Chemistry Extended Essay

"Investigating the qualities of water that are used in our school environment with respect to the amounts of calcium and magnesium ions and the levels of hardness, by performing complexiometric titrations with EDTA (Ethylene diamine tetraacetic acid)"

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ABSTRACT

As well as it's known, water is essential for life. A person can live for about one week without eating anything but he/she cannot survive even that long without drinking water. In addition to that, a good qualified drinking water is very rich in minerals, which are also essential for the body and most of the metabolic activities. The quality of water indicates the purity and hardness of water, the amounts of minerals in it and all the other characteristics of water, which form a healthy drinking water. These characteristics are determined by the Health Ministrations or other authorized organizations in every country. Since water is one of the most consumed substances in a day, a person could gain at least some of the needed mineral for the body, from the water. Therefore, especially for a teenage, who are in the age of growing so whose metabolic activities are very fast, the quality of the drinking water becomes very very important.

In order to measure the quality of water there are various types of experiments. This investigation uses the method of complexiometric titration, which is based on a principle of the high reactivity of the EDTA (Ethylene diamine tetraacetic acid) substance to form EDTA - metal complexes with the metals ions such as calcium and magnesium and giving a color change with metal indicators. By this method the aim is to find the amounts of calcium and magnesium ions in the water supplies that are used in our school environment and their hardnesses.

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INTRODUCTION

Every time that I drink water at our cafeteria, my instincts told me that there is something wrong with taste and appearance of the water. There are four main sources of water that are being drunk in our school environment. Two of them are sold at the canteen; natural spring water and refined drinking water. The others can be obtained in anytime without a need to being bought; purified water of our school campus and tap water.

All living organisms need some chemicals (minerals and vitamins), nutrients and water in order to realize their metabolic activities. Approximately 75% of the human body is water. Water helps the removal of toxic substances in the body, regulates body temperature, movement of the joins, carries oxygen and nutrients into our cells[1] and maintains homeostasis[2]. In order to carry on the necessary metabolic reactions water is essential, especially for the teenagers, since their metabolism is faster than the adult's. According to the Dietary Reference Intakes has been established by Food and Drug Administration, a teenage between ages 14-18 has to drink approximately 2.3 to 3.3 L of water in each day[2].

Besides, not only the water but also the chemicals are essential for the human nature. Again according to the Dietary Reference Intakes there is a particular amount of vitamins and minerals that should be taken each day[3]. For example, we should take 1300 mg of Calcium, 360-410 mg Magnesium, 150 μg Iodine, 1250 mg Phosphorus, 9-11 mg Zinc… Since, we have to drink liters of water each day we could get some of these minerals from the water, if there are enough amounts of these minerals in our drinking water.

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[1] Importance of water in human body <http://healthimpact.blogspot.com/2006/11/importance-of-water-in-human-body.html>

[2] Dietary Reference Intakes(DRI): Electrolytes and Water <http://www.iom.edu/Object.File/Master/20/004/0.pdf >

[3] Dietary Reference Intakes (DRI): Elements <http://www.iom.edu/Object.File/Master/7/294/0.pdf> and Vitamins <http://www.iom.edu/Object.File/Master/21/372/0.pdf>

This brings us to the quality of the drinking water. The quality of water is the physical, chemical and biological characteristics of water which is based on some standards that have been determined by the cooperation of the Health Ministration and other related ministrations and foundations of each country[4]. They determine the amounts of each mineral that should be in a drinking water and all other characteristics of water.

In other words, the quality of water is determined by the followings;

- Color of water
- pH (should be between 5.5-8.5)[5]
- Taste and odor
- Dissolved metals and salts[5]

Such as; arsenic (should be 0.01mg/L), calcium (100.00 mg/L), magnesium (50.00 mg/L), potassium (10.00 mg/L), sodium (30.00 mg/L)...

- Microorganisms (such as Escherichia coli bacteria shouldn't exist in a healthy drinking water in order not to cause any diseases)
- Heavy metals[5]

Such as; cadmium (should be 0.005 mg/L), chromium (0.050 mg/L), copper (0.010 mg/L), mercury (0.001 mg/L) are known as toxic metals that the excessive amounts of them is dangerous for the human health.

- Nitrate (should be 25.00 mg/L) and nitrite (should be 0.05 mg/L) [5]
- Dissolved organics (should be 2.00 mg/L)[5]
- Dissolved Oxygen (should be 3.50 mg/L which is used for the dissolving process of organic matters) [5]

[4] "Nutrition, Environment and Cancer symposium", Ankara: 31 March - 3 April 2002. Announcement Book, Pages: 46-47.
[5] M. Tuncer. "İçilebilir nitelikli suların istihsali, ambalajlanması, satışı ve denetlenmesi hakkında yönetmelik". Sağlık Bakanlığı Temel Sağlık Hizmetleri Genel Müdürlüğü Çevre Sağlığı Daire Başkanlığı Su Güvenliği ve Sağlığı Şube Müdürlüğü. Supplement 3: İçme suyu nitelikleri. June, 2003.

In our country the tap water is provided by the local governments and the drinking water is provided by various companies. According to the regulations, the inspection of the quality of each of the drinking water is being done periodically by the Health Ministration[6]. These inspections states whether the water is healthy or not. During these inspections the authorities don't look for an exact value but there is an agreeable range for the existence of each chemical and if the amounts of the chemicals in the examined water are in that range the water would be stated as healthy. However, since there are very little amounts of each element in the water any small change could affect the quality of it. Therefore, in order to state that a sample of water is truly healthy, the quality of it should exactly fit with the standard values.

By looking at the blurry color and the weird taste of the water in our cafeteria, I thought that although that water was stated as healthy, the quality of it wouldn't exactly fit with the standard values. That brings me to my research question: ***Do all the sources of water that are used in our school environment include the exact amount of ions, such as calcium and magnesium and have proper hardness that is determined by the Health Ministration, hence have good quality?***

[6] "Nutrition, Environment and Cancer symposium", Ankara: 31 March - 3 April 2002. Announcement Book, Pages: 46-47.

HYPOTHESIS

By the periodic inspections of the related department of Health Ministration all the drinking sources of water in our school environment are said to be healthy. However, there is an obvious difference at their taste and color, which are also the factors that determine the quality of water. The only reasonable explanation for this situation is, in my opinion, being in the agreeable quality range doesn't mean that the water is truly healthy, hence have good quality.

That idea forms my hypothesis; if we examined all the sources of water in our school environment, we would find out that some of them don't exactly fit with the standard values and are not totally suitable for drinking. Consequently, my hypothesis is; ***some (at least one) of the sources of water in our school environment do not have proper amounts of necessary minerals; such as calcium and magnesium and do not have proper hardness, hence not have good quality .***

PLANNING AND DEVELOPMENT:

When talking about the quality of water; the color, taste and odor of water, its pH, amounts of dissolved metals and salts, not containing any microorganisms, amounts of heavy metals and dissolved organics, amount of dissolved oxygen, amount of nitrate and not containing any nitrite, should be taken into consideration.

Based on my qualitative observations, firstly I determined to examine the water hardness; because, one of the reasons of the blurry color and the weird taste of the water could be the level of water hardness. Besides, water hardness is caused by the presence of some cations like; aluminum, barium, iron, manganese, but especially magnesium and calcium[7]. According to the Dietary Reference Intakes of Food and Drug Administration, the amounts of needed calcium and magnesium intakes are higher than much of the other elements[8] (Table 1).

Table 1: The daily amount of Elements that should be taken by males(M) and females(F) at ages 14-18

	Calcium (mg/d)	Chromium (µg/d)	Copper (µg/d)	Fluorine (mg/d)	Iodine (µg/d)	Iron (mg/d)	Magnesium (mg/d)	Manganese (mg/d)	Phosphorus (mg/d)	Selenium (µg/d)	Zinc (mg/d)
M	1300	35	**890**	3	**150**	**11**	**410**	2.2	**1250**	**55**	**11**
F	1300	24	**890**	3	**150**	**15**	**360**	1.6	**1250**	**55**	**9**

*This table (taken from the DRI reports, see www.nap.edu) presents Recommended Dietary Allowances (RDAs) in **bold type** and Adequate Intakes (AIs) [8].

The largest parts of the intakes are taken from the foodstuffs. However, by all of the industrial treatments the food's capacity of magnesium, calcium and as well as the capacity of many other elements have decreased[7]. That's why; the magnesium and calcium in the water might be needed in order to reach the recommended daily amounts of intakes. For instance, the recommended amount of phosphorus is also really high, but it is not possible to close its deficiency by water; because, drinking water do not contain any phosphorus.

[7] D. Selinus, B. Alloway, J. A. Centeno, R. B. Finkelman, R. Fuge, U. Lindh and P. Smedley (Eds.). "Essentials of Medical Geology: Impacts of the Natural Environment on Public Health". Elsevier, 2005. Pages:338-341.
[8] Dietary Reference Intakes (DRI): Elements <http://www.iom.edu/Object.File/Master/7/294/0.pdf>

Calcium and magnesium are the most crucial elements for human nature so that their deficiency could cause serious health problems. Magnesium is essential for the activation of too many enzymatic reactions that requires energy, which is ATP (adenosine triphosphate). Therefore, most of the important processes of the human body cannot be done without magnesium; for instance, protein synthesis, muscular contraction, transport over the cell membranes, maintaining intracellular levels of potassium and calcium, stabilizing the cardiac electric system[9]. The deficiency of magnesium would affect all these enzymatic reactions and as well as the neuromuscular activities that would lead the formation of tremors and convulsions[10]. By the effect of its deficiency all the calcium and potassium levels would also be reduced and that would affect the activity of parathyroid hormone[10], which is a hormone that controls most of the vital reactions in the body. In addition, calcium is the one of the crucial component of bones and it is also needed for the muscle contraction and blood clothing[11]. The deficiency of calcium would cause hypertension that could lead to both stroke and AMI (acute myocardial infarction), which is also known as hearth attack[9]. In order to prevent the possible causes of the deficiencies of magnesium and calcium, the recommended intakes should be taken each day and especially for the calcium and magnesium drinking water could be another supplementary source.

As well as the amounts of calcium and magnesium can be determined individually, their total concentration in the water is also commonly expressed as the water hardness as mg/L. Water hardness is the capacity of water to react with soap to form leather[12].

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[9] D. Selinus, B. Alloway, J. A. Centeno, R. B. Finkelman, R. Fuge, U. Lindh and P. Smedley (Eds.). "Essentials of Medical Geology: Impacts of the Natural Environment on Public Health". Elsevier, 2005. Pages:338-341.

[10] Groff, James L., Sareen S. Gropper, and Sara M. Hunt. "Advanced Nutrition and Human Metabolism". Minneapolis/St. Paul, Minn.: West, 1995.

[11] Linder, Maria C. "Nutritional Biochemistry and Metabolism". New York: Elsevier, 1985.

[12] D. Selinus, B. Alloway, J. A. Centeno, R. B. Finkelman, R. Fuge, U. Lindh and P. Smedley (Eds.). "Essentials of Medical Geology: Impacts of the Natural Environment on Public Health". Elsevier, 2005. Page:331.

There are two types of water hardness; temporary and permanent hardness[13]. Temporary hardness is caused by bicarbonate ions (HCO_3) that is dissolved in water and that type of hardness can be removed by boiling.

$$Ca(HCO_3)_{2(aq)} \rightarrow CaCO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$$

Permanent hardness is the type of hardness that cannot be removed by boiling and it is caused by the presence of cations like; aluminum, barium, iron, manganese, calcium and magnesium. This value is taken as the equivalent of the amount of $CaCO_3$ in the water[13]; because, the amount of calcium bicarbonate ion is greater than the other bicarbonate ions so that the amounts of others are too small to be included in the calculations. If the calculated data would be greater than 150 mg/L, it means that the water is extremely hard and if it is less than 60 mg/L, it means the water is extremely soft. Therefore, the agreeable level of water hardness is around 100 mg/L[13].

For the determination of the amounts of calcium and magnesium in the water and the level of water hardness, the most common method is the complexometric titration by EDTA. Ethylene diamine tetraacetic acid (EDTA) is one of the most important ligands that are used in the titrations based on complex formation[14]. Ligands are the molecules or ions that have at least one unshared pair of electrons and a coplexometric titration involves the reaction of a metal ion and a ligand. In this reaction the metal ion and the ligand make a coordinate covalent bond with the unshared pair of electron of the ligand[14]. If a ligand can only donate one pair of electrons then the ligand is called unidentate. For two or more electrons, the ligand is called multidentate[13]. EDTA is a common multidentate that has six unshared pair of electrons.

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[13] Determination of Water Hardness By Complexometric Titration Class Notes <http://homepages.ius.edu/DSPURLOC/c121/week13.htm>

[14] Holler, Skoog West. *Fundamentals of Analytical Chemistry*. Sixth Edition. Saunders College Publishing, 1992. Page:294-298.

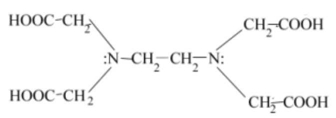

Figure 1: Structure of EDTA[15].

Dependently with the pH value of the solution, EDTA is capable of combining with the metal ions in a 1:1 ratio regardless of the charge of the metal cation[15]. The most suitable pH would be 10 for both of the reaction of EDTA with calcium and magnesium. Therefore, in order to maintain the pH using a buffer would be wisely.

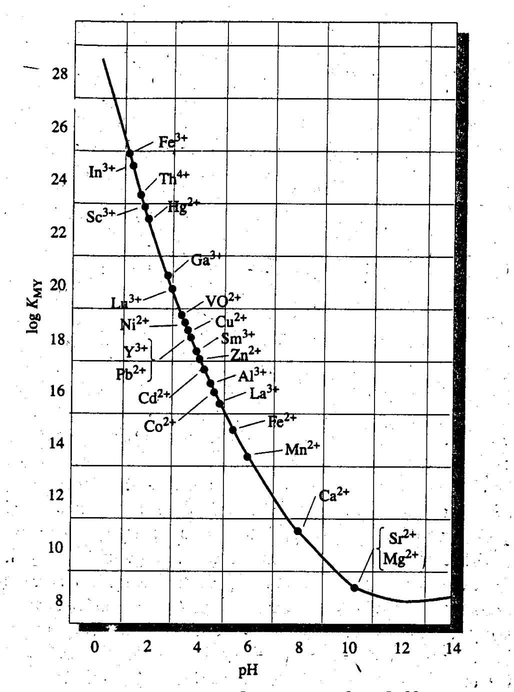

Figure 2: pH versus log K_{MY}, for different metal ions [15].
(MY: means EDTA and metal complex)

In order to determine the end points of the reactions, an indicator of metal ions, which is intensely changing color of solution, should be used. The most common indicator is Eriochrome Black T, which changes color from red to blue or blue to red depending on the type of the metal ion[15].

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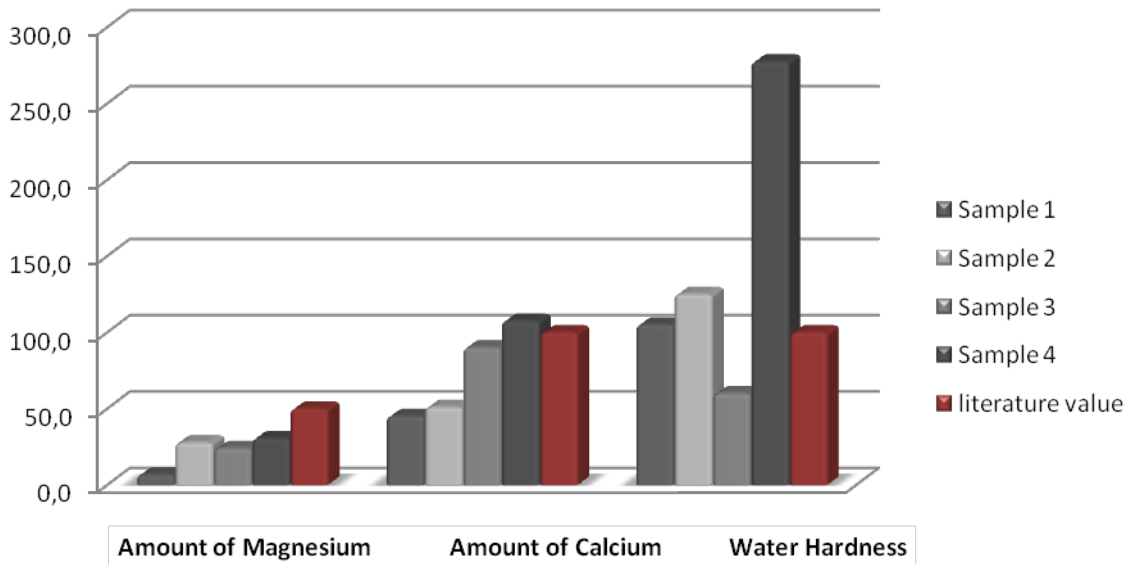
15 Holler, Skoog West. *Fundamentals of Analytical Chemistry*. Sixth Edition. Saunders College Publishing, 1992. Page:294-298.

RESULTS*

MEAN VALUES	Amount of Magnesium in water (mg/L)	Amount of Calcium in water (mg/L)	Amount of Water Hardness (mg/L)
Sample 1: Natural spring water	6.7 ± 2.4 mg/L	45 ± 26 mg/L	105 ± 5 mg/L
Sample 2: Refined drinking water	27.8 ± 2.5 mg/L	51 ± 29 mg/L	125 ± 5 mg/L
Sample 3: Purified water of our school campus	24.0 ± 2.5 mg/L	90 ± 25 mg/L	60 ± 5 mg/L
Sample 4: Tap water	30.5 ± 2.5 mg/L	107 ± 25 mg/L	278 ± 5 mg/L

Literature values: (the values that are determined by the Health Minister)	50.0 mg/L	100.0 mg/L	100.0 mg/L

Table 2: The mean values of each sample for the amount of magnesium, calcium and water hardness in mg/L.



Graph 1: The mean values of the amounts of magnesium, calcium and water hardness of each sample (1- 2- 3 and 4) and the literature values in mg/L. [16]

[16] The graph is drawn and the means values are found by using the "Microsoft Excel 2007".

*__NOTE: All the calculations and the method of the experiment are given at the appendix.__

CONLUSION AND EVALUATION OF RESULTS:

With regard to a suspicion about the drinking water supplies that are used in our school environment are really healthy, the amounts of calcium, magnesium ions and the level of water hardnesses are examined, by these experiments. As it is explained in detail at the planning and development part, a complex substance named EDTA is used. The principle of each experiment is the high reactivity of EDTA (Y) with the metals (M) in order form a complex ionic compound (MY).

$$M + Y \rightarrow MY$$

$$Mg^{2+} + Y^{4-} \rightarrow MgY^{2-} \quad , \quad Ca^{2+} + Y^{4-} \rightarrow CaY^{2-}$$

In order to observe the reaction above, an indicator of metal ions, named Eriochrome Black T (Erio T) indicator is used. By observing the color change, there complexometric titrations are made.

When the results of the experiments are combined and evaluated, it is possible for us to make a comparison between the different sources of water.

Sample 1 (natural spring water): The amount of magnesium is 86.6 % lower and the amount of calcium is 55.0 % lower than it should be. By looking at the levels of the minerals in the natural spring water we could make a conclusion that it does not have a good quality. However, in the case of the level of water hardness, it is only 5.0 % higher than the literature value; therefore its hardness could be accepted as okay.

Sample 2 (refined drinking water): The amount of magnesium is 44.4 % lower and the amount of calcium is 48.8 % lower than it should be. Besides, the level of water hardness is

25.0 % higher than the literature value. So, the refined drinking water is richer in minerals than the natural spring water, but it is a harder water.

Sample 3 (purified water of our school campus): The amount of magnesium is 52.0 % lower and the amount of calcium is 10.0 % lower than it should be. Therefore, the purified water of our school campus includes all most agreeable amounts of calcium. On the other hand, it has 40.0 % lower hardness.

Sample 4 (tap water): The amount of magnesium is 39.0 % lower and the amount of calcium is 7.5 % lower than it should be. Through all of the samples, tab water seems to be the one who is the richest in minerals. However, its hardness is unacceptably high (178.0 % higher than the literature value).

For each sample, the amounts of calcium and magnesium are lower than the recommended amounts by the Health Ministration. By looking at the results, we could make an ordering of being rich in calcium and magnesium; *tab water > purified water of our school campus > refined drinking water > natural spring water*. However, if we make an ordering of having optimum hardness the result will be the direct contrary with the amounts of calcium and magnesium. Therefore, from these results the only thing we could say is none of the water that are used in our school environment is in good quality; but in order to determine which one is healthier, we have to know whether the amounts of calcium or magnesium are most effective on the health of the water or its hardness.

The decision of investigating the calcium and magnesium ions in the water was because of their significant amounts in a good qualified drinking water and their crucial duties in the body. Magnesium ion is involved in many enzymatic reactions and activation of ATPases, which is an enzyme responsible from the synthesis of ATP (adenosine tri phosphate), the energy source of the metabolism[17]. Calcium is the essential component of the bones, needed for the muscle contraction, blood clothing and the synthesis of proteins[18]. In their deficiencies, most of the vital enzymatic processes cannot be realized, such as protein synthesis, muscular contraction, transportation over the cell membrane, stabilizing the cardiac electric system, so that all the system of the body would be affected. It could result in hypertension and heart attacks[19]. As a result, it could be said that the amounts of these ions are highly important.

On the other hand, according to the continuing studies, a variety of diseases are correlated with water hardness including the cancer. According to a research in the northern Finland (1991), there is a correlation between the hard water and several forms of cancer, especially the ones concerning the females[20]. In 1999, Yang et al, showed that there was a 42% excess risk of mortality from esophageal cancer, in the case of using soft water[20]. In addition to these, in Nottingham, England, McNally et al (1998) found a direct correlation with the prevalence of Eczema and water hardness[20]. As a result, by looking at these studies it could be said that a hard or a soft water should not be used as drinking water.

If we turn back to the results of the experiments, as a very hard water, tap water should not be used as a source of drinking water, although it is highly rich in minerals. Besides, as a soft water, the purified water of our school campus also not recommended to be used as a source of drinking water. From the other two options, the refined drinking water could be chosen as best, but unfortunately it is still low in including calcium and magnesium but better than the natural spring water, though it’s still a little hard water.

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[17] Groff, James L., Sareen S. Gropper, and Sara M. Hunt. “Advanced Nutrition and Human Metabolism”. Minneapolis/St. Paul, Minn.: West, 1995.

[18] Linder, Maria C. “Nutritional Biochemistry and Metabolism”. New York: Elsevier, 1985.

[19] D. Selinus, B. Alloway, J. A. Centeno, R. B. Finkelman, R. Fuge, U. Lindh and P. Smedley (Eds.). “Essentials of Medical Geology: Impacts of the Natural Environment on Public Health”. Elsevier, 2005. Pages:338-341.

[20] D. Selinus, B. Alloway, J. A. Centeno, R. B. Finkelman, R. Fuge, U. Lindh and P. Smedley (Eds.). “Essentials of Medical Geology: Impacts of the Natural Environment on Public Health”. Elsevier, 2005. Pages:342.

The results of the investigation are not that satisfactory. Because, according to the result, none of the sources of water has a good quality with respect to the amounts of calcium and magnesium and the water hardness. In order to decide which one is healthier, more experiments should be done to check all the conditions of having a good quality, like the pH levels, amounts of heavy metals and nitrite, not including any microorganisms… Besides, the quality of water is recently a very topical subject in our county, especially in Ankara. Therefore, by some evaluations and amplifications, even the water supply of the city could also be investigated. For such an investigation, my recommendation would be to check the amounts of heavy metals in the water; because the source of the water supply of Ankara is from the Kızılırmak River, whose water is said to be including high amounts of dissolved heavy metals.

However, at this point, as a conclusion of the investigation, by adding the necessary ions that are supposed to be dissolved in the water such as, calcium, magnesium, potassium, sodium… etc. to the natural spring water by some chemical processes and by controlling its hardness, a truly healthy and good qualified drinking water could be created.

EVALUATION FOR THE METHOD OF THE EXPERIMENT:

The percentage errors of the experiments are related to the quality of the water, but the standard deviations of the experiments show the accuracy of the results and the dependability of the investigation. The first experiments accuracy seems to be okay with showing small deviations from the means of each sample. Unfortunately, for the second and third experiments the standard deviations are high, especially for some of the samples.

First of all, the measured or calculated amounts of calcium and magnesium are really small to be measured with a hundred percent accuracy. For instance, for the second experiment, while performing the titration, according to the procedure when there is a color change stop dropping $MgSO_4$. Since there is an instant color change, it is possible for everyone to miss the point. However, in this experiment a mistake like that is unacceptable, since the recorded data are too small. Because, at the calculations that small data is multiplied with a huge coefficient like (24310, 40080 or 100090) and if such a mistake was made, by this multiplication the mistake is increased. In order to eliminate the chance of making mistake EDTA and $MgSO_4$ with lower molarity, like 0.01 M could be used. Therefore the recorded data would be higher and the chance to make a mistake would be decrease.

When the results of all the experiments are looked through, it could be seen that most of the deviations are at the third experiment. The reason of these deviations is probably caused by a systematic error while the boiling and cooling procedure is performed. The aim of the boiling is to remove the CO_2 gas so that the temporary hardness of water. However, while the sample is boiled not only the carbon dioxide gas evaporate, but also the water itself. In addition to that while the sample is cooling, it is possible that some of the gases in the air including the CO_2 gas, could be captured by water and mix with it to effect the accuracy of the results. In order to prevent this effect, after the solution is boiled, the tap of the flask should be closed with a stopper until it reaches its initial temperature. In addition to that, the volume of the sample should be measured when the temperature of the sample is adjusted. That will show us if there were any loss of water with evaporation and the calculations of the experiment could be proceed with the new volume.

Another possible source of deviations could be time factor. For the whole investigation, there are three different experiment and 16 trials for each, so the needed time to finish all the experiments was at least three weeks under the school conditions. There is a possibility that EDTA is spoiled and its high reactivity with the metals could be decreased.

All in all, although some deviations the complexiometric titration method is working and with these suggested evaluations the experiments could be performed more accurately.

--**APPENDIX**--

METHOD:

Materials:

- 0.10 M EDTA*
- pH-10 buffer*
- Eriochrome Black T (Erio T) indicator*
- Methyl red*
- 6.00 M HCl*
- 6.000 ± 0.001 M NaOH

Preparation of 6.000 ± 0.001 M NaOH: Measure 6.000 ± 0.001 g of solid NaOH and add water slowly until the total volume of the solution reaches 25.00 ml in volumetric flask.

- 0.100 ± 0.001 M $MgSO_4$

Preparation of 0.100 ± 0.001 M $MgSO_4$: Measure 12.500 ± 0.001 g of solid $MgSO_4$ and add water slowly, in order to make sure that all the solid is dissolved, then continue addition of H_2O until the total volume of the solution reaches 500.00 ml in volumetric flask.

- Volumetric flask (with the volume of 500 and 25 ml)
- At least four Erlenmeyer flask (with the volume of 250 ml)
- Burettes (with the volume of 50.00 ± 0.05 ml)
- Graduated cylinder (with the volume of 50.00 ± 0.05 ml)
- Dropper
- Thermometer (with a range of ± 0.5 °C)
- Electrometric balance (with a range of ± 0.001 g)

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* *0.10 ± 0.01 M EDTA, pH-10 buffer and the Eriochrome Black T indicator have been taken as prepared from the METU (Middle East Technical University) Chemistry Department laboratory and methyl red and 6.00 ± 0.01 M HCl is obtained from our school laboratory.* ***Therefore, their uncertainties are unknown and taken as zero****)*

Sample 1: natural spring water

Sample 2: refined drinking water

Sample 3: purified water of our school campus

Sample 4: tab water

PROCEDURE:

Experiment NO: 1

- **Aim of the experiment** is to find the amount of Magnesium in the water by realizing a direct complexiometric titration.

Constant Values: pH, pressure, temperature, initial volume of the sample, amount of the indicator and the molarity of EDTA

Independent Variables: Added amount of EDTA

Dependent Variables: The color change of the solution as a result of the reaction of EDTA and Magnesium to form a EDTA metal complex.

$$Mg^{2+} + Y^{4-} \rightarrow MgY^{2-}$$ (EDTA is shown as Y.)

Procedure of the Determination of Magnesium amount:

1. To control the pressure variable check the air pressure from local meteorology institute.
2. Record the temperature. (It should be around 21.0 ± 0.5 °C, if not use water bath or electronic stirrer to control the temperature factor)
3. Set up the mechanism of titration.
4. Take 50.00 ± 0.05 ml from the first sample in an Erlenmeyer flask.
5. To keep the pH constant add 1 to 2 ml of pH-10 buffer into the Erlenmeyer flask.

6. Add 5 drops of Erio T indicator into the Erlenmeyer flask as the indicator and observe the red color.

Picture 1: The color of the solution when the Erio T indicator is added to the sample is red.

7. Fill the burette with 0.10 M EDTA up to 0 point.
8. Place the tap of burette in Erlenmeyer flask in order to avoid EDTA spill outside.
9. Drop by drop add EDTA on the sample, while shaking the Erlenmeyer flask.
10. When a color change from red to blue is observed, stop dropping EDTA and close the tap.

Picture 2: The color of the solution before the EDTA is added and the color change from red to blue.

11. Record the volume of added EDTA.
12. Repeat the procedure at least 4 times for each sample in order to obtain an average value.
13. Repeat the steps starting from 4 for samples 2, 3 and 4 (If there is a long time passed, measure the temperature and pressure again).

Experiment NO: 2

Aim of the experiment is to find the amount of Calcium in the water by making a back complexiometric titration.

- Calcium forms very stable complexes with the EDTA, the metal ion indicators are not capable of detecting and show a color change. Therefore, we have to do a back titration and change the metal ion that we are going to observe.

Constant Values: pH, pressure, temperature, initial volume of the sample and the EDTA, amount of the indicator, the molarities of EDTA and $MgSO_4$

Independent Variables: Added amount of $MgSO_4$

Dependent Variables: The color change of the solution as a result of the reaction of EDTA and Magnesium to form a EDTA metal complex.

$$Ca^{2+} + Y^{4-}(\text{reacted}) \rightarrow CaY^{2-} \quad \text{(EDTA is shown as Y.)}$$

$$MgSO_4 \leftrightarrow Mg^{2+} + SO_4^{2-}$$

$$Mg^{2+} + Y^{4-}\ (\text{excess}) \rightarrow MgY^{2-}$$

Procedure of the Determination of Calcium amount:

1. To control the pressure variable check the air pressure from local meteorology institute.
2. Record the temperature. (It should be around 21.0 ± 0.5 °C, if not use water bath or electronic stirrer to control the temperature factor)
3. Set up the mechanism of titration.
4. Take 40.00 ± 0.05 ml from the first sample in an Erlenmeyer flask.
5. Add 10.00 ± 0.05 ml of 0.10 M EDTA into the flask.

6. To keep the pH constant add 1 to 2 ml of pH-10 buffer into the Erlenmeyer flask.

7. Add 5 drops of Erio T indicator and observe the blue color.

Picture 3: The color of the solution when the Erio T indicator is added to the sample is blue. The Erlenmeyer flask is placed under the burette.

8. Place the prepared 0.100 ± 0.001 M $MgSO_4$ solution into a burette up to 0 point.

9. Place the tap of burette in Erlenmeyer flask in order to avoid $MgSO_4$ spill outside.

10. Drop by drop add $MgSO_4$ solution on the sample, while shaking the Erlenmeyer flask

- The excess EDTA in the sample, which is left over after the added EDTA on the sample formed calcium-EDTA complex, will give a reaction with $MgSO_4$.

14. When a color change from blue to red is observed, stop dropping $MgSO_4$ and close the tap.

15. Record the volume of added $MgSO_4$.

16. Repeat the procedure at least 4 times for each sample in order to obtain an average value.

17. Repeat the steps starting from 4 for samples 2, 3 and 4 (If there is a long time passed, measure the temperature and pressure again).

Experiment NO: 3

Aim of the experiment is to find the permanent water hardness of water.

- The water has two types of hardness; the temporary hardness is caused by the bicarbonate ions in it and the permanent water hardness caused by the metal ions in it. When the sample is boiled $CaCO_3$ is formed and the solution becomes basic.

$$Ca(HCO_3)_{2(aq)} \rightarrow CaCO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$$

- In order to neutralize it HCl is added to the sample and react with $CaCO_3$ and by titrating the solution with NaOH the excess HCl is being neutralized. By this procedure the temporary water hardness is disappeared and the pH of the solution is controlled. The permanent hardness could be found by realizing a complexiometric titration with EDTA.

$$CaCO_{3(aq)} + 2HCl_{(aq)} \rightarrow CO_{2(g)} + H_2O_{(l)} + CaCl_{2(aq)}$$

$$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

$$CaCO_{3(aq)} \rightarrow Ca_{(aq)}{}^{2+} + CO_{3(aq)}{}^{-2}$$

$$Ca^{2+} + Y^{4-} \rightarrow CaY^{2-} \quad \text{(EDTA is shown as Y.)}$$

Constant Values: pH, pressure, temperature, initial volume of the sample and the HCl, amounts of the indicators, the molarities of EDTA, HCl and NaOH

Independent Variables: Added amount of NaOH and EDTA

Dependent Variables: The color change of the solution as a result of the neutralization reaction of HCl – NaOH and the color change as a result of the complexiometric reaction of EDTA and Calcium to form a metal complex.

Procedure of the Determination of Permanent Water Hardness level:

1. To control the pressure variable check the air pressure from local meteorology institute.
2. Record the temperature. (It should be around 21.0 ± 0.5 °C, if not use water bath or electronic stirrer to control the temperature factor)
3. Set up two mechanisms of titration.
4. Take 100.00 ± 0.05 ml from the first sample in an Erlenmeyer flask.
5. Add 10 drops of 6.00 M HCl into the flask.
6. Boiled the solution gently (by using the Bunsen burner) for few minutes, in order to remove the CO_2 gas.

Picture 4: The sample is boiling (evaporated CO_2 gas).

7. Cool the solution up to the recorded temperature value at the second step (record the temperature of the solution by the thermometer).
8. Add 10 drops of methyl orange indicator into the Erlenmeyer flask and observe the red color.

Picture 5: The color of the solution when the Methyl orange indicator is added to the sample is red.

9. Place the prepared 6.000 ± 0.001 M NaOH into a burette.
10. Place the tap of burette in Erlenmeyer flask in order to avoid NaOH spill outside.
11. Drop by drop add NaOH on the sample, while shaking the Erlenmeyer flask.
12. When a color change from red to yellow is observed, stop dropping NaOH and close the tap.

Picture 6: The color of the solution before the sample is titrated with NaOH and the color change from red to yellow.

13. To keep the pH constant add 1 to 2 ml of pH-10 buffer into the Erlenmeyer flask.
14. Add 5 drops of Erio T indicator into the flask.

Picture 7: The color of the solution when the Erio T indicator is added to the sample is red.

15. Place 0.10 M EDTA into a burette up to 0 point.

16. Place the tap of burette in Erlenmeyer flask in order to avoid EDTA spill outside.

17. Drop by drop add EDTA on the sample, while shaking the Erlenmeyer flask.

18. When a color change from red to blue (or dark green) is observed, stop dropping EDTA and close the tap.

Picture 8: The color of the solution after the EDTA is added, the color change from red to blue.

19. Record the volume of used EDTA.

20. Repeat the procedure at least 4 times for each sample in order to obtain an average value.

21. Repeat the steps starting from 4 for samples 2, 3 and 4 (If there is a long time passed, measure the temperature and pressure again).

DATA COLLECTION:

Sample 1	Sample 2	Sample 3	Sample 4
natural spring water	refined drinking water	purified water of our school campus	tap water

Table 1: water sources of the samples

Experiment NO: 1

used volume of EDTA (ml ± 0.05)	Sample 1	Sample 2	Sample 3	Sample 4
Trial 1	0.10 ml	0.50 ml	0.60 ml	0.60 ml
Trial 2	0.15 ml	0.70 ml	0.50 ml	0.55 ml
Trial 3	0.20 ml	0.60 ml	0.50 ml	0.65 ml
Trial 4	0.10 ml	0.50 ml	0.40 ml	0.70 ml

Table 2: used volumes of EDTA for the direct titration of magnesium in ml, for each sample.

Experiment NO: 2

used volume of $MgSO_4$ (ml ± 0.05)	Sample 1	Sample 2	Sample 3	Sample 4
Trial 1	9.70 ml	9.55 ml	9.20 ml	8.80 ml
Trial 2	9.40 ml	9.10 ml	9.10 ml	8.70 ml
Trial 3	9.60 ml	9.60 ml	9.30 ml	9.00 ml
Trial 4	9.50 ml	9.70 ml	8.80 ml	9.20 ml

Table 3: used volumes of $MgSO_4$ for the back direct titration of calcium in ml, for each sample.

Experiment NO: 3

used volume of EDTA (ml ± 0.05)	Sample 1	Sample 2	Sample 3	Sample 4
Trial 1	1.40 ml	1.40 ml	0.70 ml	2.40 ml
Trial 2	0.90 ml	1.00 ml	0.60 ml	3.10 ml
Trial 3	1.20 ml	1.20 ml	0.60 ml	2.70 ml
Trial 4	0.70 ml	1.40 ml	0.50 ml	2.90 ml

Table 4: used volumes of EDTA for the determination of water hardness in ml, for each sample.

DATA PROSSESSING and ANALYZING:

Experiment NO: 1

$Mg^{2+} + Y^{4-} \rightarrow MgY^{2-}$ (EDTA is shown as Y.)

$$mol\ number\ of\ (Y^{4-}) = mol\ number\ of\ (Mg^{2+})$$

$$molarity\ of\ (Y^{4-})(molL^{-1}) = \frac{mol\ number\ of\ (Y^{4-})\ (mol)}{volume\ of\ (Y^{4-})\ (L)}$$

$$mol\ number\ of\ (Mg^{2+})(mol) = molarity\ of\ (Y^{4-})(molL^{-1}) \times volume\ of (Y^{4-})(L)$$

$$amount\ of\ (Mg^{2+})\ in\ the\ water (mgL^{-1}) = \frac{mol\ number\ of\ (Mg^{2+})(mol) \times molar\ mass\ of\ (Mg^{2+})\ (mgmol^{-1})}{volume\ of\ the\ sample\ (L)}$$

Molarity of EDTA = 0.10 mol/L

Volume of the sample = 50.00 ± 0.05 ml = 5.00 $x10^{-2}$ ± % 0.10 L

Molar mass of Mg^{2+} = 24.31 g/mol = 24310 mg/mol

used volume of EDTA (L)	Sample 1	Sample 2	Sample 3	Sample 4
Trial 1	0.10 $x10^{-3}$ L ± %50	0.50 $x10^{-3}$ L ± %10	0.60 $x10^{-3}$ L ± %8	0.60 $x10^{-3}$ L ± %8
Trial 2	0.15 $x10^{-3}$ L ± %33	0.70 $x10^{-3}$ L ± %7	0.50 $x10^{-3}$ L ± %10	0.55 $x10^{-3}$ L ± %9
Trial 3	0.20 $x10^{-3}$ L ± %25	0.60 $x10^{-3}$ L ± %8	0.50 $x10^{-3}$ L ± %10	0.65 $x10^{-3}$ L ± %8
Trial 4	0.10 $x10^{-3}$ L ± %50	0.50 $x10^{-3}$ L ± %10	0.40 $x10^{-3}$ L ± %13	0.70 $x10^{-3}$ L ± %7

Table 5: used volumes of EDTA for the first experiment in L, for each sample with the percentage uncertainties.

Example for calculations:

$$Mg\ amount\ in\ water = \frac{(1.0 \times 10^{-4} \pm \%\ 50)\ 0.10 \times 24310}{0.05 \pm \%\ 0.10} = 4.9 \pm \%\ 50.1\ \text{mg/L}$$

Amount of Mg^{2+} in the water (mg/L)	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**
Trial 1	4.9 ± %50 mg/L	24.0 ± %10 mg/L	29.0 ± %8.4 mg/L	29.0 ± %8.4 mg/L
Trial 2	7.3 ± %33 mg/L	34.0 ± %7.2 mg/L	24.0 ± %10 mg/L	27.0 ± %9.2 mg/L
Trial 3	9.7 ± %25 mg/L	29.0 ± %8.4 mg/L	24.0 ± %10 mg/L	32.0 ± %7.8 mg/L
Trial 4	4.9 ± %50 mg/L	24.0 ± %10 mg/L	19.0 ± %13 mg/L	34.0 ± %7.2 mg/L

Table 6: amounts of Mg^{2+} in the water in mg/L for each sample.

Experiment NO: 2

$Ca^{2+} + Y^{4-}$(reacted) → CaY^{2-} (EDTA is shown as Y.)

$MgSO_4 \leftrightarrow Mg^{2+} + SO_4^{2-}$

$Mg^{2+} + Y^{4-}$ (excess) → MgY^{2-}

$$\text{mol number of excess } (Y^{4-}) = \text{mol number of } (MgSO_4)$$
$$= \text{molarity of } (MgSO_4)(molL^{-1}) \times \text{volume of} (MgSO_4)(L)$$

$$\text{mol number of reacted } (Y^{4-}) = \text{mol number of } (Ca^{2+})$$
$$= \text{mol number of total } (Y^{4-}) - \text{mol number of excess } (Y^{4-})$$

$$\text{amount of } (Ca^{2+}) \text{ in the water} (mgL^{-1})$$
$$= \frac{\text{mol number of reacted } (Y^{4-})(mol) \times \text{molar mass of } (Ca^{2+})\ (mgmol^{-1})}{\text{volume of the sample } (L)}$$

Molarity of EDTA = 0.10 mol/L

Added volume of EDTA = 10.00 ± 0.05 ml = 1.00×10^{-2} ± %0.5 L

Molarity of $MgSO_4$ = 0.100 ± 0.001 mol/L = 0.100 ± %1.0 L

Volume of the sample = 40.00 ± 0.05 ml = 4.00×10^{-2} ± %0.13 L

Molar mass of Ca^{2+} = 40.08 g/mol = 40080 mg/mol

used volume of EDTA (ml)	Sample 1	Sample 2	Sample 3	Sample 4
Trial 1	9.70 ml ± % 0.52	9.55 ml ± % 0.52	9.20 ml ± % 0.54	8.80 ml ± % 0.57
Trial 2	9.40 ml ± % 0.53	9.10 ml ± % 0.55	9.10 ml ± % 0.55	8.70 ml ± % 0.57

Trial 3	9.60 ml ± % 0.52	9.60 ml ± % 0.52	9.30 ml ± % 0.54	9.00 ml ± % 0.56
Trial 4	9.50 ml ± % 0.53	9.70 ml ± % 0.52	8.80 ml ± % 0.57	9.20 ml ± % 0.54

Table 7: used volumes of EDTA for the second experiment in ml, for each sample with the percentage uncertainties.

Example for calculations:

$$total\ mol\ of\ EDTA = 0.10\ \times (10.00 \pm \%\ 0.50) = \ 1.00\ \pm \%\ 0.50 = 1.00\ \pm 0.01\ mmol$$

$$excess\ mol\ of\ EDTA = (0.10\ \pm \%\ 1.00)\ \times (8.80 \pm \%\ 0.57) = \ 0.88\ \pm \%\ 1.57$$
$$= 0.88\ \pm 0.01\ mmol$$

$$reacted\ mol\ of\ EDTA = total\ mol\ of\ EDTA - excess\ mol\ of\ EDT$$
$$= (1.00\ \pm 0.01) - (0.88\ \pm 0.01) = \ 0.12\ \pm 0.02 = 0.12\ \pm \%19.83\ mmol$$

$$Ca\ amount\ in\ water = \frac{(0.12\ \pm \%\ 19.83) \times 40080}{(40.00\ \pm \%0.13)} = \ 120\ \pm \%\ 19.96\ mg/L$$

Amount of Ca^{2+} in the water (mg/L)	Sample 1	Sample 2	Sample 3	Sample 4
Trial 1	30 ± % 82 mg/L	45 ± % 55 mg/L	80 ± %30 mg/L	120 ± % 20 mg/L
Trial 2	60 ± % 41 mg/L	90 ± % 27 mg/L	90 ± %27 mg/L	130 ± %18 mg/L
Trial 3	40 ± % 62 mg/L	40 ± % 62 mg/L	70 ± % 35 mg/L	100 ± % 24 mg/L
Trial 4	50 ± % 49 mg/L	30 ± % 82 mg/L	120 ± % 20 mg/L	80 ± % 30 mg/L

Table 8: amounts of Ca^{2+} in the water in mg/L for each sample.

Experiment NO: 3

Temporary water hardness is;

$Ca(HCO_3)_{2(aq)} \rightarrow CaCO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$

$CaCO_{3(aq)} + 2HCl_{(aq)} \rightarrow CO_{2(g)} + H_2O_{(l)} + CaCl_{2(aq)}$

Permanent water hardness is taken as;

$CaCO_{3(aq)} \rightarrow Ca_{(aq)}^{2+} + CO_{3(aq)}^{-2}$

$Ca^{2+} + Y^{4-} \rightarrow CaY^{2-}$ (EDTA is shown as Y.)

$$\textbf{permanent water haerdness} = \textbf{temporary water herdness}$$

$$mol\ number\ of\ reacted\ (Y^{4-}) = mol\ number\ of\ (Ca^{+2}) = mol\ number\ of\ (CaCO_3)$$

$$mol\ number\ of\ reacted\ (Y^{4-}) = molarity\ of\ (Y^{4-})(molL^{-1}) \times volume\ of (Y^{4-})(L)$$

$$level\ of\ water\ hardness(mg\,L^{-1}) = \frac{mol\ number\ of\ (Y^{4-})(mol) \times molar\ mass\ of\ (CaCO_3)\ (mgmol^{-1})}{volume\ of\ the\ sample\ (L)}$$

Molarity of EDTA = 0.10 mol/L

Volume of the sample = 100.00 ± 0.05 ml = 1.00×10^{-1} ± % 0.05 L

Molar mass of $CaCO_3$ = 100.09 g/mol = 100090 mg/mol

used volume of EDTA (L)	Sample 1	Sample 2	Sample 3	Sample 4
Trial 1	1.40×10^{-3} L ± %3.6	1.40×10^{-3} L ± %3.6	0.70×10^{-3} L ± %7.1	2.40×10^{-3} L ± %2.1
Trial 2	0.90×10^{-3} L ± %5.6	1.00×10^{-3} L ± %5.0	0.60×10^{-3} L ± %8.3	3.10×10^{-3} L ± %1.6

Trial 3	1.20 x10^{-3} L ± %4.2	1.20 x10^{-3} L ± %4.2	0.60 x10^{-3} L ± %8.3	2.70 x10^{-3} L ± %1.9
Trial 4	0.70 x10^{-3} L ± %7.1	1.40 x10^{-3} L ± %3.6	0.50 x10^{-3} L ± %10	2.90 x10^{-3} L ± %1.7

Table 9: used volumes of EDTA for the third experiment in L, for each sample with the percentage uncertainties.

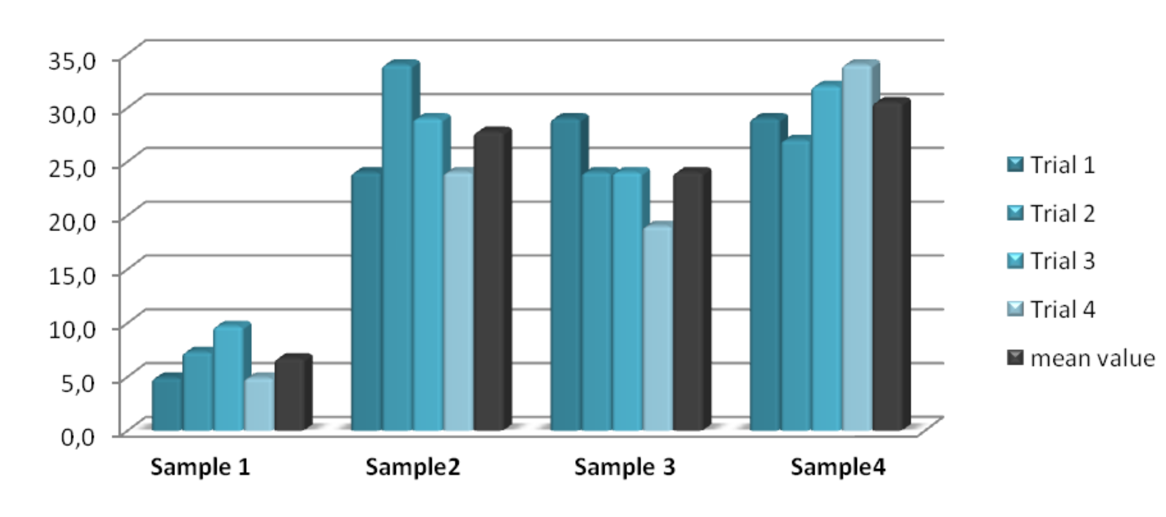
Example for calculations:

$$hardness\ of\ water = \frac{(1.4 \times 10^{-3}\ \pm \%\ 3.6)(0.10\ \pm \%\ 10) \times 100090}{0.1\ \pm \%\ 0.05}$$

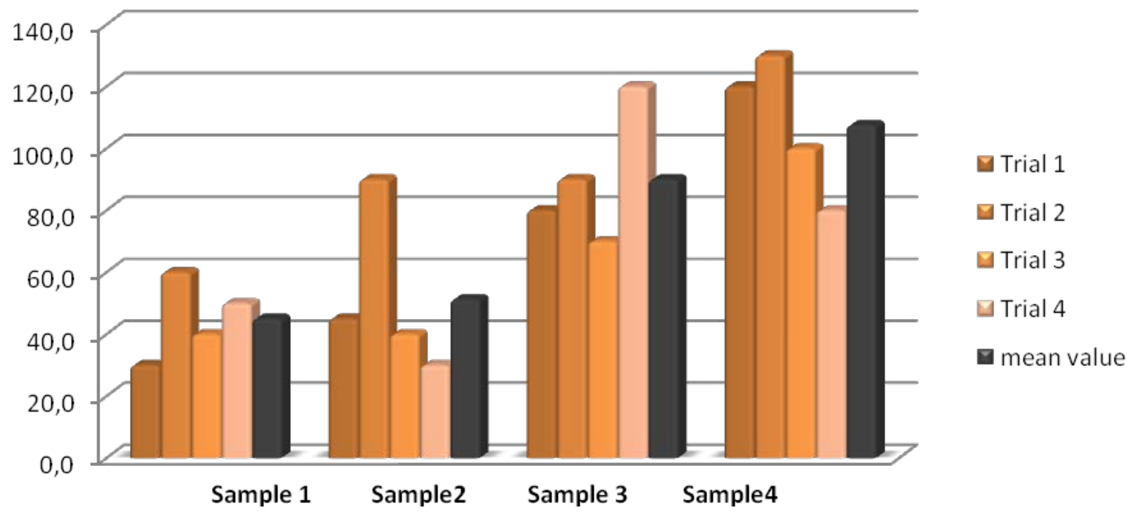
$$= 140\ \pm\ \%\ 13.62\ \text{mg/L}$$

Water hardness (mg/L)	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**
Trial 1	140 ± % 3.6 mg/L	140 ± % 3.6 mg/L	70 ± % 7.2 mg/L	240 ± % 2.1 mg/L
Trial 2	90 ± % 5.6 mg/L	100 ± % 5.1 mg/L	60 ± % 8.4 mg/L	310 ± % 1.7 mg/L
Trial 3	120 ± % 4.2 mg/L	120 ± % 4.2 mg/L	60 ± % 8.4 mg/L	270 ± % 1.9 mg/L
Trial 4	70 ± % 7.2 mg/L	140 ± % 3.6 mg/L	50 ± %10.1 mg/L	290 ± % 1.8 mg/L

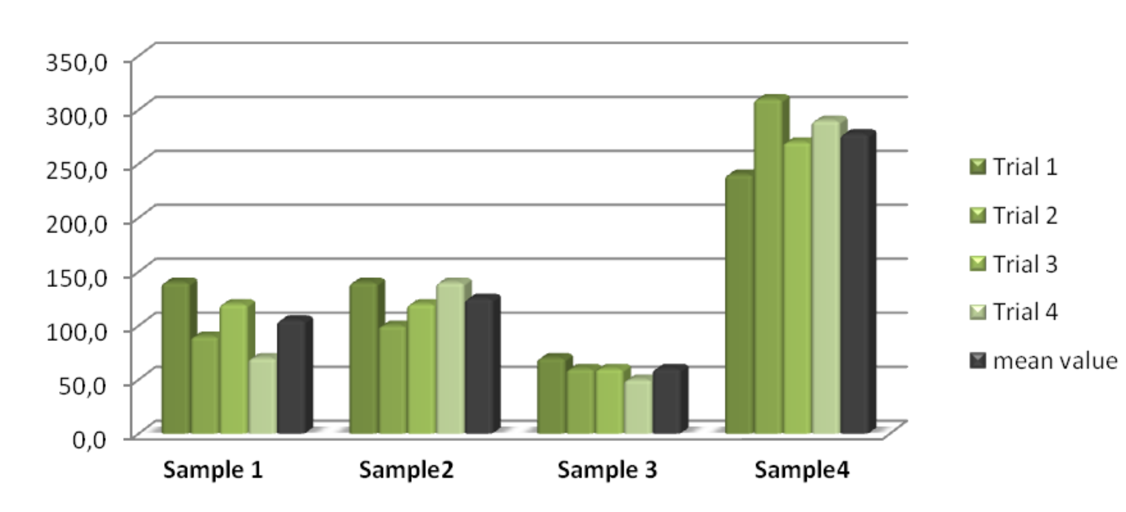
Table 10: level of water hardness in mg/L for each sample.



Graph 1: Magnesium amounts of each sample (1- 2- 3 and 4) and the mean value of the trials in mg/L.[21]



Graph 2: Calcium amounts of each sample (1- 2- 3 and 4) and the mean value of the trials in mg/L. [17]

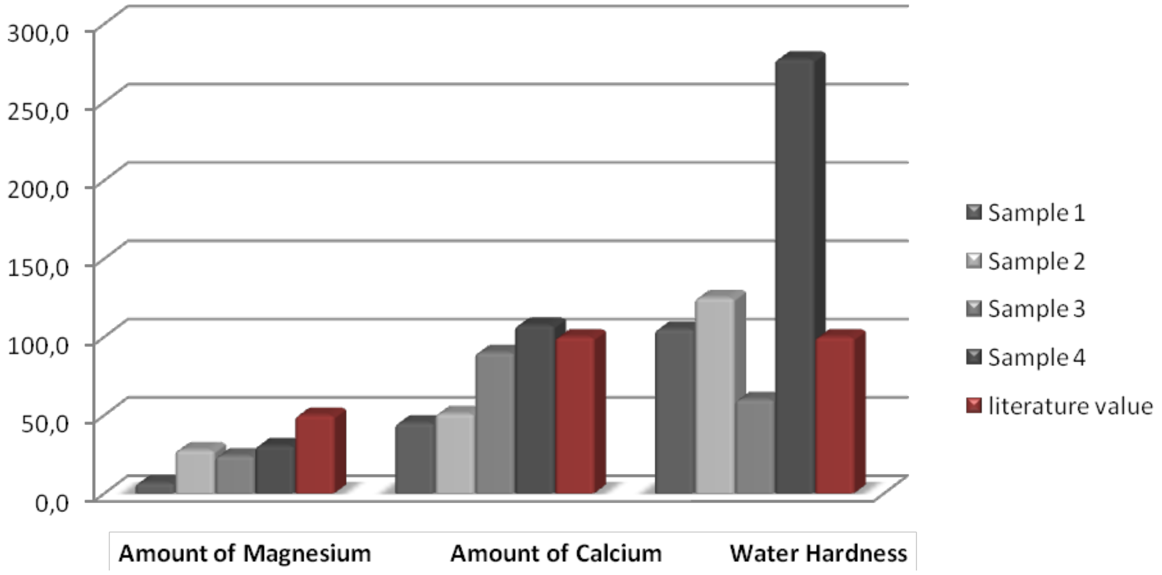


Graph 3: Amount of hardness of each sample (1- 2- 3 and 4) and the mean value of the trials in mg/L. [17]

[21] The graphs are drawn and the means values are found by using the "Microsoft Excel 2007".

MEAN VALUES	**Amount of Magnesium in water (mg/L)**	**Amount of Calcium in water (mg/L)**	**Amount of Water Hardness (mg/L)**
Sample 1: Natural spring water	6.7 ± 2.4 mg/L	45 ± 26 mg/L	105 ± 5 mg/L
Sample 2: Refined drinking water	27.8 ± 2.5 mg/L	51 ± 29 mg/L	125 ± 5 mg/L
Sample 3: Purified water of our school campus	24.0 ± 2.5mg/L	90 ± 25 mg/L	60 ± 5 mg/L
Sample 4: Tap water	30.5 ± 2.5 mg/L	107 ± 25 mg/L	278 ± 5 mg/L
Literature values: (the values that are determined by the Health Minister)	50.0 mg/L	100.0 mg/L	100.0 mg/L

Table 11: The mean values of each sample for the amount of magnesium, calcium and water hardness in mg/L.



Graph 4: The mean values of the amounts of magnesium, calcium and water hardness of each sample (1- 2- 3 and 4) and the literature values in mg/L. [22]

[22] The graph is drawn and the means values are found by using the "Microsoft Excel 2007".

ERROR PROPAGATION:

In order to find the percentage deviations of the mean values of each sample from the literature values, which are determined by the Health Ministration the following formula;

$$\text{Percentage deviation} = \left(\frac{|\text{mean value} - \text{literature value}|}{\text{literature value}} \times 100\% \right)$$

	Percentage deviation for the amount of Magnesium in water	**Percentage deviation for the amount of Calcium in water**	**Percentage deviation for the amount of Water Hardness**
Sample 1: Natural spring water	86.6 %	55.0 %	5.0 %
Sample 2: Refined drinking water	44.4 %	48.8 %	25.0 %
Sample 3: Purified water of our school campus	52.0 %	10.0 %	40.0 %
Sample 4: Tap water	39.0 %	7.5 %	177.5 %

Table 12: Calculated percentage deviations of each sample.

By looking at the percentage deviations which are found out to be very high, we could be doubt about the accuracy of the experiments so in order to test the accuracy of the each experiment the standard deviation should also be found. The formula that will be used in this process will be as the following;

$$\text{Stardard Deviation} = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

(Where, n is the total number of trials, i is the number of each trial, $\bar{x}$ is the mean value.)

SAMPLE 1: Natural spring water			
	Amount of Magnesium	**Amount of Calcium**	**Amount of Hardness**
Mean Values	6.7 mg/L	40.0 mg/L	105.0 mg/L
Standard Deviations	2.3	12.9	31.1

SAMPLE 2: Refined drinking water			
	Amount of Magnesium	**Amount of Calcium**	**Amount of Hardness**
Mean Values	27.8 mg/L	45.0 mg/L	125.0 mg/L
Standard Deviations	4.8	26.6	19.1

SAMPLE 3: Purified water of our school campus			
	Amount of Magnesium	**Amount of Calcium**	**Amount of Hardness**
Mean Values	24.0 mg/L	90.0 mg/L	60.0 mg/L
Standard Deviations	4.1	21.6	8.2

SAMPLE 4: Tap water			
	Amount of Magnesium	**Amount of Calcium**	**Amount of Hardness**
Mean Values	30.0 mg/L	107.5 mg/L	278.0 mg/L
Standard Deviations	3.1	22.2	29.9

Table 13: Calculated mean values and standard deviations of each sample.

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23. Determination of Water Hardness By Complexometric Titration Class Notes

http://homepages.ius.edu/DSPURLOC/c121/week13.htm