

DETERMINATION OF METALS IN TAP WATER USING ATOMIC ABSORPTION SPECTROMETRY: A CASE STUDY IN BANDAR SUNWAY RESIDENTIAL AREA

SARASWATHY NALATAMBI

Sunway University College

No.5, Jalan Universiti, Bandar Sunway

46150 Petaling Jaya, Selangor Darul Ehsan

Tel: +60(3)74918622 Ext. 8429

Fax: +60(3)56358633

sarasw@sunway.edu.my

ABSTRACT

Metal contamination in water is a major component in the determination of water quality. Apparently, tap water qualities in many countries are affected by industrialization. The objective of this study was to detect metal concentration in tap water in the Bandar Sunway residential area. Tap water samples were collected from four different locations. The four sampling locations were Sunway University College, Sunway Villa Apartment, Sunway Condominium and PJS 7/11. Samples were analyzed using atomic absorption spectrometry to determine the concentration of dissolved metal. The metal analysis was done to detect zinc, cadmium, chromium, lead, magnesium, calcium and copper. The results obtained were compared with guidelines for drinking water quality such as the Environmental Protection Agency (EPA) and World Health Organization (WHO) guidelines. The study showed that the piping system which is over a decade old in the Sunway Villa Apartment affected levels of lead and copper in the water, but not zinc, cadmium, chromium, magnesium and calcium.

Key words: metal concentration, zinc, cadmium, chromium, lead, magnesium, calcium and copper

INTRODUCTION

Water covers almost 70% of the earth's surface. The quantity and the quality of water are equally important. Water is always referred to as a universal solvent because it can dissolve many types of substances, but human require water that contains less impurities. The major categories of impurities in water are micro-organism, pyrogens, dissolved inorganic salts, dissolved organic compounds, suspended particles and dissolved gasses. Common impurities in water include metal salts and harmful bacteria. However, in most cases natural waters are not directly drank by human. It has to go through some treatment before it reaches the consumer.

Drinking water comes from ground sources such as groundwater and aquifers. It can also be obtained from surface water such as rivers, streams and glaciers. Other sources including rain, hail and snow, biological sources such as plants and sea through desalination.

Drinking water is exposed to different contaminants, depending on its sources. Surface water contaminations occur, when water travels over the surface of the land or through the ground. As it travels, it dissolves naturally occurring substances and pick up the

minerals resulting from the presence of animal or human activities. While for the ground water, the contaminants come from leachate from landfills and septic systems, haphazard disposal from agricultural chemicals and household cleaning products. The contaminants in ground water take more time to be cleaned because it moves slowly and isn't exposed to the natural cleansing benefits of air, sunlight and micro-organism (Nriagu & Pacyna, 1988).

Generally, the quality of drinking water is determined based on the appearance, taste, color and odor of the water. The appearance, taste, color and odor do not really tell if the water is safe to drink. Safe drinking water should also be free from hazardous compounds (Berman, 1980).

The Environmental Protection Agency (EPA) and World Health Organization (WHO) set a maximum contaminant level in drinking water supplied to municipal or population (Review of the EPA Water Security Research and Technical Support Action Plan: Part I & Part II, 2003). When a standard or guideline is exceeded in the municipal or community water system, the states required to take proper action to improve water quality level including treating the water through filtration or aeration, blending water from several sources to reduce contaminants including inorganic chemicals such as salts, metals and minerals. These substances occur naturally in geological structures or sometimes caused by mining, industrial and agricultural activities. These chemicals can badly affect human health when they are consumed in large amount. The most common inorganic contaminants in natural fresh water are shown in Table 1 (WHO, 2006).

The natural concentration of metals in raw water which has not been treated or purified varies from state to state, country to country. It depends on many factors such as geological structures, the soil, the acidity of the water and the particulate matter concentration (Berman, 1980; Nriagu & Pacyna, 1988). Most metal species in natural fresh water occur in organic compounds, organic complexes or colloids. From the point of view of health, metal can be divided into two categories:

- i. Metals with undesirable effect such as Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Cobalt (Co), Barium (Ba), Silver (Ag).
- ii. Metals with a negative toxic effect such as Arsenic (As), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Nickel (Ni), Lead (Pb), Antimony (Sb), Selenium (Se).

Table below shows metal species in natural fresh water.

Table 1: Metal species in natural fresh water

Metal	Main species
Silver (I)	Ag^+ , AgCl
Zinc (II)	Zn^{2+} , ZnCO_3
Cadmium (II)	Cd^{2+} , CdCO_3
Cobalt (II)	Co^{2+} , CoCO_3
Nickel (II)	Ni^{2+} , NiCO_3
Lead (II)	PbCO_3

Copper (II)	CuCO_3 , $\text{Cu}(\text{OH})_2$
Mercury (II)	$\text{Hg}(\text{OH})_2$
Aluminium (III)	$\text{Al}(\text{OH})_{3(s)}$, $\text{Al}(\text{OH})_2^+$, $\text{Cu}(\text{OH})_4^-$
Iron (III)	$\text{Fe}(\text{OH})_{3(s)}$, $\text{Fe}(\text{OH})_2^+$, $\text{Fe}(\text{OH})_4^-$
Manganese (IV)	MnO_2
Arsenic (V)	HAsO_4^-
Chrome (VI)	CrO_4^{2-}
Selenium (VI)	SeO_4^{2-}

(Adapted from WHO, 2006)

Drinking water quality status in Malaysia

All water sources in Malaysia depend on rainfall. Over 99% of Malaysian water sources come from stream or river and the remaining 1% of raw water comes from groundwater. Such water can contain contaminants such as sediment, salts, organic material and pathogens such as Giardia. However, water supply management and development in Malaysia is not centralized. It is managed by the state government. The Department of Environment (DOE) is responsible to determine the water quality in relation to major pollution sources, while the Ministry of Health (MOH) is responsible to ensure the water quality in the treatment plant. The State Water Authorities or private companies will supply drinking water from the treatment plant to residential areas.

In year 2008, the latest recommended raw water quality criteria and frequency of monitoring were given by Engineering Services Division, Ministry of Health Malaysia. This raw water comes from surface like lakes, reservoirs and streams and groundwater. All the metals in raw water are monitored at least four times in a year. The acceptable values of metal content in untreated and treated water are shown in Table 2 and Table 3 (Engineering Services Division, Ministry of Health Malaysia, 2000).

Table 2: The acceptable values of metal content in raw water

Contaminant and unit of measurement	Acceptable value	Source of reference
Arsenic (ppm)	0.01	Malaysia
Cadmium (ppm)	0.003	Malaysia
Lead (ppm)	0.05	Malaysia
Chromium (ppm)	0.05	WHO
Zinc (ppm)	3.00	Malaysia
Copper (ppm)	1.0	Malaysia
Mercury (total) (ppm)	0.001	Malaysia
Magnesium (ppm)	150	Malaysia

(Adapted from Engineering Services Division, Ministry of Health Malaysia, 2000)

The raw water will go through some processes in water treatment plant such as coagulation or flocculation, sedimentation, filtration, stabilization, fluoridation, chlorination and finally before allowing water to be used in the residential area, water will be tested for a few contaminants again. This is to ensure that the drinking water distributed is safe to be consumed by public. Table below show the drinking water quality standards for a few metals after treatment.

Table 3: Drinking water quality after treatment

Contaminant and unit of measurement	Acceptable value	Source of reference
Arsenic (ppm)	0.01	WHO
Cadmium (ppm)	0.003	WHO
Lead (ppm)	0.01	WHO
Chromium (ppm)	0.05	WHO
Zinc (ppm)	3.00	WHO
Copper (ppm)	1.0	WHO
Mercury (total) (ppm)	0.001	WHO
Magnesium (ppm)	150	WHO

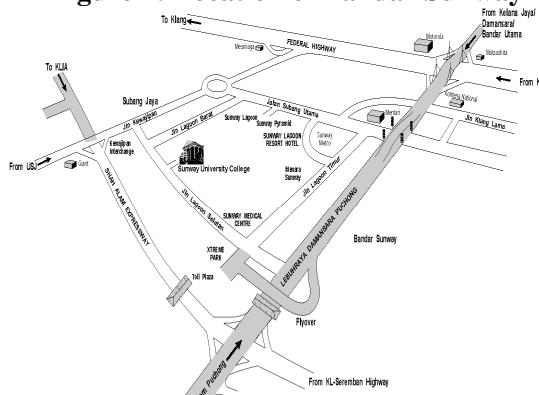
(Adapted from Engineering Services Division, Ministry of Health Malaysia, 2000)

MATERIALS AND METHOD

Location of sample spot

Bandar Sunway is a town in the Klang Valley metropolitan area in Selangor, Malaysia. It is located in the district of Petaling Jaya, Selangor. Previously Bandar Sunway was known as Sungai Way Tin and it was developed by Sunway Group, also known as Sunway Holding Incorporated Berhad. Figure 1 shows the location of Bandar Sunway.

Figure 1: Location of Bandar Sunway



Source: <http://www.dromoz.com/directory/place/?id=761&p=sunway>

Water samples were taken from four different spots

Sample 1: Sunway University College

Sample 2: Sunway Villa Apartment

Sample 3: Sunway Condominium

Sample 4: PJS 7/11 Bandar Sunway

Preparation of stock solution

Stock solutions were prepared by weighing out a specific amount of metal (salt) Table 4 and the metal was transferred into a 100 ml volumetric flask. The metals were dissolved completely by adding deionized water (Greenberg, Clesceri & Eaton, 1992).

Table 4: The amount of salt and acid used to prepare for each standard cation solution

Element	Chemical used	Purity	Mass (g)	Supplier
Ca	Calcium carbonate	98.50- 100.0%	2.493×10^{-2}	HmbG
Pb	Lead (II) nitrate	99.00%	1.598×10^{-2}	Bendosen
Zn	Zinc chloride	98.00%	4.398×10^{-2}	HmbG
Cu	Copper (II) sulfate 5-hydrate	98.00%	3.929×10^{-2}	Bendosen
Cr	Chromium (III) nitrate nonahydrate	>98.00%	2.829×10^{-2}	R&M
Cd	Cadmium nitrate	>98.00%	2.103×10^{-2}	HmbG
La	Lanthanum (III) chloride heptahydrate, 99.00%	>98.00%	1.337×10^{-1}	Merck
Sr	Strontium nitrate	98.00%	2.415	HmbG
Mg	Magnesium sulfate 7-hydrate	99.00- 100.0%	1.014×10^{-1}	HmbG
HNO ₃	Nitric acid 69.00%	68.50- 69.50%		BDH
HCl	Hydrochloric acid 37.00%	37.00- 38.00%		Merck

(Adapted from Greenberg, Clesceri & Eaton, 1992)

Four calibration standards were prepared for Cu, Cr, Cd, Zn, Pb, Ca and Mg (Greenberg, Clesceri & Eaton, 1992; Hauser, 2002). The purity of the reagents and standards used to calibrate the AAS instrument is crucial to the analytical accuracy and precision of the results. Many samples have to be processed with special reagents to eliminate any matrix effects. Other samples may require dilution to adjust their concentration to the proper analytical range. Calibration standards have to be diluted for creating standard curves. Reagent blanks are also needed to zero the instrument. Therefore, lab reagent water must be of the highest quality to prevent interferences.

Preparation of Sample

Pre-treatment process

The pre-treatment process was conducted before the analysis has been done. The sample was collected in a clean polyethylene bottles. Polyethylene bottles were used in these analyses because these glass bottles absorb metals and therefore will cause inaccuracy to analysis (Roger, 2002). The water was filtered through a $0.45\mu\text{m}$ membrane filter as soon as possible after collection. The first 50 - 100 mL of sample was used to rinse the apparatus. The required sample volume was then collected. Acidification with (1+1) nitric acid to pH 2 or less was used to stabilize the metal content. An approximately 3 mL of (1+1) nitric acid per liter of sample was sufficient for acidification. If the suspended solids content was required, the same initial procedure was used. The difference is that the filter containing the suspended solids was retained and stored in a suitable container. No preservation was needed. For a total analysis, the whole sample was acidified with (1+1) nitric acid to pH 2 or less, preferably at the time of collection. The sample was not filtered (Greenberg, Clesceri & Eaton, 1992; Hauser, 2002).

Treatment and analysis

Dissolved metal analysis

Firstly, the water sample was filtered through $0.45\mu\text{m}$ membrane filter as soon as possible after collection. The first 50-100 mL of sample was used to rinse the apparatus and discard the filtrate. Then, required sample volume was collected. Acidification with (1+1) nitric acid to pH 2 or less was used to stabilize the metal content (Greenberg, Clesceri & Eaton, 1992; Hauser, 2002).

Suspended metal analysis

Basically a similar method for soluble metal was used. The residues and membrane were transferred to a 250 mL beaker and 3 mL HNO_3 was added. The beaker was covered with a watch glass that provides a surface to evaporate a liquid to hold solids while being weighed, or as a cover for a beaker. The sample was heated until all the water has been evaporated to dryness. Then, the solution was cooled and 3 mL of HNO_3 was added. Then the solution was heated again until digestion was completed. This could be indicated by light color residue. Then, 2 mL of HCl (1+1) was added and heated gently again to dissolve the residue. Watch glass and beaker had been washed with H_2O and then filtered. The filter was washed and then discarded. The filtrate was diluted with H_2O to concentrate within the range of instrument (Greenberg, Clesceri & Eaton, 1992; Hauser, 2002).

Total metal analysis

Total metal analysis was obtained from the total of both dissolved and suspended metal ions (Greenberg, Clesceri & Eaton, 1992; Hauser, 2002). Triplicate of samples were run

independently in each case to ensure high accuracy in the quantitative results. Results of metal analysis were reported as $X \pm 2\sigma$ in ppm units.

Calibration of Atomic Absorption Spectrometry (AAS)

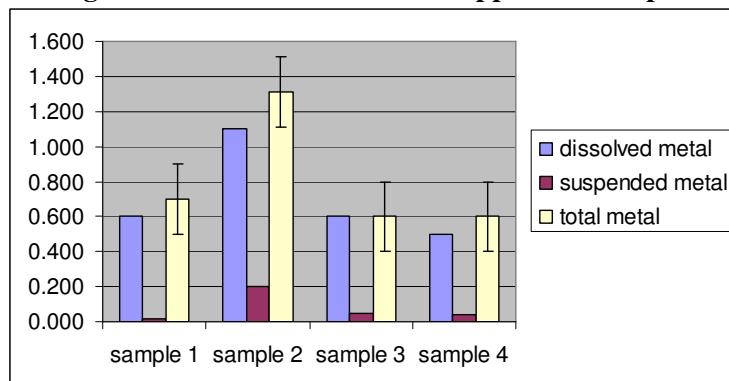
The characteristic concentration check value is the concentration of element (in mg/L) that will produce a signal of approximately 0.2 absorbance units under optimum conditions at the wavelength listed. By using the characteristic concentration check, the operator can determine whether instrumental parameters are optimized and whether the instrument is performing up to specifications. Calibration of AAS was carried out by using an external calibration curve. The external calibration curve was prepared from solution of known concentrations of the sample element, which was also known as stock solution. High purity metal salts dissolved in high purity acids were used to make the stock solution. Working standards were diluted from the stock standard.

RESULTS AND DISCUSSION

The analysis was carried out on tap water at several locations in Bandar Sunway to determine the concentration of seven metals ($\text{Cr}^{3+}/\text{Cr}^{6+}$, Cd^{2+} , Mg^{2+} , Ca^{2+} , Cu^{2+} , Zn^{2+} and Pb^{2+}). The concentration of each metal was detected and tabulated in Table 5.

Copper

Figure 3: The concentration of copper in 4 samples

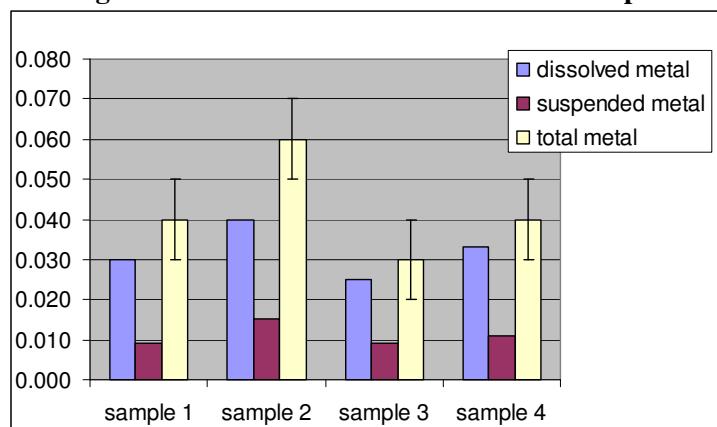


The concentrations of copper ion in tap water for various locations were given in Figure 3. Based Figure 3, all four samples contain more dissolved metal than suspended metals. The copper ion concentration was the highest in sample 2 and the lowest in sample 3 and sample 4. The copper ion concentration in sample 2 has exceeded EPA standard limit which is 1.3 mg/L. This could be due to the old piping system in Sunway Villa Apartment. Tap water becomes contaminated with copper when it flows from local treatment plant into apartment,

and much of the contamination actually results from in-home plumbing. Once water is treated, it must travel along pipes and water picks up copper along its journey, from pipes that are soldered by or lined with copper. The concentration of copper ion in tap water could be reduced by drawing water in the morning or after a work day. Flushing the system for longer time until the water gets as cold as possible will reduce the copper concentration in tap water (National Research Council Staff). Even though copper is an essential element in human diet but human eats and drinks copper approximately $1.00\mu\text{g}$ per day. It is also occur naturally in plants and animals. If the EPA action level of 1.3 mg/L for copper ion is exceeded, then the immediate health effects are vomiting, diarrhoea, stomach cramps and nausea. The effects are much higher in children under one year old than adults. However, long term exposure which is more than 14 days to copper in the drinking water can cause serious problems like kidney and liver damages in infants (Soylak, Divrikii, Saracoglu & Elci, 1998; Hutzinger, 1995).

Lead

Figure 5: The concentration of lead in 4 samples

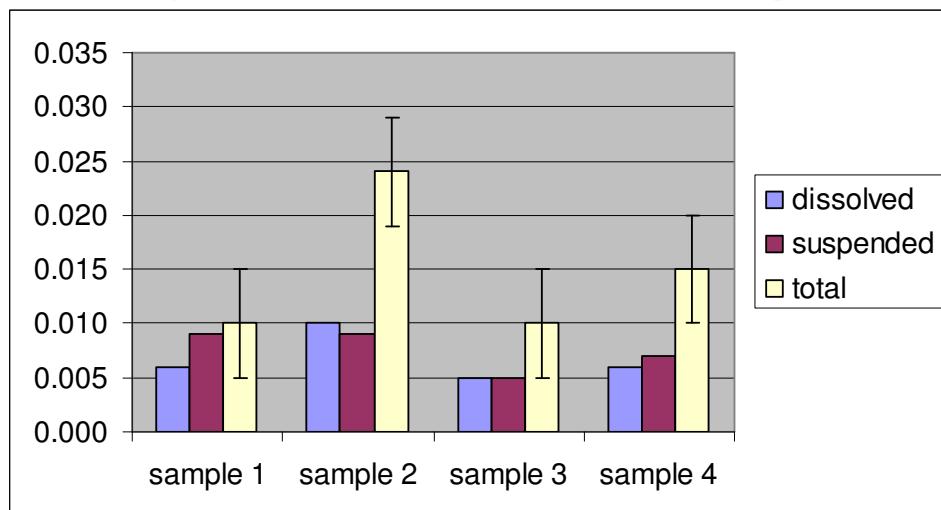


For lead, all four samples contained more dissolved metal than suspended metal. Lead contamination is the highest in sample 2 and the lowest in sample 3. The concentration of lead in sample 2 has exceeded the EPA standard level which is 0.05 mg/L . In this case, although concentration of lead after treatment was less than 0.05 mg/L , but it gets contaminated when it reached consumers in Bandar Sunway Villa Apartment. This could be due to the plumbing systems in the apartment itself. Usually lead in drinking water originated between the water main in the street and the household faucet. Most lead in drinking water comes from lead lined pipes, lead solder and brass plumbing fixtures inside the apartment. The EPA estimates that 98% of all homes have pipes, fixtures or solder joints in the household plumbing that can contribute some level of lead to the tap water (National Research Council Staff). Exposure to lead is very dangerous for young children compared to an adult. This is because young children's growing rate is much higher than an adult. Lead can accumulate in human body over some time and cause serious damage to brain, kidney,

nervous and red blood cells. For infants, large amount of lead can cause delays in physical and mental development (Hutzinger, 1995).

Chromium

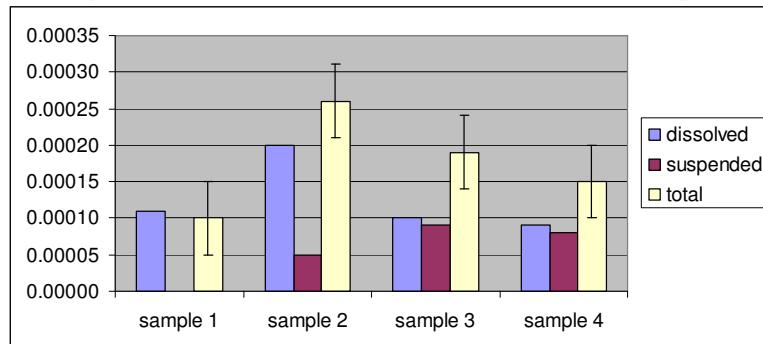
Figure 7: The concentration of chromium in 4 samples



Basically all samples consist of chromium ion either in dissolved or suspended form. The concentration of chromium was the highest on sample 2 and the lowest is in sample 1 and 3. Even though the chromium metal is detected in all tap water samples but the concentration is within the standard level which is 0.05 ppm. Usually Chromium concentrations in water are very low. The natural total chromium content in water is approximately 0.5-2 ppb. (World Health Organization, Geneva, 1996). This is because the chromium metal gets into drinking water through certain industrial facilities where sodium dichromate solutions (hexavalent) were used to prevent corrosion in piping. In Malaysia there is no heavy industry involving chromium. So in our country it occurs in combination with other elements as chromium salts, some of which are soluble in water (Soylak, Divrikii, Saracoglu, & Elci, 1998). Eventually, chromium VI will be reduced to chromium III by organic matter. Chromium III contamination exit 0.1 mg/L can affect internal hemorrhage, respiratory disorders and kidney damage, while chromium VI can cause dermatitis and ulceration (Ideris, 2008).

Cadmium

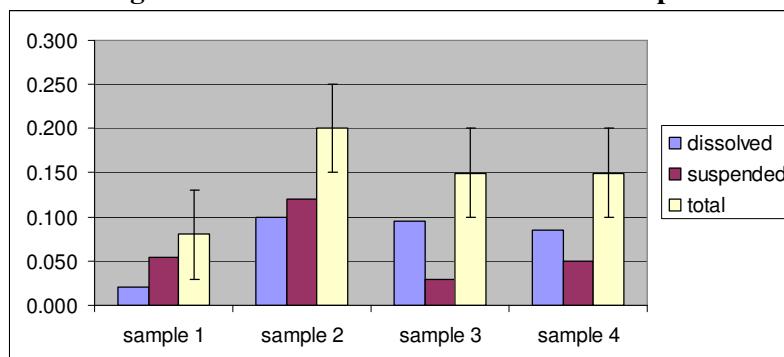
Figure 8: The concentration of cadmium in 4 samples



Generally, cadmium is found naturally in small quantities in water. Cadmium can be released to drinking water from the corrosion of some galvanized plumbing and water main piping materials. Higher levels of cadmium may be found in water near industrial areas or hazardous waste sites. In this case, the concentration of cadmium in tap water is low. The concentration of dissolved metal is higher than the suspended ones. The highest concentration was detected in sample 2, while the lowest concentration was detected in sample 1. The EPA standard level for cadmium is 0.003 ppm (Soylak, Divrikii, Saracoglu & Elci, 1998). The EPA has discovered that cadmium has high potential to cause health effect like nausea, vomiting, diarrhea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure in short period of time. In a lifetime exposure to cadmium at levels exceed 0.005 mg/L can cause kidney, liver, bone and blood damage (Ideris, 2008).

Zinc

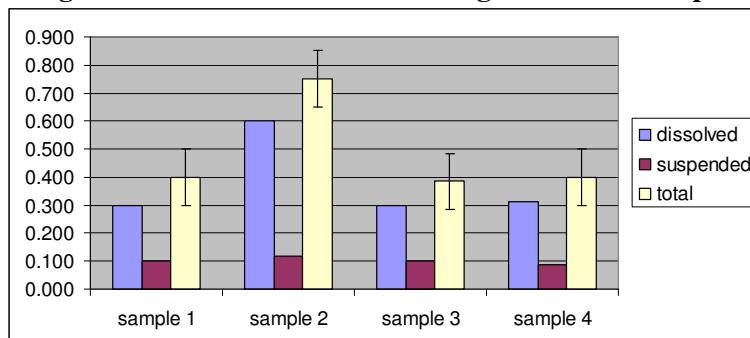
Figure 9: The concentration of zinc in 4 samples



The concentration of zinc is highest on sample 2 and the lowest in sample 1. However, the concentrations of all samples are lower than the EPA standard limit which is 3 ppm. Usually zinc is introduced in tap water through corrosion of galvanized plumbing materials. Many galvanized pipes in old buildings were manufactured using zinc that probably contained high levels of lead, which is a common impurity in the zinc. Galvanized pipes are still common in older homes and many commercial buildings. Galvanized pipes will corrode over time and as a result it leaves many symptoms like high levels of zinc in tap water, a "metallic" taste of the water, poor water flow due to blockage from mineral buildup and discolored water (brown, red or yellow water) (Hutzinger, 1995). Zinc is an essential element in human diet. Zinc is a low concentration and also high concentration can cause health problem. Too little zinc can cause slow wound healing and skin sores, decreased sense of taste and smell, loss of appetite and damage in immune system. In August 2005, Agency for toxic substances and disease registry (ATSDR) reported that, by putting low levels of zinc acetate and zinc chloride on the skin of rabbits, guinea pigs, and mice caused skin irritation. They conclude that, skin irritation will probably occur in people (Agency for Toxic Substances and Disease Registry (ATSDR), 2005). While in larger amount, for a short period of exposure time it can cause stomach cramps, nausea and vomiting. For a long period of exposure time, it can cause anemia, pancreas damage and low levels of high density lipoprotein cholesterol. Harmful effects generally begin at levels 10-15 times higher than the amount needed for good health (Agency for Toxic Substances and Disease Registry (ATSDR), 2005). EPA recommended maximum contamination level is 5 mg/L (Ideris, 2008).

Magnesium

Figure 11: The concentration of magnesium in 4 samples

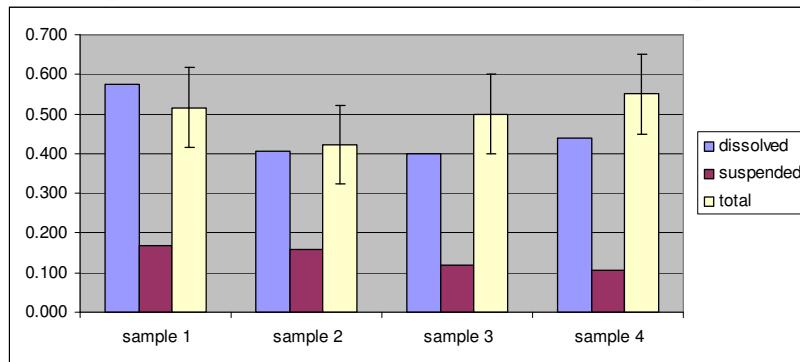


Calcium and magnesium ions dissolved in water are the two most common minerals that make water "hard." The degree of hardness becomes greater as the calcium and magnesium content increases. The concentration of dissolved magnesium ion is lesser than the concentration of suspended magnesium. The highest concentration was detected in sample 2 and the lowest in sample 3. The amounts of magnesium detected in all four samples fall within the EPA standard limit. All the four samples were categorised under soft water. Soft

water is more likely to dissolve certain metals from pipes than hard water. These metals include cadmium and lead, which are potentially toxic. Hard water is not a health hazard.

Calcium

Figure 13: The concentration of calcium in 4 samples



The highest concentration of calcium was detected in sample 4 and the lowest in sample 2 (Figure 9). The concentrations of all samples are within EPA standard limit which temporary hardness is caused by a combination of calcium ions and bicarbonate ions in the water. Permanent hardness is hardness (mineral content) that cannot be removed by boiling. It is usually caused by the presence of calcium and magnesium sulfates and/or chlorides in the water, which become more soluble as the temperature rises. There is no water hardness standard from EPA, but the Water Quality Association (WQA) has established the water hardness standards (Ideris, 2008).

Table 12: The Measurement for Water Hardness by Water Quality Association (WQA)

Hardness Level	gpg	mg/L or ppm
Soft	less than 1.0	less than 17.1
Slightly Hard	1.0 to 3.5	17.1 to 60
Moderately Hard	3.5 to 7.0	60 to 120
Hard	7.0 to 10.5	120 to 180
Very Hard	10.5 and above	180 and above

(Adapted from Zafifi Bin Ideris, 2008)

Basically the concentrations of dissolved metals are lower than suspended metals. This is due to water treatment process. During raw water treatment, not all metals can be removed

but most of the suspended metals will be removed from drinking water through this process (Ideris, 2008).

CONCLUSION

This study was carried out to investigate the concentration of metals ions in Bandar Sunway residential area. Seven metals were detected in all four samples collected in Bandar Sunway residential area. Only lead and copper in Sunway Villa Apartment exceeded EPA standards. This could be due to the plumbing system in the building itself. However, more analysis is needed to test on other metals such as mercury, antimony, selenium, barium and iron to determine the water quality standard in Bandar Sunway.

ACKNOWLEDGEMENT

The author thanks Associate Professor Dr Rashid Atta Khan for his guidance and Monash University Malaysia for technical support.

REFERENCES

- Agency for Toxic Substances and Disease Registry (ATSDR). (2005). Toxicological Profile for Zinc (Update), Atlanta, GA: U.S. Department of Public Health and Human Services, Public Health Service.
- Berman, E. (1980). *Toxic metal and their analysis*. New York: Hayden and Sons Ltd.
- Engineering Services Division, Ministry of Health Malaysia. (2000). National Standard for Drinking Water. Retrieved 10 April 2009 from <http://www.syabas.com.my/community/StandardDrinkingWater.pdf>
- Greenberg, A.E., Clesceri, L.S. & Eaton, A.D. (Ed.). (1992). *Standard Methods for the Examination of Water and Waste Water* (18th ed.). Washington, DC: American Public Health Association.
- Hauser, B.A. (2002). *Drinking Water Chemistry, a Laboratory Manual*. USA: CRC Press
- Hutzinger, O (1995). *The Handbook of Environmental Chemistry and Water Pollution* (Vol. 5). Berlin: Springer-Verlag.
- Ideris, Z. (2008). *Study of the Quality of Commercial Bottled Mineral Waters in Malaysia* (Masters dissertation, University Malaya, 2008).
- Helrich, K. (1990). *Official Methods of Analysis of the Association of Official Analytical Chemistry*, (15th Ed). Association of Official Analytical Chemists Inc.

- King W.G, J.M Rodriguez et al. (1998). *Standard method for the examination of water and waste water* (20th ed.). Washington NW: Water Environment Federation, the American Water Works Association, and the American Public Health Association.
- Manickam, K. (2008). *Geochemical Analysis for Seawater Intrusion in Klang River Basin*, (Masters dissertation, University Malaya, 2008).
- National Research Council Staff. (1999). *Drinking Water and Health*. (Vol. 5). Washington DC: National Academic Press
- National Research Council Staff. (1999). *Identifying Future Drinking Water Contaminants*. Washington DC: National Academic Press
- Nriagu, J.O. & Pacyna, J.M. (1988). Quantitative assessment of worldwide contamination of air, water and soils by trace metals, *Nature publishing group*, 333, 101-192.
- Reeve, R. (2002). *Introduction to Environmental Analysis*. England:John Wiley and Sons Ltd.
- Review of the EPA Water Security Research and Technical Support Action Plan: Part I & Part II. (2003). Panel on Water System Security Research Council Nation Academies Press.
- Soylak, M., Divrikii, U., Saracoglu, S. & Elci, L. (1998). Membrane Filtration – Atomic Absorption Spectrometry Combination for Copper, Cobalt, Cadmium, Lead and Chromium in Environmental Sample. *Environmental Monitoring and Assesssment*, 127,1-3.
- World Health Organization. (2006). Guidelines for Drinking-water Quality, First Addendum to Third Edition, Vol. 1 Recommendations. Geneva, Switzerland. Retrieved 10 April 2009 from http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/
- World Health Organization. (1996). Guidelines for drinking-water quality (2nd ed., Vol. 2). Health criteria and other supporting information. Geneva, Switzerland. Retrieved 10 April 2009 from http://www.who.int/water_sanitation_health/dwq/2edvol2p1.pdf