate and maintain, it is preferable to have rigid, transparent and large containers. With low concentration of strength, clogging problems of the hypochlorite solution can be minimized.

6. In all future designs which involve chlorine gas system, a back-up arrangement for calcium hypochlorite solution has to be considered. Proper housing for chemical storage and sampling point after chlorination and in the network has to be provided.

7. Training, motivation and supervision of the people who work at the plant has to be compulsory. Organization like WSSA has sufficient experienced staff to provide on the job training and to do the supervision. Also, the training programme of water technicians at the Arba Minch Water Technology College has to be continued.

8. The routine analysis of water quality (pH, turbidity and residual chlorine) should be carried out by each treatment plant. To support the activity they have to be strengthened with the necessary equipment and chemicals by WSSA.

9. Monitoring and controlling the bacteriological quality of the source and the distributed water has to be the responsibility of WSSA and Ministry of Health. Surveillance responsibility has to be shared by the health authorities.

10. The existing regional laboratories of WSSA have to be strengthened with manpower, chemist and biologist and equipment. Although, priority has to be given to establish the laboratories in all regional offices.

11. The drinking water quality guidelines developed by WHO are intended for use of countries as a basis for formulating their national standards. Currently Ethiopia has no national water quality standards, so the WHO guidelines have to be adopted. It is WSSA's responsibility to set the water quality standards of those parameters which are difficult to adopt the WHO guidelines in the prevailing local circumstances.

7 REFERENCES

Aieta, E.M., Roberts, P.V. and Hernandez, M. 1984. Determination of chlorine dioxide, chlorine, chlorite and chlorate in water. Journal American Water Works Association. Vol. 76, no. 1, p. 64 - 70.

Aieta, E.M. and Roberts, P.V. 1986. The chemistry of oxo-chlorine compounds relevant to chlorine dioxide generation. Jolley et al eds. in: Water chlorination chemistry, environmental impact and health effects. Lewis Publishers, Inc., Michigan. Vol. 5, p. 783 - 794.

Anghern, M. 1984. Ultraviolet disinfection of water. Aqua. Vol.33, no.2, p. 109 - 115.

Anon 1987. Chlorine dioxide for water treatment. Developing World Water. Vol. 2, p. 178.

APHA- (American Public Health Association) AWWA- (American Water Works Association) WPCF (Water Pollution Control Federation). 1985. Standard methods for the examination of water and waste water. 16th ed. New York. p. 294 - 319.

ASCE (American Society of Civil Engineers). 1983. The incidence, monitoring and treatment of viruses in water supply systems. A state of the art review. New York. 85 p.

AWWA (American Water Works Association). 1971. Water quality and treatment: a handbook of public water supplies. 3rd ed. McGraw Hill, New York. p. 158 - 224.

Barnes, D. and Wilson, F. 1983. Chemistry and unit operation in water treatment. Applied Science Publishers, London. p. 122 - 148.

Cairncross, S. and Feachem, R.G. 1983. Environmental health engineering in the tropics. An introduction text. John Wiley and Sons, Chichester. 283 p.

Contruvo, J.A. and Vogt, C.D. 1986. Regulatory aspects of disinfection. Jolley et al eds in: Water chlorination chemistry, environmental impact and health effects. Lewis Publishers, Inc., Michigan. Vol. 5, p. 91 - 96.

Cox, C.R. 1973. Operation and control of water treatment processes. World Health Organization. Geneva, Switzerland. 392 p.

Dufour, A.P. 1976. Escherichia coli: The faecal coliform. Hoadley and Dutkov eds in : Water hazards associated with water. American Society for Testing and Materials, Philadelphia. p. 48 - 59.

Encylopaedia Britannica. 1957. Vol, 5. p. 604 - 608.

Ethiopia. 1988. Project proposal (Draft). Demonstration project for sustainable community managed rural low-cost water supply and sanitation. Addis Ababa, Ethiopia. 28 p.

EWRA (Ethiopian Water Resource Authority). 1978. Indicative five year programme for the development of rural water supply. Annexes. Addis Ababa, Ethiopia.

Evans III, F.L. 1972. Ozone technology. Evans III, F.L. ed in: Ozone in water and waste water treatment. Ann Arbor Science Publishers Inc., Michigan. p. 1 - 3.

Fair, G.M., Geyer, J.C. and Okun, D.A. 1971. Elements of water supply and waste water disposal. 2nd ed. John Wiley and Sons, New York. p. 500 - 523.

Gill, W.A. 1988. Potable water chlorination. Developing World Water. Vol. 3, p. 147 - 149.

Gorchev, H.G. 1988. Drinking water quality and health. Developing World Water. Vol. 3, p. 340 - 344.

Gordon, G., Cooper, W.J., Rice, R.G. and Pacey, G.E. 1988. Methods of measuring disinfectant residuals. Journal American Water Works Association. Vol. 80, no. 9, p. 94 - 108.

Hach Company. 1981. Water analysis handbook. p. 2 - 55.

Hanna, B. 1985. Water quality report southern region. Ethiopian Water Works Construction Authority. Awassa, Ethiopia. 10 p.

Hatch, G.L. and Yang, V. 1983. Determining residual chlorine: Effect of temperature on the titrametric starch-iodine end point. Journal American Water Works Association. Vol. 75, no. 3, p. 154 - 156.

Hiisvirta, L. 1988. Advantage and disadvantage of alternative disinfection treatments. International Water Supply Association Conference Proceedings. Rio de Janeiro. Special Subject 19. p. 13 - 14.

Hofkes, E.H. ed. 1987. Technology of small water supply systems in developing countries. Small community water supplies. IRC (International Reference Centre for Community Water Supply and Sanitation). Technical Paper Series no. 18. The Hague, the Netherlands. 442 p.

Hutchinson, M. and Ridgway, J.W. 1977. Microbiological aspect of drinking water supplies. Kinner et al eds in: Aquatic Microbiology Society for Applied Bacteriology Symposium Series no. 6. Academic press, England. p. 179 - 218.

Hutton, L. 1986 a. Water quality and bacteriological testing. Developing World Water. Vol. 1, p. 211 - 214.

Kinmann, R.N. 1972. Ozone in water disinfection. Evans III ed. in: Ozone in water and wastewater treatment. Ann Arbor Science Publishers, Inc. Michigan. p. 123 - 143.

Krasner, S.W., Barrett, S.E., Dale, M.S. and Hwang, C.J. 1989. Free chlorine versus monochloramine for controlling off-tastes and off-odours. Journal American Water Works Association. Vol. 81, no. 2, p. 86 - 93.

Lehmusluoto, P.O. 1979. Final report of consultant for water quality laboratories Addis Ababa, Ethiopia. 80 p.

Mann, H.T. 1983. Water disinfection practice and its effect on public health standards in developing countries. The Review Journal of the International Water Supply Association. Great Britain. Vol. 1, p. 231 - 240.

Mark, C. 1987. Water test. Developing World Water. Vol. 2, p. 513 - 516.

Masschelein, W.J. 1983. Scope and limitations of water by ultra violet radiation. The Review Journal of the International Water Supply Association. Great Britain. Vol. 1, p. 205 - 229.

McGuire and Meadow. 1988. AWWARF Trihalomethane survey. Journal American Water Works Association. Vol. 80, no. 1, p. 61 - 68.

Millipore Corporation. 1965. Portable water laboratory operating and maintenance instructions. Bedford, Massachusetts. 10 p.

Morris, J.C. 1966. Future of chlorination. Journal American Water Works Association. Vol. 58, no. 11, p. 1475 - 1482.

Nathanson, J.A. 1986. Basic environmental technology. Water supply, waste disposal and pollution control. John Wiley and Sons, New York. p. 178 - 179.

NWRC (National Water Resources Commission). 1984 Organizational set up and duties and responsibilities for the Natioal Water Resources Commission and its executive authorities and agency. Addis Ababa, Ethiopia. 17 p.

Oliveri, V.P. 1986. Human pathogens, disinfection and chlorine. Jolley, R.L. et al. eds in: Water chlorination chemistry, environmental impact and health effects. Lewis Publishers Inc., Michigan. Vol. 5, p. 3 - 18.

Packham, R.F. 1988. Disinfection. A review of current practice. International Water Supply Association Conference. Rio de Janeiro. Special Subject 19. p. 14 - 16.

Palin, A.T. 1980. Disinfection. Lewis, W.M. ed in: Development in water treatment 2. Applied Science Publishers, London. p. 141 - 162.

Pretorius, W.A. 1983. Appropriate technology in water purification and sewage treatment. Seminar on Appropriate Technology Transfer in Water Supply and Sanitation. Venda, South Africa. 9 p.

PAS (Public Administration Service). 1982. Organization and management study of the Ethiopian Water Works Construction Authority. Addis Ababa, Ethiopia. p. 4.

Rakotavahiny, E. and Arrestat, G. 1982. Water disinfection in developing countries. First African Water Technology Conference Programme. Nairobi, Kenya. 24 p.

Randtke, S.J. 1988. Organic contaminant removal by coagulation and related process combinations. Journal American Water Works Association. Vol. 80, no. 5, p. 40 - 56.

Richard, V. 1987. Disinfection in the treatment of drinking water. Developing World Water. Vol. 2, p. 215 - 217.

Rosa, A. and Fabris, M. 1988. Disinfection. International Water Supply Association Conference Proceedings. Rio de Janeiro. Special Subject 19. p. 1 - 17.

Rosen, H.M. 1972. Ozone generation and its relationship to the economical application of ozone in wastewater treatment. Evan III, F.L. ed. Ozone in water and wastewater treatment. Ann Arbor Science Michigan. p. 101 - 122.

Sayre, I.M. 1988. International standards for drinking water. Journal American Water Works Association. Vol. 80, no. 1, p. 53 - 60.

Scott, C.A. 1987. Ultraviolet sterilizers drinking water with renewable energy systems. Montanari, F.W. et al eds in: resource mobilization for drinking water and sanitation in developing nations. Proceedings of the International Conference. San Juan, Puerto Rico. p. 686 - 691.

Smethurst, G. 1988. Basic water treatment. 2nd ed. London. p. 136 - 142.

Snoeyink, V.L. and Jenkins, D. 1980. Water chemistry. John Wiley and Sons, New York. p. 386 - 404.

Steel, E.W. and McGhee, T.J. 1988. Water supply and sewerage. 5th ed. McGraw Hill, Singapore. p. 274 - 282.

Stratman, S. 1988. Rapid specific environmental coliform monitoring. American Laboratory.

Symon, J.M., Stevens, A.A., Clark, R.M., Geldreich, E.E., Love, O.T. and Demarco, J. 1981. Removing trihalomethanes from drinking water. Journal Water/Engineering and Management. Vol. 128, no. 7, p. 50 - 64.

Thompson, T.P. 1987. Drinking water quality surveillance and control in developing countries. Montanari, F.W. et al eds in: Resource mobilization for drinking water and sanitation in developing nations. Proceedings of the International Conference. San Juan, Puerto Rico. p. 630 - 639.

Tobin, R.S., Smith, D.K., Hortton, A. and Amstrong, V.C. 1983. Methods for testing the efficacy of ultraviolet Light disinfection devices for drinking water. Journal American Water Works Association. Vol. 75, no. 9, p. 481 - 484.

Twort, A.C., Law, F.M. and Cowley, F.W. 1987. Water supply. 3rd ed. Edward Arnold Publishers Ltd, Hong Kong. 548 p.

Umphres, M.D., Trussel, A.R., Tate, C.H. and Trussel, H. R. 1981. Trihalomethanes in drinking water. Journal Water Engineering and Management. Reference Handbook. No. 81, p. 65 - 76.

UWSA (Urban Water and Sewerage Agency). 1980. Twelve towns water supply project/Ethiopia. Engineering report Debre Zeit. Addis Ababa, Ethiopia. p. 10 - 25.

Vigneswaran, S., Shanmuganantha and Al Mammon, A. 1987. Trends in water treatment technologies. Environmental sanitation reviews. Bangkok, Thailand. No. 23/24, p. 52 - 87.

WSSA (Water Supply and Sewerage Authority). 1983. Twelve Towns Water Supply Project/Ethiopia. Engineering Report. Arba Minch. Addis Ababa, Ethiopia. p. 13 - 18.

WSSA (Water Supply and Sewerage Authority). 1984. Urbans water supply condition in Ethiopia. Historical literature (original in Amharic). Addis Ababa, Ethiopia. 55 p.

WSSA (Water Supply and Sewerage Authority). 1985 a. Awassa water supply scheme. Operation and maintenance manual. Addis Ababa, Ethiopia. p. 1 - 4.

WSSA (Water Supply and Sewerage Authority). 1985 b. Yirga Alem water supply scheme. Operation and maintenance manual. Addis Ababa, Ethiopia. p. 1 - 4.

WSSA (Water Supply and Sewerage Authority). 1986. Six centers water supply project. Technical report on well testing. Mojo. Addis Ababa, Ethiopia.

WSSA (Water Supply and Sewerage Authority) 1988. Tariff report. Addis Ababa, Ethiopia. 15 p.

White, G.C. 1968. Chlorination and dechlorination. A scientific and practical approach. Journal American Water Works Association. Vol. 60, no. 5, p. 540 - 561.
White, G.C. 1972. Handbook of chlorination. Van Nostrand Reinhold Company. New York. 744 p.

White, G.C. 1982. Design and application of potable water chlorination systems. Sanks, R.L. ed in: Water treatment plant design for the practical engineer. p. 371 - 372.

White, G.C. 1986. Handbook of chlorination. 2nd ed. Van Nostrand Reinhold Company, New York.

Williams, P.G. 1983. Chlorination of small scale water supplies. Seminar on Appropriate Technology Transfer in Water Supply and Sanitation. Venda, South Africa. 7 p.

Wilson, T.E. and Hsu, M. 1988. Chlorination vs. alternative disinfectants: Which is the best choice? Journal Water Engineering and Management. Vol. 135, no. 10, p. 42 - 45.

Wolfe, R.L., Ward, N.R. and Olson, B.H. 1984. Inorganic chloramines and drinking water disinfectants. A Review Journal American Water Works Association. Vol. 76, no. 5, p. 74 - 88.

Wolfe, R.L., Means III, E.G., Davis, M.K. and Barrett, S.E. 1988. Biological nitrification in covered reservoirs containing chloraminated water. Journal American Water Works Association. Vol. 80, no. 9, p. 109 - 114.

WHO (World Health Organization). 1984 a. Guidelines for drinking water quality. Recommendations. Geneva. Vol. 1, 130 p.

WHO (World Health Organization). 1984 b. Guidelines for drinking water quality. Health criteria and other supporting information. Geneva. Vol. 2, 335 p.

WHO (World Health Organization). 1985. Guidelines for drinking water quality. Drinking water quality control in small community supplies. Geneva. Vol. 3, 120 p.

Zeh, T.G. 1986. Water disinfection methods. Developing World Water. Vol. 1, p. 146 - 152.