CHEMICAL COMPOSITION OF DRINKING WATER IN TARAT AREA,
AND THE RESIDUAL CONTENT OF VCM IN WATER PASSING
THROUGH PVC HOSES

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بسم الله الرحمن الرحيم
(أفركم الماء الذي تشربون، إنكم أنزلتموه من أعلى آرض مدن)
(نحن المنذرون)
(صدق الله العظيم)
DEDICATION

To My Family.
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I am also grateful to Mr. Zehn El Abdoon Osman for typing this thesis.
Little information is known about the chemical composition of drinking water in the Gezira area. Water samples from two sources: wells and rivers, were collected from Gezira area (Tabat council) and Khartoum area.

Water from the two sources from the two locations were found potable, according to the international standards.

No significant variations in the chemical composition of well-water and river water was found.

Toxic heavy metals were not detected in all samples tested. Water samples from Gezira area were tested microbially, and were found to be safe.

Polyvinyl chloride (PVC) hoses could allow the migration of the toxic vinyl chloride monomer (VCM) to the water. In this study, water stored in PVC hoses for up to seven months was found to be free of residual VCM. PVC resins which are used for the production of hoses, were also found to be free of residual VCM.

It could be said that locally made PVC hoses are as safe in as much as the migration of VCM to water from PVC hoses is concerned.
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CHAPTER ONE

INTRODUCTION
INTRODUCTION

Drinking water, vital to life as it may be, is subject to chemical and microbial contamination. Thus it could be a real health hazard.

Polyvinyl chloride resins (PVC) are used in the production of plastic containers, water hoses and a variety of other products. PVC itself is not harmful, but there is a risk that it would be contaminated with traces of vinyl chloride monomer (VCM) which was proved to be harmful. (Uzych, 1984). VCM which may contaminate PVC containers may partly migrate to the contents of the container, partly to the air and some will remain in the walls of the container.

Modern technology has, however, made it possible to produce PVC products containing less than 0.00001% VCM.

In the Sudan, a good amount of plastic containers are produced by a number of plastic factories. It was feared that the modern technology that allows the production of VCM-free containers will not be available to the Sudanese industry. Therefore, all factories located in the national capital were surveyed. Fortunately, none of these factories used PVC for the production of food containers. Instead, all of them use polyethylene resins which are cheaper.
On the other hand, all domestic hoses are manufactured from PVC. The risk of having drinking water contaminated with PVC was alarming. For this reason, this research was planned and conducted to study the possibility of migration of PVC from PVC hoses into water. Various possible conditions of storage and handling of domestic hoses within a Sudanese home were simulated, and the possibility of having traces of PVC in drinking water was studied.

A separate part of this research studied the chemical composition of drinking water in Tabot area (Central State). Water from different surface wells were studied. In the rural areas no water treatment takes place regardless of the source of water. For this reason, the "Debye" was taken as an example and a thorough investigation to the water in Tabot area was made.

In the Sudan, a great deal of attention is needed for drinking water, particularly where water is scarce (Western Sudan). Research and investigation on the quality of drinking water is needed in many parts of the country.

It is not only the quantity of water that counts, but the quality of water is as important.
CHAPTER 2

LITERATURE REVIEW
CHAPTER 2

LITERATURE REVIEW

Vinyl polychloride (PVC) or (P.C.V), is a thermoplastic resin obtained after polymerization or juxtaposition of the molecule of a monomeric substance called vinyl chloride (VC) or vinyl chloride monomer (VCM).

Vinyl chloride monomer (VCM) is a colourless gas and colourless liquid at ambient temperature and pressure.

It was first prepared or made in 1835 by the renowned French chemist and physicist Henri-Victor Regnault, but it was not used industrially as a polymer until a century later. VCM commercialization did not begin until the 1930's and did not reach high volume until after 1945 (Anon, 1974a).

VCM has a sweetish odour at higher concentrations. It is normally stored and handled under pressure as colourless liquid.

The properties of VCM are as follows:

- Freezing point: \(-139.5^\circ C\)
- Boiling point: \(-13.5^\circ C\)
- Flash point: \(-78^\circ C\)
- Molecular weight: 62.5
- Gas number: \(7.5 \times 10^{-4}\)

Synonyms: Vinyl chloride monomer, vinyl chloride, monochloroethylene, monochloroethene
Structural and molecular formula of VCM → PVC:

\[
\begin{align*}
\text{H} & \quad \text{Cl} \\
\text{C} \quad \text{C} & \quad \text{H}_2 \quad \text{Cl} \\
\text{H} & \quad \text{H}
\end{align*}
\]

It is heavier than air and requires thorough safety precautions in handling (Barna et al., 1927).

Upper explosive limit \(26\% \text{ v/v}\)

Lower \(\quad \text{v/v}\) \(3.6\% \text{ v/v}\)

Liquid density \(\quad \text{relative to the air at } 20^\circ\text{C}\) \(2.15\)

Partition coefficient limit \(\text{log } P = 0.6\)

Solubility: Readily soluble in most organic solvents, but only slightly soluble in water (0.11 g per 100 g of water at 25°C).

VCM is stable in the absence of sunlight or oxygen. Above 400°C, it decomposes into acetylene and hydrochloric acid. The combustion of VCM in the air (at 515°C – 795°C) produces mainly carbon dioxide, hydrogen chloride and carbon monoxide. Traces of phosgene are also formed (Jersy and Sokal, 1989).
Production of VCM

The classic process for the production of VCM involves the catalytic hydrochlorination of acetylene. The reaction is generally carried out in tubes with activated carbon, impregnated with mercuric chloride catalyst. The temperature normally varies from 100°C to 280°C, the temperature being increased as the catalyst activity decreases with time.

In the usual configuration, where elemental Cl$_2$ and ethylene are the feedstocks, Ethylenedichloride (EDC) is produced by the direct chlorination of ethylene. The HCl produced as a by-product of the cracking of EDC to VCM.

HCl is reacted with ethylene in the oxychlorination process to produce EDC for recycling (Anon, 1974b).

The manufacturing procedure is as follows:

Direct chlorination of ethylene

\[
\text{C}_2\text{H}_4 + \text{Cl}_2 \rightarrow \text{ClC}_2\text{H}_4\text{Cl} \quad (1)
\]

Thermal dehydrochlorination of EDC (EDC cracking)

\[
\text{ClC}_2\text{H}_4\text{Cl} \rightarrow \text{CH}_2\text{C} = \text{CHCl} + \text{HCl} \quad (2)
\]

Oxychlorination of ethylene

\[
\text{C}_2\text{H}_4 + \text{HCl} + \frac{3}{2}\text{O}_2 \rightarrow \text{ClC}_2\text{HCl}_2 + \text{H}_2\text{O} \quad (3)
\]
Uses

VCM is mainly used for the production of poly-vinylchloride (PVC). The first PVC was reported in 1872. In 1985 worldwide annual production of the polymer reached about 12 million tonnes. Minor uses of VCM are as a co-monomer with vinylacetate or vinylidene chloride, and as a raw material for the manufacture of 1,1,1-trichloroethane and monochloroacetaldehyde (Anon, 1988a).

VCM was formerly used as a propellant for many aerosol products, such as hair sprays and deodorants. Consumers using such products were exposed to moderately high concentrations of VCM (WHO, 1984a).

PVC is used as a raw material in the plastics, rubber, paper and glass industries. PVC is used in the manufacture of electrical wire insulation and cables, piping industrial and house hold equipment, medical supplies, food packing material (bottles and films) and construction products.

PVC and VCM copolymers are distributed and processed in various forms, including dry resins, plastisid (dispersions in plasticizers) emulsion (dispersion in plasticizers plus volatile solvent) and latex which is a colloidal dispersion in water used to coat paper, fabric or leather (Anon, 1987a).
Polyvinyl alcohol was prepared in 1924 from hydrolyzed PV acetate. Acetates were found to be soft and chlorides too hard, so in 1928 vinyl acetate was prepared. The copolymers proved to be very useful, with addition of plasticizers, a series of coated and calendered fabrics were produced. The first shower curtains and rain coats of early 1940's had strong odours from their migratory plasticizers, however, as technology improved, better polymers and better plasticizers were used.

In 1958 neat shrinkable PVC film was introduced commercially, and this was the first strong entry of vinyls into the packing field. VC-acrylic copolymer have made excellent rigid molded articles. VC and vinyl ether copolymer have found use in laquers (Sacharow and Griffin, 1970).

Degradation Products and Pathways

In the atmosphere VOC reacts with hydroxy radicals and ozone, ultimately forming formaldehyde, carbon monoxide, hydrochloric acid and formic acid. The half-time of VC in the atmosphere amounts to about 20 hours (Anon, 1994a).
VCM released to surface waters migrates to atmosphere in a few hours or days. VCM which is released to the ground does not adsorb onto soil and migrates readily to ground water.

Evidence from laboratory studies suggests that VCM in ground water may be degraded to CO₂ and Cl⁻. However, VCM may remain in ground water for several months or even years.

VCM has been reported to be a degradation product of trichloroethylene and tetrachloroethylene in ground water (Anon, 1987a).

In aquatic environment where high concentration of chlorine/chloride occur, vinyl chloride may be converted to more highly chlorinated products (Anon, 1984a).

Polymerisation of VCM

The gas is polymerized at temperature between 40°C to 80°C using an atmospheric pressure of 6-15 bars. Nevertheless, polymerization is never complete. The speed of a chemical reaction depends on the concentration of the substances involved. In case of VCM, the concentration drops substantially in the polymerisation tanks and this then causes polymerisation to slow down.
The reaction generally stops when 90% of VCM has been polymerised. After polymerisation, PVC resin is obtained as a white porous powder resembling semolina.

Various ingredients are added to this resin and the resulting product is known as PVC compound. This then passes through extrusion and blowing operations to produce the PVC bottles.

Nowadays, the development of technology permits the manufacture of finished products containing under 0.00001% VCM. The levels of VCM is further reduced during the subsequent stages in the manufacturing process. After some time, some of this VCM may migrate from bottles or hoses into the liquid contained in them. Some migrates into the air and some remains in the bottle or hose wall. There is a ratio between the VCM concentration in the wall and the amount that migrates into the liquid.

By comparing the result of hundreds of analysis, it has been possible to establish a theoretical curve for the migration from the container to the contents and this curve has been accepted by an international panel of exports. This curve show that after 3 months, in the most extreme instances, migration can reach a maximum of 20%. After 6 months, it is in the order of 30%. After a year, it can reach 40%.
Figure 2, Theoretical curve for the migration of VCM from the container to content (Maltoni et al., 1981).
Experiments have demonstrated that the 40% maximum was the same, regardless of the liquid packaged.

Naturally, the equilibrium is reached after a shorter or a longer period in the case of some products, but after a year the migration level is the same for all liquids, this value is never achieved because the bottle closure always allows some of the VCM residue to escape.

It is known that the PVC bottle walls contain at most 0.1 ppm VCM, and that 40% of this quantity is liable to migrate. Apparently, the quantity of migrating VCM would depend on three parameters: The VCM content of the material; the temperature and the length of the storage time.

VCM is not known to occur as a natural product. The occurrence of VCM in the air, in water, and in food has been reviewed (Anon, 1979a; WHO, 1984a; Anon, 1984b; WHO, 1987; Anon, 1988a).

Occurrence in Water

There is very little information on current concentration of VCM in water.

VCM in samples of waste water from seven areas in the USA (associated with PVC, VC manufacturing plants) ranged from 0.05 to 30 mg/l (WHO, 1984a).
Table 1. Determination of the theoretical daily exposure of consumers based on total liquid intake in France.

(Assuming that everything drunk is packaged in PVC and that the compounds used to manufacture the bottles all had a VCM level of 0.1 ppm).

<table>
<thead>
<tr>
<th>Quantity of VCM in packaging in mg</th>
<th>Maximum quantity of VCM that may migrate in mg</th>
<th>Maximum daily intake recorded in litres</th>
<th>Quantity of VCM that may be taken in mg</th>
</tr>
</thead>
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<tr>
<td>Water 0.0035</td>
<td>0.0014</td>
<td>0.547</td>
<td>0.0007658</td>
</tr>
<tr>
<td>Wine 0.0035</td>
<td>0.0014</td>
<td>0.303</td>
<td>0.0004242</td>
</tr>
<tr>
<td>Oil 0.0035</td>
<td>0.0014</td>
<td>0.023</td>
<td>0.0000350</td>
</tr>
<tr>
<td>Vinegar 0.0035</td>
<td>0.0014</td>
<td>0.007</td>
<td>0.0000098</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>0.0013348</strong></td>
</tr>
</tbody>
</table>
The highest concentration of VCM detected in drinking water in USA was 10 ug/litre. In a five-city survey in the USA concentrations of VCM up to 1.4 ug/litre were detected in drinking water taken from distribution systems constructed with PVC pipes (WHO, 1984a).

VCM has been detected only occasionally in samples of drinking-water taken in 100 cities of Federal Republic of Germany. The highest level of 1.7 ug/litre was ascribed to dissolution from PVC tubing (WHO, 1984a).

However, in a number of countries a considerable part of the water network consist of plastic, mainly PVC-pipes.

The maximum VCM intake per person per day in the UK was calculated to be 0.1 ug in 1976 and less than 0.02 ug in 1978. The Food Drug Administration arrived at similar values. They calculated the intake from oil, liquor and wine bottle, food packed in PVC or VC-VDC co-polymer film, and other sources. The upper limits of this were to give a total maximum daily intakes of 0.025 ug (Amos, 1988a).

The maximum permissible level of VCM to be inhaled by human is 0.015 mg/kg (Zarembo and Gummenny, 1982).
Occupational exposure to VCM occurs during manufacture and polymer production and in PVC-processing plants. Prior to the mid 1970's, VCM concentration in the atmosphere of polymerization plant amounted to hundred ppm with peak exposure levels of several thousand ppm.

Relative Significance of Different Routes of Exposure

The most important exposure route is air contamination from VCM and PVC production facilities.

Assuming inhalation of 10 m³ air per working day, and VCM concentration of 10 mg/m³, the most exposed part of working population would now inhale about 30 mg of VCM daily. The background levels of VCM in ambient air are likely to lead to average exposures of 2-10 µg/day. Heavy smokers may inhale additionally up to 0.5 µg/day. Assuming the highest level of VCM in drinking water to be 1-2 µg/litre, Elution of VCM from PVC resin pipes in the absence and presence of Cl in water were compared by headspace analysis. VCM concentration in the absence of Cl in water after contact with PVC pipes were dependent on the residual VCM content in these pipes (trace = 190 µg/l); in the presence of Cl lower concentrations of VCM were observed for all PVC pipes examined (trace = 75 µg/l).
The decrease in both VCM and chlorine concentration were also recognized when these chemicals were mixed in water, especially under acidic conditions. Gas chromatograph-Mass-spectrophotometry of ether extract from the aqueous solution showed the reaction product of VCM and chlorine to be 2,2-dichloroethanol (Tabata et al., 1985).

Migration of VCM from PVC packaging materials containing very low concentrations of residual VCM appears essentially zero, particularly at low temperature (Apostolopoulos and Gilbert, 1986).

Extraction test of VCM from the pipes was carried out by filling the pipes with tap-water and standing for 72 hours at 20°C. VCM extracted by water was related to residual VCM concentration and found in water that had filled pipes which contained from 1 to 540 ppb VCM (Nakamura and Misura, 1977).

**Human Health Effects**

The health effects of VCM have been recently reviewed and summarized in several documents and review articles (Anon, 1984; Jedrzychowski and Chmielnicka, 1985; WHO, 1987; Anon, 1988a, Anon, 1988b; Dych, 1988). There are many reports of employees exposed to VCM auditor in polymer plants becoming dizzy and unconscious. Because VCM was
considered to be relatively innocuous, it had a threshold limit value (TLV) of 500 ppm (Jorkelson et al., 1961; ACGIH, 1974; Lester et al., 1963).

VCM is a narcotic agent and loss of consciousness can occur from exposure approaching 25,000 mg/m³.

Several effects of chronic exposure were documented. The symptoms observed included Raynaud’s phenomenon, a painful vasospastic disorder of the hands; pseudoscleroderma; hepatomegaly and noninfective portal fibrosis with portal hypertension and splenomegaly. These disorders were noted among individuals exposed to VCM in polymerization plants. There is sufficient evidence of carcinogenicity of VCM in humans. A large number of studies and case reports have been published. Several comprehensive reviews and evaluations of existing data are available (Anon, 1979b; WHO, 1987; Purchase et al., 1987; Doll et al., 1988).

According to Anon (1988a), VCM can be also associated with hepatocellular carcinoma, brain tumors, lung tumors and malignancies of the lymphatic and hematopoietic tissues.
However, other reports claimed that no positive evidence of a hazard of any type of cancer other than angiosarcoma of the liver has been found except possibility of small hazard of lung cancer when exposure was heavy (Jerly and Sokal, 1989).

The VCM belongs to the poisonous substances category with cumulative effects when the repeating of microdoses lead to severe organic damages of an irreversible kind most of the time, and more particularly carcinogenic effects (Anon, 1974b).

Properties and Chemical Composition of Water

Potability of Water

Water is said to be potable when its general physical characteristics are acceptable by the average consumer. There are many substances that might change the water appearance, colour, odour or taste. The chemical substances that affect the potability of water usually do not affect the health. These substances are iron, manganese, copper, zinc, magnesium, calcium, sulphates, chlorides and total solids (Hassan, 1986).
Hardness of water

Water hardness is caused when polyvalent metallic ions are dissolved in it. In fresh water, the principal hardness causing ions are magnesium and calcium. Ions of strontium, iron, barium and manganese also contribute (Anon, 1976).

The degree of hardness of drinking-water has been classified in terms of its equivalent CaCO₃ concentration as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Concentration (mg/litre)</th>
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<tr>
<td>Soft</td>
<td>0-60</td>
</tr>
<tr>
<td>Medium hard</td>
<td>60-120</td>
</tr>
<tr>
<td>Hard</td>
<td>120-180</td>
</tr>
<tr>
<td>Very hard</td>
<td>180 mg/litre and above</td>
</tr>
</tbody>
</table>

Hardness has also been classified in terms of equivalent concentration of CaO or Ca(OH)₂ (Globmann, 1976).

Hardness of water is caused by cations such as carbonate and noncarbonates. The carbonate hardness (temporary) refers to the amount of carbonates and bicarbonates in solution, and can be removed by boiling. The noncarbonates (permanent) hardness cannot be removed by boiling (Sawyer and McGarty, 1967).
Alkalinity, an index of the buffering capacity of water, is closely linked to hardness. For the most part, alkalinity is produced by anions or molecule species of weak acids, mainly carbonates, hydroxide and bicarbonates (Thomas, 1973).

Ground water is generally harder than surface water. The taste threshold for the calcium ion in drinking water varies from 100 to 300 mg/l depending upon the anions present. For magnesium ion, the taste threshold is less than this value (Zoeteman, 1980).

There is no firm evidence that water hardness causes ill effects in man (Sokerega, 1975).

There are a number of studies where the result suggests that water hardness protects against disease.

**Common Chemical Constituents of Water**

**Sodium**

Sodium is present in a number of compounds in water treatment chemicals such as sodium fluosilicic, sodium silicofluoride, sodium hydroxide, sodium carbonate, sodium bicarbonate and sodium hypochlorite. In most countries, the majority of water supplies contain less than 20 mg/l Na. But in some countries sodium level can exceed 250 mg/l.
Most of people are exposed to less than 50 mg of Na per day by drinking tap-water (based on a consumption of 2 litres per day). The sodium salts are very soluble, virtually all the sodium present in water, whether consumed directly, in the preparation of beverage and incorporated into food, will be absorbed.

In general, sodium salts are not acutely toxic substances, because of the efficiency with which kidneys excrete sodium (Anon, 1978; Anon, 1980).

Excessive intake of NaCl causes vomiting and the elimination of much of salt. Acute effect may include convulsions, muscular, twitching and rigidity and cerebral and pulmonary oedema (Anon, 1978; Anon, 1980).

Acute effects and death have been reported in case of accidental overdoses of sodium chloride (WHO, 1979). The total sodium intake should be kept as low as possible (WHO, 1979).

Manganese

In natural surface water manganese (Mn) occurs in both the dissolved and suspended forms. Anaerobic ground water often contains elevated levels of dissolved manganese.
Fresh water may contain from one to a thousand mg/l depending on location. Manganese intake through drinking water is normally lower than intake from food. Mn presence in water is objectionable because it precipitates and thus alters the appearance of water, turning to turbid yellow, brown to black. In addition, it will cause staining of plumbing fixtures and laundry and the growth of microorganisms in distribution systems in the presence of Fe and Mn.

The guideline value for Mn level in drinking water is recommended at 0.1 mg/l, based on considerations of the staining properties of Mn.

No specific syndrome due to Mn deficiency has been described in man, it has been suggested that there may be an association between manganese deficiency disorder such as anaemia, bone changes in children (Pier, 1973).

There is no evidence that Mn is carcinogenic (SpiveyFox, 1972).

Heavy Elements

Cadmium (Cd)

Drinking water normally contains very low concentration of Cd, approximately 0.5 μg/l. In rare occasions levels...
reach up to 10 mg/l. Estimated daily exposure to Cd via water based on water consumption of 2 litres per day, range from substantially less than 1 µg per day to over 10 µg per day.

Health effects have been demonstrated in industrial workers heavily exposed to cadmium oxide fumes and dust (Anon, 1979a).

The classical renal effects of cadmium poisoning are associated with proteinuria, diuresis and aminoaciduria (Anon, 1980).

The evidence that cadmium may be carcinogenic to man is rather weak (Lyon, 1979; Anon, 1980).

However, prolonged and heavy industrial exposures may constitute an increased risk of prostate cancer (Kupling and Waterhouse, 1987; Lehman, 1975).

Cadmium has a long biological half-time in the body (10-38 years).

**Lead**

The levels of lead in domestic tap water are relatively low, normally well below 10-20 µg/l. The high levels are associated with soft water or that of a low pH.
Variations in lead levels in tap water depend on factors such as the stagnation time of the water in lead service pipe and length of pipes.

Lead in high doses has been recognized for centuries as a cumulative general metabolic poison. Some of the symptoms of acute poisoning are tiredness, nausea, slight abdominal discomfort, irritability, anemia and in the case of children behavioral changes (WHO, 1977).

Lead also has an affinity for amino acid containing sulphur, leading to interference in the regulation of oxygen transport and energy generation (Stoll, 1979).

Zinc

Zinc causes corrosion of pipes in fresh water. In the presence of oxygen corrosion causes the formation of zinc hydroxide film.

\[ \text{H}_2 + \text{Zn} \rightarrow \text{ZnH}_2 \]  
\[ \text{ZnCl}_2 + \text{Zn} \rightarrow 2\text{ZnCl}_2 \text{H}^+ + 2\text{e}^- \]

Zinc hydroxide \( \text{Zn(OH)}_2 \) is quite soluble below pH 8.1. At pH value above 8.8 \( \text{Zn(OH)}_2 \) is also formed by the equation

\[ \text{Zn} + \text{OH}^- \rightarrow \text{Zn(OH)}_2 + \text{e}^- \]

The reaction may be violent, and the zinc hydroxide precipitate is pulled out off the metal surface to form a fluffy white deposit of considerable thickness.
Zinc ions are rarely present in natural water in considerable concentrations, but zinc does enter the water supplies by solution of the metal from zinc galvanized on pipes and tanks. Cadmium and lead, both toxic, are common impurities in zinc galvanizing. Their concentration ranges from 0.01 to 0.5 for cadmium, and from 0.34 to 0.45 for lead.

It was indicated that zinc is a normal constituent of the human body; its presence in drinking water up to 40 ppm appears to have no health significance, but it imports a stringent taste to water, so it will precipitate as Zn(OH)₂ or ZnCO₃ in alkaline waters to produce a milky turbidity (Camm and Reserve, 1973).

Copper

The nature of copper (Cu) in water depends on the pH and carbonate concentration in water and the other anions in solution (Nees and Wells, 1963).

Water treatment processes usually result in the removal of trace metals from water, but the copper concentration in drinking water at consumer's tap can be higher than in either the source or the treated water entering the supply. Copper in solution imparts a colour and undesirable taste to drinking water (Pope, 1973).
Copper levels in drinking water vary normally from 0.01 to 0.5 mg/litre (Zastemaa and Brinkman, 1976). Copper is an essential element in human metabolism, having roles in erythrocyte formation, release of tissue iron and the development of bone, the central nervous system and connective tissue. Copper is usually combined with protein.

Intake of excessively large doses by man lead to severe mucosal irritation and corrosion, widespread capillary damage hepatic and renal damage.

Application of copper in water has an unpleasant, astringent taste. The taste threshold is above 3.0 mg/litre, although taste is detectable in distilled water at 2.6 mg/litre (Cohen, 1960).

Iron
Iron occurs in water mainly in the divalent and trivalent (ferrous and ferric) forms.

Both, cast iron and steel pipes are employed for drinking water distribution to the consumers. In the production of potable water various salts of iron used as coagulating agents (WHO, 1984).
Presence of iron in a concentration greater than 1 mg/l have been reported to occur in ground water (Dart, 1974).

Concentration of Fe in drinking water are normally less than 0.3 mg/l and the intake from food is substantially higher than that from drinking water. Fe is an essential element in human nutrition (Vott and Merrill, 1963; Vogg, 1973).

It is contained in a number of biologically significant protein such as haemoglobin and cytochromes and also in many oxidation reduction enzymes.

The minimum daily requirement for iron vary from 7-14 mg depending upon age and sex. Pregnant women may require Fe in excess of 15 mg per day (Aron, 1975).

The presence of iron in drinking water supplies is objectionable for a number of reasons unrelated to health (Molnar and Wolf, 1973; Dart, 1974; Zoeteman and Bremkamp, 1976). Iron can change the colour of water to yellow, brown or black causing staining of plumbing fixtures and laundry. It also enhances certain bacteria to grow. Growth of microorganisms may be changed from metallic astringent to medicinal (WHO, 1971). The above problems makes it necessary to maintain Fe levels below the value of 0.3 mg/l.
CHAPTER 3

MATERIALS AND METHODS
CHAPTER 3
MATERIALS AND METHODS

Materials

1. Tap water from two different sources, the river or wells, was collected from 3 different localities: Khartoum town, Omdurman and Khartoum North. A total of 28 samples were collected from Khartoum district (each 1 litre). Also 25 samples (each 1 litre) were collected from north west Gezira area (Tabat council).

2. Polyethylene bottles (60 ml and 1 litre capacity).

3. Glass vials (5, 25 ml) with septum and crimp.

4. Sterile glass bottles (250 ml) containing 0.1 ml of 10% sodium thiosulphate solution.

5. Plate count agar.

6. Domestic PVC hoses (locally made).
   a) New PVC hoses (100 meter)
   b) Used PVC hoses (2 meters)

The two types in different colours: yellow, green, blue, red and white.

Reagents

1. Air (to obtain air a compressor was used).

2. Acetylene and nitrogen of standard commercial grade was supplied by Liquid Air Company, Khartoum North.
3. LaO$_3$, CaCO$_3$, NaCl, KCl, Na$_2$SO$_4$, Cd metal, Cu$_2$O, Co metal, Zn, Pb (NO$_3$)$_2$ were supplied by Sigma Chemicals.

4. N,N-dimethylacetamide (DMAC), spectro grade was supplied by Eastman-Kodak, Rochester, N.Y., U.S.A.

5. Standard VCN solution was dissolved in DMAC. Supplied by the French company V😄fפ.

6. Tetrahydrofuran (THF) was supplied by E. Merck, Darmstadt, Germany.

7. Eosin methylene blue agar.

8. Lactose broth.


All other chemicals used were at analytical grade.

Equipment used:

1. Gas liquid chromatograph (GLC), Pye unicum, GLC was used with stainless steel column packed with PEGA and equipped with a flame ionization detector and AR 35 linear recorder.

2. Atomic absorption spectrometry Parkin Elmer 2380.

3. Flame photometer Corning N400 made in U.K.

4. Copper wire and Bunsen burner.

5. Incubators (37°C and 44°C).
Methods

Method of chemical composition

Metal content of water samples

This was done using atomic absorption spectrophotometer.

Nebulizer was first rinsed by aspirating water containing concentrated HNO₃ (1.5 ml/l).

When determining calcium or magnesium, 100 ml of samples were mixed with 10 ml lanthanum solution before atomisation. In the case of iron and manganese, 100 ml of test solution was mixed with 25 ml Ca solution before aspiration.

Standard curves for potassium and sodium

Standard sodium or potassium solutions containing the following concentrations were prepared: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 ppm, and standard curves were produced after reading in the flame photometer.

1. Standard lanthanum solution

58.6 g of lanthanum oxide La₂O₃ was dissolved in 250 ml concentrated HCl. Acid was added slowly until the material was dissolved and diluted to 1000 ml with distilled water.

2. Standard calcium solution

650 mg calcium carbonate (CaCO₃) was dissolved in 50 ml of (1:5 HCl) and made up to 1 litre with distilled water. One ml of 1 mg Ca (1:5 HCl) denotes that 1 volume concentrated HCl is to be diluted with 5 volumes of distilled water.
3. **Standard sodium solution**

2.542 g of NaCl dried at 140°C was dissolved in distilled water and made up to 1 litre. 1 ml = 1 mg Na.

4. **Standard potassium solution**

1.907 g of KCl was dissolved in distilled water and made up to 1000 ml. 1 ml = 1 mg K.

5. **Standard magnesium solution**

4.952 g of MgSO₄ was dissolved in 200 ml distilled water. To this 1.5 ml concentrated HNO₃ was added and made up to 1 L with distilled water. 1 ml = 1 mg Mg.

6. **Standard iron solution**

1 g of iron wire was dissolved in 50 ml of HNO₃ and made up to 1 litre with distilled water. 1 ml = 1 mg Fe.

7. **Standard cadmium solution**

1 g of Cd metal was dissolved in a minimum volume of HCl and made up to 1 litre with distilled water. 1 ml = 1 mg Cd.

8. **Standard cobalt solution**

1.407 g of cobaltic oxide Co₉O₄ was dissolved in 20 ml hot concentrated HCl cooled and diluted with distilled water to 1 L. 1 ml = 1 mg Co.
9. **Standard copper solution**
   1 g of copper metal was dissolved in 15 ml of 1+1 HNO₃ and diluted to 1000 ml with distilled water. 1 ml = 1 mg Cu.

10. **Standard zinc solution**
    1 g of zinc metal was dissolved in 20 ml 1+1 HCl and diluted to 1000 ml with water. 1 ml = 1 mg Zn.

11. **Standard lead solution**
    1.598 g of lead nitrate Pb(NO₃)₂ was dissolved in about 200 ml water added 1.5 ml concentrated HNO₃ and diluted to 1000 ml with water. 1 ml = 1 mg Pb.

The atomic absorption spectrophotometer was used for the analysis of the following elements: Pb, Zn, Co, Fe, Ca, Cu, Cd, Mg and Mn. The flame photometer was used for the analysis of Na and K.

**Alkalinity of water**

Alkalinity, expressed as CaCO₃ mg/l, was done by titrating against 0.002 N. HCl to pH 4.5 and was calculated from the following equation:

\[
\text{Alkalinity (mg CaCO₃/l)} = \frac{A \times N \times 50}{\text{Vol. Sample (ml)}}
\]

Where:
- \( A \) = Titre (ml)
- \( N \) = Normality of acid
Fig. 3. Determination of Na by Flamephotometer (mg/l).
Fig. 4. Determination of K ions by Flamephotometer (mg/l)

Reading of Flamephotometer

Concentration of K in ppm
Microbiological methods

Total colony count was done by the pour plate method using plate count agar (Difco Laboratories, Detroit, Mich.). Phosphate buffer was used as diluent. The plates were incubated at 37°C for 48 hours. Counting was carried out with the aid of an Astell colony counter (Laboratory Service Co. Ltd, London, England).

The three-tubes procedure using lactose broth (Difco) was used for estimating the most probable number (MPN) of coliform organisms. Tubes were incubated at 37°C for 48 hours and the MPN was obtained according to American Public Health Association (1980).

The confirmed coliform test was done by culturing the positive tubes into brilliant green bile broth (BGB) and incubating at 37°C for 48 hours. Differentiation of faecal coliform was done by plating positive tubes from the (BGB) cultures on eosin methylene blue agar. Colonies from these plates were then differentiated by the indole, methyl red, voges-proskauer, citrat (IMViC) tests.

The MPN of faecal coliforms was done by transferring three loopfuls from each positive confirmed coliform test tube to brilliant green bile broth tubes and incubating at 44.5 ± 0.2°C for 24 hours. Tubes showing any amount of gas production were considered positive, and
PBN was obtained from tables in standard methods of water and waste water (American Public Health Association, 1980).

Rapid test for PVC (granules and hoses) by Meli (1994).

1. Bellstein test

This is a test for the presence of halogens in a material.

A clean copper wire is heated on a Bunsen flame before touching the material to be tested. The wire is then heated again. If flame turns green, this indicates presence of halogens.

2. Ignition test

PVC samples were conglabated to a Bunsen flame to check their ignition ability and characteristics.

Solubility tests for PVC (granules and hoses)

Solubility in the following solvents:

1.4, dioctan, cyclohexanone, tetrahydrofuran,
methanol and heptane were tested.

Preparation of standard curves of PVC

Standard curves using standard PVC was prepared.

Standard PVC concentration was 0.5 g/l.
VCN concentrations were prepared: 5, 10, 15, 20 ppm, and 5, 10, 20, 30, 40 ppb were plotted and concentrations of VCN in hoses, granules and water were worked out from these standard curves. Samples injected were 0.1 μl for high concentration (ppm) and 5 μl for low concentration (ppb).

**Determination of VCN in PVC (hoses and granules)**

GC with stainless steel column (length 4 meter) packed with PEGA was used. The temperature of oven 110°C, injector and detector temperature 150°C. Gas syringe (5 ml), and microsyringe (1, 10, 100 μl) were employed.

**Determination of VCN in PVC (granules and hoses)**

One hundred grams of PVC granules or PVC hoses cut into portions were dissolved in 8 ml DMAC. One hundred μl samples were directly injected in the GC at 110°C, according to method Gahi ○ and Kist (1978); Germany Federal Republic of Bonn-Basedow, German (1976).

**Determination of VCN in drinking water**

Water samples were put in an oven (45°C) for 2 hours before 100 μl samples of water vapour was taken using Hamilton microsyringe (Italy, 1976; Anon, 1977).
CHAPTER 4

RESULTS AND DISCUSSION
CHAPTER 4
RESULTS AND DISCUSSION

**Rapid Tests for Identification of PVC in Different Samples**

Some rapid tests are used to test presence of PVC in samples. These are a group of tests known as Beilstein test and also solubility tests.

**Table 1** shows the parameters tested by Beilstein test for PVC.

As expected, granules and hoses showed PVC characteristics, while a plastic bottle did not match with the others in same parameters indicating that it is not made of PVC (Table 1).

Solubility tests showed that all granules and hose samples were soluble in DMF and cyclohexanone and insoluble in 1,4-dioxan, methanol and hexane. This has been reported to be the same pattern of solubilities of PVC (Anet, 1981). However, the plastic bottle was insoluble in all the organic solvents tested (Table 2).
Table 1. Beilstein test.

<table>
<thead>
<tr>
<th>Sample of flame</th>
<th>Colour</th>
<th>Rate of combustion</th>
<th>Smoke</th>
<th>Aspect of smoke</th>
<th>Softening temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue (A, B)</td>
<td>Green</td>
<td>Very slow: Aride by the Cl escape</td>
<td>Black, very abundant</td>
<td>Brown</td>
<td>60 ± 90°C</td>
</tr>
<tr>
<td>Red (A, B)</td>
<td>&quot;</td>
<td>Very slow: Aride</td>
<td>Black, very abundant</td>
<td>&quot;</td>
<td>60 ± 90°C</td>
</tr>
<tr>
<td>Green (A, B)</td>
<td>&quot;</td>
<td>Very slow: Aride</td>
<td>Black, very abundant</td>
<td>&quot;</td>
<td>60 ± 90°C</td>
</tr>
<tr>
<td>Yellow (A, B)</td>
<td>&quot;</td>
<td>Very slow: Aride</td>
<td>Black, very abundant</td>
<td>&quot;</td>
<td>60 ± 90°C</td>
</tr>
<tr>
<td>Brown (A, B)</td>
<td>&quot;</td>
<td>Very slow: Aride</td>
<td>Black, very abundant</td>
<td>&quot;</td>
<td>60 ± 90°C</td>
</tr>
<tr>
<td>White (A)</td>
<td>&quot;</td>
<td>Very slow: Aride</td>
<td>Black, very abundant</td>
<td>&quot;</td>
<td>60 ± 90°C</td>
</tr>
<tr>
<td>Bottles of plastic</td>
<td>&quot;</td>
<td>Very slow: Not detected acide</td>
<td>Less than above</td>
<td>&quot;</td>
<td>60 ± 90°C</td>
</tr>
</tbody>
</table>

Where A = PVC granules
n = PVC hose
<table>
<thead>
<tr>
<th>Sample</th>
<th>Tetrahydrofuran</th>
<th>Cyclohexanone</th>
<th>1,4 Dioxan</th>
<th>Methanol</th>
<th>Hexane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue (A,B)</td>
<td>Soluble</td>
<td>Soluble</td>
<td>Insoluble</td>
<td>Insoluble</td>
<td>Insoluble</td>
</tr>
<tr>
<td>Green (A,B)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>Yellow (A,B)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>Red (A,B)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>Brown (A,B)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>White (A)</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>Bottles of plastic</td>
<td>Insoluble</td>
<td>Insoluble</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Where
A = PVC granules
B = PVC hose
Measurement of VOC Content by GLC Method

Measurement of VOC levels was accomplished by using GLC method, calibrations curve for VOC were prepared using VOC free-water, the concentration ranges from 5 ppb to 20 ppm and lower limit of detection was about 1 ppb.

The results obtained showed linear relationship between the concentration ranges used.

The regression equation obtained:

Peak height \( (Y) = \text{slope} \times \text{conc. (x)} + \text{intercept (C)} \)

For VOC in ppb:
\[
Y = 0.123x + 1.1 \quad (R = 0.967)
\]
and in ppm
\[
Y = 0.02x + 0.233 \quad (R = 0.9998)
\]

Where:
- \( x \) = Concentration
- \( R \) = Coefficient of correlation
- \( Y \) = Peak height

There was no significant difference between the two curves, but the curve of ppm is better than the other because the coefficient of correlation (R) was approaching one (0.999) (see above equation), i.e. all spots within the line and intercept (C) nearest to zero.

Concn. = \( \frac{1}{\text{slope}} \times \text{peak height} \)
Figure 5. Concentration of VCM at 5 ppm (VCM dissolved in DMAC)
Figure 6. Concentration of VCM in standard solution (VCM, v/v%) dissolved in DMAC.)
Figure 7. Standard VCM was dissolved in DMAc to concentrations of 5, 10, 15 and 20 ppm. Injected sample Vol. was 0.1 µl.
Figure 8. Concentration of VCM in standard solution.
(VCM was dissolved in DMAC).
Figure 9. Concentration of YCM in standard solution.
(YCM was dissolved in DNAC).
Figure 10. Concentration of VCM in standard solution.
(VCM was dissolved in DMAC).
Figure 11. Concentration of VCM in standard solution (VCM was dissolved in DMAC).
The standard curves were plotted, one giving concentrations of VCM in ppm and the other giving concentration in ppb. This was done to give a wide range of VCM concentration to meet different possibilities of low or high VCM concentration in test samples.

This method was followed in many studies such as that reported by Kinigas et al. (1967).

**Determination of VCM in PVC Granules and Hoses**

PVC granules and hoses were tested for the presence of VCM by Gas Liquid Chromatography (GLC).

All samples tested showed no detectable amounts of VCM. No peak apart from the solvent (n-heptane) appeared. This indicates that the monomer is missing in all PVC samples. This will allow the use of the hoses and other materials made from PVC.

Many workers have shown that migration of VCM from PVC hoses does not occur except at very low concentrations, if ever. This work was repeated here because of the hazard expected particularly that PVC hoses are made locally and the risk of not meeting international specification is there. But we can now say that PVC hoses made locally in the Sudan are safe for that matter.

Apostolopoulos and Gilbert (1968) claimed that the migration of VCM from PVC packing material containing very low concentration of residual VCM appears essentially not to occur particularly at low temperature.
Figure 13. Concept of PVC (granules and hosen). (PVC dissolved in DMAC)
Figure 14. Conc. of VCM in PVC (granules and hoses).
(PVC dissolved in DMAc).
Figure 13. Concentration of VCM in PVC (granules and hoses).
(PVC dissolved in DMAC).
Kotominas et al. (1985) indicated that at very low concentration of VCM in the PVC packaging material, no migration of VCM to the contents occurs.

The maximum permissible residual concentration of VCM are less than 10 ppm in PVC resin and less than 1 ppm in the PVC packaging (Stankievich et al., 1984).

Iffenecker (1980) observed migration levels are very low and far below legal tolerances, e.g. 0.1 ppm VCM in the packaging material (tolerance 1 ppm) and less than 5 ppb in the product (tolerance 10 ppb).

Gilbert (1976) also concluded that VCM in packaging material corresponds to an "effective zero" migration to the contacting phase.

Determination of VCM in Drinking Water

Water samples used for analysis were collected from two sources: well and river (treated).

Before analysis, water samples were kept under condition for different periods.

Water samples kept in plugged PVC hoses (10 meters) were stored under the sun in the shade or fridge for a period up to 7 months.

As Figures (16, 17, 18, and 17) indicate, all water samples collected from different conditions, were free of residual VCM. In the figures, the minor peaks that appear could be read water vapour as indicated by Fujii (1977) who showed that small peaks at retention
time identical to those reported in this work were of water vapour. Fujii (1977) confirmed this result using gas liquid chromatography - mass spectrometry (GLC-MS).

Fujii (1977) used a method for VCM determination and described the method to be precise for the analysis of VCM in the water samples. He analysed VCM in drinking tap water in five locations near Tokyo. VCM was not found to be present in all tested tap water samples even at ultra trace levels. A few river water samples were also tested, one of them - the Itachi river water in Toyama prefecture - was found to contain VCM at the level less than 0.1 ppb.

The official Italian GLC method for the determination of the migration of VCM out of PVC containers was criticised with special reference to the procedure for preparation of standard curves and the injection of liquid samples into the GLC (Rienzi, 1973).

However, Rienzi (1973), using the same method, described in this work, showed that the uptake of VCM from PVC by water is negligible.
Figure 16. VOC content in water samples stored in PVC boxes for 1 day to 7 months under room temperature.
Figure 17. VOC content in water samples stored in PVC hoses for up to 7 months under sun.
Figure 16. YCN content in water sample stored in PVC hoses for 1 day up to 7 months under shade.
Figure 12. PH content in water samples stored in PVC hoses for one day up to 7 months under cold temperatures.
Where:

T.W. = Tap water
D.W. = Distilled water
DR = Water of river stored for
    = days (1-6)
    = weeks (1-3)
    = months (1-7)
WK = " well "
= days (1-6)
= weeks (1-3)
= months (1-7)
WW = " will "
MW = " month "

These were applied in all figures 16, 17, 18 & 19.
Tabata et al. (1985) observed the VCM contents in water were dependent on the residual VCM in PVC pipes; these contents are usually at ultra low concentration (Trace - 190 ppb) in the absence of Cl and were trace to 70 ppb in the presence of Cl.

In this study, if any VCM was to be detected, it was expected to have higher levels of it in well water samples than in river water samples which are usually chlorinated.

VCM was not detected in drinking water samples from ordinary use (Hamamura et al., 1976). However, among 106 samples of drinking water from sources which were not used frequently, e.g. a tap in public garden, VCM was detected in 28 samples, their average was 1.8 ± 9.8 ppb (Hamamura et al., 1976).

The maximum permissible level of VCM intake by humans is 0.015 ppm. VCM content in water samples stored for 40 days in bottles containing 30 ppm VCM were 0.2 ppb (Zaremba and Gumenyi, 1982).

Seventy-two samples of commercially available PVC pipes in Tokyo metropolitan area were analysed for VCM.
VCM level in the range from 0.0 to 540 ppb, and concentration greater than 100 ppb was present in about 14% of all examined samples. Extraction test of VCM from the pipes was carried out by filling the pipes with tap water and standing for 72 hours at 20°C. VCM extracted by water was related to residual VCM concentration and from 0.1 to 78 ppb were found in water (Nakamura and Mihara, 1977).

A concentration of 5 ppb was the maximum permissible concentration of VCM in reservoir water (Kurlyandeski et al., 1981).

Chemical Composition of Water

pH of water

The levels of pH in all samples examined were found to be within the permissible range of recommendations at WHO (1984b) (pH 6.5-8.5).

Calcium

Calcium ions contents of water samples were tested and were below the permissible level which ranges between 75-100 mg/l (WHO, 1984b).

Sodium

Na ions content of water samples varied from one source to another. Higher levels were recorded in samples
of Wadi Shair Elmuderia, Elamara Kasir, Fetais Elmahata, Ezbiberate and Tabat Market. But even these higher levels were within the recommended levels of WHO (1984b).

**Potassium**

Maximum permissible levels of K ions are reported to range between 10-12 mg/l in drinking water (Anon, 1973). All samples tested were within the permissible range.

**Magnesium**

Mg is present in all different samples of water from the different sources, but does not exceed the permissible levels according to WHO (1984b). The maximum permissible level is 150 mg/l.

**Total solids (T.S)**

Total solids are also in concentrations lower than the maximum allowed by WHO (1984b).

All samples tested showed T.S level lower than 1000 ppm. Some variations were noticed between samples coming from different sources. The highest being Fetais Elmahata (894 ppm) and Wadi Shair Elmuderia (775 ppm).
<table>
<thead>
<tr>
<th>Water source</th>
<th>T.S.</th>
<th>Bact.</th>
<th>S.S.</th>
<th>Total coli</th>
<th>coliform</th>
<th>E.Coli</th>
<th>Total nitrates</th>
<th>pH</th>
<th>Hardness</th>
<th>Alkalinity</th>
<th>Total CO2</th>
<th>S.G.</th>
<th>Cu</th>
<th>Co</th>
<th>Fe</th>
<th>Zn</th>
<th>Mg</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Zaidar</td>
<td>2 x 10^5</td>
<td>≤5</td>
<td>-</td>
<td>568.45</td>
<td>246.2</td>
<td>7.70</td>
<td>213.5</td>
<td>21.0</td>
<td>2.14</td>
<td>9.12</td>
<td>32.3</td>
<td>86.70</td>
<td>-</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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*Note: T.E.C. stands for Total Electrolyte Content.*

"...well sites in Giza area (Johr Council)"
### Table 4. Chemical analysis of drinking water (river and wells) in the National capital (Khartoum).

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Table 1 (cont.)
Table 5. Standards for drinking water quality in Sudan and other countries.

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<td>Min. - Max. 6.5 - 8.5</td>
<td>Min. - Max. 6.5 - 8.5</td>
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<tr>
<td>T.S</td>
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<td>Conductivity 45/cm</td>
<td>100 - 500</td>
<td>100 - 500</td>
<td>100 - 500</td>
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<td>Hardness ppm</td>
<td>75 - 200</td>
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<td>Calcium mg/l</td>
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<td>Magnesium mg/l</td>
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<tr>
<td>Sodium mg/l</td>
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<tr>
<td>Potassium mg/l</td>
<td>-</td>
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<td>Toxic substances:</td>
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<tr>
<td>Cadmium mg/l</td>
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<td>Copper mg/l</td>
<td>0.05 - 1.5</td>
<td>0.05 - 1.5</td>
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<tr>
<td>Iron mg/l</td>
<td>-</td>
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<tr>
<td>Manganese mg/l</td>
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<td>0.05 - 0.1</td>
<td>0.05 - 0.1</td>
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<tr>
<td>Lead mg/l</td>
<td>0.1 - 0.05</td>
<td>0.1 - 0.05</td>
<td>0.1 - 0.05</td>
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<tr>
<td>Zinc mg/l</td>
<td>1.5 - 5</td>
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<td>Microbiology:</td>
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<tr>
<td>Total coliforms/100 ml</td>
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<td>0</td>
<td>3</td>
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<tr>
<td>Faecal coliforms/100 ml</td>
<td>0</td>
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Note: The table provides standards for drinking water quality in various countries, including Sudan, with specific parameters such as pH, T.S. (Turbidity), conductivity, hardness, calcium, magnesium, sodium, potassium, toxic substances (cadmium, copper, iron, manganese, lead, zinc), and microbiology (total coliforms, faecal coliforms). The standards are compared across different sources: WHO (1972), WHO (1984), and EFS (1976) with draft standards from April 1973 and a report from 7-9/1984.
Hardness

The hardness is present as CaCO₃ in water. The contents of hardness in all samples of water coming from two regions (Khartoum and Gezira areas) were shown under the limiting levels recommended by WHO (1972), and WHO (1984b) were 500 ppm; all the samples of water in Gezira area can be classified under the very hard water (180 and above) and also 7 samples in Khartoum region, i.e., the remaining samples can be classified under the class of soft and medium hard water.

Toxic Substances "Heavy Metals"

Mn, Cd, Fe, Cu, Co, Pb, and Zn were not detected in all sources of water (Tables 3 and 4). This indicates that there is no contamination with these toxic metals.

Statistical Analysis

Statistical analysis was done to show whether river water and well water in Khartoum area showed significant differences in their chemical constituents (Little and Hills, 1977).

Chemical constituents in different sources of water were within the permissible levels and all water samples tested were classified as safe for that matter. Nevertheless,
### Table 6. Statistical analysis.

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<th>Parameter</th>
<th>t tabulated</th>
<th>t calculated</th>
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<td>Conductivity</td>
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<td>NO3</td>
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<td>Mg</td>
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</table>
samples showed variations in some aspects. Statistical analysis showed that well water did not vary significantly from river water in their pH, Na content, Na/K, conductivity, total alkalinity and T.S. While significant differences were shown between river and well waters in their Ca, K, HCO₃, CO₃ and Mg contents.

**Microbiological Analysis**

Table 1 shows the microbiological analysis of water in Gezira area (Tabat Council).

**Coliform Organisms**

In all samples tested, total coliform organisms are found to be less than 4/100 ml of water. This number indicates low concentration of these water samples. WHO (1994) recommended a maximum of 3 number/ml of coliform.

**Dominant spp.**

Among the organisms which were found in these samples, the dominant spp were *Pseudomonas stutzeri* and *Klebsiella oxytoca* and *Bacillus* spp.
The total coliform bacteria in tap water and mineral water was found to be less than 3 cells/100 ml according to Abdal Magid et al. (1984). Colony count values of tap water are variable, but mostly low (Hammad and Dirar, 1982).

The same workers found that the colony count was in the order of $10^3$ cells/ml in sebeseal water. In general, the counts were higher for school and street sebeseals than for mosques and houses. However, coliforms were found to be less than 3 cells per 100 ml. Hammad and Dirar (1982) also showed eight most dominant genera of bacteria in sebeseal water (Pseudomonas, Listeria, Lactobacillus, Aerococcus, staphylococcus, Micrococcus, Streptococcus and Arthrobacter).

Abdal Magid (1984) observed that Na⁺ and Cl⁻ ion concentrations are much higher in well water than in the Nile water (untreated).
CONCLUSIONS AND RECOMMENDATIONS

The objectives of this work were of two dimensions:

(a) Chemical constituents of drinking water in Taqah area.

(b) To investigate whether PVC monomer is released to water when PVC domestic hoses are used.

The study revealed that water from the two sources in Taqah area was both potable and safe. Moreover, it showed that there was no significant difference (P<0.5) in quality parameters between the two sources of water (well and river).

The investigation on PVC release by PVC hoses, showed that, under the conditions specified in the study, PVC hoses were safe to use and no PVC was released to the water.

The survey revealed that food containers manufactured in the Sudan are made from polyethylene and not PVC. Nevertheless, foods contained in PVC containers could be imported. In this case, quality control measures at different ports should take care of this in order to guarantee that these PVC containers and the food they contain are safe.


American Public Health Association (1980), Standard method for the examination of water and wast-water. 15th ed. Washington, DC, APHA.


Anon (1979b). Sodium chlorides and conductivity in drinking water, Copenhagen, Regional Office for Europe, Europe Report and studies No. 2.


