

CIVIL ENGINEERING

Levels of Trace Metals in Riyadh Drinking Water at the Consumer Taps

Abdullah El-Rehaili and Mohammed Misbahuddin

*Civil Engineering Department, College of Engineering,
King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia*

(Received 18/11/1992; Accepted for publication 22/6/1993)

Abstract. Three hundred and twenty water samples were collected from 40 homes in the city of Riyadh and analyzed to evaluate the levels of trace metals iron, copper, chromium, lead, zinc and cadmium and to examine any possible correlations with plumbing type, age, and water characteristics. The mean and peak concentrations of the trace metals were compared to health and/or aesthetic guideline values given by the Saudi Arabian Standards Organization (SASO).

The study revealed that 88% of the homes studied utilize galvanized iron plumbing, whereas, PVC and copper plumbings are used in 10 and 2%, respectively. Homes with galvanized iron plumbing showed higher levels of trace metals than those with PVC and copper plumbings. The optimum standard for iron as specified by SASO was exceeded in 34% of the samples, while that for copper was exceeded in 23% of the samples. Only 3% of the samples exceeded the maximum standard for lead, and none of the samples exceeded the chromium, zinc and cadmium optimum/maximum standards. The analyses concluded that a positive correlation exists between water characteristics and trace metals levels and that the elevated levels of metals were the result of corrosion and leaching from both the distribution network and in-house plumbing.

Introduction

Trace metals are ubiquitous, persistent and toxic pollutants at certain concentrations. Iron, copper, chromium, lead, zinc, cadmium, nickel, mercury and silver are the metals commonly classified as heavy or trace metals. Some metals are essential for health, whereas, others have no known biological function and have toxic effects. The adverse effects of some heavy metals on human health are well documented.

Each metal has its own peculiar chemistry and toxicity patterns. Birth defects, cancer and a number of chronic diseases have all been linked to heavy metals [1, p.1]. Arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver have toxic effects on the internal organs of the human body. However, the trace metals of arsenic, barium, hexavalent chromium, mercury, selenium and silver are rarely found in significant concentrations in public drinking water [2, p.155].

Trace metals may be present in natural groundwater or surface water. The sources of these trace metals are associated with either natural processes or man's activities. Two important natural processes contributing trace metals to natural water are chemical weathering and soil leaching. The factors affecting the release of trace metals from primary materials and soil and their solution and stability in water are solubility, pH, adsorption characteristics, hydration, co-precipitation, colloidal dispersion, and the formation of complexes [3, p.205].

The treatment of raw water to render it acceptable for public consumption may include the removal of trace metals. However, some trace metals may be added to water as a result of treatment and subsequent distribution throughout a community. Treatment chemicals themselves, or associated impurities, may contribute to the trace metals content of the finished water. The occurrence of corrosion within the municipal distribution network, house connections, and in-house plumbing may also trace metals to finished water before it reaches the consumer [4]. The concentration of the metals depends mainly on pipe material, chemical properties of the water, the length of pipes through which it passes and the time it has stood in the pipes [5]. It is also influenced by how far and how quickly the tap is turned, and by the temperature of the water and thus the season [6].

The aim of this study was to assess the quantities and causes for the presence (if any) of six important trace metals in drinking water within selected homes in the city of Riyadh. The trace metals selected were iron (Fe), copper (Cu), chromium (Cr), lead (Pb), zinc (Zn) and cadmium (Cd). The concentrations were related to type of plumbing material, age and water characteristics such as pH, alkalinity and total hardness.

Materials and Methods

Riyadh water supply and distribution network

The water supply for the city of Riyadh comes from shallow and deep ground water and from desalinated sea water. Desalinated sea water from Jubail on the Arabian Gulf constitutes about 65% of the total supply to Riyadh, which averaged about

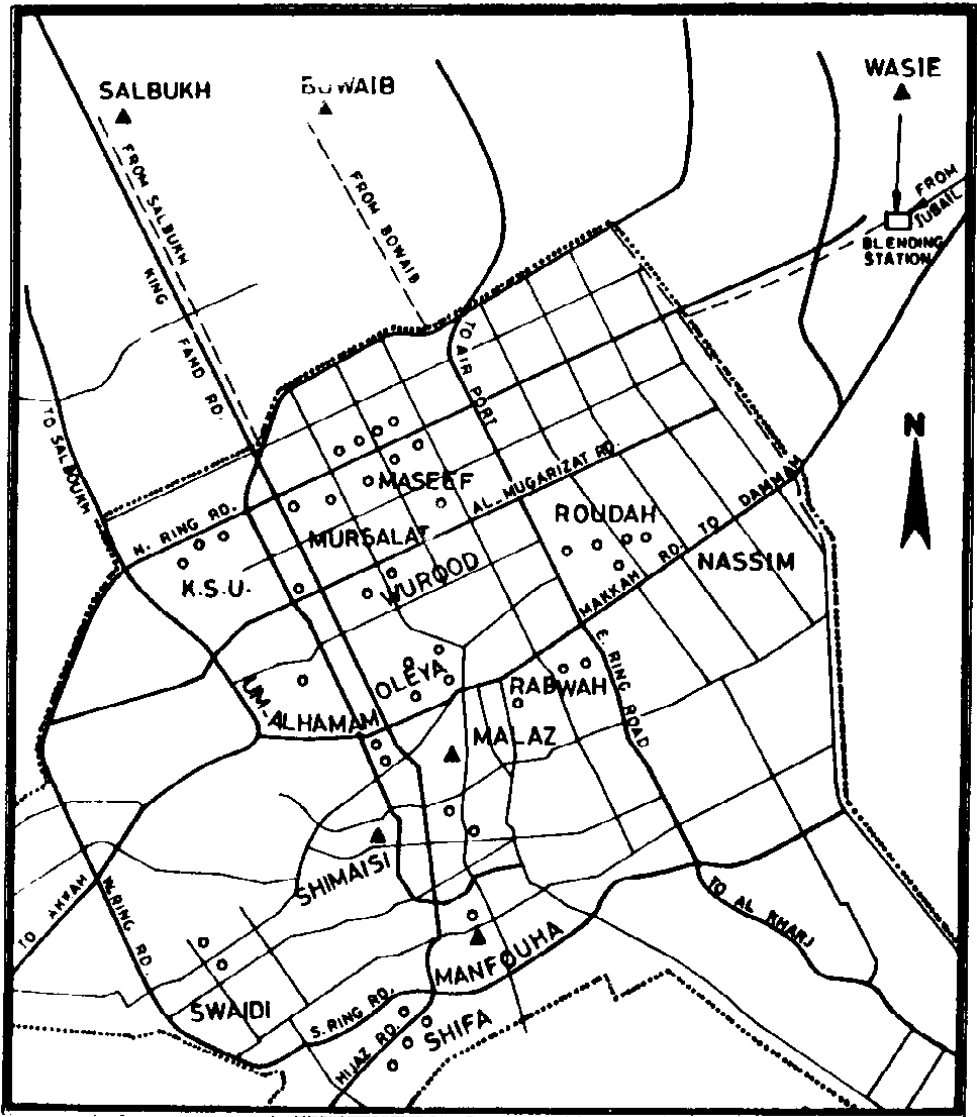
1.1 million m³/day in 1990-91. The water from Jubail is blended with ground water in Wasie, north east of Riyadh. The majority of ground water comes from deep aquifers which contain high concentrations of hardness and dissolved solids (TDS in the range of 1000 to 1600 mg/l). Ground water is treated at five treatment plants with a typical scheme of lime-soda softening followed by reverse osmosis desalination. The treated or blended water is then fed to Riyadh water distribution network. The network consists mostly of ductile iron feeders (dia. > 150 mm), PVC distribution mains (100-150 mm dia.), and high density polyethylene (HDPE) service connections.

Sampling locations and methodology

Samples were collected from 40 homes in different localities of Riyadh representing different water quality characteristics, plumbing materials and home age. Four samples were collected from each home following a specific sampling arrangement during both winter (March-April) and summer (July-August) seasons of 1990. Figure 1 shows the distribution of sampling locations within the city of Riyadh. The four (first, second, third and fourth draw) samples were collected at each house as follows: First draw samples of 250 ml each were collected early in the morning from the kitchen cold water faucet before wasting any water. The next 250 ml of water sample was the second draw, collected immediately after the first draw without any loss of water. Third draw samples (500 ml) were collected after letting the water flow for about five minutes. The fourth draw samples, also 500 ml, were collected either from the pipe flowing into the ground tank, or from the garden tap (if it came directly from the distribution network) after flushing for five minutes.

Clean polyethylene bottles were used for collection of all samples. Determinations for pH, alkalinity and hardness were made immediately after the samples were brought to the laboratory. The samples were then acidified with concentrated nitric acid to pH < 2 and stored in the refrigerator for later determination of trace metal concentrations. Information regarding piping material and building age were collected from the residents in order to assess possible causes of elevated metal levels if observed.

Samples were also collected from the six main water treatment or blending stations serving Riyadh. These are located in Shimaisy, Malaz, Manfouha, Buwaib, Salbukh and Wasie (Fig. 1).



- ▲ Water treatment plant
- Sampling point
- Riyadh network boundary
- Main feeding lines
- Network grid

Fig. 1. Distribution of sampling locations and water sources for the city of Riyadh.

Tests and analytical procedures

Determination of trace metal concentrations for all samples and standards was performed by chelation with Ammonium Pyrrolidine Dithiocarbamate (APDC) under optimum pH conditions and followed with a 15-fold concentration by extracting into Methyl Isobutyl Ketone (MIBK). The extracts (organic phase) were then analysed by Pye-Unicam SP9-800 Atomic Absorption Spectrophotometer using air-acetylene flame. Techniques given in Standard Methods [7] were followed for extraction and analysis.

Results and Discussion

Type of plumbing

Analysis of the data showed that the majority of homes studied utilize galvanized iron plumbing. Out of a total of 40 homes, 88% (35 homes) have galvanized iron plumbing, 10% (4 homes) have plastic (PVC) plumbing, and 2% (1 home) has copper plumbing. Hence, in the presentation and discussion of results emphasis will be put on homes with galvanized iron pipes, and results for buildings with PVC and copper pipes will be compared with the galvanized iron plumbing results.

Trace metal concentrations

Table 1 shows the statistical levels of the six trace elements (Fe, Cu, Cr, Pb, Zn, and Cd) measured in homes with galvanized iron plumbing. The levels of each element will be discussed and compared with the Saudi Arabian drinking water standards [8].

Table 1. Statistical levels of six heavy metals in homes with galvanized iron plumbing

Trace element	Sample ^a	Standard conc. ^b $\mu\text{g/l}$		Concentration of trace elements, $\mu\text{g/l}$			% of samples > stand. conc. ^c
		Optimum	Maximum	Average	Maximum	Median	
Iron (Fe)	I	100	1000	159	657	146	42
	II			98	448	78	30
	III			86	609	61	22
	IV			121	783	87	39
	All			116	783	93	34
Copper (Cu)	I	50	1500	41	517	31	18
	II			32	156	25	18
	III			42	1085	32	15
	IV			120	1431	50	27
	All			59	1431	34	23

Table 1. Continued.

Trace element	Sample ^a	Standard conc. ^b $\mu\text{g/l}$		Concentration of trace elements, $\mu\text{g/l}$			% of samples > stand. conc. ^c
		Optimum	Maximum	Average	Maximum	Median	
Chromium (Cr)	I		50	2	34	0	0
	II			<1	7	0	0
	III			3	34	0	0
	IV			2	25	0	0
	All			2	34	0	0
Lead (Pb)	I		100	7	218	0	3
	II			<1	9	0	0
	III			9	342	0	3
	IV			18	389	0	4
	All			9	369	0	3
Zinc (Zn)	I	5000	15000	288	330	295	0
	II			268	350	280	0
	III			220	330	250	0
	IV			118	340	0	0
	All			224	350	300	0
Cadmium (Cd)	I		10	1.4	2	0	0
	II			0.8	1	0	0
	III			0.6	1	0	0
	IV			1.2	2	0	0
	All			1.0	2	0	0

^a I = First Draw, II = Second draw, III = Third draw, IV = Fourth draw, All = Overall samples.

^b Saudi Arabian Standards for Unbottled Drinking Water [8].

^c Optimum standard for Fe, Cu, Zn and Max. for Cr, Pb, and Cd.

Iron (Fe)

Figure 2 illustrates the percent distribution of samples among several iron concentration levels. At least 32% of the samples in any category have iron concentration of less than 50 $\mu\text{g/l}$. Twenty eight percent of the first draw samples contained iron levels higher than 200 $\mu\text{g/l}$, compared to only 10% in the third draw samples. The average iron concentration was highest (Table 1) in the first draw samples which were collected early in the morning from the kitchen taps before wasting any water. The average levels in the second, third and fourth draw were 98, 86 and 121 $\mu\text{g/l}$, respectively. The higher levels of iron in the fourth draw samples (collected before water enters into the house after flushing for 5 minutes) relative to some in-house samples seems contrary to expectations. This effect could be a result of improper sampling at some locations due to the possibility that some home owners may have

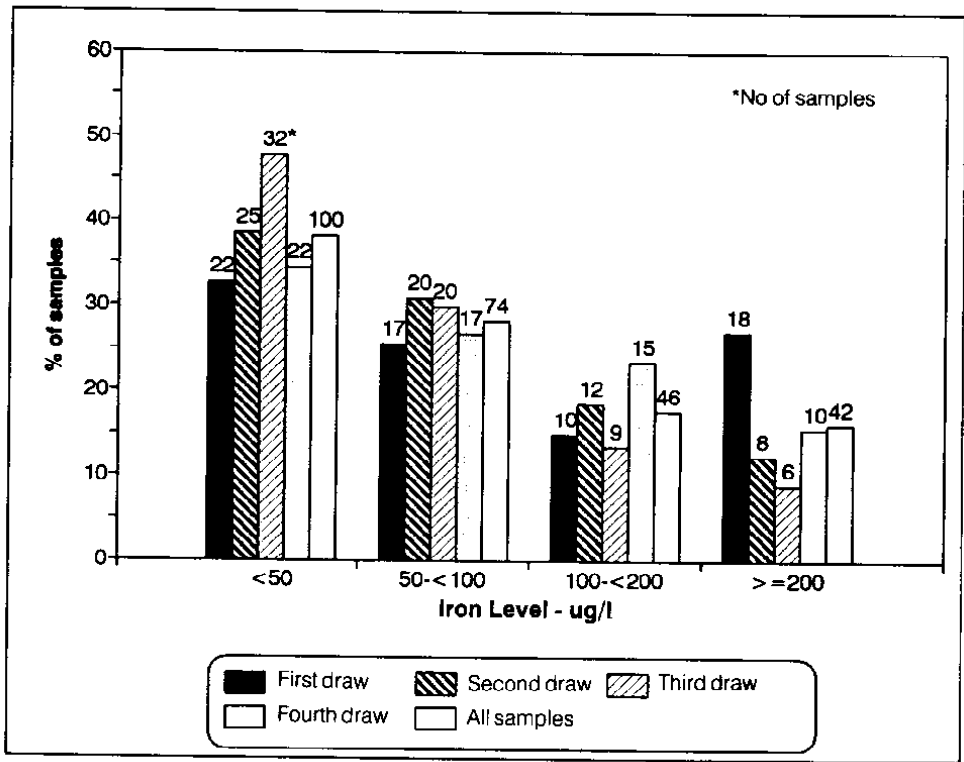


Fig. 2. Levels of iron in homes with galvanized iron plumbing.

collected the samples from the taps without previously flushing the line. Moreover, the presence of metallic pipes/fittings between the city supply main and the sampling point might have elevated the trace metal levels in the fourth draw samples.

The higher levels of iron in most of the first draw samples reflect the effect of overnight stagnation of water in the pipes which induces more corrosion products. It should be emphasized, however, that by examining the trace element levels in samples withdrawn from each individual location it does not necessarily follow that the first draw samples contain the highest level. This could result from the fact that some parts of the corrosion products are not totally dissolved, hence some will settle or be part of the corrosion settleable complexes. This was clearly obvious in few samples where the flushed second or third draw samples showed higher trace element levels than the stagnant first draw sample and/or the fourth (network) sample. If trace elements are completely dissolved, the inner samples (I, II, III draws) will continuously be found to contain levels equal to or greater than the fourth sample. The maximum

observed concentration of iron was 783 $\mu\text{g/l}$, with an average of 116 $\mu\text{g/l}$ and a median of 93 $\mu\text{g/l}$. The optimum Saudi drinking water standard for iron (100 $\mu\text{g/l}$) was exceeded in 34% of the samples withdrawn from galvanized iron plumbing. No sample exceeded the maximum stipulated limit of 1000 $\mu\text{g/l}$ for total iron. Although there is no indication that iron is carcinogenic if present in large amounts [9, p. 266], yet it can impart a bitter taste and staining of plumbing fixtures.

Copper (Cu)

Copper, one of the essential elements in human diet, when found in water supplies is generally related to the corrosion of copper and copper containing alloys used in pipes and fittings within the system. Water containing more than 1300 $\mu\text{g/l}$ of copper can cause green stains on sanitary fittings as well as stomach and intestinal distress and at much lower concentrations can cause accelerated corrosion of other metals in the same system.

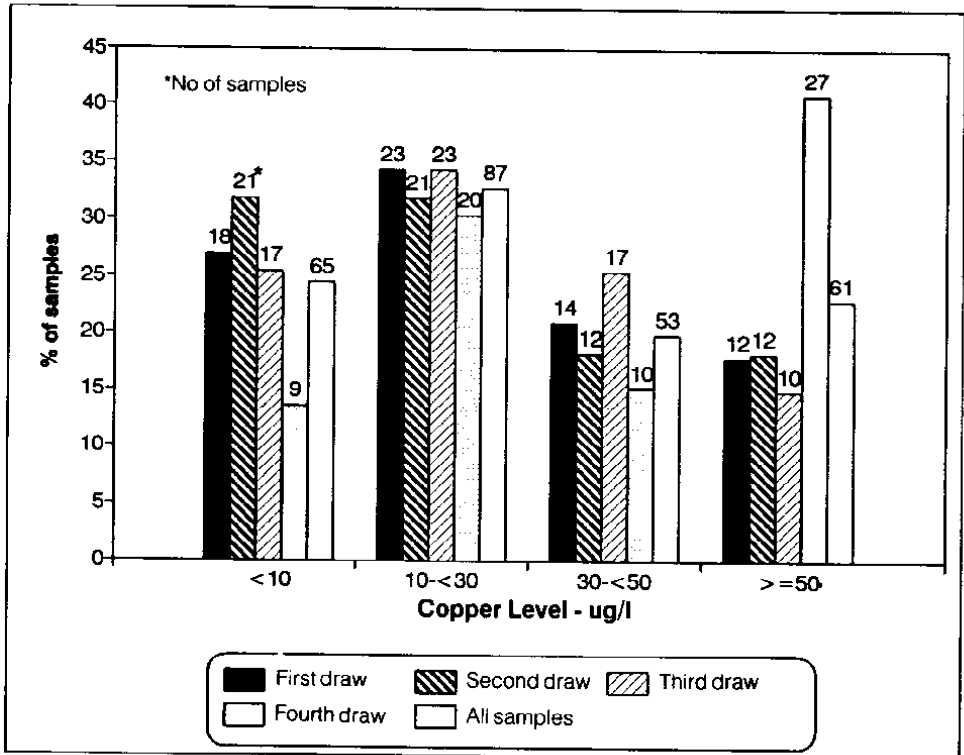


Fig. 3. Levels of copper in homes with galvanized iron plumbing.

The same effects observed for iron were also observed for copper levels, but in this case the fourth draw samples showed the highest average level. Figure 3 shows samples distribution for various copper concentration ranges. Table 1 indicates that the average copper levels were 41, 32, 42 and 120 $\mu\text{g/l}$, respectively, for first to fourth draw samples. The maximum copper level was found to be 1431 $\mu\text{g/l}$, the average was 59 $\mu\text{g/l}$, and the median was 34 $\mu\text{g/l}$. The optimum Saudi standard of 50 $\mu\text{g/l}$ was exceeded in 23% of the samples, however, none of the samples exceeded the maximum limit of 1500 $\mu\text{g/l}$ for copper.

Chromium (Cr)

The results showed an overall maximum chromium concentration of 34 $\mu\text{g/l}$ with an average of 2 $\mu\text{g/l}$ (Table 1). Figure 4 shows samples distribution for various chromium concentration ranges. The maximum Saudi standard for chromium is 50 $\mu\text{g/l}$. None of the samples showed a chromium level higher than this standard value indicating no apparent human health concern due to the presence of chromium.

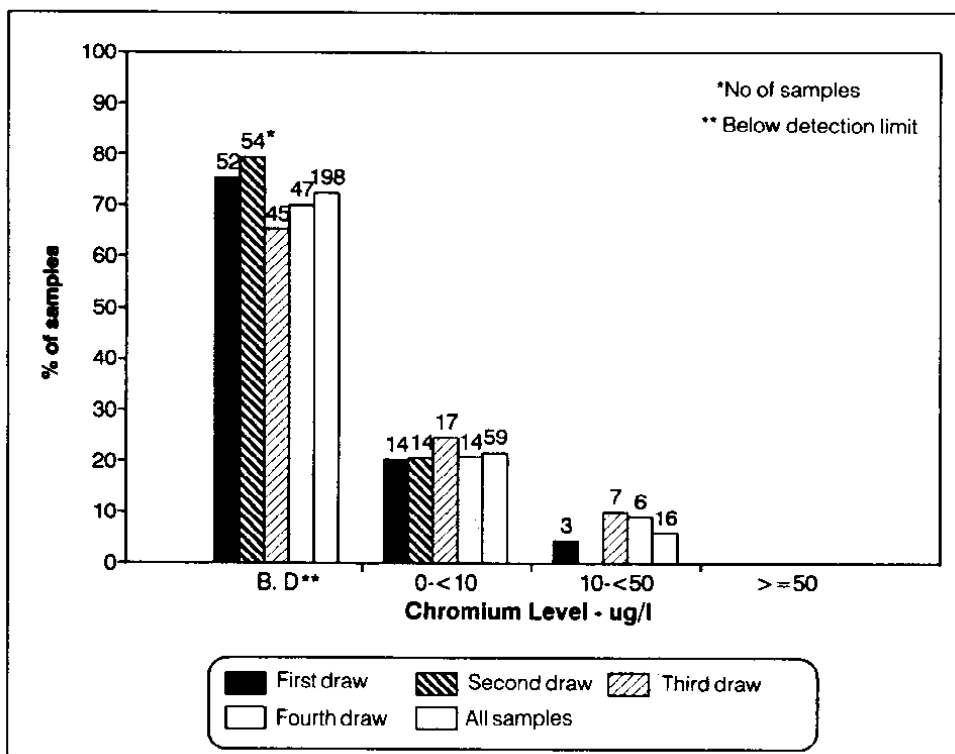


Fig. 4. Levels of chromium in homes with galvanized iron plumbing.

Lead (Pb)

Contamination of drinking water with lead has received much more attention than other corrosion products. Lead is toxic, accumulates in the body, causes nervous system and kidney damage, and has no known physiological functions. Lee *et al.* [5] have conducted a survey of more than 1400 sampling sites in the United States and concluded that lead based solder is the most significant source of lead at the tap. Brass faucets, however, were found to contribute about one third of the lead in a first draw sample at the sites with lead-soldered joints.

The distribution of lead concentrations in four individually drawn and grouped samples is shown in Fig. 5 and Table 1. As seen from Table 1 the maximum observed lead level was 389 $\mu\text{g/l}$, with an average of 9 $\mu\text{g/l}$. The maximum limit for lead according to the Saudi standards is 100 $\mu\text{g/l}$. Only 3% of all the samples analyzed exceeded this limit.

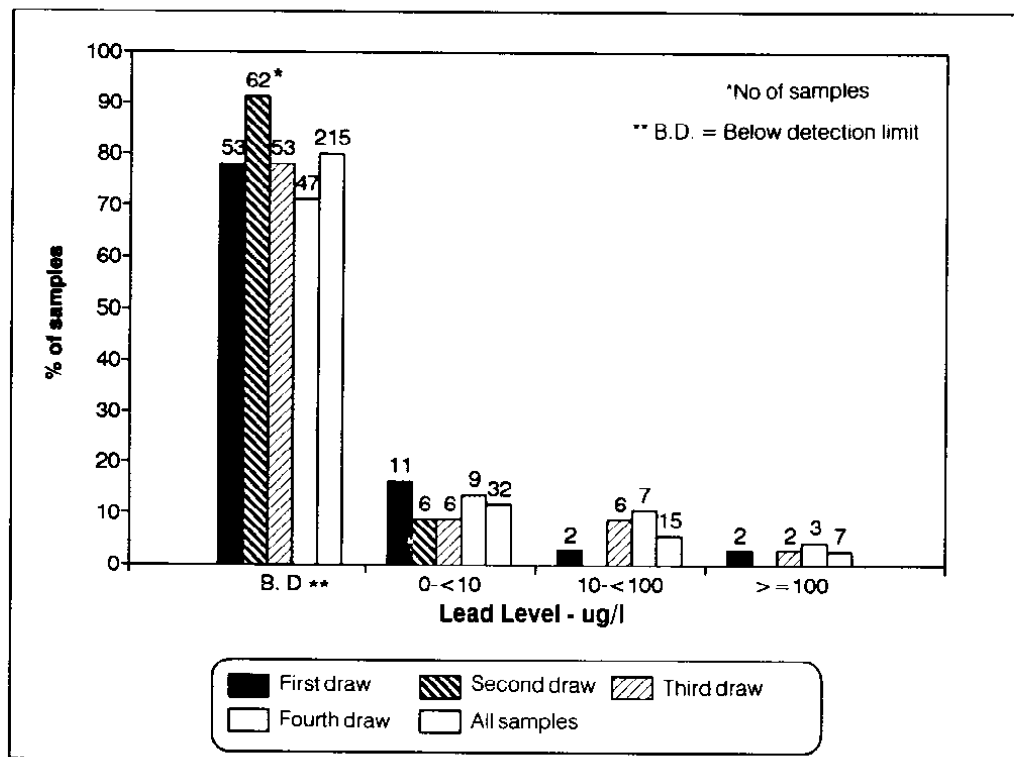


Fig. 5. Levels of lead in homes with galvanized iron plumbing.

The standard for lead was revised in 1991 by the United States Environmental Protection Agency (USEPA), the action level for lead had to be decreased from 50 $\mu\text{g/l}$ down to 15 $\mu\text{g/l}$ with the goal concentration established at zero [10]. If the lead results of this study are compared to the new action level of USEPA, it will be found that 6% of the samples exceeding the limit.

Zinc (Zn)

First draw samples showed the highest average zinc level, 288 $\mu\text{g/l}$, compared to the average of other draws (Table 1). None of the samples tested showed a zinc concentration higher than the optimum Saudi standard of 5000 $\mu\text{g/l}$. The overall average Zinc concentration was 224 $\mu\text{g/l}$ with a maximum observed value of 350 $\mu\text{g/l}$.

Cadmium (Cd)

None of the samples tested showed a level of cadmium higher than the maximum Saudi standard of 10 $\mu\text{g/l}$. Again, first draw samples showed the highest cadmium average, 1.4 $\mu\text{g/l}$, compared to the other draws. The maximum observed cadmium level was 2 $\mu\text{g/l}$.

Impacts of Water and Plumbing Characteristics

Several water characteristics are commonly cited as important factors in the process of corrosion within metallic water pipes, and hence affect the levels of trace metals in drinking water at the consumer's tap. The important water characteristics include pH, alkalinity, total hardness, and water temperature [5]. Lower pH values cause corrosion of piping in the distribution system leading to expensive replacements as well as introduction of metal ions such as Cu, Pb, Zn, and Cd in the water. The desirable range of pH is 7.0 to 8.5. The alkalinity of water is important because it affects the control of corrosion in the distribution system [11, p. 323]. No limits are set for alkalinity levels in potable water, the main requirement is that the water should be non-corrosive. The problems associated with excessive hardness are mainly economic in terms of scale formation in boilers and hot water systems. Conversely, water softer than 30-50 mg/l as CaCO_3 tends to be corrosive and should always be examined for plumbosolvency (liability to take lead into solution). A statistical connection between the hardness of water and the incidence of cardiovascular diseases has been found [12;13].

The effects of water characteristics (pH, alkalinity, hardness and temperature) on the levels of iron and copper are discussed below for the galvanized iron pipes only. The results for lead are not presented as only few samples (< 3%) exceeded the

maximum stipulated SASO limit and in majority of the rest of samples lead can not be detected. No attempt was made to analyze the results of chromium, zinc and cadmium as related to water quality and plumbing age or type. This is because most of the samples showed non-detectable levels, or levels far lower than the optimum/maximum concentrations for the above metals.

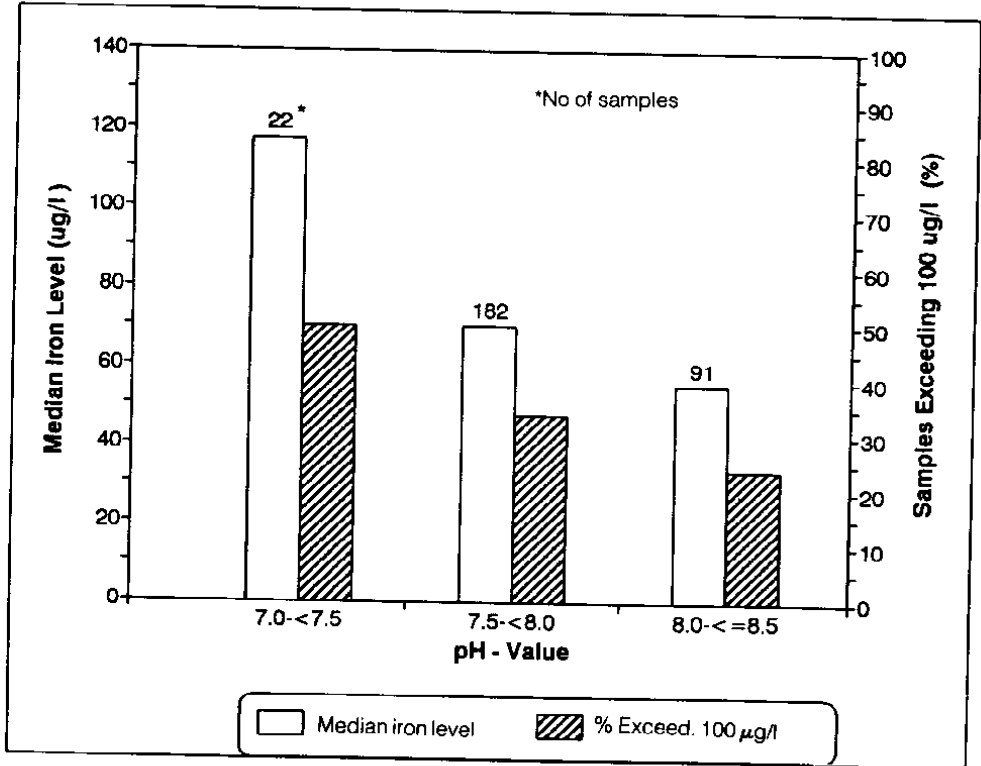


Fig. 6. Effect of pH on iron levels (all samples).

pH

Figure 6 shows the correlation between pH value and median iron levels for all samples. pH values in the samples ranged between 7.0 and 8.4, with the majority of samples (93%) in the pH range of 7.5 to 8.4. Samples with pH between 7.0 and 7.5 (7%) showed the highest median level of iron ($115 \mu\text{g/l}$), with 50% exceeding the Saudi optimum standard of $100 \mu\text{g/l}$. Samples in the high pH range of 8.0 to 8.5 (31%) showed the lowest median iron level ($55 \mu\text{g/l}$) with only 25% of which exceeding the optimum standard.

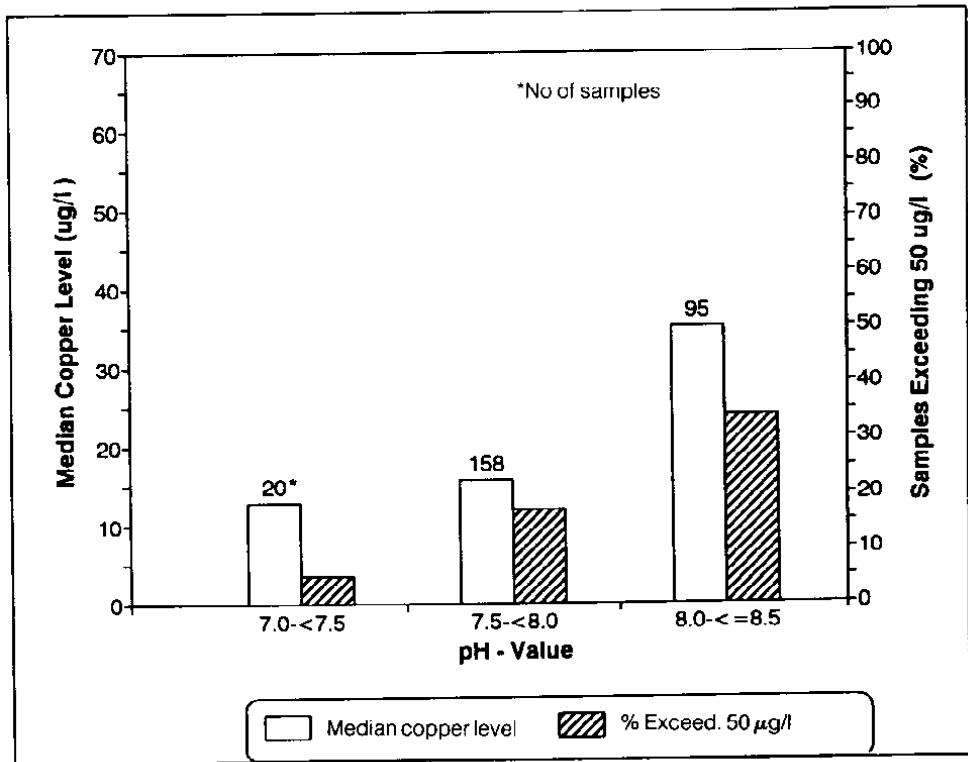


Fig. 7. Effect of pH on Copper levels (all samples).

The effect of pH on copper levels is presented in Fig. 7. The result shows a reverse effect compared to the case of iron, *i.e.*, increasing pH resulted in an increase of copper level. It can be noted that the median levels concerned are small (13-35 µg/l), which may not justify any major conclusions on pH effects.

The results discussed above, for iron in particular, generally conform to the widely accepted notion that the rate of corrosion and dissolution of metals increases with decreasing water pH. It should be noted, however, that the effect of pH can not be separated completely from the influence of water alkalinity, which is known to be important in the control of pipe corrosion. Also the narrow range of observed pH values (7.0-8.5) does not permit the drawing of major conclusions.

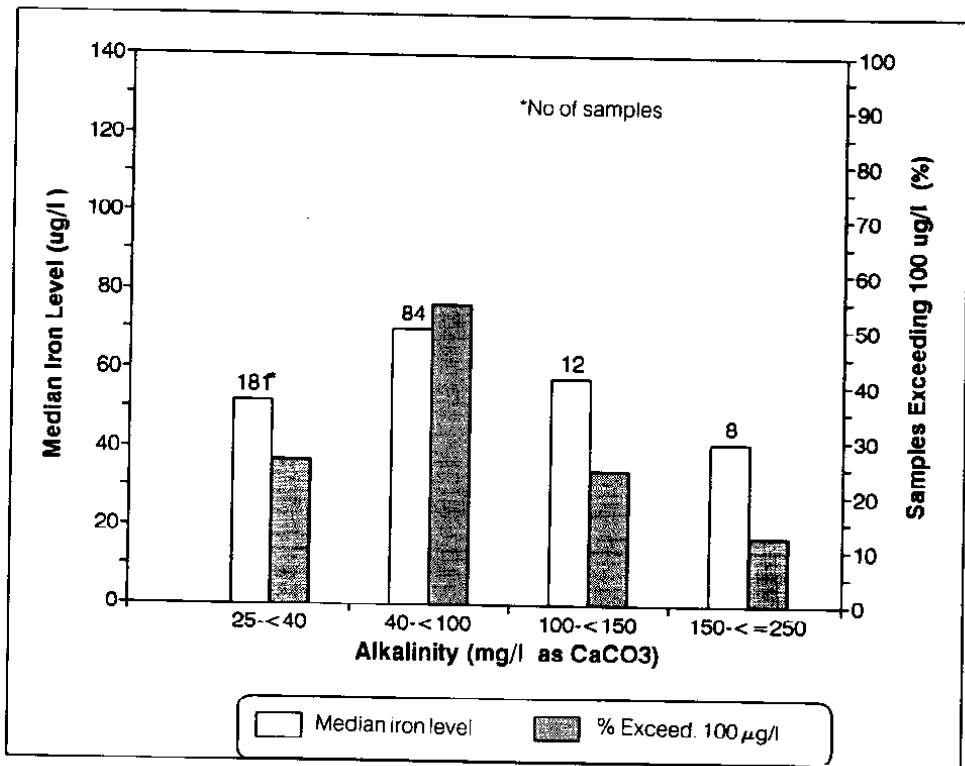


Fig. 8. Effect of alkalinity on iron levels (all samples).

Alkalinity

Figure 8 shows the effect of water alkalinity on iron concentration. Total alkalinity distribution among samples in mg/l as CaCO₃ were: 25 to 40 (64%), 40 to 100 (29%), and 100 to 250 (7%). An increase in alkalinity resulted in reducing the median iron level from 53 to 42 µg/l, with the exception for samples in the alkalinity range of 40 to 100 mg/l. Figure 9 shows the effect of alkalinity on copper levels. The variation of copper levels with alkalinity was similar to that observed for iron.

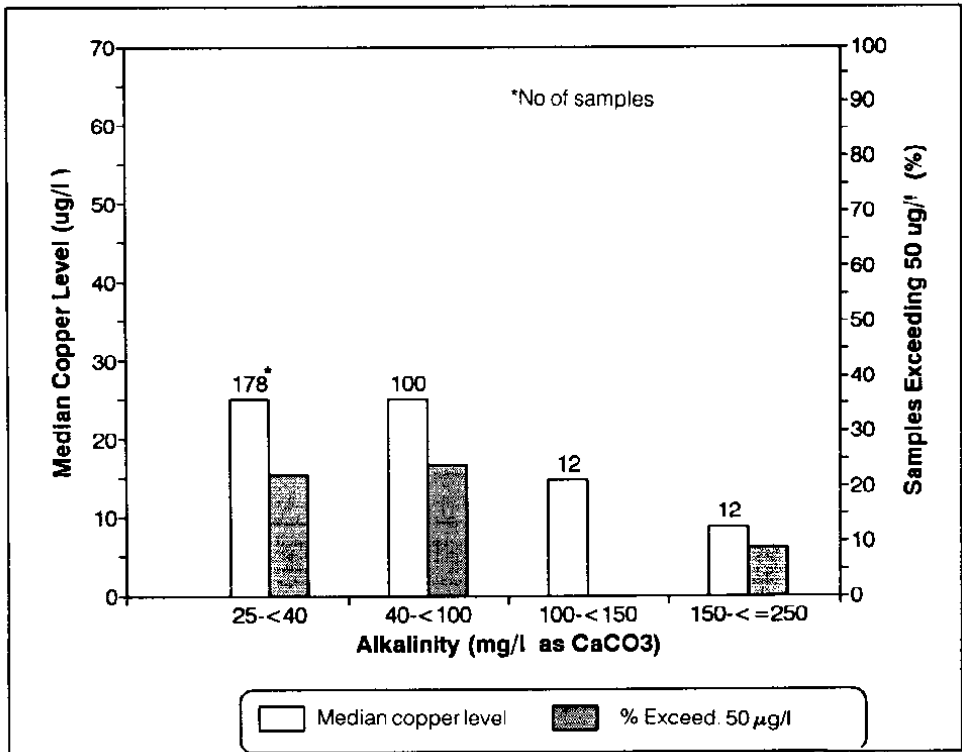


Fig. 9. Effect of alkalinity on copper levels (all samples).

Hardness

Correlation of iron with total hardness, as presented in Fig. 10, shows somewhat similar trends as those for alkalinity. Hardness distribution among samples in mg/l as CaCO₃ was: 120 to 150 (56%), 150-200 (34%), and 200-600 (10%). Since groundwater samples with high alkalinity generally show high hardness levels, the effect of hardness does resemble that of alkalinity. Hardness effects on copper (Fig. 11) showed a similar trend as observed for iron.

Very high levels of alkalinity and hardness result with less concentrations of iron and copper, but samples with these levels are the exception and represent only a minor fraction of the samples tested. Also going up to these levels could violate the standard for allowable total hardness. It should be emphasized that these conclusions should only be treated as apparent effects, due to the fact that many factors can influence the observed metal levels at the same time. A true effect can only be realized by keeping all other factors constant, which is not the case.

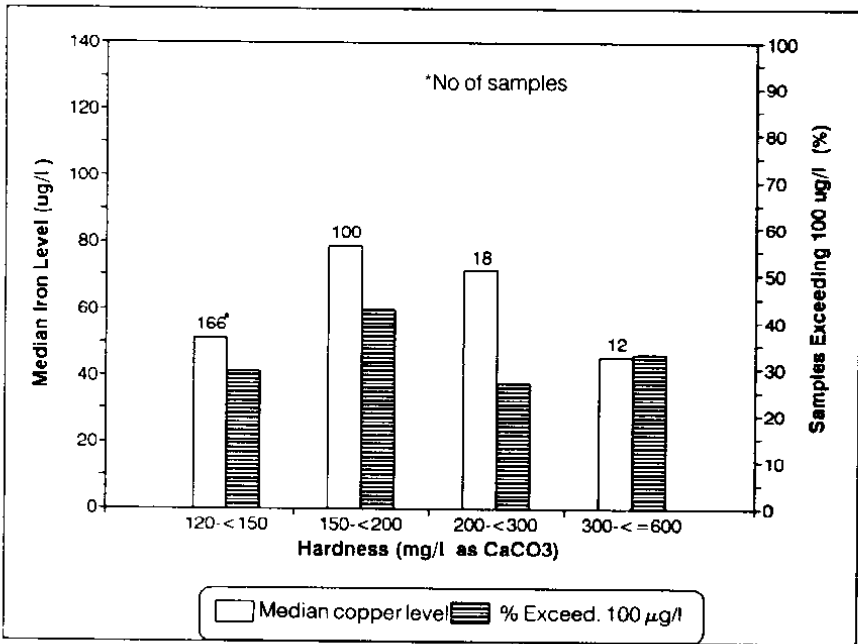


Fig. 10. Effect of hardness on iron levels (all samples).

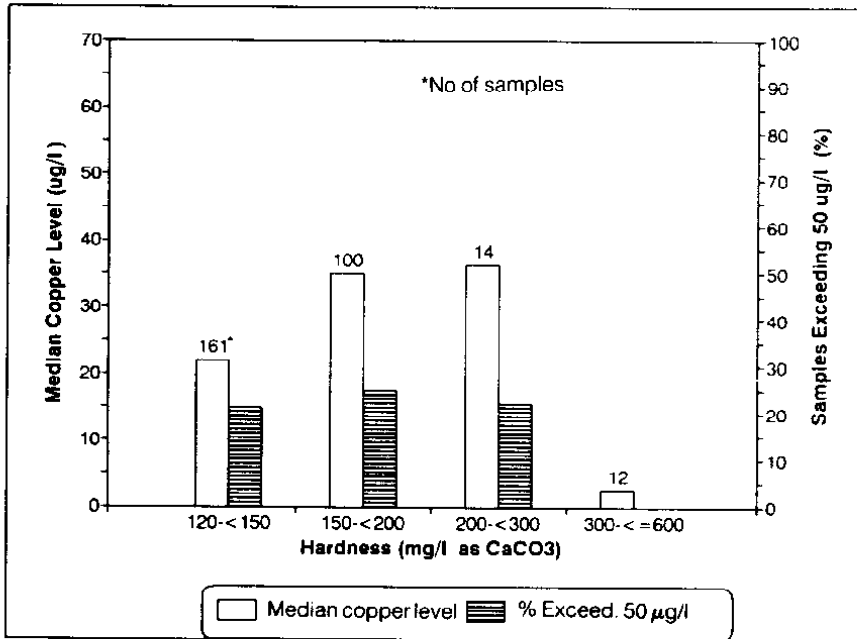


Fig. 11. Effect of hardness on copper levels (all samples).

Temperature

No attempt was made in this study to specifically evaluate temperature effects. However, samples taken in the warm season did show a slight increase in trace element concentrations. At the same time, other water quality parameters have shown slight changes between warm and cold seasons. The observed effect cannot be totally related to temperature variability. Studies by other investigators have shown that levels of some trace elements in drinking water fluctuate seasonally with water temperature [6].

Plumbing Material

As reported earlier, the majority of houses studied (88%) have galvanized iron plumbing, whereas only a few (10%) have PVC plumbing. Analysis of the results showed that houses with PVC plumbing systems have lower levels of trace elements in their water supplies. However, some samples in this type of plumbing did show levels comparable to those observed for galvanized iron pipes. This reflects the contribution of corrosion in the public network and the fact that some of the fixtures and fittings within PVC plumbing systems are actually made of galvanized iron or other metals. As seen from Table 2, the average levels for iron in galvanized and PVC pipes are comparable, whereas the average copper concentration in galvanized iron is double that in PVC pipes. The mean lead level in the galvanized iron plumbing is three-fold than in PVC plumbings.

Table 2. Comparison of trace element levels ($\mu\text{g/l}$) between homes with galvanized iron and plastic plumbings

Metal	Galvanized iron*		Plastic**	
	Maximum	Average	Maximum	Average
Fe	783	116	683	111
Cu	1431	59	195	31
Cr	34	2	11	2
Pb	389	9	54	3
Zn	350	224	276	128
Cd	2	1	1	<1

* 270 samples (35 homes)

** 32 samples (4 homes)

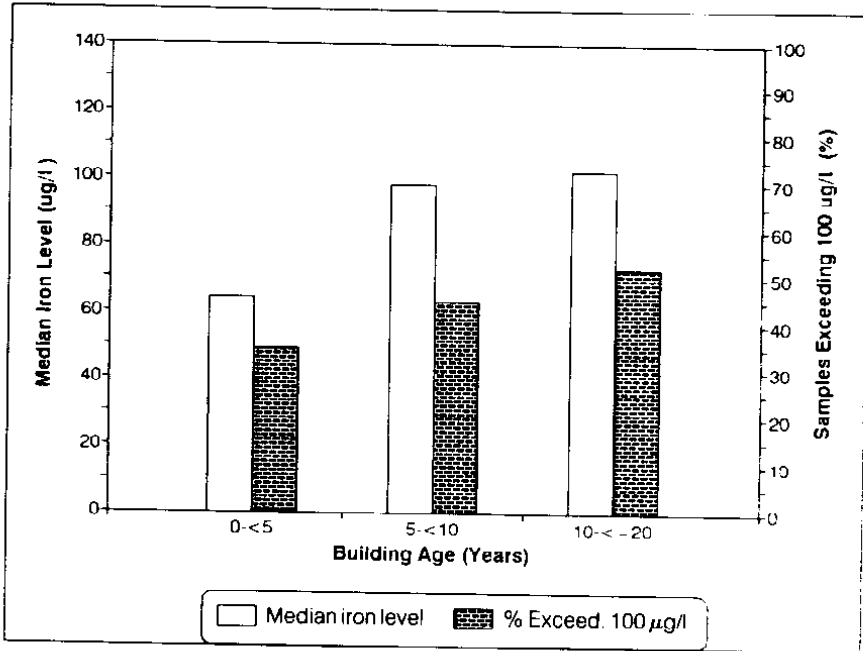


Fig. 12. Effect of building age on iron levels.

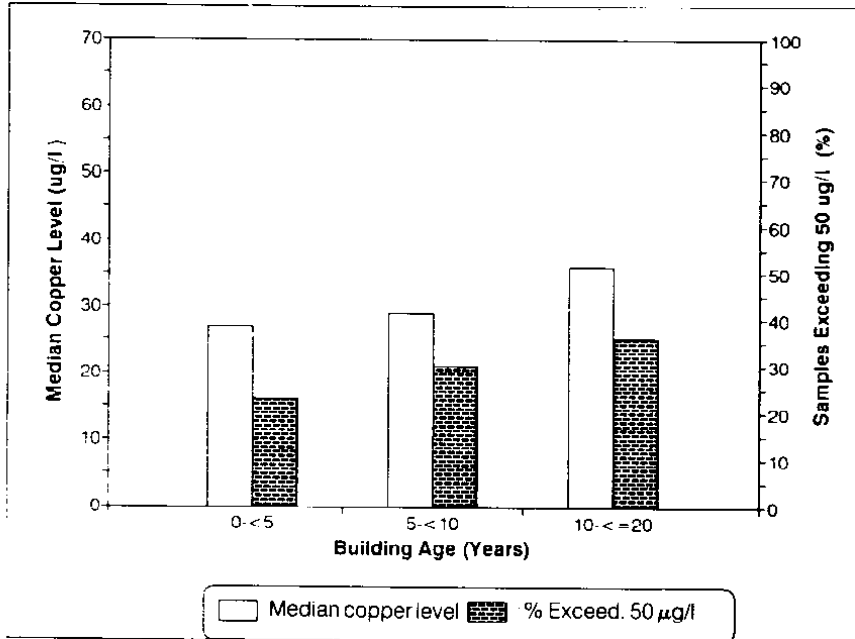


Fig. 13. Effect of building age on copper level.

Plumbing age

The age of the pipe is also considered an important factor, although its contribution is very much related to the water quality. The influence of plumbing age on levels of iron and copper are presented in Figs. 12 and 13, respectively. Median iron and copper levels increased with increasing plumbing age. For new plumbing (0 to 5 years), the median iron level was 64 $\mu\text{g/l}$ with 35% of the samples exceeding the optimum level of 100 $\mu\text{g/l}$. For older plumbing (10 to 20 years), the median iron level was 102 $\mu\text{g/l}$ with 52% of the samples exceeding the optimum level. The increase in the case of copper was minimal, ranging from 27 $\mu\text{g/l}$ for the new plumbing to 36 $\mu\text{g/l}$ for the old plumbing.

Quality of Riyadh water supply

Table 3 shows analyses performed on water samples collected from the treated waters supplying the city of Riyadh. These generally represent the quality of water supplied to the distribution network. It is clear that these waters contain negligible levels of the six trace metals under investigation.

The high levels of trace metals observed at homes can be related to the contributions from the distribution network and the in-house plumbing. In some cases the trace metal levels were reduced within the in-house plumbing, probably due to the possible complexation and scaling within in-house pipes. The contribution of the network comes mainly from the ductile iron pipe (size greater than 150 mm). The distribution mains (PVC) and service connections (HDPE) are not expected to be the contributors to observed trace metal concentrations. The langelier saturation index (LSI), an indicator of water stability, was also calculated for the six water sources of Riyadh and is presented in Table 3. The calculations for LSI were based on average water quality parameters for a period of one month. The LSI values show that all water sources are slightly aggressive, indicating some corrosion potential. However, these values are within the typical range of water quality in similar systems.

Conclusions

Analysis of the results obtained in this study revealed valuable information regarding the levels of the six trace metals iron, copper, chromium, lead, zinc and cadmium in drinking water within Riyadh homes. It also provided some observations related to the influence of water quality and plumbing age on the elemental levels. The major conclusions are:

- Galvanized iron plumbing is utilized in 88% of the houses studied, while PVC

Table 3. Characteristics of the treated water supplied to the Riyadh Water Distribution Network. (One month average, Aug. - Sept., 1991)

Treatment plant	pH	Alkalinity ^b	Total hardness	Ca-hardness	TDS (mg/l)	LSI ^c	Concentrations of trace elements, µg/l						
							Fe	Cu	Cr	Pb	Zn	Cd	
Shimaisy	7.3	93	215	115	524	-0.72	BD	BD	BD	BD	BD	BD	BD
Malaz	7.4	41	270	115	1312	-1.09	BD	BD	BD	BD	BD	BD	BD
Manfouha	7.4	69	138	68	533	-0.98	BD	BD	BD	BD	BD	BD	BD
Buwaib	8.0	29	370	175	1495	-0.48	BD	BD	BD	BD	BD	BD	BD
Salbukh	7.3	33	200	80	832	-1.40	BD	BD	BD	BD	BD	BD	BD
Wasie ^a	7.9	45	140	100	276	-0.40	3	5	BD	BD	BD	BD	BD

^a Blending Station

^b Alkalinity and hardness are expressed in mg/l as CaCO₃

^c Langelier saturation index calculated at 25°C.

BD = Below detection limit

is used in 10% of the houses, followed by copper in only 2%.

- Average iron levels were highest in the first draw samples (159 $\mu\text{g/l}$) and lowest in the third draw samples (86 $\mu\text{g/l}$). The fourth sample (reflecting the distribution network level) contained an average iron level of 121 $\mu\text{g/l}$. This shows the possible settlement of part of the iron within the in-house plumbing and/or ground tank.
- The maximum copper level observed was 1413 $\mu\text{g/l}$, the average was 59 $\mu\text{g/l}$, and the median was 34 $\mu\text{g/l}$. The optimum copper standard (50 $\mu\text{g/l}$) as specified by SASO was exceeded in 23% of the samples.
- The maximum chromium level was 34 $\mu\text{g/l}$, and the average was 2 $\mu\text{g/l}$; none of the samples exceeded the chromium maximum standard of 50 $\mu\text{g/l}$. Similar observations are applicable to zinc and cadmium.
- The maximum and average lead levels were 389 $\mu\text{g/l}$ and 9 $\mu\text{g/l}$, respectively; only 3% of the samples exceeded the limit of 100 $\mu\text{g/l}$ for Pb.
- The average metal levels observed for homes with plastic plumbing were generally lower than those observed for galvanized pipes.
- The observed levels of metals were the result of corrosion and leaching from the distribution network and the in-house plumbing. In many houses the majority of the metal concentrations are contributed by the distribution network.
- Positive correlations were observed between trace element levels and water characteristics. pH, hardness and alkalinity seem to influence the levels of trace elements, with levels of iron clearly elevated with decreasing water pH and alkalinity.
- A general trend of higher trace element concentrations with increasing plumbing age was observed. The effect was more pronounced in the case of iron compared to copper.

Recommendations

The results of this preliminary investigation clearly support the need for a more comprehensive investigation covering more sampling locations of the city of Riyadh. It is also worth noting that some of the discrepancies acknowledged in the results are due to improper sampling by house owners. This necessitates the need for sample collection by trained personnel in any future studies.

The actual source of lead in the network water samples should be thoroughly investigated and steps should be taken to control contamination of water by lead.

Acknowledgement. The authors would like to acknowledge the contribution of Engineer Salah Abdullah Al-Khonaine who worked on the initial part of this research for his B.S. degree senior project.

References

- [1] Beszedits, S. and Wei, N. *Removal of Heavy Metal from Wastewater*. Toronto: B & L Information Service, 1980.
- [2] Hammer, M.J. *Water and Wastewater Technology*. New York: John Wiley & Sons, 1986.
- [3] National Academy of Science. *Drinking Water and Health*. 1, Washington, D.C.: NAS, 1977.
- [4] Sandhu, S.S.; Warren, W.J. and Nelson, P. "Trace Inorganics in Rural Potable Water and Their Correlation to Possible Sources." *Water Research* 12, No. 4 (1978), 257-261.
- [5] Snoeyink, V.L. and Kuch, A. "Principles of Metallic Corrosion in Water Distribution Systems", *Internal Corrosion of Water Distribution System*. Denver, Colo: AWWA Res. Fdn., 1985.
- [6] Trussel, R.R. and Wagner, I. "Corrosion of Galvanized Pipe", *Internal Corrosion of Water Distribution System*. Denver, Colo: AWWA Res. Fdn., 1985.
- [7] Nefe, C.H. "Impact of Copper, Galvanized Pipe and Fittings on Water Quality." *Plumbing Materials and Drinking Water Quality: Proceedings of a Seminar*. EPA-600/9-85/007, 1985.
- [8] Schock, M.R. "Treatment of Water Quality Adjustment to Attain MCLs in Metallic Potable Water Plumbing Systems." *Plumbing Materials and Drinking Water Quality: Proceedings of a Seminar*. EPA 600/9-85/007, 1985.
- [9] Bailey, R.J., et al., *Lead Concentrations and Stagnation Time in Water Drawn Through Lead Domestic Pipes*. UK: Centre, Water Research, 1986.
- [10] Karalekas, P.C. Jr.; Ryan, C.R. and Taylor, F.B. "Control of Lead, Copper, and Iron Pipe Corrosion in Boston." *Jour. AWWA*, 75, No. 2 (1983), 92-102.
- [11] Lelyved, H.V. ED. *International Symposium on Water Supply and Health Science of the Total Environment*. 18 Amsterdam: Elsevier, 1981.
- [12] *Standard Methods for the Examination of Water and Wastewater*. 16 ed. Washington, DC: APHA-AWWA-WPCF, 1985.
- [13] Saudi Arabian Standards Organization. *Bottled and Unbottled Drinking Water Standards*. Riyadh: SASO, 409 (1984), 2-5.
- [14] Goyen, R.A. and Mehlman, M.A. *Toxicology of Trace Elements*. Washington, DC: Hemisphere, 1977.
- [15] Lee, R.G.; Becker, W.C. and Collins, D.W. "Lead at the Tap: Sources and Control." *Jour. AWWA*, 81, No. 7 (1989), 52-62.
- [16] Pontius, F.W. "The New Lead and Copper Rule." *Jour. AWWA*. 83, No. 7 (1991), 12-20.
- [17] Twort, A.C.; Law, F.M. and Gowley, F.W. *A Textbook of Water Supply*. London: Edward Arnold, 1963.
- [18] Train, R.E. *Quality Criteria for Water*. Kent: Castle House, 1976.

تركيزات العناصر المعدنية الثقيلة في مياه الشرب داخل المنازل بمدينة الرياض

عبدالله محمد الرحيلي و محمد مصباح الدين

قسم الهندسة المدنية، كلية الهندسة، جامعة الملك سعود، ص.ب ٨٠٠،

الرياض ١١٤٢١، المملكة العربية السعودية

(استلم في ١٨/١١/١٩٩٢م؛ قُبل للنشر في ٢٢/٦/١٩٩٣م)

ملخص البحث. تم خلال هذا البحث جمع عدد ٣٢٠ عينة مياه شرب من ٤٠ منزلاً في مدينة الرياض وتحليلها لتقدير تركيزات العناصر المعدنية الثقيلة: الحديد، النحاس، الكروم، الرصاص، الزنك، والكاديوم، ولدراسة العلاقات المحتملة بين هذه التركيزات ونوعية الأنابيب المستخدمة وعمرها وخصائص المياه. وقد تم مقارنة تركيزات العناصر المذكورة مع المواصفات القياسية الصادرة عن الهيئة العربية السعودية للمواصفات والمقاييس.

ومن دراسة النتائج تبين أن ٨٨٪ من المنازل التي تم دراستها تستخدم أنابيب من الحديد المجلفن، بينما استخدمت الأنابيب البلاستيكية (ب ف س) في ١٠٪ من المنازل والأنابيب النحاسية في ٢٪ فقط. وقد وجد أن تركيزات العناصر الثقيلة في مياه المنازل ذات الأنابيب الحديدية أكبر منها في مياه المنازل ذات الأنابيب البلاستيكية أو النحاسية، وقد تجاوز ٣٤٪ من عينات المياه الحد المثالي لتركيز الحديد، كما تجاوز ٢٣٪ منها الحد المثالي للنحاس، وتجاوز ٣٪ من العينات الحد الأقصى للرصاص. ولم يتجاوز أي من العينات الحدود المثالية للكروم والزنك والكاديوم.

وذلك الدراسة على أن هناك علاقة بين خصائص المياه وتركيزات المعادن الثقيلة وأن التركيزات العالية لبعض هذه المعادن كانت نتيجة لعمليات التآكل والإحلال للشبكات العامة والشبكات المنزلية.