Maximum allowable values of the heavy metals in recycled water for household laundry

Bandita Mainali[a], Thi Thu Nga Pham[a], Huu Hao Ngo[a]*, Wenshan Guo[a],

[a] Centre for Technologies in Water and Wastewater, School of Civil and Environmental Engineering,

University of Technology, Sydney,

NSW 2007, Australia

*Corresponding author: h.ngo@uts.edu.au, Telephone: 61-2-95141693, Fax: 61-2-9514-2633

ABSTRACT

Household laundry as a new end use of recycled water in dual reticulation systems has a great potential as the significant amount of potable water from urban households can be saved. However, there is still no sufficient evidence and supporting recycled water quality guidelines for this particular use. A key gap in knowledge is the impact of heavy metals in recycled water on clothes and washing machines. Thus, this study aims to determine the maximum allowable values (MAVs) of the heavy metals Iron (Fe), Lead (Pb), Zinc (Zn), Copper (Cu), and Manganese (Mn) in recycled water for washing clothes in washing machines. Six different concentrations of each targeted metals were prepared in tap water for the washing machine experiments. The tearing/ tensile strength tests were used for the assessment of cloth durability. MINITAB 16 as a statistical tool was used and ANOVA one way test was applied for the significance analysis (Turkey's test $p < 0.05$). The results show that the MAVs of the heavy metals Fe, Pb, Zn, Cu and Mn were found to be 1mg/l, 1mg/l, 10mg/l, 5 mg/l and 1 mg/l respectively in terms of cloth durability.

Author keywords: Recycled water, heavy metals, washing machine, clothes

1. Introduction

Rapid urbanization all around the world in conjunction with the climate change and water pollution leads to the increasing demand for water which has begun to outstrip the available supplies. Sydney, Mexico city, Californian cities, Jakarta, Beijing, Tokyo and many other are some of the urban cities of the world where urban water demands have reached the capacity of the existing water supply system. Huge demand on cities' water supply systems posed by emerging climate change and increasing population impels to develop new water resources (Miller, 2005) and new action plans with the aim of sustainable water management while meeting the customer demands (Henderson et al., 2009). Not only in the dry regions, but even in countries with high rainfall such as Japan and England, the need of developing new water resources is immensely observed (Tillman et al., 1999; Dixon et al., 1999; Ogoshi et al., 2001; Janosova et al., 2005). In line to this, recycled water as an alternative source has been globally recognised and has become a priority for the future sustainability. Persisting and increasing water stress attribute to the increased demands on water utilities to develop urban recycled water. Dual reticulation systems have already been introduced in many cities in the world including Australia and this is likely to expand in many other cities in the future (Mainali et al., 2011). The existing dual reticulation schemes in Australia include Rouse Hill (Sydney), Newington (Sydney), Mawson Lakes (Adelaide), New Haven Village (Adelaide), Aurora (Melbourne), Marriott Waters (Melbourne) and Pimpama Coomera (Gold Coast) (Radcliffe 2004; Hurlimann 2008; Willis et al., 2010). A study by Willis et al. (2011) analysed the effective potable end use water savings in a dual reticulated supply areas of Pimpama Coomera region, Gold Coast, Australia. The study revealed significant reductions in peak potable water demand (32%) in dual reticulated supply areas when compared with single reticulated supply areas. Rouse Hill and New Haven Village have been known with savings between 35–50% of potable water (Sydney Water, 2008, Fearnley et al., 2004). The end use of recycled water in urban communities however has been confined to toilet flushing, garden irrigation and car washing. Developed and proposed dual reticulation schemes in urban areas demand more end uses of the recycled water for the substantial replacement of potable water with recycled water to ensure system optimisation and the sustainability of water supplies (Mainali et al., 2011). Considerable amount of drinking water from urban households can be conserved provided washing machine as a new end use of recycled water. A world wide survey conducted by Pakula and Stamminger (2010) revealed that the volume of water used for laundry washing significantly influences the total water consumption of households in most of the countries. NSW State of the Environment Report on typical water usage in Sydney metropolitan households dictates that the laundry use consumes up to 20% of total water demand of households (Ngo et al., 2009). However, sufficient investigation and study in regards to the laundry use of recycled water is not observed to the required extent and hence until today there is no sufficient evidence and supporting recycled water quality guidelines for this particular use (O'Toole et al., 2008; Pham et al., 2011, Mainali et al., 2011). There has been no information of this new end use of recycled water in the Australian guidelines (Hurlimann and McKay, 2006; Mainali et al., 2011). Moreover, the effects of various heavy metals present in recycled water on clothes and washing machines have not been reported to a required extent (Ngo et al., 2009).

Dolnicar and Schäfer (2009) advocated that general public who are the ultimate end users are found to have very less information about recycled water. Advanced wastewater technology in today's world can result the recycled water quality almost the same as that of drinking water. However, the "brand image" as advocated by Dolnicar and Schafer (2009) plays a huge negative role for the easy acceptance. Community surveys commissioned by many researchers (Dolnicar and Saunders, 2006; Roseth, 2008; Pham et al., 2011) shows support for the concept of using recycled water in washing machines. However, amongst the concerns raised by the participants were the effects of recycled water on public health, aesthetics and discolouration of laundry, cloth as well as machine durability. O'Toole et al. (2008) in their study investigated the microbiological safety of using recycled water in washing machines and concluded that highly treated recycled water used for machine washing would not lead to the transmission and consequent exposure of users to micro-organisms likely to cause enteric diseases thus addressing one of the important concerns raised by the community. However, in addition to health issue, as revealed from community attitude surveys, general public are equally concerned about the durability and aesthetic appearances of cloth and washing machine. Recycled water sources range over a broad spectrum of chemical quality depending upon the source of the recycled water and the degree of treatment (Radcliffe, 2004). Such water may contain slightly higher concentrations of heavy metals compared to the potable water. The water with higher concentrations of heavy metals may be corrosive or aggressive in nature. As a consequence, the cloth durability may not sustain its usual life span and perhaps more importantly, neither does the washing machine. For that reason, to come up with the clear and concise results to develop the sense of belief among the general public, this study was carried out for predicting the long term effects on the durability of cloth samples and observing the long term effects like scaling or corrosion of washing machines due to the varying concentrations of heavy metals.

Fabric utility parameters most often depend on its mechanical properties. Tensile strength and tearing strength both are the most important strength parameters of cloth fibres exhibiting the durability of the cloth material (Witkowska and Frydrych, 2005). The lifespan of a textile product is directly related to the number of wash cycles it can endure. Therefore, tensile and tearing strength tests of cloth samples washed in tap water and various concentrations of aqueous solutions after various wash cycles have been carried out and a comparative study was done. MINITAB 16 as a statistical tool was used and ANOVA One way test was applied for the significance analysis (Turkey's test $p<0.05$). One-Way ANOVA was used to compare the means of three or more groups to determine whether they differ significantly from one another.

According to the Australian guidelines for drinking water (ADWG, 1996), staining of sanitary ware and laundry is more likely to occur at Cu concentrations above 1 mg/l, Mn concentrations above 0.1mg/l, Fe concentrations above 0.3mg/l and Zn concentrations above 3mg/l. In addition to this, Fe, Mn and Zn are the heavy metals which have minor contributions on total hardness of water (WHO 2011). Therefore the heavy metals Iron (Fe), Zinc (Zn), Lead (Pb), Copper (Cu) and Manganese (Mn) are selected as the first targeted study elements for this research. Robust guidelines presenting the MAVs of heavy metals in recycled water for washing clothes will not only ensure fewer problems with clothes washing but also develop a sense of belief among the recycled water users. This will encourage beneficial and sustainable use of more recycled water by maximising the reuse of recycled water through minimising and managing any risks associated with its use. This paper, therefore, aimed to inform future recycled water quality guidelines to support the use of recycled water in washing machines.

2. Methodology

2.1.Experimental set up and aqueous solution preparation-

The laboratory-scale experimental unit consists of two main components, namely a feeding system (water tank and feed pump) and a washing machine. The experiments were designed for estimating the concentration response to risks caused by the contaminants in terms of appearance, stains on fixtures and clothing, odour, white deposits on fixtures, hard-to-lather soap, corrosion of washing machine etc. A single component (individual element) based aqueous solution with various concentration of the component was prepared with tap water for all targeted study elements. The concentration variation was formulated according to a thumb rule of 20 times the normal availability of that element in normal drinking water (WHO, 2004; ADWG, 2004; EPA, 2011). In addition, the normal trend of availability of these heavy metals in the recycled water supplied in dual supply systems of few suburbs in

Sydney (Storey, 2009) was used as reference value and a thumb rule of 10 times those values was used for pre-determining the tested concentration.

For instance, the maximum contaminant level of Fe in drinking water according to EPA is 0.3 mg/l (Colter and Mahler, 2006). Normal availability of Fe in potable water is 0.02mg and recycled water is 0.04mg/l (Storey, 2009). Therefore, the concentration range from 0.1mg/l to 6mg/l has been chosen for investigations with Fe. It has been suggested that taking into account the recent studies on humans, the derivation of a guideline value of Zn is not required at this stage of time. However, drinking-water containing Zn at levels above 3 mg/l may not be acceptable to consumers. According to the WHO (2003), drinking water containing Zn at levels above 3 mg/l tends to be opalescent. The ADWG (2004) also suggested only the aesthetic-based guideline value which is 3mg/l of Zn. Hence, for our research purpose the concentration range from 1mg/l to 60mg/l was chosen for investigations with Zn. The health-based guideline value of Pb according to WHO standards and ADWG is 0.01mg/l (WHO, 2004; ADWG, 2004). The concentration range from 0.01mg/l to 2mg/l was also selected for investigations with Pb. Similarly, the concentration range from 0.01mg/l to 2mg/l has been chosen for investigations with Mn while the concentration range from 1mg/l to 20mg/l has been chosen for investigations with Cu (Mainali et. al., 2012).

Table 1.

There are numerous types of cloth fabrics. Basically, five types of representative cloth textile are selected for the tests. They are Polyester (Po), Satin (S), Polycotton (PoC), Denim (De) and Cotton (C). The most sensitive colour (white coloured fabrics) was employed to be washed in the prepared aqueous solution. The selected test cloth materials were applied to wash in normal tap water and the various prepared aqueous solutions of the heavy metals of various concentrations. The details are summarized in Table 2. According to the International fair claims guide for consumers textiles products, assuming normal wear, most of clothes are expected to last somewhere between two and three years (http://www.drycleaningcomplaints.com/Fair%20Claims%20Guide=DIA.pdf). This leads to around 50 laundering of the cloth fabrics in an average during its normal life span. Therefore, washing of the clothes was performed up to 50 wash cycles in tap water as well as all other aqueous solution of heavy metals. After washing, the test samples were progressed for drying.

Table 2.

2.2 Testing methods -

To investigate the effects of aqueous solutions on cloth durability, tearing strength tests and tensile strength tests of the washed cloth samples were carried out using Instron 6022 10kN Universal Testing Machine according to the ASTM standards (ASTM, 2006; ASTM, 2010). The washed cloth samples were prepared according to the test standard as per ASTM. Constant-rate-of-extension (CRE) tensile testing machine used was moved with a speed of 300mm ± 10mm. For the tensile strength test (strip method), each specimen was cut with the width of 25 mm (±1) and at least 150 mm in length with theular use. Specimens were cut with their long dimensions parallel to the warp (machine) direction. A test specimen was clamped in a tensile testing machine and a force was applied to the specimen until it was torn off. Values for the breaking force and elongation of the test specimen were obtained from a computer interfaced with the testing machine. Similarly, for tearing strength tests, each specimen was cut with the sample size of 75 mm by 200 mm. It was made sure that specimens were cut with their long dimensions parallel to the cross-machine direction. A preliminary cut of 75 mm (lengthwise) was made at the centre of the 75 mm width. The two cut edges of the specimen were then clamped in a tensile testing machine and a force applied to the specimen. Firstly, the tensile and tearing strengths of original samples were measured. Similarly, tensile and tearing strengths of the same cloth samples washed in tap water and aqueous solutions of various concentrations of heavy metals were then determined. Basically, the measurement of tensile and tearing strength of the samples at 1^{st} wash, 5^{th} wash, 10^{th} wash, 20^{th} wash, 30^{th} wash and 50^{th} wash were conducted. The specific maximum concentration of heavy metals up to which there is no significant reduction of tensile and tearing strengths of cloth samples compared to the tensile and tearing strengths of same cloth samples washed in tap water for same number of wash cycles, is referred as the maximum allowable value of that heavy metal. ANOVA One way test (Turkey's test $p<0.05$) was applied to see if the values differ significantly or not. Visual inspection of washing machine is carried out for the signs of pitting, crevice corrosion, stress- corrosion cracking or other localised corrosion.

3. Results and discussion

3.1 Tensile and tearing strength

To investigate the effects on cloth durability, it is important to analyse the change in the tensile and tearing strengths of the cloth samples. The cloth samples were washed in normal tap water for number of cycles. Similarly, the cloth samples were washed in aqueous solutions of various concentrations of heavy metals Fe, Zn, Pb, Cu and Mn for same number of wash cycles. The tensile and tearing strength tests were then employed and comparative study of the tensile and tearing strengths of cloth samples washed in tap water and in various concentrations of heavy metals at same number of wash cycles were carried out.

The comparative study of tensile and tearing strengths of the cloth samples (De, S, Po, Co, PoC) washed in tap water at different wash cycles (1^{st}, 5^{th}, 10^{th}, 20^{th}, 30^{th} and 50^{th}) and the cloth samples washed in various concentration of Fe, Pb and Zn at respective number of wash cycles were conducted. No significant variation of tensile strength was observed in the first few cycles of washing. The percentage change in tensile/tearing strengths of the cloth samples after 10th washing was therefore considered for the analysis. Denim and Satin seem to be the strongest cloth fibres (Tensile strength>500N) in terms of tensile strength test followed by Polycotton, Polyester and Cotton (Tensile strength<200N) (Table 3). In terms of tearing strength (Fig 1a, b and c) Denim is the strongest cloth type (>60N) while Polyester and Satin seem to have similar tearing strengths (≈ 40N). Polycotton which holds its position as third strongest cloth type in terms of tensile strength was observed to hold fourth position in terms of tearing strength (≈25N). Cotton was found to have the lowest tearing strength (<15N).

3.1.1. Tensile strength

The results of mean values of tensile strengths of cloth samples washed in various concentrations of aqueous solutions (Fe, Pb and Zn) at 10th wash cycles are summarized in Table 3.

Table 3.

Table 3 shows that most of cloth types for 10 wash cycles in all six concentrations of Fe, there was less than 5 % (in an average) reduction in tensile strength of cloth samples washed in tap water. They were observed to have almost the same tensile strength as that of the cloth sample washed in tap water or even more. For more reliable results, ANOVA- One way test ($p<0.05$) was employed to test the significance difference of the tensile strengths of the cloth samples washed in tap water and in various aqueous solutions of Fe. No significance difference in the tensile strengths of all cloth samples washed in Tap water (TW), 0.1mg/l and 0.3 mg/l of Fe was observed. Cloth sample Polyester and Polycotton did not show any significant change in tensile strength compared to that of TW up to 1mg/l (≤1mg/l) of Fe concentration (Turkey's test $p<0.05$). For Cotton cloth sample, up to 3mg/l of Fe solution, no significant reduction of strength was observed. For Denim and Satin, at Fe concentration of 1 mg/l or above (≥1mg/l), there was significant change in the tensile strengths compared to the same washed in tap water. However, these cloth samples were found to have increased tensile strength but no reduction. Hence, from this analysis, it is summarised that up to 1 mg/l of Fe solutions, there is no negative impacts on the tensile strengths of cloth samples compared to that of TW.

The samples washed in higher concentrations of Fe (≥0.3mg/l) however were observed to turn as brownish yellow in appearance, suggesting the impact on aesthetic appearance of cloth samples.

Table 3 further indicated that all cloth samples washed in Pb solutions showed a trend of reduced tensile strengths with the increase in concentration of Pb. From the significance analysis ($p<0.05$), no significant reduction in tensile strength for cloth Satin was observed at 0.5 mg/l of Pb (≤0.5mg/l). 1mg/l of Pb (≤1mg/l) was found to be safe for the cloth sample Polycotton and Denim. Up to 2mg/l of Pb (≤2mg/l), there was no significance difference in tensile strength of cloth samples Polyester and Cotton compared to that of TW. Hence, 1mg/l of Pb is recommended safe in terms of tensile strength.

The change in tensile strengths of cloth samples Denim and Satin were significant at Zn concentration above 30mg/l. However, all other cloth samples Polyester, Polycotton and Cotton washed in tap water and in various concentrations of Zn solutions up to the 10^{th} wash cycle showed no significant reduction in tensile strengths (Turkey method $p<0.05$).

Therefore, 60mg/l of Zn seems to be safe in terms of tensile strength test up to 10 wash cycles.

3.1.2 Tearing strength

The results of mean values of tearing strengths of cloth samples washed in various concentrations of aqueous solutions (Fe, Pb and Zn) at 10^{th} wash cycles are summarized in Figure 1.

Fig.1

The results from ANOVA One way test ($p<0.05$) as shown in Fig.1a revealed that there was no significant difference in tearing strength of the all cloth samples washed in Fe concentrations 0.01mg/l, 0.03mg/l and 1mg/l compared to the same cloth samples washed in tap water. Cloth samples Polycotton and Cotton washed in all six concentrations of Fe had no significant reduction in tearing strengths when compared to that of TW. Similarly, no significant difference in tearing strengths of cloth samples (Denim washed in Fe 0.3mg/l, Satin washed in Fe 1mg/l and Polyester washed in Fe 3mg/l respectively) was observed when compared with those of TW. At 1mg/l of Fe, all cloth samples have no significant reduction in tearing strengths except De, however at higher concentration (above 1mg/l) of Fe, there were found significant reduction in tearing strength. Therefore, 1mg/l of Fe concentration in terms of tearing strength of cloth samples is recommendable.

Results from tearing strength analysis (Fig.1b) showed that no significant reduction in the tearing strength of cloth samples Cotton, Polycotton and Denim washed in various concentration of Pb (up to 2mg/l) compared to the tearing strengths of cloth samples washed in tap water. For cloth samples Satin and Polyester, no significant difference was observed up to 1mg/l of Pb. Therefore, in terms of tearing strength of cloth samples, 1 mg/l of Pb is recommended.

From Fig 1c, all cloth samples at all concentrations did not show significant difference (Turkey's test $p<0.05$) in the strength at 10^{th} wash cycles observation, giving the idea that 60mg/l of Zn is safe to use in washing machine for washing clothes in terms of cloth durability.

3.1.3 Long wash cycle tests

For further assurance, the comparative study of tearing and tensile strengths of cloth samples washed in tap water at 20^{th}, 30^{th} and 50th wash cycles and cloth samples washed in recommended values of Fe (1mg/l), Pb (1mg/l) and Zn (60mg/l) as above were carried out. Figures 2 and 3 represents the comparative study of tensile strengths and tearing strengths of cloth samples washed in recommended concentrations of heavy metals and washed in tap water for different wash cycles. The average mean value of change in % of tensile and tearing strengths of cloth samples washed in recommended values of heavy metal solutions compared to the tensile and tearing strengths of cloth samples washed in tap water at various wash cycles were analysed. Few cloth samples were observed to have better tensile and tearing strengths compared to the tensile and tearing strengths of cloth samples washed in tap water for same number of wash cycles.

Fig. 2 and Fig.3

There was no significant reduction of tearing and tensile strengths (<5%) of all cloth samples at 1mg/l of Fe for all cycles of washings (Turkey's test $p<0.05$). The analysis further revealed that with the increasing number of wash cycles, the difference of the tensile strength and tearing strength was significant for the concentration of Fe above 1mg/l. Therefore, 1mg/l of Fe is recommended to be the maximum allowable concentration in terms of tensile and tearing strength.

Similarly, to assure 1mg/l of Pb is safe without harsh impacts on the cloth's strengths, comparative study of tensile and tearing strength between the cloth samples washed in tap water at different wash cycles (10^{th}, 20^{th}, 30^{th} and 50^{th}) and the cloth samples washed in aqueous solution of 1mg/l of Pb was carried out. No significant reduction (Turkey test $p<0.05$) of tensile or tearing strengths of all cloth samples at 1mg/l of Pb for all cycles of washings was observed (Figure 2 b and c). Therefore, 1mg/l of Pb is recommended to be the maximum allowable concentration in terms of tensile and tearing strength.

For further confirmation that 60mg/l of Zn is safe without harsh impacts on the cloth's strengths, comparative study of tensile and tearing strength between the cloth samples washed in tap water at different wash cycles (10^{th}, 20^{th}, 30^{th} and 50^{th}) and the cloth samples washed in aqueous solution of various concentrations of Zn was also conducted. The analysis revealed that with the increasing no of wash cycles, at 30mg/l and 60 mg/l of Zn, the reduction in tearing and tensile strength of cloth samples were significant. Only up to 10 mg/l of Zn (≤10mg/l Zn), even at 50^{th} wash cycle, there was still no significant reduction of tensile or tearing strengths of all cloth samples compared with the cloth samples washed in tap water for same number of wash cycles. Therefore, 10mg/l of Zn is recommended to be the maximum allowable concentration in terms of tensile and tearing strength.

The similar analysis was carried out for the heavy metals Cu and Mn and the results indicated that MAV for Cu and Mn in terms of tensile and tearing strength is 5mg/l and 1 mg/l respectively (Mainali et al., 2012).

3.2 Visual inspection of washing machine

Long term visual inspection of washing machine was carried out. Washing machine was visually examined for signs of pitting, crevice corrosion, stress- corrosion cracking or other localised corrosion. 50 wash cycles of cloth samples in almost 30 different concentrations of Fe, Pb, Zn, Cu and Mn (about 600 wash cycles) were carried out. The observation revealed no signs of corrosion or stain on the washing machine.

4. Conclusion

To establish the guidelines for the new use of recycled water for household laundry, the effects of heavy metals (Fe, Pb, Zn, Cu, Mn) in terms of cloth quality and washing machine durability are one of the essential investigations. The specific findings are as follows:

- 1mg/l of Fe, 1mg/l of Pb, 10mg/l of Zn, 5mg/l of Cu and 1 mg/l of Mn are the MAVs in recycled water for using in washing machine in terms of tensile and tearing strengths.
- No signs of corrosion on washing machine throughout the washing of cloth samples up to 50 cycles with varying concentrations of Fe, Pb, Zn, Cu and Mn indicated that even at higher concentrations of these heavy metals, there is no impact on the machine's aesthetic appearance and functional system.
- Visual inspection of cloth materials washed in higher concentrations of Fe, Cu and Mn were observed to be very different than the normal. Therefore, to address the aesthetic effects of these heavy metals on cloth, SEM images of the cloth samples and integrating spectrometer analysis of the cloth samples are recommended.

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Table 1. Concentration range of heavy metals in drinking water.

Heavy metals	WHO, 2004 (Health/Aesthetic) (mg/l)	ADWG, 2004 (Health/Aesthetic) (mg/l)	EPA, 2011 (mg/l)	Concentration for lab investigations (mg/l)
Fe	0.3	0.3	0.3	0.1-6
Zn	3	3	3	1-60
Pb	0.01	0.01	NA	0.01-2
Mn	0.05/0.4	0.5/1	NA	0.01-2
Cu	2	2/1	1.3	1-20

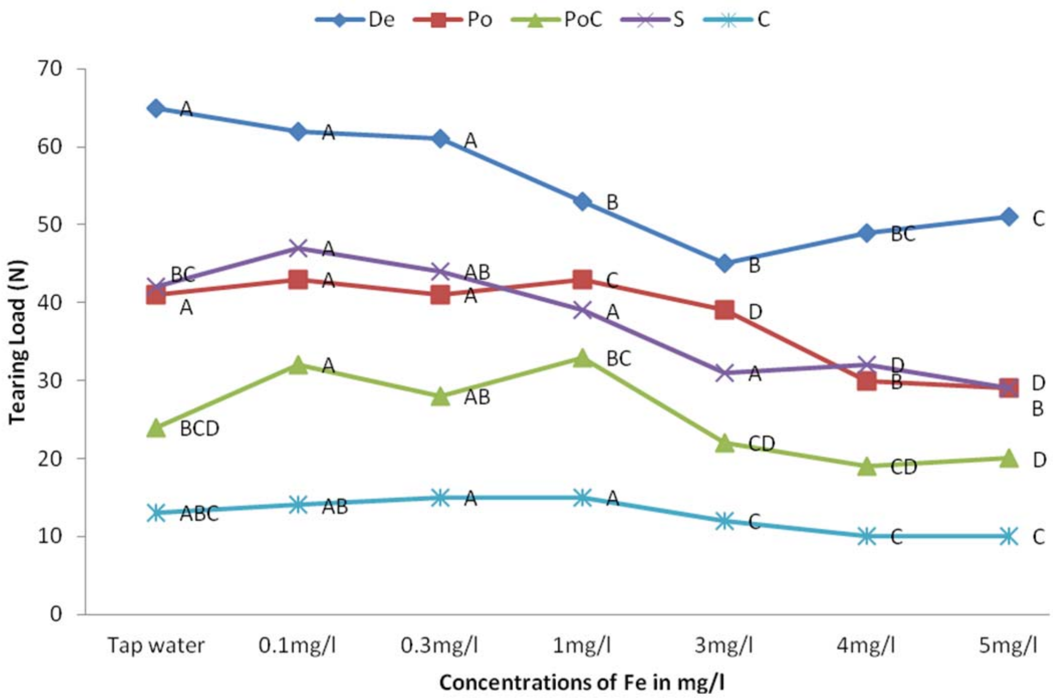
Table 2. Summarized details of the lab set up.

Washing machine type	Simpson (5.5 kg), Top loading
Mode of washing	Light and fast
Washing powder	Omo
Water supply	Cold form of supply of tap water
Size of cloth swatches	25cm x 20cm
Cloth category	Polyester (Po), Satin (S), Polycotton (PoC), Denim (De) and Cotton (C)

Table 3. Tensile strengths (in N) with Fe, Zn and Pb washings at 10^{th} wash cycle.

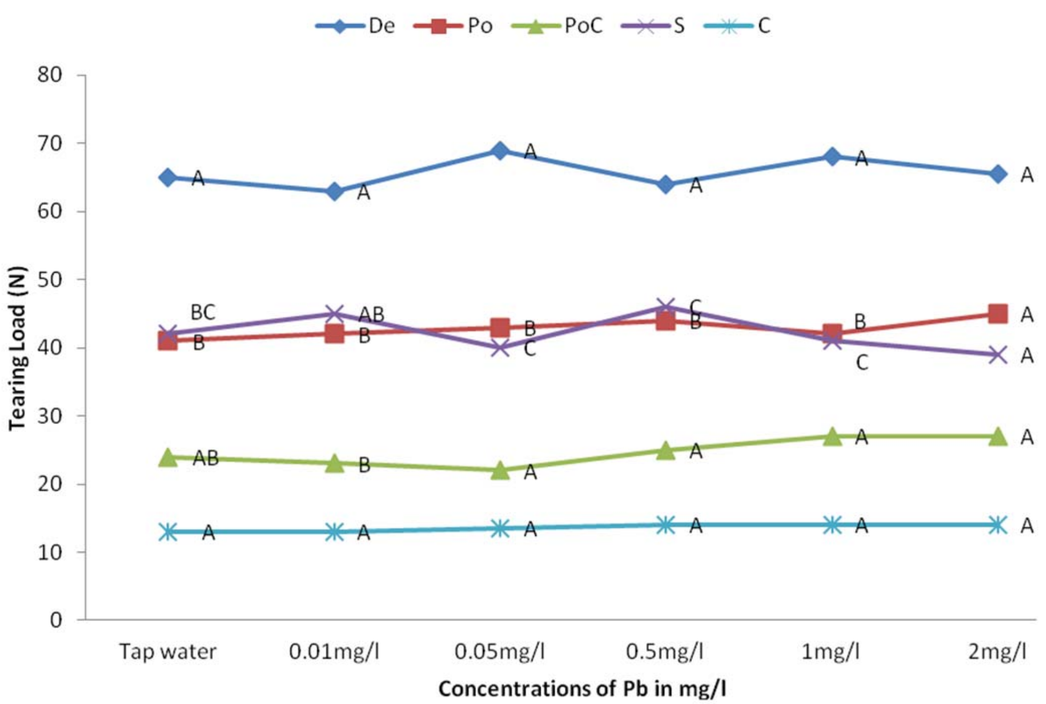
Heavy metals	Cloth / Conc. (mg/l)	De	Po	PoC	S	C
	TW	531^{C}±9.5	315^{A}±3.9	398^{CD}±10.5	551^{C}±6.3	151^{A}±6.3
Fe	0.1	530^{C}±10.1	308^{ABC}±7.2	392^{D}±5.4	550^{C}±6.1	152^{A}±4.3
	0.3	538^{BC}±7.3	307^{ABC}±6.2	402^{C}±8.8	545^{C}±5.0	157^{A}±4.6
	1	541^{B}±7.8	311^{AB}±5.3	399^{CD}±4.1	560^{B}±5.5	156^{A}±6.2
	3	557^{A}±4.4	300^{CD}±4.2	411^{B}±7.2	569^{A}±2.5	150^{A}±4.3
	4	554^{A}±4.9	299^{D}±10.8	431^{A}±4.7	565^{AB}±4.4	141^{B}±4.1
	5	551^{A}±3.9	304^{BCD}±5.1	434^{A}±2.7	566^{AB}±3.5	145^{B}±4.2
	TW	531^{A}±9.5	315^{AB}±3.9	398^{AB}±10.5	551^{A}±6.3	151^{AB}±6.3
Pb	0.01	524^{AB}±18.3	309^{B}±11.8	388^{BC}±11.2	548^{A}±9.7	154^{A}±7.5
	0.05	522^{AB}±15.6	309^{B}±13.6	409^{A}±11.4	540^{AB}±14.8	150^{AB}±6.5
	0.5	520^{ABC}±17.6	305^{B}±13.4	388^{BC}±10.4	533^{BC}±6.9	144^{B}±7.3
	1	511^{BC}±14.6	308^{B}±12.7	385^{C}±8.0	529^{C}±6.3	145^{AB}±9.6
	2	503^{C}±12.5	297^{A}±15.8	379^{C}±9.4	528^{C}±7.5	146^{AB}±8.5
	TW	531^{AB}±9.5	315^{AB}±3.9	398^{A}±10.5	551^{A}±6.3	151^{A}±6.3
Zn	1	535^{A}±13.3	305^{B}±13.4	396^{A}±15.3	540^{AB}±11.5	149^{A}±9.7
	3	542^{AB}±11.8	301^{B}±13.8	388^{A}±23.0	555^{A}±16.5	144^{A}±10.9
	6	533^{AB}±12.5	304^{B}±14.3	387^{A}±15.9	557^{A}±10.2	145^{A}±11.1
	10	529^{AB}±9.0	319^{AB}±16.6	395^{A}±10.6	554^{A}±9.5	148^{A}±9.5
	30	519^{BC}±17.3	328^{A}±16.9	396^{A}±12.4	539^{AB}±19.7	145^{A}±9.1
	60	505^{C}±20.7	310^{AB}±15.9	392^{A}±16.4	527^{B}±20.1	147^{A}±9.2

Note: A, B, C, D represents the group according to ANOVA-One way analysis (Turkey's test $p<0.05$, $n=11$). The values sharing the same alphabets represent no significant difference in tensile strength. (±values are the standard deviations)



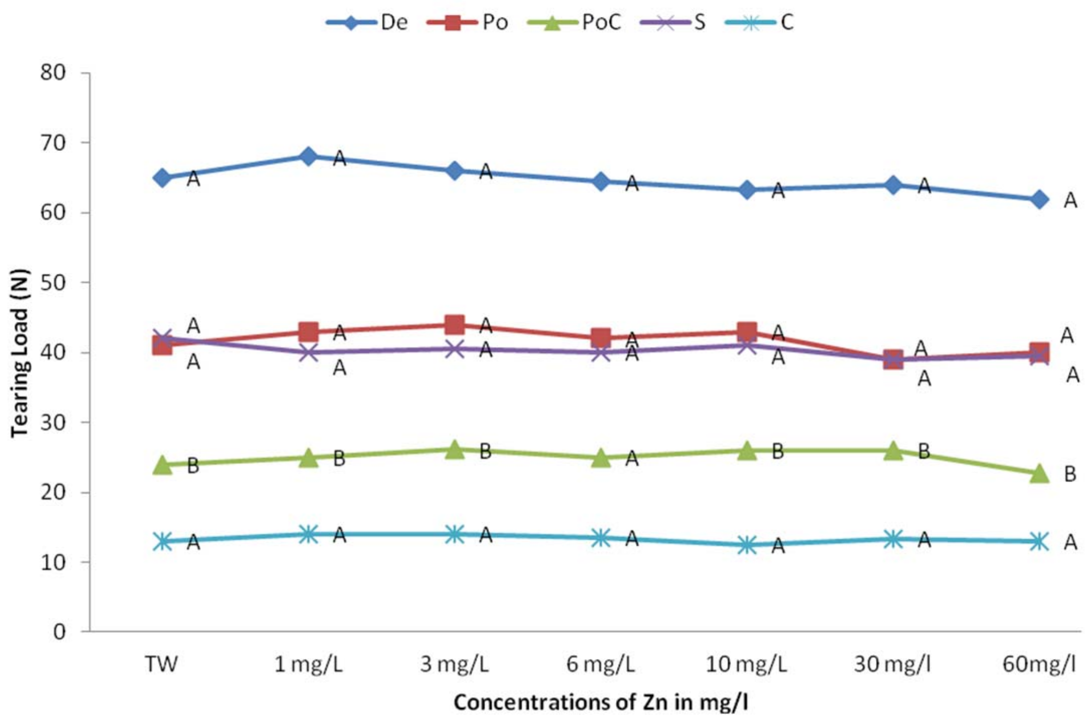
De
Po
PoC
S
C
Tearing Load (N)
Tap water
0.1mg/l
0.3mg/l
1mg/l
3mg/l
4mg/l
5mg/l
Concentrations of Fe in mg/l

(a)



De
Po
PoC
S
C
Tearing Load (N)
Tap water
0.01mg/l
0.05mg/l
0.5mg/l
1mg/l
2mg/l
Concentrations of Pb in mg/l

(b)



(c)

Figure 1 (a, b and c). Tearing strength of cloth samples washed in various concentration of Fe, Pb and Zn solutions and tap water.

Note: A, B, C, D represents the group according to ANOVA-One way analysis (Turkey's test $p<0.05$, $n=11$). The points sharing the same alphabets represent no significant difference in tearing strength.

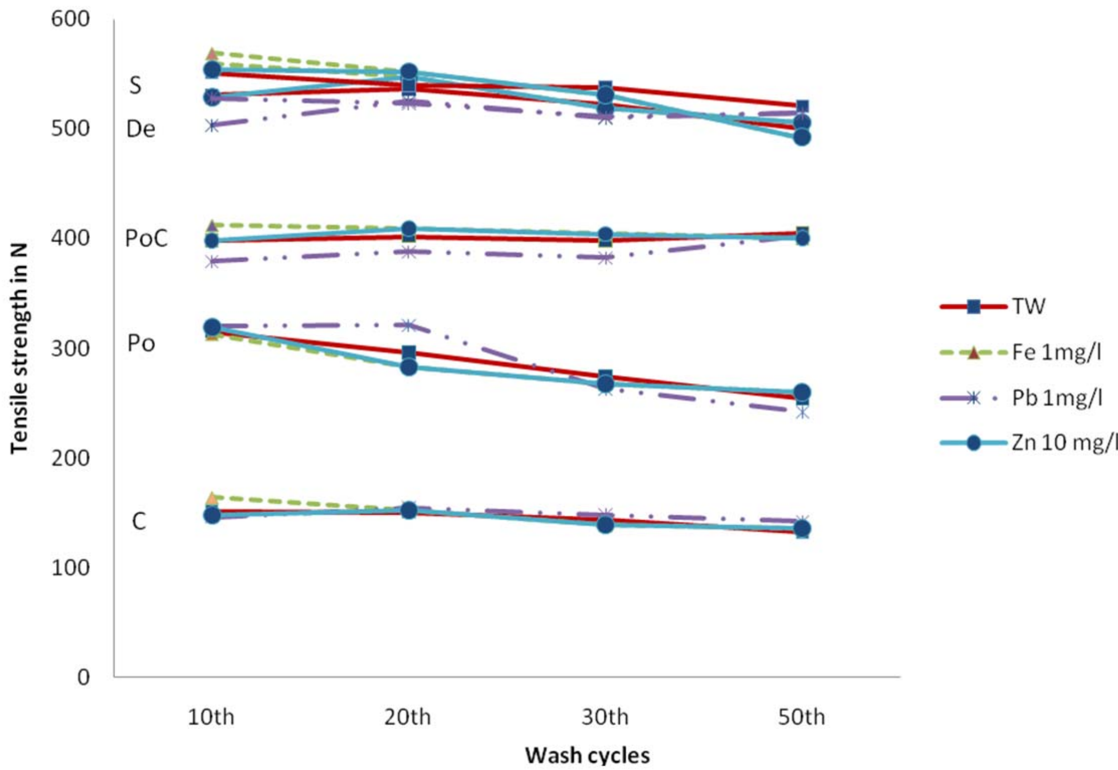


Figure 2. Comparative study of tensile strengths of cloth samples washed in tap water (TW), 1mg/l of Fe, 1mg/l of Pb and 10mg/l of Zn solutions at 10th, 20th, 30th and 50th wash cycles respectively.

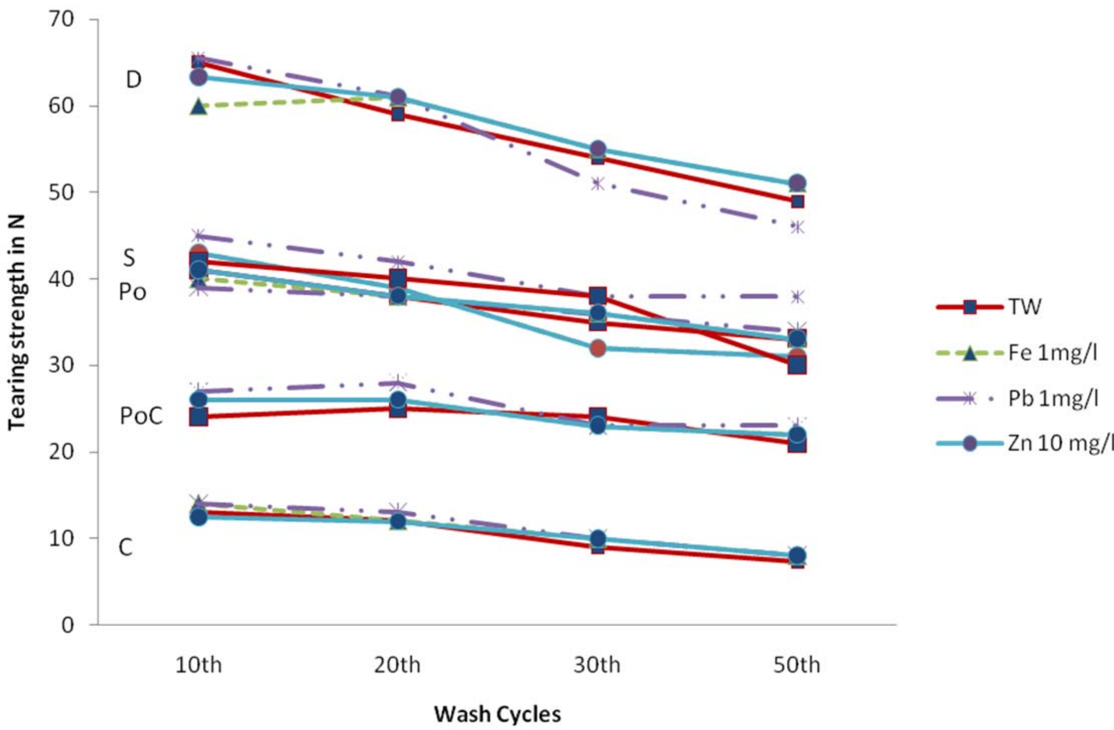


Figure 3. Comparative study of tearing strengths of cloth samples washed in tap water (TW), 1mg/l of Fe, 1mg/l of Pb and 10mg/l of Zn solutions at 10th, 20th, 30th and 50th wash cycles respectively.