Chapter 2

Literature Review

As the theme of my thesis is on quality of tap water, I would like to show briefly the importance of these parameters which controls the aesthetic value of our water and also the presence of some heavy metals and microorganisms which are of health significance. Before that, I would like to begin this chapter by showing how the water gets processed from the main source to our tap. This literature review section is included in my thesis as it serves as background data for my discussion in later chapters.

2.1 How is the water treated?

According to the information from Jabatan Bekalan Air, water from its main source for example rivers or reservoirs has to undergo a few stages of treatment before it is ready to be supplied to our homes. Water from the main source passes through bar racks, then the grit chamber before being pumped into the water treatment plant. Bar racks are for preventing large objects from reaching the grit chamber. At the grit chamber, the sand and the pebbles settle out from the raw water before entering the treatment plant.

The treatment plant consist of aerator, mixing plume, flocculation tank, sedimentation tank and filter tank. The raw water is aerated to enable separation of some of the mixture present in the water. Alum and iron salts or other chemicals are added where required at the mixing flume. At the flocculation tank, small particles are combined into larger particles which settle out of the water as sediment. Settling or sedimentation is simply a gravity

process that removes flocculated particles from the water which takes place at the sedimentation tank. After passing through the sedimentation tank, the water is filtered to remove remaining particles which include clays and silts, natural organic matter, precipitants of other treatment processes, iron and manganese, and microorganisms. Filtration clarifies water and enhances the effectiveness of disinfection.

The filtered water then enters the clear water well where chlorine is added to kill dangerous microbes. The clean water which fulfils the guidelines set by the Malaysian Health Ministry is then pumped to the balancing tank and the service reservoir for storage before being supplied to consumers. Fig 2 is a picture diagram which shows the summary of what happens to the water from the main source before entering the distribution system to the consumers.

2.2 Physical Parameters which determines the aesthetic quality of our tap water

2.2.1 Colour

Colour in water is an important constituent in terms of aesthetic considerations. Colour in drinking water is mainly due to organic matter, usually humic material colloidal forms of iron and manganese. The organic matter is usually responsible in giving drinking water an earthly smell and taste. The colour value of water is extremely pH-dependent and invariably increases as the pH of the water increases. The presence of inorganic iron and manganese in water either as natural impurities or as corrosion products may impart red and black hue respectively.

Colour producing organic substances are not themselves thought to be harmful to health. However they can react with chlorine to produce undesirable levels of chlorination by-products including trihalomethanes. Besides that, the humic substances in water readily form complexes with most metals which can greatly increase their solubility (Shapiro, 1964).

Water should be virtually free from substances which produce objectional colour. Generally colours below 15 TCU are usually acceptable to consumers however the level of acceptability varies depending on local circumstances. No health based guideline value is proposed for colour in drinking water. Based on the results of table most tap water collected in these areas are colourless, about 5 TCU with two exception of 15 TCU.

2.2.2 Turbidity

Turbidity is a measure of water's ability to absorb or scatter light. Turbidity is caused by the presence of particulate matter in water such as clay, silt, colloidal particles, plankton and other microscopic organisms (Katz, 1986). Turbidity can be effectively removed by simple filtration or coagulation, sedimentation and filtration.

Turbidity can have a significant effect on the microbiological quality of drinking water. High level of turbidity has shown to protect pathogenic microorganisms from the effects of disinfectants, stimulate the growth of bacteria in distribution systems and increase the chlorine demand (LeChevalier, 1981).

The appearance of water with the turbidity of less than 5 NTU is usually acceptable to consumers, although this may vary from one to the other. Although there is no proposed health based guideline value for turbidity, it is recommended to keep the turbidity level as low as possible because of its microbiological effects. The recommended criterion value of turbidity in drinking water is 1 NTU for safe drinking water using chlorine as disinfectants.

2.3 Inorganic Constituents which determines the aesthetic quality of our tap water

2.3.1 Copper

Copper metal has many commercial uses. Copper is an important heat and electrical conductor. Some of the major uses of copper metal include production of copper tubing, copper wire, copper compounds, brass and bronze, roof coverings and in the arts (Sloof, 1989).

Copper is an essential element in human metabolism with a recommended daily allowance of 2.0 to 3.0 mg/day. It is generally considered to be non-toxic for man at the levels encountered in drinking water. The only health effects concern is in the case of people with Wilson's disease, a congenital syndrome which keeps the body from properly metabolising copper (US EPA 1987). Besides that, neonates during the first few months of life are as sensitive compared to that of a person suffering Wilson's disease. This is probably due to the fact that they lack a fully developed homeostatic mechanism unlike adults to regulate copper in their systems and that there is a normally high level of copper in their livers (Eife et al, 1991). Therefore in

view of some remaining uncertainty regarding copper toxicity in humans, a health-based guideline value for drinking water of 2 mg/litre is provisional.

Although the presence of copper in a water supply is generally not considered as a health hazard, its presence may interfere with the intended domestic uses of the water. Copper in public water supplies increases the corrosion of galvanised iron and steel fittings. At levels above 5 mg/litre, it also imparts a colour and an undesirable bitter taste to drinking water (Page, 1973). Staining of laundry and plumbing fixtures occurs at copper concentrations above 1 mg/litre (Cohen et al, 1960).

Copper is extensively used in domestic plumbing systems, and levels in tap-water can therefore be considerably higher than the level present in water entering the distribution system. Based on the provisional health-based guideline of 2 mg/litre, copper in tap water should not give rise to taste problem however staining of laundry may occur.

2.3.2 Hardness

The principal natural sources of hardness in water are dissolved polyvalent metallic ions from sedimentary rocks, seepage and run-off from soils. Calcium and magnesium are two principal ions which contribute to the total hardness of water. The other minor contributors are aluminium, barium, iron, manganese, strontium and zinc. Hardness is measured in terms of mg $CaCO_3$ equivalent per litre.

Water with the hardness above approximately 200 mg/l may cause scale deposition in the distribution system, as well as increased soap consumption. In contrast, soft water, with a hardness less than about 100 mg/litre, has a greater tendency to cause corrosion of pipes, resulting in the presence of certain heavy metals, such as cadmium, copper, lead and zinc in drinking water. The degree to which such corrosion and solubilization of metals occurs also depends on the pH, alkalinity and dissolved oxygen concentration.

There is no conclusive evidence that water hardness causes adverse health effects in humans. Several epidemiological studies have shown a statistically significant inverse relationship between the hardness of drinking water and cardiovascular disease. However, the available data are inadequate to permit the conclusion that the association is causal.

No health-based guideline value for water hardness is proposed. The recommended standard for water hardness is 100 mg/l as $CaCO_3$ based on a comprising balance of the corrosion and incrustation properties.

2.3.3 Iron

Iron is the second most abundant metal in the earth's crust which accounts for about 5%. Iron is most commonly found in the form of oxides. Other forms of iron are in hydroxides, carbonates, and sulfide (Elinder, 1986).

Iron is used as constructional material for drinking water pipes. Iron oxides are used as pigments in paints and plastics. Other iron compounds are used as

food colours and for the treatment of iron deficiency in human. Various salts are used as coagulants in water treatment.

The presence of iron in our drinking water may contribute a certain taste which might not be acceptable. However the taste is usually not noticeable at iron concentration below 0.3 mg/litre.

Iron (II) salts in our drinking water supplies are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as a rust-coloured silt. Iron at levels above 0.05 – 0.1 mg/litre may cause turbidity and colour to develop in the piped systems. At concentrations above 0.3 mg/litre, staining of laundry and plumbing may occur. Besides staining, iron also promotes undesirable bacterial growth in water works and distribution systems, resulting in the deposition of a slimy coating on the piping (Dep. Nat. Health & Welfare, Canada, 1990).

Iron is an essential element in the human nutrition. The absorption of iron depends on the individual's iron status and is regulated so that excessive amounts of iron are not stored in the body. The largest fraction is present in the haemoglobin, myoglobin and haem-containing enzymes. Adults have often taken iron supplements for extended periods without deleterious effects (Bothwell TH et al, 1979) and an intake of 0.1 – 1 mg/kg of body weight per day is unlikely to cause adverse effects in healthy persons (Finch, 1972).

There is no proposed Health-based guideline value for iron. But as a precaution against storage of excessive iron in the body, JECFA established a provisional maximum tolerable daily intake (PMTDI) in 1983 of 0.8 mg/kg of

body weight. An allocation of 10% of this PMTDI to drinking water gives a value of about 2 mg/litre, which does not present a hazard to health (Joint FAO, WHO , 1983). However, the precaution value of 2 mg/litre, will usually affect the taste and appearance of drinking water. Therefore, it is recommended that 0.3 mg/l be adopted as the standard for domestic water supply.

2.3.4 Manganese

Manganese is one the more abundant metals in the earth's crust. Manganese is used in the manufacture of iron, steel and other alloys. Manganese dioxide and other manganese compounds are used in other products such as batteries, glass and fireworks. Potassium permanganate is used as an oxidant for cleaning, bleaching and disinfection purposes (US EPA 1984).

Manganese affects the organoleptic properties of drinking water as well as human health, however at different concentrations. At concentration exceeding 0.1 mg/litre, the manganese ion imparts an undesirable taste to beverages and stains plumbing fixtures and laundry (Griffin, 1960). At a concentration even as low as 0.02 mg/litre, manganese will form coatings on piping that may later slough off as black precipitate (Bean, 1974). Generally, manganese at concentration of 0.1 mg/litre should be acceptable to consumers however there are cases where water discolouration due to deposition from water mains may not be acceptable.

Typically, the human body absorbs 3 – 8 % of manganese of the ingested dose, where it is closely linked to the presence of iron, calcium and

potassium. No specific manganese deficiency syndrome has been described in human though manganese is an essential element for us human.

Laboratory studies on animals tested with drinking water of different manganese concentration shown that neurotoxic and other effects were observed . Therefore based on the above and the weight of evidence from actual daily intake, a provisional health-based guideline value of 0.5 mg/litre should be adequate to protect public health.

If the concentration of manganese is below 0.1 mg/litre, then both guidelines for organoleptic properties and health guidelines can be met.

2.3.5 pH

The pH level is a measure of the hydrogen ion in water. The principal system regulating pH in natural waters is the carbon dioxide-bicarbonate-carbonate equilibrium system (Goldman et al, 1972). This system involves various equilibria, all of which are affected by temperature. In pure water, pH will decrease by about 0.45 when the temperature is raised by 25°C (Langelier, 1946).

Although pH usually has no direct impact on water consumers, it is one of the most important operational water-quality parameters. During water treatment process, the effectiveness of chlorine disinfection will depend on the pH level. The effect of pH on chlorine in water is as shown in the following equation:-

$$HOCl \Leftrightarrow H^{+} + OCl^{-}$$

The pH should be less than 7 for more effective disinfection with chlorine (Butterfield et al, 1943). This could be attributed to the reduction in hypochlorous acid concentration with increasing pH. However, in general the lower the pH, the higher the level of corrosion. Corrosion in the water supply system not only can lead to expensive replacement, can also introduce metal contamination such as copper, lead, zinc and cadmium in drinking water (Craun, 1975). Generally above pH 6 the corrosion of lead and cadmium is insignificant. Careful attention to pH control is necessary to ensure satisfactory water clarification, disinfections and to minimize corrosion of water mains and pipes. Failure in doing so will result in contamination and adverse effects on its taste, odour and appearance.

Although no health-based guideline value is proposed for pH, the recommended interim standards for pH is in the range 6.5 – 8.5 for drinking water supply.

2.3.6 Residual Chlorine

In Malaysia, chlorine is widely used to disinfect drinking water. It is important to know and control the concentration of free chlorine in the water, as it is one of the parameters that determine the taste and odour of water. Concentration higher than the taste and odour threshold of 5 mg/litre and 2 mg/litre may give rise to complaints from consumers.

Chlorine is usually present in disinfected drinking water at concentrations of 0.2 – 1 mg/litre (White, 1978). Specific adverse treatment-related effects have not been observed from exposure to chlorine in drinking water. However a

guideline of 5 mg/litre have been set based on NOAEL of 15mg/kg of body weight.

2.3.7 Sulfate

Sulfate is one of the least toxic anions. Sulfate is a substance that occurs naturally in drinking water. Besides that, sulfates discharged into water from mining, wood-pulp, metal and plating industries and leather processing may contribute to the sulfate content of surface waters.

Health concerns regarding sulfate in drinking water have been raised because of reports that diarrhea may be associated with the ingestion of water containing high levels of sulfate. This condition is enhanced when sulfate is consumed with magnesium. Of particular concern are groups that may be at greater risk from the laxative effects of sulfate when experience an abrupt change from drinking water with low sulfate concentrations to high concentrations. However, it was reported that with time humans can adapt to higher concentrations (US EPA, 1985).

The presence of sulfate in drinking water can also results in a noticeable taste. Taste thresholds vary according to the associated cation and are in the range of 200 – 500 mg/litre, the lowest threshold being the sodium sulfate at 250 mg/litre (National Academy of Sciences, 1977). In addition, metal corrosion may be increased by high sulfate levels.

There is currently no health-based guideline for sulfate. However based on aesthetic effects which is the taste and odour, the guideline value for sulfate in drinking water is 250 mg/litre.

2.3.8 Zinc

Zinc occurs in small amounts in almost all igneous rocks. Zinc is used in the production of corrosion-resistant alloys and brass, and for galvanizing steel and iron products. Zinc oxide, is used in rubber as a white pigment, for example, is the most widely used zinc compound (Elinder, 1986). Zinc carbamates are used as pesticides.

Water containing zinc at concentrations 3 - 5 mg/litre tends to impart an undesirable astringent taste, appear opalescent and develops a greasy film when boiled (Cohen et al, 1960). Tap water might have higher concentration of zinc than in the distribution system due to leaching from piping and fittings. The leaching appears to be more in water with low pH, high carbon dioxide content and low mineral salts content (Nriagu, 1980).

Zinc is an essential element in human nutrition. The daily requirement is 4 – 10 mg depending on age and sex. Long term ingestion of quantities considerably in excess of these amounts does not result in adverse effects. Therefore the guideline value of zinc in drinking water is 5 mg/litre based on taste or aesthetic considerations.

2.4 Chemicals which are of health significance in our drinking water

2.4.1 Barium

Barium in water comes primarily from natural sources, the igneous and sedimentary rocks. The solubility of barium compounds increases as the pH level decreases (US EPA, 1985).

Barium compounds are used in plastic, rubber, textiles, electronic industries. It is also used in the pharmaceutical and cosmetics industries as a lubricant additives as well as in the oil and gas industry as a wetting agent for drilling mud (Miner, 1969).

Barium is not considered to be an essential element for human nutrition (Schroeder, 1972). Acute exposure to barium in humans results in a variety of cardiac, gastrointestinal and neuromuscular effects. Barium exposure has been associated with hypertension and cardiotoxicity. However, based on clinical study on 11 healthy men exposed to barium in drinking water of 0 mg/litre for 2 weeks, 5 mg/litre for the next 4 weeks and 10 mg/litre for the last 4 weeks, there were lack of adverse effects observed in this study.

As there is no evidence that barium is carcinogenic (WHO, 1990), the guideline for barium in drinking water is derived using the TDI approached. Based on a 20 % allocation of the TDI to drinking water, therefore barium in drinking water is regulated at 0.3 mg/litre.

2.4.2 Cadmium

Cadmium is a metal with an oxidation state of +2. Cadmium is used as an anticorrosive, pigments in plastics, and in electroplating, nickel cadmium batteries and nuclear reactors (Ros eds. 1987).

Contamination of drinking water may occur as a result of the presence of cadmium as an impurity in the zinc of galvanised pipes or cadmium containing solders in fittings and taps in the distribution system. Levels of cadmium in tap water could be higher in areas supplied with soft water of low pH as this would tend to be more corrosive in plumbing system containing cadmium. Levels of cadmium in piped water can likely be a functions of how long the water has been in contact with the plumbing.

Cadmium causes both acute and chronic types of poisoning and effects depend partly on the route of entry. Acute ingestion causes nausea, vomiting, abdominal cramps, diarrhoea and shock. Chronic exposure to cadmium in humans result in kidney dysfunction, hypertension, anaemia and liver damage.

However since cadmium has not been shown to be carcinogenic through ingestion exposure, the compound is regulated based upon chronic toxicity data. A guideline value for cadmium of 0.0003 mg/litre is established based on an allocation of 10% of the provisional tolerable weekly intake to drinking water.

2.4.3 Chromium

Chromium and its salts are used in leather tanning industry, in photography, the manufacture of paints, pigments and catalyst, chrome alloy, chrome plating and corrosion control (Slooff et al, 1989). Chromium can exist in oxidation state of +2 and +6. In general, chromium (VI) salts are more soluble than those of chromium (III), making chromium (VI) relatively mobile.

Drinking water only constitute 1.9 – 7 % of the total intake of chromium where as the major contribution comes from food intake which is 93 – 98 %. Oral exposure studies found that the corresponding absorption for human could be as much as 10% of the total intake of chromium compounds. In humans, the highest concentrations are found in hilar lymph nodes and lungs

In some occupational studies, it was found that workers exposed to chromium (VI) compounds had increased incidences of genotoxic effects such as chromosomal aberrations and sister chromatid exchanges (Janus, 1990). In epidemiological studies, an association has been found between occupational exposure to chromium (VI) compounds and mortality due to lung cancer.

There is sufficient evidence of respiratory carcinogenicity in men occupationally exposed during chromate production. However, oral carcinogenicity of chromium has never been demonstrated. Therefore the guidelines for water quality was derived on the basis of toxicity data.

In principle, because the effects are determined largely by the oxidation state, different guideline values for chromium (III) and chromium (VI) should be derived. However, current analytical methods and the variable speciation of

chromium in water favour a guideline value of total chromium. Therefore, the current provisional guideline for total chromium is 0.05 mg/litre.

2.4.4 Copper

As discussed in section 2.3.1

2.4.5 Lead

Lead is the commonest of the heavy elements. Lead is used in the production of lead acid batteries, solder, alloys, pigments, rust inhibitors and plastic stabilizers (WHO 1989). From the drinking water perspectives, lead pipes may be used in older distribution systems and plumbing. The amount of lead dissolved from the plumbing systems depends on several factors, including the presence of chloride and dissolved oxygen, pH, temperature, water hardness, and standing time of the water, soft, acidic water being the most highly plumbosolvent (Schock, 1989).

Lead is a cumulative general poison. Infants, children up to 6 years of age, the foetus and pregnant women being the most susceptible to adverse health effects. Lead poisoning is of greatest for foetus, infants and children as they absorb lead more readily than adults. Moreover, infants on formula and children drinking juice concentrates consume much more water for their weight than adults. Also, their bodies are smaller so they get rid of less lead, so it tends to accumulate if there is an exposure.

Lead causes damage to the kidneys and liver, and to the nervous, reproductive, cardiovascular, immune and gastrointestinal systems. At higher levels, lead has many additional severe effects including kidney disease, blindness, seizures and death. Lead can slow a child's normal growth (both mental and physical) and cause behavioural problems, mental retardation and damage the nervous system permanently (WHO, 1989; US EPA, 1988).

The evidence for the carcinogenicity of lead in humans is inoclusive because of the limited number of studies, the small cohort sizes, and the failure to take adequate account of potential confounding variables. Therefore based on the assumption of 50% allocation of PWTI to drinking water for a 5 kg bottle-fed infant consuming 0.75 litres of drinking water per day, the guideline value for lead is 0.01 mg/litre. This guideline value will be protective for all age group as infants are considered the most sensitive subgroup.

2.4.6 Magnesium

Magnesium is mainly present in sedimentary rocks, the most common being limestone and also in seawater. However, it is also present in a wide variety of industrial products mainly in light constructional alloys and are common constituents of food (Cotton, 1987). Magnesium in water is always link to the water hardness as calcium and magnesium generally contribute to the bulk of total hardness.

Of all the cardiovascular risk factors, magnesium now takes first place as judged by the accumulation of epidemiological, pathophysiological, clinical and experimental data, both pharmacological and therapeutic. Among all the factors

studied in drinking water, the highest inverse correlation has been observed between magnesium and cardiovascular mortality and morbidity. The myocardial magnesium level is significantly lower in soft water areas than in hard water areas (Durlach, 1985; Marier, 1985).

The importance of the magnesium intake in drinking water is both quantitative and qualitative. Magnesium in water may represent the amount of magnesium required to bring an insufficient dietary magnesium level to a correct level. In fact, the adult magnesium intake is marginal in developed countries and in some cardiovascular disease populations particularly (Durlach, 1985; Lakshmanan et al, 1984). Magnesium in water is more readily assimilated by the intestinal tract than the same quantity in food, therefore resulting in higher bio-availability (Dawson, 1978).

"Absolute" and "relative" magnesium deficit induces increased secretion of several neurohormones which are pathogenic for the cardiovascular system, ie adrenaline, insulin and PTH, and it also induces a decrease in secretion of CT, a hormone with protective properties for the cardiovascular system. In addition, magnesium deficit induces other neurohormonal or metabolic disturbances which may have deleterious consequences, for example increased production of renin and aldosterone, calcinosis, dyslipidaemias and alterations in haemostasis. Therefore the importance of adequate intake of magnesium in water may in particular palliate "absolute" marginal magnesium deficit with a critical supply over the marginal intake, and qualitatively palliate a "relative" magnesium deficit by supplying magnesium of high bio-availability.

Magnesium deficiency increases while magnesium load decreases toxicity of cadmium and lead. Magnesium does not appear to be a panacea which antagonizes all noxious agents, but it seems to be an antagonist of the two main polluting metals which induce the nephro-cardiovasotoxicity of some corrosive drinking waters (Durlach et al, 1984).

It is advisable to have 30 mg/litre of magnesium in drinking water. If the water is not corrosive, it is not advisable to enrich it with magnesium in the course of the processing since its corrosivity index would also increase. A magnesium salt can only be added after the water has been collected. If the water is corrosive, it will be filtered in processing stations through an anticorrosive filter with optimum Mg/Ca ratio to ensure the highest Mg/Ca ratio in tap water with the best anticorrosive power.

2.4.7 Manganese

As discussed in section 2.3.4

2.4.8 Nickel

Nickel is used in a large number of alloys, including stainless steel, in batteries, chemicals, and catalysts, and in the electrolytic coating of items such as chromium-plating taps and fittings used for tap water.

Nickel concentration in drinking-water around the world are normally below 20 µg/litre. However nickel concentrations in drinking water may be increased if raw waters are polluted by natural or industrial nickel deposits or if leaching

from nickel-chromium plated taps and fitting occurs. Levels up to 1000 μg/litre have been reported in first-run water that had remained in the tap overnight (Grandjean et al, 1989).

In humans, absorption of soluble nickel from drinking water may be 40 times higher than that of nickel from food (Sunderman et al, 1988). However, the intake from food is averagely 5 times higher. In one of the incidences, during haemodialysis, 23 patients were exposed to nickel-containing water which recorded a plasma nickel concentration of approximately 3 mg/litre. Their symptoms were nausea, vomiting, abdominal discomfort, diarrhoea, giddiness, lassitude, headache, cough, shortness of breath which typically lasted for a few hours. All recovered rapidly without evident sequelae (WHO, 1991).

Based on the epidemiological data on respiratory exposure, it is concluded that inhaled nickel sulfate is carcinogenic to humans. Due to the fact that there is lack of data on long term studies, reproductive effects and carcinogenicity by the oral route, the health based guideline is set based on an allocation of 10% of the TDI to drinking water. The health-based guideline value is 0.02 mg/litre, which should provide protection for nickel-sensitive individuals.

2.4.8 Zinc

As discussed in section 2.3.8