

Physical Characteristics of Water Used by Haramaya University and the Effects of Heating and Cooling on the Amount of Extracted Solids

Mebratu Meselge, Gelana Amente* and Tesfahun Kebede

Haramaya University, College of Natural and Computational Sciences, P O Box 138, Dire Dawa, Ethiopia

Abstract: This study was conducted at Haramaya University to assess the levels of physical water quality parameters in water samples collected from four wells, the main water reservoir and taps delivering water to three zones of the campus. The physical water quality parameters examined were total solids, dissolved solids, suspended solids, turbidity, pH and electrical conductivity. Besides, heating and cooling temperatures at which most of the solids could be extracted were also tested. The results from the wells were compared pair-wise and likewise the results of each water sample from the three zones with the water sample from the main reservoir. One of the four wells (W3) and two of the distribution zones (Z1 and Z2) had total solids in excess of 1000 mg L⁻¹. All the sampling sites showed dissolved solids in excess of 500 mg L⁻¹. Suspended solids at all the sites accounted for less than 25% of the total solids. One of the wells (W3) showed significant difference ($P < 0.05$) from the rest in most of the physical parameters. Except this well, the rest were within the WHO limits with regard to total, dissolved and suspended solids. Two distribution zones (Z1 and Z2) showed significant differences ($P < 0.05$) from the reservoir in most of the physical parameters. Both heating and cooling showed effects on the amount of solids extracted from the water. From the temperatures tested, heating the water above 80 °C and cooling it to less than 15 °C resulted solid extraction of higher solids. Heating and cooling at temperatures close to these temperatures removed most of the cations that accounted for water hardness.

Keywords: Total Solids; Dissolved Solids; Suspended Solids; Turbidity; Electrical Conductivity

1. Introduction

Water needed for domestic use does not always occur in nature in sufficient quality, due to the presence of dissolved or suspended impurities in most natural water bodies (Goldface, 1999). The major fresh water sources for human use are surface water bodies such as rivers and lakes, and underground aquifers (groundwater).

Groundwater quality can be affected by various pollution sources. Hamilton and Helsel (1995) have indicated the connection between agricultural practice and groundwater pollution. Land application of waste or storm water may also have impact on groundwater quality.

Water quality is defined by its physical, chemical, and biological characteristics (FAO, 1998). The quality of water varies due to variation both in the natural geological and hydro-geological conditions and human impact. Water-soil interaction plays an important role in controlling the quality of groundwater. Some of the minerals found in groundwater are due to dissolution of minerals and weathering reactions taking place close to the earth's surface (Andualem, 2008). Well heads that are not well-protected can also let in some hazardous chemicals that are created either naturally or due to human activities (Hailemariam, 2010).

Physical testing of water for domestic use is necessary not only to assure its safety and palatability but also to determine treatment techniques (Avcievala, 1991). Water has a wide range of physical parameters with which its quality is gauged.

Total solids in water are generally found in the form of dissolved solids (DS), a portion that passes through a filter of 2 µm or smaller pore sizes (Sawyer *et al.*, 2003)

and suspended solids (SS), which are retained by the filter. Dissolved solids include inorganic salts, principally calcium, magnesium, potassium, sodium, bicarbonate, chloride, sulfate, and small amounts of organic matter that are dissolved in water (WHO, 2004). In domestic water, dissolved solids mostly originate from natural sources and vary considerably in different geological regions owing to differences in the solubility of minerals. The presence of high levels of dissolved solids in domestic water may be objectionable (WHO, 2004) and concentrations above 500 mg L⁻¹ may necessitate treatment (Sawyer *et al.*, 2003) since it may have adverse effect on the taste of drinking water.

Suspended solids in water systems reduce clarity and act as binding sites for toxic substances and lead to increased water temperature by absorption of sunlight (Manahan, 2000). Furthermore, these decrease the depth of water container while settling. Suspended particles regulate mineralization, oxygen consumption and concentration (Hakanson, 2005).

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through water sample. It is a measure of the cloudiness of water and is used to indicate water quality and filtration effectiveness. Turbidity is generally caused by total solids but primarily influenced by the amount of suspended solids in water (WHO, 2004). In natural water, turbidity is caused by the presence of compounds such as clay, mud, organic matter, bacteria, and algae. In the form of suspended particles, turbidity is associated with colloids and settleable particles. Hence, turbidity is basically used to measure the presence of colloids since true solutions and

*Corresponding author. E-mail: amentegelana@yahoo.com

coarse suspensions do not produce light scattering effect (Sawyer *et al.*, 2003). The standard for turbidity measurement according to Viessman and Hammer (2005) is a suspension of silica of specified particle size selected so that a 1.0 mg L⁻¹ suspension measures 1.0 NTU (Nephelometric Turbidity Unit).

Specific conductance (SC) is a measure of how well water can conduct electrical current (Lechevallier *et al.*, 1990). Conductivity increases with increasing amount and mobility of ions (Lehtola *et al.*, 2002). These ions come from the breakdown of compounds and conduct electricity because they are either negatively or positively charged when dissolved in water (Lee *et al.*, 2003). Therefore, SC is an indirect measure of the presence of dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron, and can be used as an indicator of water pollution (Murphy, 2007). Changes in conductivity of water sample may signal the changes in mineral composition of water's seasonal variation in reservoirs and pollution of water from other sources (AWWA, 2000).

Heating and cooling is one of the methods of extracting among others calcium and bicarbonate, which are responsible for water hardness. Both boiling and cooling result in coagulation of solid particles (Sawyer *et al.*, 2003). Boiling modifies the degree of hydration of solid particles and enables the particles to overcome the energy barrier. Cooling on the other hand, forces colloids to come close together (i.e., diminishes the diffuse layer thickness) so that the particles can coalesce after which they settle to the bottom of a container.

Haramaya University (HU) gets its water from several wells situated at different locations on and off campus. The levels of solid particles of these wells have not been scientifically tested so far. The solid contaminants may be from the water from the wells, from the reservoir in which the water is stored or from the distribution pipes most of which are generally old and leaky. This study

aimed at assessing the level of solid (dissolved and suspended) particles in water samples collected from four wells, the main water reservoir and taps delivering water to three zones of HU campus.

Accordingly, this study focused on three main objectives i.e., to, compare the physical quality of water obtained from four wells that serve the University community; compare the physical quality of water obtained from the three distribution lines with that of the main reservoir and finally, determine the optimum heating and cooling temperatures for removal (extraction) of extractable solid particles from the water so as to reduce the concentration of total solids.

2. Materials and Methods

2.1. Description of the Area

The study was conducted at Haramaya University, which is located at 510 km east of Addis Ababa. The site is located at an altitude of 2016-2087 meters above sea level (masl) with latitude of 9° N and longitude of 42° E. The mean annual maximum and minimum temperatures are 23 °C and 8 °C, respectively.

2.2. Sampling Location

In this study, a total of eight sampling points were selected to collect water samples. These included four water wells, a water reservoir and three water distribution zones (Table 1). All the wells are located on or very close to the campus. In addition to the wells, the other four sampling points were: the main reservoir (R) in which water from three wells (W₁, W₂ and W₄) are collected and water samples collected from taps of three zones (i.e., the west-zone distribution line (Z₁) serving student cafeterias and student dormitories, the south-zone (Z₂) serving staff cafeteria and the surrounding areas, and the east-zone (Z₃) serving the PhD students' residences).

Table 1. Information regarding the water wells and distribution zones.

Sampling point	Location	Depth (m)	Average discharge rate (L s ⁻¹)	Altitude (masl)	Latitude	Longitude
Well 1	Lakebed	77	6	2016	09° 24.605' N	042° 01.644' E
Well 2	Close to weather station	53	3	2024	09° 24.886' N	042° 01.174' E
Well 3	Near motor pool	39	1	2020	09° 25.370' N	042° 01.774' E
Well 4	Lakebed	*	*	2023	09° 24.040' N	042° 01.764' E
Reservoir	Main reservoir			2087	09° 25.603' N	042° 02.226' E
Zone 1	Student cafeteria			2059	09° 25.410' N	042° 02.102' E
Zone 2	Staff cafeteria			2047	09° 25.352' N	042° 02.258' E
Zone 3	PhD students residence			2064	09° 25.523' N	042° 02.377' E

*Even though the fourth well (W₄) does not belong to the University, water is obtained on daily basis for the University from this well; masl = Meter above sea level

All sampling points were selected to test the physical parameters of the groundwater. Sampling was made from each of the four wells (i.e., W₁-W₄) so as to assess the contamination status of water at the particular well before it is transferred into the main reservoir. Water samples were obtained from each well. Likewise,

samples of water were also collected from the three distribution zones (i.e., Z₁-Z₃) and compared with the sample from the main reservoir.

2.3. Sample Collection and Preparation

The water samples were collected once every week for a period of five weeks from each sampling point. A total of forty water samples were collected from the eight sampling points. Water samples from all the points were collected in two-liter plastic bottles for different water physical quality tests. Prior to sample collection, sampling bottles were washed with nitric acid and then rinsed with distilled water to avoid contamination. Sampling from the wells was done close to the sources. Reservoir sample collection was done by tying the sampling bottle using a clean rope and directly immersing the sampling bottle into the reservoir. For the distribution lines, water samples were taken directly from the water taps. The samples were then taken to the laboratory and were analyzed within a time limit of an hour of collection, except for the total, dissolved and suspended solids, which were analyzed within six hours of collection.

2.4. Sample Analysis

The collected water samples were analyzed for the important physical water quality parameters that include total solids, dissolved solids, suspended solids, turbidity, pH and electrical conductivity (WHO, 2004). Total solids and dissolved solids were determined by evaporation method. Since the total solids contain both dissolved and suspended particles, filtration technique was applied to separate the suspended particles. Centrifugation and gravity settlement methods were employed to separate suspended solids but both of them did not yield measurable amounts of suspended particles. Hence, determination of suspended solids (SS) was done by filtering 50 ml of stirred water by pre weighed filter paper. The pre weighed filter paper was wetted in distilled water and 50 ml of the stirred sample was filtered. Then the filter paper was transferred to evaporating dish and dried in an oven until the liquid completely evaporated. The filter paper was then removed from the desiccators and allowed to cool after which it was weighed. Finally, the weight of the suspended solid was calculated by subtracting the weight of the filter paper as:

$$\text{Suspended solids (mg L}^{-1}\text{)} = \frac{W_2 - W_1 \times 1000 \text{ (mg)}}{\text{Volume of sample used (ml)}} \quad (1)$$

where W_1 = weight of the filter paper (mg) and W_2 = weight of filter paper and dried residue (mg).

Determination of total solids (TS) was done using a 50 ml of stirred samples measured into a pre-weighed evaporating dish, which was then dried in an oven until the water completely evaporated. The dish was then transferred into desiccators and allowed to cool to room temperature and was weighed. The total solids was obtained using the relation:

$$\text{Total solids (mg L}^{-1}\text{)} = \frac{W_2 - W_1 \times 1000 \text{ (mg)}}{\text{Volume of sample used (ml)}} \quad (2)$$

where W_1 = initial weight of evaporating dish and W_2 = final weight (evaporating dish and residue).

For the determination of dissolved solids (DS) by gravimetric method, a portion of stirred water was filtered out and 50 ml of the filtrate measured into a pre-weighed evaporating dish. Following the procedure for the determination of total solids above, the dissolved solids' content of the water was calculated as:

$$\text{Dissolved solids (mg L}^{-1}\text{)} = \frac{W_2 - W_1 \times 1000 \text{ (mg)}}{\text{Volume of sample used (ml)}} \quad (3)$$

where W_1 = initial weight of evaporating dish and W_2 = final weight (evaporating dish and residue).

Turbidity was determined using a standardized turbidimeter (ELE paqua lab model-T950513). Each sample was poured into the sample vial and the sample bottle was then inserted into the turbidimeter and readings were obtained. The pH of each water sample was determined on the spot using portable pH meter (Jenway, model-3310). The pH meter was calibrated just before analysis using calibration samples of pH 4.0, 7.0 and 10.0. It was rinsed with distilled water in between successive measurements. Electrical conductivity measurement was done using a Jenway conductivity meter (model 4310).

Determination of optimum temperatures to which the water has to be heated and cooled to extract maximum amount of solid particles were determined by heating 250 ml of water to different temperatures in five degree centigrade intervals between 50 and 90 °C in pre-weighed glasses. The maximum temperature was limited to 90 °C since heating water above this temperature results in evaporation loss. Preliminary tests were made to determine maximum and minimum cooling temperatures. Accordingly, the minimum temperature was set to 50 °C because using temperatures below this value did not result in sufficient solid extraction. Then, the heated water was subdivided and transferred into five smaller containers and cooled to temperatures of 20, 18, 15, 13 and 10 °C. The minimum cooling temperature was selected based on the amount of extracted solids, which did not increase below this temperature. The cooled water samples were removed from the refrigerator and distilled into other containers and the settled solids in the glasses were heated again until all the water evaporated. Then, the glass containers of the solid particles were cooled again to room temperature in the desiccators and the total weights of the glasses were measured. Finally, the extracted solids were calculated by subtracting the glass weight from the total weight of the glass and the dried residue. This process was repeated and the maximum average extracted solids were recorded.

2.5. Data Analyses and Interpretation

Data were recorded, organized, summarized and objectives one and two were achieved by statistical methods using completely randomized design (CRD) first by using one way analysis of variance (ANOVA) and thereafter by using pair comparison. For the third objective, results were compared using the amount of extracted solids.

3. Results and Discussion

3.1. Total Solids (TS) of the Wells

The total solids of the wells ranged between 715.4 mg L⁻¹ (W₂) and 1087 mg L⁻¹ (W₃). There were significant differences ($P < 0.05$) among the wells as shown in Table 2. All the wells were different except the well

from the lakebed (W₁) and the well serving Harar town (W₄), both of which showed similar TS. Except for W₃, concentration of TS in all other wells remained below 1000 mg L⁻¹. This well has objectionable concentration for potable water according to Sawyer *et al.* (2003). However, water from this well is not added to the main reservoir and it is not used for human consumption. The highest TS in W₃ may be explained in terms of the amounts of the dissolved and suspended solids. The fact that this well is the shallowest of all the wells must have contributed to higher TS, which must have passed to the soil after only partially filtered. This well is also one of the oldest and more solids must have passed into the aquifer overtime.

Table 2. Comparisons of physical properties of water samples collected from the wells.

Site	Mean values					
	TS (mg L ⁻¹)	DS (mg L ⁻¹)	SS (mg L ⁻¹)	Turbidity (NTU)	EC ($\mu\text{S cm}^{-1}$)	pH
W ₁	848.2	670.2 (79)	178.0 (21)	1.11	942.2	7.06
W ₂	715.4	573.6 (80)	141.8 (20)	1.11	749.2	7.29
W ₃	1087.0	970.8 (89)	116.2 (11)	1.34	931.8	6.95
W ₄	879.0	677.2 (77)	201.8 (23)	1.09	905.4	7.55
F-test ($\alpha = 0.05$)	*	*	*	*	*	ns
CV (%)	17.4	23.8	23.8	10.2	10.2	3.7
Identical pairs	W ₁ & W ₄	W ₁ & W ₄	W ₁ & W ₄ W ₂ & W ₃	W ₁ & W ₄ W ₁ & W ₄ W ₂ & W ₄	W ₁ & W ₃ W ₁ & W ₄ W ₃ & W ₄	All

TS = Total solids; DS = Dissolved solids; SS = Suspended solids; EC = Electrical conductivity; W₁ = Well number.1; W₂ = Well number2; W₃ = Well number 3; W₄ = Well number.4; CV= Coefficient of Variation; * = Significant at $P < 0.05$; ns= not significant at $P < 0.05$; NTU = Nephelometric turbidity unit. Numbers in brackets represent the percent of DS and SS in terms of TS. For the parameters considered, average values were not considered since the wells did not have equal contribution when it comes to water getting into the main reservoir.

3.2. Dissolved Solids (DS) of the Wells

The amount of dissolved solids is one measure of suitability of water for domestic use. In potable water, most of the solids are in dissolved form (Sawyer *et al.*, 2003) and in this study, DS in all the well waters accounted for over three fourth of the TS (Table 2). Hardness increases with increase in DS and affects taste and lathering of water. The DS for potable water generally falls within the range of 20-1000 mg L⁻¹. However, DS of less than 500 mg L⁻¹ is more desirable for domestic use (Sawyer *et al.*, 2003). Based on this value, all of the four wells fall within this range. To bring DS of all the wells to a more desirable level, water from all the wells may require some kind of treatment.

Analysis of one way ANOVA of DS indicated significant ($P < 0.05$) differences between the water samples of all the wells as in the case of the TS (Table 2). Well at the weather station located at the eastern side of the campus (W₂) showed the lowest average dissolved solids (573.6 mg L⁻¹) and the well close to the motor pool at the northern part of the campus (W₃) showed the highest value (970.8 mg L⁻¹). Unlike locations of other wells, this well was dug in an area, which has been under lake for a long time until the lake

dried up. This makes the soil formation (close to surface) of the area predominantly of fine particles (silt and clay) and also rich in dissolvable minerals. Furthermore, the location of the well gets runoff from student residential areas and the motor pool, which means that there is high probability that the runoff contains more dissolved solids that percolate into the well. Pair comparisons showed significant ($P < 0.05$) differences between all the wells except W₁ and W₄. The two wells showed similar DS possibly because of their proximity (both located on the southern part of the campus).

3.3. Suspended Solids (SS) of the Wells

Variability of SS among the wells ranged from 116.2 mg L⁻¹ (W₃) to 201.8 mg L⁻¹ (W₄) (Table 2). The reason why there was low SS in water sample of W₃ may be due to better filtration in the soil that takes care of most of the suspended solids, which is generally true in soils of smaller particle sizes (silt and clay). The waters from W₁ and W₄ showed pair-wise similarities in their amounts of SS because of their proximity (i.e., similarities of the soil types through which the water percolate). Compared to the level of DS in all the wells,

the levels of SS were generally lower (less than one fourth fraction of the TS). Since the SS carry larger fraction of pollutants in proportion to their sizes, reducing the fraction of these solids is very important not only for the clarity of the water but also to reduce the amount of contaminants (Butler and Davis, 2004).

3.4. Turbidity of the Wells

The turbidity values were approximately the same for water samples of all the wells except for W₃, which showed slightly higher turbidity of 1.34 NTU (Table 2). But it is not of concern since the water from this well is not used for human consumption. As far as the standard limit of turbidity is concerned (which is less than 1 NTU for potable water (Sawyer *et al.*, 2003), turbidity values of the water samples from all of the wells were higher. The fact that the water from W₃ showed low SS but high turbidity may be due to the contribution of other sources such as DS to turbidity. Pair-comparisons using mean differences indicated significant differences ($P < 0.05$) in turbidity between W₁ and W₃.

3.5. pH Differences of the Wells

The benefit of measuring pH is for water softening and corrosion control (Sawyer *et al.*, 2003). Water samples from all the wells showed pH between 6.95 (W₂) and 7.55 (W₄) as shown in Table 2. The pH values obtained are within the acceptable limit of 6.5 to 8.5 (WHO, 2004) for water of domestic use. The pH values less than 6 becomes acidic and the one greater than 7 becomes alkaline. Statistically, there was no significant difference ($P < 0.05$) between the mean pH values of the water samples of all the wells.

3.6. Electrical Conductivity of the Wells

The average electrical conductivity (EC) for all of the well water samples were found to fall between 749.2 $\mu\text{S cm}^{-1}$ (W₂) and 942.2 $\mu\text{S cm}^{-1}$ (W₁) (Table 2). The low average conductivity in W₂ is related to the low DS in the same well. In fact, according to Sawyer *et al.* (2003), DS is directly related to conductivity with a proportionality constant ranging between 0.55 and 0.9, when DS and EC are expressed in mg L^{-1} and $\mu\text{S cm}^{-1}$, respectively. Most dissolved inorganic substances in water are in ionized form and their conductivities increase with increase in temperature (Sawyer *et al.*, 2003). In this study, conductivity versus DS computed for three data points (excluding data of W₃) gave a constant of proportionality of 0.75 and the error between the measured and calculated DS was less than 5%. Data of W₃ did not conform well to the other points during this computation perhaps due to anthropogenic influences such as addition of organic

and inorganic DS that are added to this well unlike the other three.

3.7. Total Solids of Water at the Distribution Zones and the Reservoir Water

TS of the three distribution zones compared with that of the Reservoir ranged between 890 mg L^{-1} at Reservoir and 1144 mg L^{-1} at Z₂ (Table 3). Pair comparisons showed the total solids of the water samples from the Reservoir and Z₃ to be similar at the low end and Z₁ and Z₂ similar at the high end. The higher TS readings at Z₁ and Z₂ may be due the leaks and rusts of the water pipes since the pipes of these distribution zones are older than the line serving the PhD residence zone. The average number of solids in the reservoir is not exactly equal to the mean total solids of the wells since the water contribution of the wells to the reservoir is not the same for all the wells (weighted average would have been better but the discharge rates vary because of reasons such as down times of the pumps and fluctuation in the amount of water discharged from every well).

3.8. Dissolved Solids of Water at Distribution Zones and the Reservoir Water

The dissolved solids (DS) varied among the distribution zones and also with the reservoir (Table 3). The DS ranged from 704 mg L^{-1} at the Reservoir to 1011 mg L^{-1} at Z₂ (Table 3). Distribution Z₁ and Z₂ showed similarity at the high end and Z₃ and R at the low end as in the case of TS. The increase in DS in the two former zones might be due to increased amount of inorganic and organic loads in the water distribution pipes. Organic matter that can enter the pipes through joints and leakage points and dissolving metals due to the age of pipes might have contributed to the higher values of DS at Z₁ and Z₂.

3.9. Suspended Solids of Water at Distribution Zones and the Reservoir Water

SS of the zones and reservoir water samples were found to fall between 115 mg L^{-1} (Z₁) and 213 mg L^{-1} (Z₃). Table 3 indicates statistically significant differences ($P < 0.05$) among the three zones and the reservoir. Pair comparisons showed similarity between Z₁ and Z₂ at the low end and between Z₃ and R at the high end. The fact that Z₁ and Z₂ showed low suspended solids may be due to coagulation and settling of suspended particles or due to conversion of some of the SS into DS, but either way the mechanism is unclear. Compared to the level of DS of Z₃ and the reservoir, the proportions of SS at the other two zones were lower.

Table 3. Comparisons of water samples collected from the three distribution zones with the water from the reservoir.

Site	Mean values					
	TS (mg L ⁻¹)	DS (mg L ⁻¹)	SS (mg L ⁻¹)	Turbidity (NTU)	EC (μS cm ⁻¹)	pH
Z ₁	1125	1010 (90)	115 (10)	1.19	756.0	7.63
Z ₂	1144	1011 (88)	133 (12)	1.16	749.6	7.64
Z ₃	939	726 (77)	213 (23)	1.04	742.4	7.17
R	890	704 (79)	186 (21)	1.11	727.6	7.24
W̄	882	723	159	1.16	882.2	7.21
F-test (α= 0.05)	*	*	*	*	*	ns
CV (%)	15.5	19.9	29.3	5.9	1.6	3.4
Identical pairs	<u>Z₁ & Z₂</u>	<u>All</u>				
	<u>Z₃ & R</u>	<u>Z₃ & R</u>	<u>Z₃ & R</u>	<u>Z₁ & R</u>	<u>Z₃ & R</u>	
				<u>Z₂ & R</u>	<u>Z₁ & Z₃</u>	
				<u>Z₃ & R</u>		

TS = Total solids; DS = Dissolved solids; SS = Suspended solids; EC = Electrical conductivity; R = Reservoir; Z₁ = Distribution line of zone one; Z₂ = Distribution line of zone two; Z₃ = Distribution line of zone three; NTU = Nephelometric turbidity unit; CV = Coefficient of variation; * = Significant at P < 0.05; ns = Not significant at P < 0.05. Numbers in brackets represent the percents of DS and SS in terms of TS. What got into the reservoir was the weighted average of the three wells (W₁, W₂ and W₄) and the reservoir parameters represent the true values than the average of all the wells.

3.10. Turbidity of Water at Distribution Zones and the Reservoir Water

The average turbidity ranged from 1.04 NTU (Z₃) to 1.19 NTU (Z₁). All turbidity values were above the allowable limit of 1 NTU. Pair comparisons depicted in Table 3 showed similar turbidity between Z₁, Z₂ and R. Perhaps this may be due to the amount of the TS or the sensitivity of the turbidimeter. The higher turbidity value at Z₁ and Z₂ did not go well with the amount of SS. Overall, turbidity did not show clear differences between the reservoir and the different zones.

3.11. pH of Water at Distribution Zones and the Reservoir Water

The pH levels of the three zones and the reservoir indicated that the mean pH at the zones and the reservoir did not show significant statistical differences at (P > 0.05). However, pH values of the samples were higher than 7 (Table 3) showing slight alkalinity.

3.12. Electrical Conductivity of Water at Distribution Zones and the Reservoir Water

Electrical Conductivity among the three sampling zones and the reservoir showed the Reservoir (R) have the lowest and Z₁ the highest values (Table 3). Pair-comparisons showed similarities between Z₁, Z₂ and Z₃. Except Z₂, the other two zones showed significant differences from the electrical conductivity of the reservoir. Fluctuation in conductivity throughout sampling period was greater at the distribution zones. The high electrical conductivity of the water samples of Z₁ and Z₂ positively correlated well with the high DS.

3.13. Optimum Heating and Cooling Temperatures to Extract TS from Water

In Figure 1, a plot of total solids extracted versus heating temperature is shown for different cooling temperatures. Generally, there is a positive correlation

(R² > 0.95; Figure 1) between heating temperature and the amount of solids extracted after cooling the water. Heating breaks bonds between the ions and the water molecules thereby freeing the ions to coagulate. At higher temperatures, more energy is supplied to the compound and more ions have chances to liberate themselves from the bond.

The amount of solids precipitated increased as heating temperature increased from 50 to 90 °C but the increment was dependent on cooling temperature as well. The amount of solids extracted at 90 °C was close to the maximum amount extractable compared to the amount of dissolved solids in the reservoir (93%) but only 64% of the dissolved solids in Z₁ (zone from which the water was obtained for test) (Table 3). Above 80°C, more DS could be removed from the water provided that sufficient time was given for the precipitate to settle out or the water is cooled to the right temperature. Heating the water above 90 °C was not tried since higher temperature also increases the amount of water that evaporates.

Both heating and cooling have influence on the amount of solids extracted. Heating temperature resulted in high solid extraction when the temperature exceeded 80 °C. Only 10 and 13 °C cooling temperatures resulted in higher dissolved solids extraction at lower heating temperatures (T < 80 °C). For heating temperatures above 80 °C, cooling temperature of 15 °C resulted in nearly the same amount of solid extraction as 10 and 13 °C.

The influence of cooling is more pronounced at low heating temperatures (T < 80 °C) where the slope shows fast increase especially for cooling temperatures of 15 and 18 °C (Figure 1). It means that at low heating temperatures cooling temperatures have more influence while, at high heating temperatures, the differences between cooling temperatures are subdued as the cooling temperatures fell below 20 °C. From among the

five cooling temperatures, cooling to 10 °C has resulted in maximum solid extraction followed by 13 °C, which

also peaked at the same heating temperature.

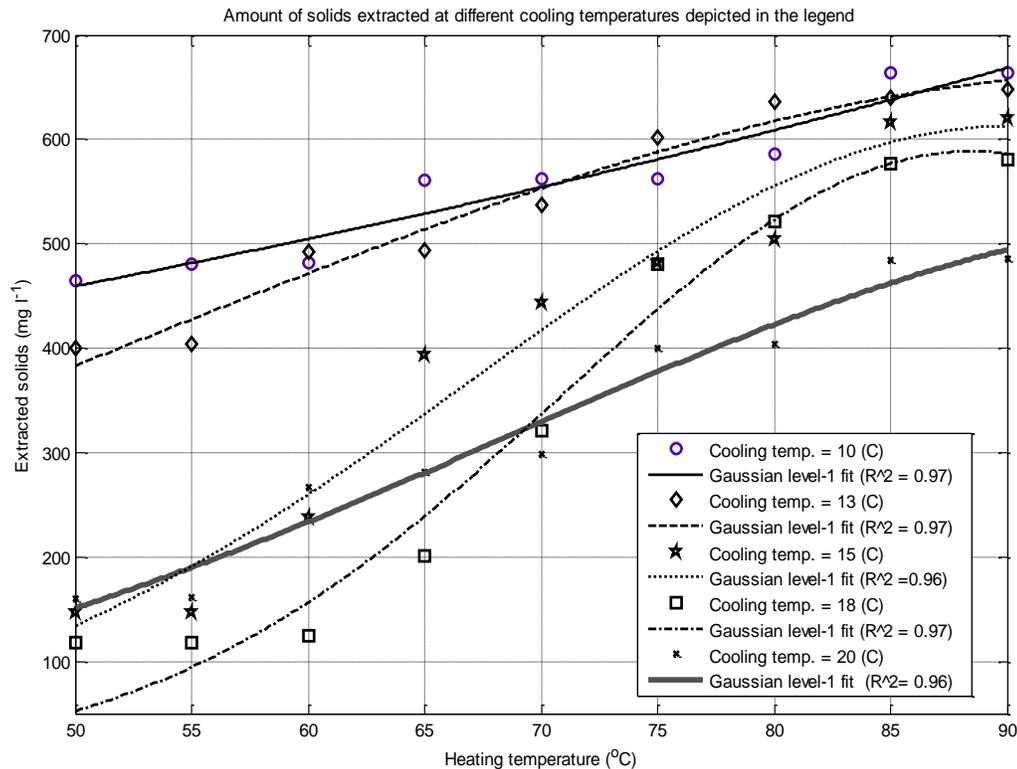


Figure 1. Total amount of solids precipitated as a function of heating temperature shown for different cooling temperatures. The (C) shown in the legend represent (°C) and the (R^2) represents R^2 .

The difference between the 10 and 13 °C at the same curve fitted heating temperature of 85 °C is less than 4%. Whether it is important to cool the water to 10 °C to extract the remaining less than 4% dissolved solids or to cool it to only 13 °C and tolerate the remaining extra 4% dissolved solids is the choice that has to be made by the user. When looked at from energy conservation view point, heating the water to 85 °C and cooling to 13 °C seems to be more beneficial than heating to the same temperature and cooling to 10 °C.

The amount of solids precipitated was about 660 mg L⁻¹ for water cooled to 10 °C and this was the maximum value for the given heating temperature of 85 °C. The minimum average value of solids precipitated was nearly 480 mg L⁻¹ when the water was cooled to 20 °C. When the water was cooled to 13 °C, the amount of solids precipitated was about 640 mg L⁻¹, which was almost the same (within margin of error) to the amount of precipitated solids when the water was cooled to 10 °C at the same heating temperature of 85 °C. As cooling temperature of the water decreased, the amount of solids precipitated increased. Similarly, as heating temperature increased, the effect of cooling temperature relatively diminished. Cooling temperature showed a more observable effect particularly for water that was heated to modest temperatures (50-60 °C).

There was no difference between heating temperature of 85 and 90 °C at all cooling temperatures except cooling to 20 °C. In general, for 85 and 90 °C heating temperatures, cooling the water to 13 °C produced almost the same amount of precipitated solids as the water cooled to 10 °C. For the sake of energy saving, it is sufficient to heat the water to 80-85 °C and to cool it to around 13 °C to extract substantial amount of solids.

Overall, heating has more impact than cooling when it comes to removal of total dissolved solids. Removal of dissolved particles reduces hardness of water, which improves its leatherability and its test. However, heated water must be well aerated by pouring the water back and forth between two containers to incorporate adequate oxygen to bring the taste of the water to an acceptable level.

4. Conclusions

Among the four wells, the well near the motor pool (W₃) showed the highest levels of total solids, dissolved solids and turbidity. The level of suspended solids was the highest in the well serving Harar town. The well at the lakebed (W₁) and the wells serving Harar town (W₄ is combination of a couple of wells) showed similarity in most physical parameters. The well at the eastern part of the campus (W₂) showed the lowest total solids,

dissolved solids and electrical conductivity. The amount of dissolved solids in all the wells is about 3 times that of the suspended solids. As far as physical water parameters are concerned, all the wells fell within the recommended range (2004). Water samples of the staff and student cafeteria zones showed higher total and dissolved solids compared to the water sample of the reservoir. In order to extract most of the total solids, heating the water to a temperature close to 85 °C and cooling to about 13 °C resulted in optimum extraction of solids. When heating temperature increased, the effect of cooling temperature relatively diminished. Cooling water to appropriate temperature after heating helps in removing most of the perceptible solids. To get precise temperatures of heating and cooling to extract maximum amount of dissolved solids, more tests have to be made with smaller temperature intervals.

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